OECD

STI

REVIEW No. 22

SCIENCE TECHNOLOGY INDUSTRY

Special Issue on "New Rationale and Approaches in Technology and Innovation Policy"

Featuring papers from
a Conference jointly
organised by the OECD
and the Austrian Government,
held in Vienna on 30-31 May 1997

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

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Publié en français sous le titre :

STI REVUE
Numéro spécial :
Politique de l’innovation et de la technologie : nouveaux fondements et nouvelles approches
N° 22

FOREWORD

Prepared by the OECD Directorate for Science, Technology and Industry, the *STI Review,* published twice yearly, presents studies of interest to science, technology and industry policy makers and analysts, with particular emphasis on cross-country comparisons, quantitative descriptions of new trends and identification of recent and future policy problems. Because of the nature of OECD work, the *STI Review* explores structural and institutional change at global level as well as at regional, national and sub-national levels. Issues often focus on particular themes, such as surveys of firm-level innovation behaviour and technology-related employment problems.

Issue 22 of the *STI Review* is devoted to new approaches for technology and innovation policy. The articles presented are based on the contributions to the conference on ‘‘New Rationale and Approaches in Technology and Innovation Policy’’, held in Vienna on 30-31 May 1997. This conference took place in the context of the second phase of the OECD project on Technology, Productivity and Job Creation, which aimed at identifying best policy practices in technology and innovation policy. It was hosted by the Austrian Ministries for Science and Transport and for Economic Affairs and organised jointly by the Austrian TIP programme – a technology policy research and consultancy programme carried out by the Austrian Institute for Economic Research (WIFO) and the Austrian Research Centers Seibersdorf (ARCS) – and the OECD.

Approaches to technology and innovation policy are examined both from an analytical and a political view. The analytical contributions discuss the limits of the ‘‘market failure’’ approach and propose to widen the policy rationale to take account of ‘‘systemic failure’’. Contributions from policy makers describe their experiences in applying this new policy rationale and discuss the implications for government policy management and institutions.

The view expressed in this publication do not necessarily reflect those of the Organisation or of its Member countries. The *STI Review* is published on the responsibility of the Secretary-General of the OECD.

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INTRODUCTION: NEW RATIONALE AND APPROACHES IN TECHNOLOGY AND INNOVATION POLICY

This special issue of the *STI Review* has its origin in the Conference on ''New Rationale and Approaches in Technology and Innovation Policy'', which was held in Vienna on 30-31 May 1997 and was jointly organised by the OECD's Directorate for Science, Technology and Industry and the Austrian government. The Vienna Conference was organised in the context of the OECD project ''Technology, Productivity and Job Creation''. It was attended by policy practitioners and researchers who discussed the changing rationale of technology and innovation policy and the concrete implications for policy making in a globalised knowledge-based economy.

While technology has always been key to productive resource use, firms and governments alike are currently confronted with new challenges in mastering the opportunities and risks associated with technological progress. The cumulative nature and growing complexity of technology make effective innovation increasingly dependent on the appropriate combination and co-ordination of multiple assets and functions.

The direction and consequences of technological change are thus influenced by a range of conditions, including the properties of product and factor markets, and the extent to which technical change is accompanied by organisational change and human capital development. Market forces, government institutions, regulations and other policies influence the preconditions for technical change, often with different components strengthening or interfering with each other. Although countries differ in important respects, there is great potential for mutual learning from, and interdependence between, technology-related policies in different countries (*Andersson*).

Views of what technology and innovation policy can achieve and how it should achieve it have changed markedly. These changes have three main sources:

– ***A better understanding of innovation and technology diffusion processes*** owing to advances in economic theory. The traditional rationale for technology policy has been that of market failure. Governments intervene to provide for public goods, as well as to mitigate externalities, inefficient market structures and barriers to entry, imperfect markets for information, etc. The need to temper intervention because of the limits to the effectiveness of government action has long been recognised.

However, recent research (*Metcalfe and Georghiou; Lipsey and Carlaw*) demonstrates ways in which the factors shaping technical progress increasingly call for measures to address ‘‘systemic failure’’, the lack of coherence among institutions and incentives, through new approaches to support innovation in the business sector (*Mowery and Ziedonis; Teubal; Eliasson*) and to the development of infrastructures (*Link and Scott*).

– ***A new policy-making environment.*** The economic environment in which both government and firms operate is being fundamentally transformed, first and foremost, by globalisation that makes some national policy instruments less applicable, or less efficient, whereas those determining a country’s attractiveness as a location for knowledge-intensive production take on increasing importance (*Reger*). There are also important changes in macroeconomic conditions, including more stringent fiscal policies and evolving societal demands in a context of regional integration, calling for joint or co-ordinated action at the international level (*Caracostas*).

– ***Lessons learned from successes and failures in implementing policies.*** While governments should be guided by common core principles regarding policy rationale, these do not always translate into similar priorities and instruments for concrete action, depending on country-specific institutional features (*Ormala; Sulzenko*).

Jean Guinet
Wolfgang Polt

MANAGING A SYSTEMS APPROACH TO TECHNOLOGY AND INNOVATION POLICY

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I. INTRODUCTION

While technology has always been key to productive resource use, firms and governments alike are currently confronted with new challenges in mastering the opportunities and risks associated with technological progress. The cumulative nature and growing complexity of technology make effective innovation increasingly dependent on the appropriate combination and co-ordination of multiple assets and functions. At the same time, there are growing challenges to master the combination of long-term investment decisions and adaptation to changing conditions.

The direction and consequences of technological change are thus influenced by a range of conditions, including the properties of product and factor markets, and the extent to which technical change is accompanied by organisational change and human capital development. Market forces, government institutions, regulations and other policies influence the preconditions for technical change. With expanding codification of information, international trade and mobility of production factors, there is also increased potential for mutual learning from, and interdependence between, technological progress in different countries.

In this setting, governments need to raise their awareness and understanding of how a broad spectrum of institutions and policies bear upon technological change. Relevant and effective technology and innovation policy must rely on a sound rationale. Although the fundamental cornerstone for all economic policy action is that of addressing *market* failure, extensive consideration must clearly be given also to *government* failure. Governments cannot *a priori* be assumed to do better than markets, even when the latter fail. Beyond this, the basis for and implementation of technology policy is subject to *systemic* issues.

Both theoretical and empirical observations point to the inadequacies of a piecemeal policy approach to technology. As will be further discussed below, maximising the *benefits* of technological advance increasingly calls for a *systems-based* approach.[1] However, such an approach is also associated with certain *costs.* One fundamental question in this respect concerns the requirements of a systems approach in terms of understanding country-specific conditions. To what extent does its adoption reduce the scope for general lessons, increasing the need for – and making policy success dependent on – the ability of public authorities to gather and respond to idiosyncratic information? If a high dependency of this sort emerges, there is a risk of diminishing scope for checks on government policy, possibly leading back to a situation of costly government failure, and making it harder to achieve virtuous policy learning and co-ordination between countries.

A related tricky question is whether countries differ with respect to the options for governments to boost competitiveness in knowledge-intensive activities. The influential so-called ‘‘new growth theory’’ (Romer, 1987) has paid considerable attention to the conditions that determine, or endogenize, technical progress. For instance, because knowledge-intensive activities tend to be characterised by increasing returns to scale, the outcome of technological effort may depend on a critical mass of resources being devoted to it. Moreover, inter-country specialisation in production may also be driven by different abilities to attract knowledge-related production factors and capabilities. Krugman (1991*a* and 1991*b*) argued that segmentation of product markets makes large economies enjoy a comparative advantage in production based on economies of scale. In relatively small economies, on the other hand, there would instead be specialisation in more standardised production based on constant returns to scale. Related considerations apply to the continued development prospects of newly industrialised countries, such as Korea and Mexico, and to the former socialist transition economies of Eastern Europe.

If countries are confronted with inherently dissimilar risks and opportunities with respect to technological development, this may underscore the importance of a systems approach which can determine and address those interconnecting issues which are relevant for the individual country. On the other hand, it cannot be taken for granted that all countries will be in a position to capture sufficient benefits to compensate for the potential costs of adopting such an approach. For example, governments in larger economies may have greater resources to invest in analytical capacity. If a country has an inherent disadvantage in fostering knowledge-creating activities; for example, because of limited size, embarking on a demanding systems approach to technology policy may not be worthwhile.

A first systematic evaluation of technology-related policy performance applying a systems perspective was recently undertaken in OECD (1998). Based on the results of that study, the next section reviews current challenges and policy responses. Issues related to the adoption of a systems approach to technology and innovation policy are reflected on in Section III. Further aspects of these issues, arising from the international dimension, are examined in Section IV. Principles of relevance to the sound implementation of a systems approach are discussed in Section V. The last section concludes.

II. CHALLENGES AND POLICY RESPONSES

Against the backdrop of soaring unemployment along with a weakening of productivity growth in OECD countries since the 1970s, the OECD set out in 1994 to systematically examine the links between technology, productivity and employment. Based on extensive new firm- and industry-specific data, OECD (1996) provided an encouraging message: the industries and firms which create new jobs are generally those which are able to exploit new technology successfully, and which raise productivity and strengthen competitiveness. Problems arise because there may be a lag before positive effects materialise, and because the winners and the losers may not be the same – leading to social tensions and opposition to adjustment. Less-educated or less-skilled workers are relatively badly hit by technological change, as indicated by widening income differentials and/or higher unemployment rates among the unskilled. However, if technical progress can be appropriately matched by investment in human skills, organisational change and structural reforms in product and labour markets, higher economic growth will be accompanied by the creation of more and better jobs.

On this basis, the 1996 meeting of the OECD Council at Ministerial level called upon the OECD to identify best practices in innovation and technology diffusion policies, and to draw lessons therefrom. The resulting examination (OECD, 1998)[2] represents a somewhat new characterisation of the policy challenges in this area. Innovation and diffusion of technology is an increasingly complex process, the success of which crucially hinges on the extent to which there can be continuous interplay and mutual learning between many different types of knowledge and actors. Inter-firm collaboration, networking and the formation of clusters of industries are examples of such interactions. Countries can be viewed as having ‘‘national innovation systems’’, with distinctive attributes and structures of interactions, *e.g.* between the enterprise sector and the science system. As firms focus on core strengths and learn to combine and contract for complementary inputs, there are also more horizontal links between firms within and between countries. Thus, national innovation systems are increasingly interdependent, although national characteristics remain of great importance for performance.

In the wake of the prolonged depression of the early 1990s, evidence from most of the OECD area demonstrates that strong productivity growth does not necessarily translate into jobs. This applies particularly at an aggregated level of countries or industries: the European countries display particularly rapid technology growth coupled with a weak employment record. Certain countries, such as Finland and Poland which have also been subject to harsh external shocks, are outliers in this respect. North American countries, the United Kingdom, Australia and New Zealand display weaker productivity growth but stronger employment performance. The East Asian countries have fared significantly better in terms of both productivity and job creation but these countries were in a sense in a ‘‘technological catch-up phase’’ and have recently run into trouble.

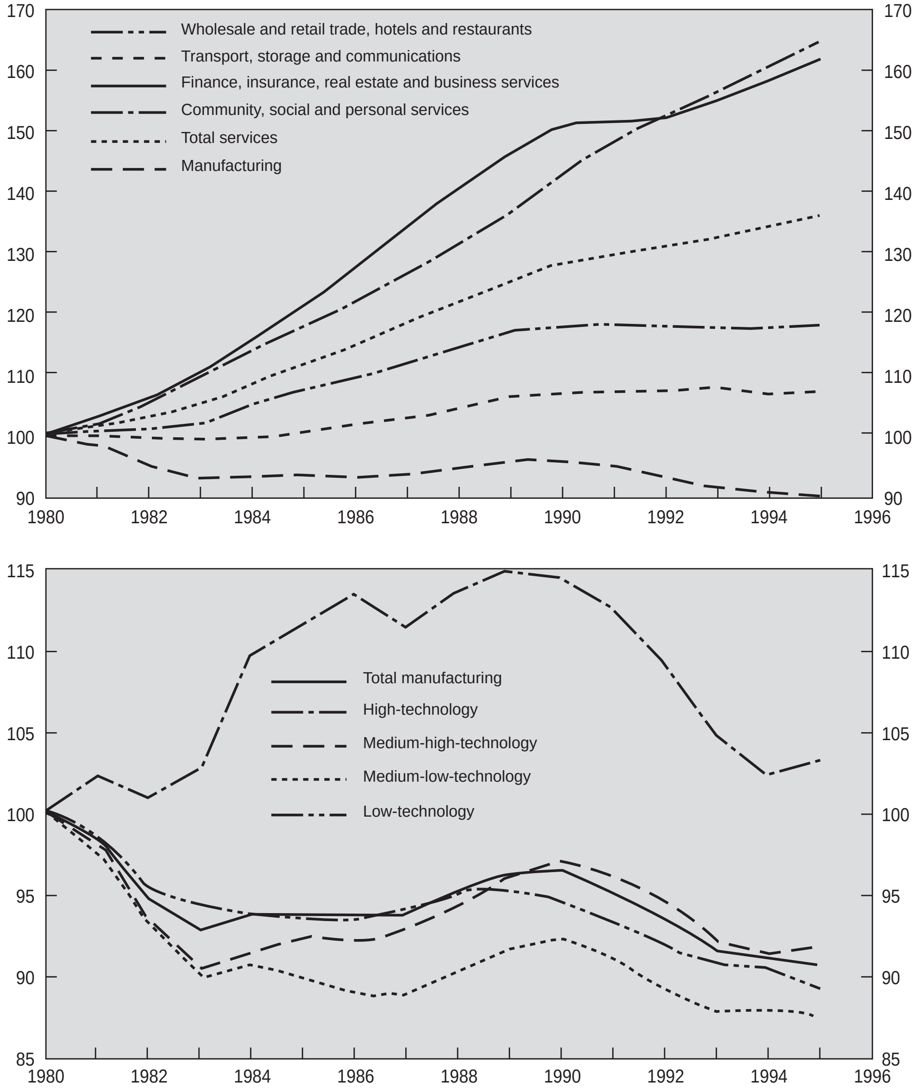
Contrary to popular belief, technology-intensive activities have not in themselves contributed to an expansion of job opportunities in the last decade (Figure 1). The important role of these activities in the jobs context emanates from their function within national innovation systems. The economy-wide effects of technological change crucially depend on how innovation interacts with diffusion, and how technology is absorbed and exploited throughout the economy. For increasingly rapid technological progress to be accompanied by more jobs, workers must upgrade and reorient their skills, and be prepared to move from shrinking industries and firms to those offering new opportunities. Firms, on the other hand, must be able and willing to expand into new industries, products and markets, and to employ and invest in new workers.

At the same time, there is diminishing public support for research and development (R&D). New empirical analysis shows that this has contributed to the leveling-off in private R&D efforts that has occurred since the 1980s (OECD, 1998). There are parallel indications of a shift in the orientation of innovative efforts away from long-term exploratory research and towards more short-term applied R&D. On the other hand, there has been a raised efficiency in innovative efforts, and more networking is taking place between firms, and between firms and research institutes, etc., accounting for compensating mechanisms to develop and exploit technology. No significant negative impacts on productivity are yet visible from the decline and change in the size and orientation of R&D, but the current trends do raise important long-term questions about the viability of innovation systems.

Current trends in OECD-area technology and innovation policies reflect changes in the perception of the rationale and effectiveness of government measures, as well as evolving priorities as the macroeconomic situation changes. Pressures on public finances are increasing, resources are becoming more internationally mobile, and so on. As can be seen from the summary of country assessments in Table 1, many OECD countries pursue technology-related policy-approaches that can be considered successful. All countries also show weaknesses and there is scope for improvement. The table summarises the results of the various chapters of OECD (1998). Areas covered range from the ‘‘traditional’’ core of technology policies, such as managing the science base and financial incentives to industrial R&D, to more novel realms such as facilitating growth in new demand, policies conducive to high-performance work places and measurement of intangible assets, and designing an institutional framework for consistent formulation and implementation of policy.

Figure 1. **Employment trends by industry, total OECD**

1980 = 100



Source: OECD, 1998.

Table 1. **Overview of best policy practice and policy recommendations in individual areas of innovation and technology diffusion policy**[1]

	Chapter 4[2]	Chapter 5	Chapter 6	Chapter 7	Chapter 8	Chapter 9	Chapter 10		Chapter 11
	Institutional framework for policy formulation and implementation	Evaluation	Managing the science base	Financial incentives to industrial R&D efforts	Technology diffusion policies and initiatives	Promoting new technology-based firms	Facilitating growth in new demand		High-performance workplaces and intangible assets
							Internet-based	Environment	
Australia	•/♦	•	•/♦	•	•/♦	♦	•/♦	♦	o
Austria	o	o	♦	♦	•/♦	o	♦	♦	♦
Belgium	o	♦	♦	o		o	♦	o	♦
Canada	•/♦	•	•/♦	•/o	•/♦	•/♦	•	•	•/o
Czech Republic		o	o		o	o		o	
Denmark	♦	♦	•	♦	•/♦	♦	♦	♦	•
Finland	•	♦	•	•/♦	♦	•	•	•	•/♦
France	♦	♦	o	•/o	•/♦	•/o	♦	♦	♦
Germany	♦	♦	♦	♦	•/♦	•/♦	♦	♦	•/o
Greece	o	o	o		•/o	o	o	o	o
Hungary		o	o		o	o		o	
Iceland			•				♦	♦	♦
Ireland	♦	o	•	♦	♦	♦	o	o	•/♦
Italy	o	o	o	o		♦	o	o	o
Japan	o	♦	•/o	o	•/♦	o	•/♦	•	•/o
Korea	♦	o	o	♦	•/o	o	♦	o	♦
Luxembourg							♦	♦	
Mexico	o	o	o	•/o	o	o	♦	o	o
Netherlands	•/♦	♦	•	♦	•/♦	♦	•	•	•
New Zealand		♦	♦				•/♦	•/♦	♦
Norway	♦	♦	♦	♦	•	♦	♦	•	•
Poland	o	o	o	o	♦	o	♦	♦	o
Portugal	o	o	♦				o	o	o
Spain	o	o	•/o	o	•/o	o	o	o	o
Sweden	♦	♦	•/♦	♦	♦	o	•/♦	•	♦
Switzerland	♦	♦	♦	•/♦	•/o	o	♦	♦	♦
Turkey	o	o	o	♦	♦		o	o	o
United Kingdom	♦	•	•/♦	•/♦	•	♦	•	♦	•/o
United States	o	•/♦	•/♦	•/♦	•/♦	•	•	•/o	•/o
EC	•/o	•/♦		•/♦	•/o	♦	•	•	•

Key: • = represents case of best policy practice; ♦ = represents minor policy recommendation; o = represents major weakness calling for policy adjustment.

1. The table should be interpreted with caution and not be read as a ranking of countries. Five situations are distinguished: *i)* case of best policy practice; *ii)* partial best practice policy, with minor policy recommendation; *iii)* minor policy recommendation; *iv)* partial best practice policy, with remaining major weakness; *v)* major weakness. A blank means that available information was insufficient to draw conclusions.
2. This column is also based on judgement derived from other chapters.

Source: OECD (1998).

In terms of country patterns, three groups can be distinguished. A first group (*e.g.* Australia, Canada, Finland, the United Kingdom, the United States) has no pronounced weaknesses. However, except in the case of Finland, vocational and technical education and training do constitute a weak point. In Finland, as in Sweden, infrastructure for diffusion needs to better serve interactions between small and large firms. In Canada, financial support to industrial R&D should be rationalised. There is also room for improvement in the overall co-ordination of innovation and technology diffusion policies in most of these countries, including the United States.

By contrast, a number of OECD countries face a far-reaching reform agenda. They include: the new Member countries (Czech Republic, Hungary, Korea, Mexico, Poland), where the institutional set-up for innovation and technology diffusion policies is not yet complete; European countries with less policy experience in this area (Greece, Ireland, Portugal, Spain, Turkey); but also more advanced countries such as Austria and Italy, which face lasting problems of policy co-ordination that weaken efficiency in every technology policy area. The remaining Member countries, including Japan and most European OECD countries, fall in between, displaying more contrasted profiles of strengths and weaknesses. The weaknesses, *e.g.* in France, Germany and Sweden, partly reflect rigidities in the public research sector and related difficulties in adjusting financing and regulatory policies to the requirements of the emerging entrepreneurial model of knowledge generation and use.

III. TOWARDS A SYSTEMS APPROACH?

Since technological advance depends on the ability of firms and individuals to invest, innovate and promptly respond to changing conditions with a view to earning profits which may often materialise only in the long term, an appropriate policy framework hinges on consistency and credibility. The challenge for government in this respect goes beyond technology policy, and even innovation policy, in a narrow sense. It incorporates the need to overcome institutional inertia as well as addressing social cohesion problems arising from transition costs and redistribution of incomes and jobs, primarily away from workers who are low-skilled or whose skills are becoming obsolete. For this to be feasible and to ease transition problems, technology policies need to be made part of a broader package, developed in consultation with the social partners.

Relatively few ‘‘best practices’’ in OECD, as displayed in Table 1, are actually found in areas where a systemic approach tends to be inherent to the success of policy, namely: the institutional setting for policy formulation, implementation and evaluation, as well as the promotion of new technology-based firms and policies fostering growth in new demand.[3] In other areas, such as technology diffusion or the management of the science base, where examples of best practices abound, they frequently do not translate into satisfactory performance because their impact depends in part on conditions created by other policies. For example, efforts to make the science base contribute better to economic growth hinge on the uptake of scientific inputs by business – especially by small technology-based firms and in new growth areas. Industrial renewal brought about by firm creation and expansion of new markets will in turn enhance the effects of schemes for promoting technology diffusion.

On the whole, the available assessments of country policies point towards too much emphasis on measures to support the development of new technologies in the small high-technology segment of the economy. Prevailing deficiencies in evaluation practices in Member countries, including an emphasis on cost efficiency rather than on economic impacts, and insufficient consideration of systemic impacts. A strengthened systems approach thus stands out as a key challenge to OECD policy makers. However, compared to the treatment of each area in isolation, addressing the interrelated impacts of disparate institutions and incentive structures signifies a more ambitious agenda, requiring greater analytical effort and possibly higher costs in policy design and implementation. The application of a systems approach is, in fact, associated with certain risks, or pitfalls. In the following, three such pitfalls are discussed: neglecting the limitations of governments; missing out on priorities; and failing to distinguish between lessons that are general *vis-à-vis* those that are context- and country-specific.

First, determining the rationale for policy is closely connected to what can realistically be expected of governments in terms of their ability to collect, process and act upon available information. There are no doubt limitations to governments' ability, as well as high opportunity costs in employing those capabilities. The limitations arise from, *e.g.* the competence of government officials (often with respect to first-hand experience and understanding of the private sector), the time available to them, and the influence of vested interests.

Second, the limitations on government capacity make it important to determine priorities. Governments should not be called upon to do everything that could theoretically pay off, or to do everything at once. The more governments try to do, the more stretched their administrative capacity and the lower their ability to correctly implement the various measures. Setting priorities regarding the issues felt to be the most important and urgent to address, as well as those likely to be most effectively addressed by policy, becomes particularly important in a systems approach as it may produce a range of suggested policy adjustments.

Third, a systems approach raises issues with respect to the generalisation of policy principles and lessons. Country-specific conditions matter in, at least, the following respects:

- Policy objectives are influenced by the specific issues with which individual countries are confronted. Although there are certain commonalities across the OECD, there are also considerable differences in country *performance* with respect to growth, productivity, job creation, establishment of new firms, industrial restructuring, etc.
- Which policy instruments are the most relevant and efficient is influenced by country-specificity in the *mechanisms* underlying innovation, technology diffusion, and closely linked processes such as organisational change and upskilling of the work force.
- Country specificities influence the *lessons* that countries can draw from the experience of others.

The importance of country specificities is more pervasive in technology-related policy than it may appear at first sight. It is obviously almost always desirable to have more growth, higher labour productivity, or a greater number of jobs. However, as already noted, countries are confronted with distinct sets of strengths and weaknesses. As of the late 1990s, for instance, the United States and the United Kingdom encounter critical policy challenges in the rapid take-up of scientific discoveries in science-based industries. Other countries, such as Japan and Korea, enjoy effective adaptation of existing technologies but have major problems in basic research capabilities. Australia, Canada, Denmark, Finland and Norway encounter challenges in upgrading the knowledge content of resource-based clusters of industries. Germany, the Netherlands, Sweden and Switzerland are confronted with challenges arising from the rapid internationalisation of R&D in large firms. This is further discussed in the following section.

The cross-country differences are, of course, real. However, the piecemeal application of market or government failure as the rationale for policy means that policy makers restrict themselves to understanding situations on the basis of general principles. By contrast, applying a systems approach requires an attempt to understand and gauge the interplay between a range of issues and mechanisms which, by definition, will be more or less context-specific. In many cases, as made clear above, such an approach will lend itself to more relevant and effective policy responses. At the same time, it cannot be taken for granted that a systemic approach is equally desirable irrespective of these different challenges. Moreover, countries differ in their preparedness or capacity to manage it. Judging from Table 1, Finland, Canada, the Netherlands and, in some respects, the European Commission appear to be the furthest advanced as far as the institutional framework is concerned. The United States and the United Kingdom seem to have the greatest ability to guard against pitfalls through their relatively comprehensive approach to evaluation. Finally, again, while experience gained in pursuing the principles of market and government failures is readily transferable across countries, a systemic framework makes it more difficult to draw lessons from the experience of others.

IV. THE INTERNATIONAL DIMENSION

The international dimension adds further perspectives on a systems approach. Globalisation of trade, investment and knowledge flows reduces the scope for ‘‘national’’ technology and innovation policy. Producers increasingly serve customers in different national markets; production factors are allocated to more than one country; and/or there are spillover effects in the form of externalities, both positive (*e.g.* when the gains of investment in knowledge or higher growth transcend national barriers) and negative (as when the costs of environmental damage are partly borne by other countries). For such reasons, purely national policies may be ineffective and/or lead to unwanted effects.

Insofar as there are identifiable losers with regards to globalisation, the political process will most likely lead to demands for countering domestic measures (*e.g.* against delocalisation of jobs or R&D). It is important, however, that the resulting strategies do not give rise to a negative-sum game which reduces the internationally available (or nationally applicable) stock of knowledge. The challenge for policy is to put in place conditions that allow for complementarity between increased internationalisation in knowledge flows and domestic innovative capacity.

There are diverging views in the literature on what it takes to generate such complementarity. Porter (1990), for instance, has argued that a country should design policy which can help to further exploit and upgrade the specific assets which have already been created within ‘‘industrial clusters’’, exploiting the prevailing strengths of national innovation systems. Reich (1991) has emphasized the importance of a labour force which is capable of ‘‘tapping into’’ mobile resources, thus attracting more-or-less foot-loose international production assets. The establishment of flexible subcontractors, responsive technological institutes or wage/remuneration systems which can attract such resources represents other similar avenues.

In practice, it is neither possible nor desirable to prescribe any single, general strategy for maintaining or attracting innovative production capabilities. Countries naturally differ with respect to their comparative advantages, as well as with respect to their possession of favourable assets or conditions which are attractive to mobile ventures. What may be more worrying from a policy perspective is the extent to which countries differ in their ability to sustain production based on price competition and that based on increasing returns to scale. With the exception of the knowledge-intensive, innovative activities already present in a country, the size of the economy, its openness and level of development and even its cultural heritage may influence its ability to cherish various economic activities.

For instance, country size matters, partly because the development of new technology is typically associated with economies to scale due to, *e.g.* asymmetric information and costs to exercising control over the quality or diffusion of technology (Ethier, 1986; Horstmann and Markusen, 1987). In a world of segmented national markets, firms based in relatively large countries may enjoy advantages in technology creation. A large domestic market can make it easier for companies to grow, and can accommodate a greater number of firms which can produce and benefit from mutually strengthening external economies associated with the upgrading of work force skills, educational institutions, the ability of financial institutions to evaluate technology, the quality of public services, etc. A large country may hence enjoy a comparative advantage in fostering activities which benefit from economies of scale and scope while small countries specialise in production based on constant returns to scale. Krugman (1991*a;* 1991*b*) suggested that liberalisation further benefits knowledge creation in relatively large countries, because the competitive advantage inherent to market size ensures a greater share of integrated markets.

There is ample empirical evidence to show that country size does make a difference. R&D expenditure has historically been concentrated in the largest industrial countries. In 1985, for instance, the ‘‘major seven’’ OECD countries (G7), which accounted for 84 per cent of total GDP in the OECD area, were the base for as much as 91 per cent of R&D. On the other hand, several of the countries with the highest R&D intensity in the world are relatively small, Sweden, Switzerland, the Netherlands and Finland. For these particular countries, however, globalisation of their production base through outward direct investment has been a key factor accounting for their high R&D intensity (Andersson, 1998).

It is commonly supposed that R&D takes the form of a public good within a company, meaning that the output can be exploited anywhere in the organisation irrespective of location and distance to the R&D activity. Provided that transfers of technology are not associated with excessive costs, and in the presence of economies of scale at the plant level and/or difficulties in co-ordinating R&D between geographically disparate locations, R&D will concentrate in a single location or in a limited number of locations. The country of origin typically comes out strong, as reflected in patent statistics. This applies especially to large countries such as France, Germany, Italy, Japan and the United States. Lasting links have typically been established between the assets of multinational firms (MNCs) and the characteristics of home country institutions, applying to educational systems, public procurement practices, informal networks between firms, etc. Making R&D effective in a foreign location is likely to require fixed costs of learning how to master different conditions, costs which become sunk in that specific environment.

R&D in small countries is not simply a result of internationalisation. The very existence of MNCs is presumed to hinge on firm-specific assets that cannot easily be traded at arm's length, including R&D (Dunning, 1977; Caves, 1982). A simultaneous relationship may be expected; high R&D expenditures favour the development of MNCs which in turn supports R&D. Only in a few small countries have firms embarked on mutually enforcing knowledge development and internationalisation.

Even when such processes have been put in place, a concentration by MNCs of R&D within their home economies cannot be taken for granted. Total technology transfer is neither possible nor desirable even within the networks of an MNC. Compared to arm's length exchange, internal technology transfers are likely to differ in degree rather than in kind. Empirical studies have found shorter time lags when technology is transferred within a firm than between separate companies (Mansfield and Romeo, 1980; McFetridge, 1987). Davidson and McFetridge (1985) concluded that technology trade is more likely to be internalised the closer it is to the main line of business in the company group.

Today, there is a marked tendency for globalisation in goods and factor markets to be followed by globalisation in knowledge-generating activities (Reger, 1998). In patent activity, rapid internationalisation has been observed, especially for firms from smaller countries (Belgium, the Netherlands, Switzerland) and in the United Kingdom, which hosts a number of companies with globally dispersed activities. In foreign R&D, there is evidence of a shift away from addressing local market needs to establishing competence centres carrying out R&D for the whole corporation. The share of R&D located abroad in US manufacturing MNCs increased from 6 per cent in 1970 to about 10 per cent in 1989. In the case of German MNCs, employment in R&D personnel abroad is reported to have grown more rapidly than total employment abroad (UNCTAD, 1992). Again, however, MNCs based in small economies recorded the most rapid increase in foreign R&D: Swedish and Finnish MNCs displayed increases from about 15 per cent in the mid 1980s to 25 and 29 per cent respectively in the early 1990s. In parallel, both countries displayed weak industrial performance at home, and Sweden in particular fared badly in knowledge-intensive production. From the home-country perspective, the internationalisation of R&D reduces the concentration of R&D by domestic firms at home, with the potential risk of dismantling the innovative capacity of the home country.

From the host country perspective, domestic firms are more R&D-intensive than foreign affiliates in most OECD countries (*e.g.* Canada, France, Germany, the Netherlands, Sweden and the United Kingdom). In a few, however, R&D intensity is roughly balanced (Finland, Japan, the United States), while it is higher in foreign affiliates in Australia and Ireland. Foreign R&D is attracted to the United States by the quality of its research institutions, while locating R&D in Ireland is motivated more by the need to upgrade and adapt products and processes. In the United States, inward foreign R&D is expanding already-intensive knowledge interactions, but is also a source of knowledge outflows. In Ireland, inward foreign R&D is a major driving force in the technological catching-up process.

The apparent importance of MNCs for knowledge creation and production in the small economies that have attained a strong position in this area, together with the particularly marked tendency for MNCs to internationalise R&D at a fast pace, raises questions regarding the extent to which knowledge creation is becoming concentrated in larger economies. While the internationalisation of production can enable small countries to perform on a par with bigger economies, is the continuing internationalisation of the knowledge base now eroding the abilities of small countries to compete in knowledge creation and production?

Such a conclusion is doubtful on several grounds. It cannot be taken for granted that small countries will face increasing difficulties in competing in knowledge creation, even if the move towards relatively higher intensity of such activities in large economies were to continue. Foreign R&D strengthens the ability of firms to increase their sales abroad, expand their overall resources and investment and absorb foreign technology more effectively. Analysis of firm-specific data in Sweden and Finland has shown that increased foreign R&D can be explained by the need to overcome the cost of transferring technology from home, but the picture is mixed with regard to whether this trend is becoming more pronounced as technical sophistication increases and whether foreign R&D substitutes for, or complements, research efforts at home, thus providing no support for any inherent disadvantage in knowledge creation for small countries (Andersson, 1998; Åkerblom, 1994).

Furthermore, technology diffusion embodied in capital goods and intermediaries has increased in importance *vis-à-vis* direct R&D, as have flows from abroad in many countries, although in larger countries such as Germany, Japan and the United States domestic flows of embodied R&D still outweigh flows from abroad (OECD, 1996). While the supply of technology is concentrated in a few high-technology industries, the use of embodied technology is widespread and considerably increases the ‘‘technology content’’ of industries typically rated as ‘‘low-’’ or ‘‘medium-’’ technology. For many countries, innovation surveys have found the most important channels for technology transfers to be equipment, customer-supplier relations and the hiring of skilled personnel. In particular, the United States is the source of substantial international R&D spillovers, which are magnified by FDI originating in other countries. In a study covering 22 countries for 1971-90, Lichtenberg and Van Pottelsberghe de la Potterie (1996) in fact found outward FDI to be more conducive than inward FDI to technology transfers (through sourcing).

While the mechanisms for technology diffusion are primarily market-mediated, the systemic perspective calls attention to a number of measures which governments can undertake to facilitate more conducive conditions: strengthening the absorptive capacity of domestic firms, particularly SMEs, *e.g.* by providing the means and support for vocational training; attracting FDI and technology by fostering synergy gains with domestic industry and research institutions; adopting market-compatible incentives to improve conditions for research work and increase mobility of researchers, including attraction of foreign research personnel; and practices of public procurement and quality of government programmes which can influence the build-up of consultancy services – one of the mechanisms for technology transfer.

Governments similarly have an important joint responsibility to facilitate international knowledge transfers by, *e.g.* developing mutual recognition of educational attainment levels, fostering international technology co-operation, catalysing desirable international technology collaboration through public procurement, etc. In this respect, the rationale for technology and innovation policy in one country may be interrelated with policies pursued by other countries. Greater openness to international technology co-operation in one country may help to encourage openness elsewhere, inducing greater mutual gains. The Fifth Framework Programme of the European Commission provides an example of an important initiative in this area.

V. PRINCIPLES OF SOUND IMPLEMENTATION

On this basis, all OECD countries encounter major technology-related policy issues, and systemic considerations stand out as relevant throughout. It is important to address the inherent problems and difficulties of such an approach. Its fundamental feature, however, is the incorporation of means to identify how the leverage of policy measures can be enhanced by implementing mutually reinforcing measures, irrespective of whether these belong in a particular or in disparate policy areas. This is not the same as having governments do more, become more interventionist or assume greater responsibility in the economy, than what would have been the case in an approach based on market failure. In fact, for governments to be able to identify and respond to crucial interlinkages, they need to sharpen their ability to determine not only what to do, when and how to do it, but also on what *not* to do.

A systemic approach must be based on comprehensive policy co-ordination, while breaking down counter-productive empire-building by those responsible for different fields within governments. This is related to the development of evaluation methods and practices: many policy measures should be made conditional on the implementation of acceptable evaluation practices. As adopting a systems approach pinpoints this need, its adoption may help to raise awareness of the fundamental value of checks against government failure, such as institutions furthering their own special interests. This should result in better articulated demand for transparency, supporting ‘‘audits’’ and international benchmarking of how policy organisation and formulation relate to economic behaviour and performance, reinforcing a critical process of self-examination in governments.

If properly implemented, a systems approach should translate into a more explicit demand for recommendations which are as universal and transparent as possible. There are clearly benefits to adhering to, and applying, general principles such as taking into account the impacts of policies on incentive structures, applying the concept of additionality, taking economy-wide effects into account, and so on (see further OECD, 1997). The prospects for productive policy co-ordination between countries are, for instance, facilitated by transparency, shared terminology and logic in the approaches pursued. On the other hand, general conclusions, if taken too far, apply only to a non-existent stylised model. Common core principles regarding policy rationale can, and do, translate into different priorities and instruments for concrete action. Pursuing a systems approach thus requires balancing the specific *vis-à-vis* the generally applicable, differentiating between levels and kinds of principles or insights that apply more or less to all economies irrespective of institutional set-ups, and those that apply only within a specific context.

A systems approach requires the implementation of appropriate co-ordination mechanisms between ministries and other key public authorities. Appropriate incentive systems are needed to engineer such co-ordination, which needs to be actively supported at the highest levels of government. Financial pressures can also be used creatively to spur change in governance, and to encourage the adoption of assessment mechanisms designed to induce innovative behaviour. In addition, the relevant stakeholders should be involved in the formulation of policy, without allowing those that are disproportionately well-organised to dominate the process. Denmark, the Netherlands, Finland, the United Kingdom and the United States stand out as fore-runners in this area. New forms of interaction with the private sector have helped dynamise research systems and better link them to economic and societal goals, *e.g.* in Germany, the Netherlands and the United States, as well as within the framework of the new Innovation Action Plan of the European Union.

How, then, can better performance be implemented? To some extent, the ability to advance may hinge on the political will to push through difficult decisions, handle the associated transition costs and demonstrate positive outcomes. In some countries, a crisis situation has helped muster support for far-reaching reform (*e.g.* Finland, Japan). One strategy is to begin with those measures that appear to be the most feasible, that are universally supported and whose effects are likely to be the most evident. Once these measures have been in existence for some time and their effects have been evaluated, necessary corrections can be implemented and more difficult decisions pushed through. Science and technology policies in Finland, Iceland, Japan and the Netherlands have been able to evolve along these lines. Even in cases where ‘‘big bang’’ policies have been introduced, technology policy has generally evolved gradually over a period of decades (*e.g.* New Zealand).

Irrespective of the avenue chosen, a thorough understanding of the opportunities and risks of a systems approach is required. Potentially, there are mutual gains for all countries from more widespread international adoption of policy packages which are not delimited to piecemeal technology policies, but which can help pinpoint and address the key bottlenecks and inconsistencies hampering increased dynamism in the OECD area. The costs and risks of going astray can be reduced through the active involvement of well-established fora for the exchange of information and organised, mutual learning between countries, such as the OECD. In this way knowledge – at least of what has proven to work or not to work in specific contexts – can be exchanged. Such fora can also help to provide checks against the adoption of misplaced actions or institutions as well as facilitating joint policy action (for instance on a regional basis, as in the European Union).

VI. CONCLUSION

In sum, market, government and systemic approaches are not mutually exclusive, and all require policy makers’ attention. Each approach has its limitations and pitfalls, and missing out on one of them is likely to hamper effective innovation and technology diffusion policy. Market failure remains the basis for technology policy in many areas, while addressing government failure is essential for limiting the risk of costly intervention. At the same time, the factors that shape technical progress increasingly call for strategies that can cope with systemic failure and provide coherence among the underlying institutions and incentive structures. Instead of concentrating on piecemeal improvements, governments need to optimise the contributions of innovation and technology diffusion to the economy as a whole.

An effective strategy should include measures to cope with the potential risks of a systems approach: overestimating the capacity of governments, losing track of priorities or getting out of balance in addressing the specific *vis-à-vis* the generally applicable. The adoption of a systems approach can, however, increase demand for transparency, comprehensive evaluation practices and incentive structures within the policy-making process, providing greater consistency and credibility. Established fora for exchange of information, and organised assessment of past performance, can help countries effectively implement the much-needed systems perspective in policy making.

NOTES

1. The basis for this approach is rooted in the concepts of national innovation systems and appropriate framework conditions. See further OECD (1998).
2. Also addressed are areas raised by the G7 at its Jobs Summit in Lille – conditions for high-performance work places, investment in intangible assets and, to a lesser extent, interaction between macroeconomic and structural policy. This work was undertaken under the ageis of a ‘‘Joint Expert Group’’, consisting of members of the three main committees of the Directorate for Science, Technology and Industry. Work on evaluation of intangible assets was undertaken jointly with the Directorate for Education, Employment, Labor and Social Affairs, whereas co-operation with the Economics Department contributed to work on the interactions between macroeconomic and structural policy.
3. See OECD (1998) for the methodology and definitions of ‘‘best policy practice’’.

BIBLIOGRAPHY

ANDERSSON, T. (1998), ''Internationalization of Research and Development and Implications for a Small Economy'', forthcoming, *Economics of Innovation and New Technology.*

ÅKERBLOM, M. (1994), ''Internationalization of R&D in Finnish Multinational Firms'', Discussion Paper, Statistics Finland.

CAVES, R.E. (1982), *Multinational Enterprise and Economic Analysis,* Cambridge University Press, Cambridge.

DAVIDSON, W.H. and D.G. McFETRIDGE (1985), ''Key Characteristics in the Choice of International Technology Transfer'', *Journal of International Business Studies,* 15, pp. 5-21.

DUNNING, J.H. (1977), ''Trade, Location of Economic Activity and the MNE: A Search for an Eclectic Approach'', in B. Ohlin, P.O. Hesselborn and P.M. Wijkman (eds.), *The International Allocation of Economic Activity: Proceedings of a Nobel Symposium held in Stockholm,* Macmillan, London, pp. 395-418.

ETHIER, W. (1986), ''The Multinational Firm'', *Quarterly Journal of Economics,* Vol. 101.

HORSTMAN, I. and J. MARKUSEN. (1987), Licensing vs. Direct Investment: A Model of Internationalization by the MNE, *Canadian Journal of Economics,* pp. 464-81**.**

KRUGMAN, P. (1991*a*), ''Increasing Returns and Economic Geography'', *Journal of Political Economy,* 99, pp. 483-500.

KRUGMAN, P. (1991*b*), *Geography and Trade,* MIT Press, Cambridge, MA.

LICTENBERGH, F. and B. van POTTELSBERGHE de la POTTERIE (1996), ''International R&D Spillovers: A Re-examination'', NBER Working Papers No. 5668, Cambridge, MA.

McFETRIDGE, D.G. (1987), ''The Timing, Mode and Terms of Technology Transfer: Some Recent Findings'', in A.E. Safarian and G.Y. Bertin (eds.), *Multinationals, Governments and International Technology Transfer,* Croom Helm, London.

OECD (1996), *Technology, Productivity and Job Creation, Analytical Report,* Paris.

OECD (1997), ''Technology, Productivity and Job Creation – Towards Best Policy Practice'', unpublished memorandum, Paris.

OECD (1998), *Technology, Productivity and Job Creation – Best Policy Practices,* Paris.

PORTER, M.E. (1990), *The Competitive Advantage of Nations,* Free Press, New York.

REGER, G. (1998), ‘‘Changes in the R&D Strategies of Transnational Firms: Challenges for National Technology and Innovation Policy’’, *STI Review* (see this volume), OECD, Paris.

REICH, R.B. (1991), *The Work of Nations: Preparing Ourselves for 21st Century Capitalism,* Knopf, New York.

ROMER, P.M. (1987), ‘‘Growth Based on Increasing Returns Due to Specialization’’, *American Economic Review,* 77, pp. 55-62.

UNCTAD (1992), *World Investment Report 1992. Transnational Corporations and Engines of Growth,* New York.

VENABLES, A. (1987), ‘‘Trade and Trade Policy with Differentiated Products: A Chamberlinian-Ricardian Model’’, *Economic Journal,* 97, pp. 700-717.

TECHNOLOGY POLICIES IN NEO-CLASSICAL AND STRUCTURALIST-EVOLUTIONARY MODELS

TABLE OF CONTENTS

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SUMMARY

In this paper, we compare and contrast the policy implications that follow from neo-classical and structuralist-evolutionary views of the world. We argue that, although not always diametrically opposed, the two views do lead to some major conflicts in policy advice, conflicts that can only be resolved by choosing between them. We then outline some of the important policies that are suggested by the structuralist-evolutionary view. Next, we illustrate the real and important differences between the two approaches by briefly describing the different evaluations of a Canadian programme called the Industrial Research Assistance Program (IRAP) that have been made by eminent economists in the two camps. In a study we are currently doing for Industry Canada, we rate IRAP a clear success on structuralist grounds. Indeed, in our judgement, it is one of Canada's most successful technology policies. Yet neo-classical critics would abolish it. This is no small difference of emphasis, but rather a major difference in kind. Finally, we suggest some criteria that can be used to assess focused and blanket policies when direct information is not available on their achievements.

I. TWO VISIONS OF THE ECONOMY

The two visions of the economy are the neo-classical and the structuralist-evolutionary. There is a strong temptation, seen among other places in some OECD documents, to assume that these are just two slightly different ways of looking at the same reality, each focusing on different aspects. They are not. They represent alternative visions and those who would use theory to enlighten their policy decisions often need to choose between them.[1] In this section, we go into a bit more detail than readers might think necessary because much of what comes later depends on some detailed comparisons and contrasts between the two views.

In the well-known neo-classical model, competition refers not to a process but to an end state which, if the competition is ‘‘perfect’’, yields a unique optimal equilibrium. Departures from this optimum are due to market failures, the removal of which fully defines the tasks for policy. In contrast, in evolutionary models, competition refers to a process in which firms strive to differentiate themselves in profit-enhancing ways and which typically does not lead to an equilibrium – let alone a unique optimal one.[2] Although they offer no way to derive a set of scientifically determined, welfare-maximising policies, structuralist models can help to develop informed judgements about the areas in which the chances of useful intervention are relatively high.

Neo-classical theories

Traditional analyses of market successes, market failures and the rationale for interventionist government policies are usually conducted using neo-classical models of the type formalised by Arrow and Debreu. We consider five of the defining characteristics of such models.

Maximising behaviour: All agents maximise. This requires, among other things, that all situations that depart from perfect foresight can be treated as *problems in risk.* Two individuals with the same endowments and tastes, faced with the same choice between two alternative courses of action and possessed of the same full set of relevant information, will choose the same alternative: the one that maximises the expected value of their net welfare.

Unique equilibrium: Standard neo-classical models feature a unique, competitive, welfare-maximising equilibrium, characterised by constant tastes and technology. In standard welfare economics, the many ancillary conditions that are needed to rule out the possibility of non-existence of equilibrium, or of multiple equilibria, are assumed to be fulfilled.

Technology is kept behind the scenes: Typically, the details of technology are not explicitly modelled. Instead, the influence of technology is captured by the form of the relevant production functions which determines the output flows that result from given inputs. In microeconomic analysis, the structure of the capital that provides the inputs of capital services is not made explicit. Also, because of maximisation, a unit of expenditure on any activity, including R&D, creates the same expected marginal value no matter where it occurs.

Technological change seen only by its results: Because technology is not explicitly modelled, the process and the structure of technological change is observable only by its results. These are changes in at least one of: the nature of the inputs, or the production function, or the ‘‘Solow residual’’ (when given inputs are fed into a given production function but produce different outputs).

No explicit economic structure: Typical neo-classical models do not contain an explicit modelling of the economic structure in the sense that we define it later in this paper. Although many neo-classical economists have been interested in institutions, and although specific branches of neo-classical theory do model such aspects of structure as the location of industry and the internal management of firms, the general-equilibrium, Arrow-Debreu-type model on which general policy prescriptions are usually based, does not model institutions and other explicit aspects of what we call the facilitating structure.

Structuralist-evolutionary theories

Theories that we call structuralist-evolutionary, or just ‘‘evolutionary’’ for short, are designed to make technology and institutions explicit and to study the *process* of growth-creating technological change.[3] In these models, technological change is largely endogenous to the system in the sense that it responds to economic incentives. Although this class contains many distinct theories and models, most of them display the following five characteristics which contrast sharply with those of the neo-classical model described above.

Non-maximisation

Evolutionary modellers accept the evidence that uncertainty is pervasive in the process of endogenous technological change since innovation means doing something never done before. This uncertainty implies that agents will often be unable to assign probabilities to a full set of alternative future states in order to conduct risk analysis as conventionally defined. The assumption of rational maximising behaviour is, therefore, replaced by some alternative assumption such as groping in a purposeful, profit-seeking manner. Whatever explicit theory of choice is used, the key implication of genuine uncertainty is that two individuals with the same endowments and tastes, faced with the same choice between two alternative courses of action and possessed of the same bounded set of relevant information, may make *different* choices. In effect, each is deciding to back different horses in a race with unknown odds. Under uncertainty, neither individual’s choice can be said to be irrational.

The above argument applies to any actions designed to develop, adapt or adopt new technologies. For example, in making R&D expenditures directed at a major technological advance, similarly situated firms may make radically different decisions, backing different technological possibilities. Neither can be judged irrational *ex ante,* although it may well become clear *ex post* that one made a better judgement than the other.

No unique equilibrium

The assumption that firms seeking significant technological advances are groping in the face of uncertainty, rather than maximising in the face of risk, has a serious implication: *the absence of a unique, welfare-maximising equilibrium.* In some structuralist-evolutionary models there is no equilibrium, only perpetual change. In others, there is punctuated equilibrium, with long stable periods alternating with bursts of change whose timing and substance are not predictable in advance. In yet other formulations, there are multiple equilibria; historical accidents then determine which equilibrium will be reached or approached at any one time.

Technology is made explicit[4]

Technologies interact with each other in myriad ways, and these interactions are one of the sources of the complementarities that play such an important part in the economic system's reactions to changes in specific technologies.

First, call the technology that specifies each physically distinct, stand-alone, capital good a ‘‘main technology’’ and note that most main technologies have differentiated parts. For example, a commercial airliner is made up of a large number of sub-technologies which include an engine to deliver power, a thrust technology to turn that power into movement, a body, an undercarriage, a navigation system and an internal control system. Analysis of these sub-technologies shows them to be made up of sub-sub-technologies. An aircraft's navigation system is composed, for example, of compasses, gyroscopes, computers, sensing devices, radios, radar, and so on. Analysis of each of these shows them, in turn, to be made up of sub-sub-sub-technologie, and so on. This fractal-like nature of the aircraft's makeup is typical of virtually all capital goods. It is also typical of consumers' durables, such as automobiles and refrigerators, that deliver services for use in consumption.

Second, main technologies are typically grouped into ‘‘technology systems’’, which we define as a set of two or more main technologies that co-operate to produce some range of related goods or services. They co-operate within one firm, among firms within one industry, among firms in closely linked sets of industries, and even across industries that are seemingly unrelated from an engineering point of view.

Third, technological interrelationships occur in the vertical relations among industries when outputs of some industries are used as inputs into others. Materials producing industries, such as iron and steel, forest products and aluminium, create inputs used in many manufacturing industries. Industries that produce power and those that produce human capital provide inputs for most other industries, which may or may not be gross complements in the theoretical sense.

Fourth, some industries that produce different and unrelated outputs use similar process technologies – a phenomenon which Rosenberg (1976) calls ‘‘technological convergence’’. Technological convergence facilitates radical, discontinuous jumps in product technologies because each such product may not have to develop its own radically different process technology. For example, in the early 1900s, the radically new product of aircraft used process technologies that were already well developed by the bicycle and sewing machine industries. New technologies that require radical jumps in *both* product and process technologies are relatively rare in the history of innovation (although much less rare in the history of failed government attempts to encourage new technological developments!).

Technological change is made explicit

Endogenous technological change: Neo-classical micro theory treats technological change as exogenous. However, an abundance of empirical evidence suggests that competition in both product and process technologies is critical in many industries, making it the driving force behind much technological change. In the explicit modelling of technological change, an important role is played by such sources of non-convexities as once-for-all sunk costs of developing and acquiring technological knowledge, positive feedbacks from current market success to further R&D efforts, and complimentary relations among various technologies. In a model with uncertainty, the resulting non-linearities can give rise to path-dependent processes that may select any one of several available equilibria, or lead to no equilibrium at all (whereas if a unique equilibrium exists, only a limited role is played by these forces).

Complementarities: The concept of complementarity refers to the response to some change. When dealing with technological changes we need to distinguish two types of complementarities which we call Hicksian and technological. The Hicksian concepts of complementarity and substitutability in production (and consumption) theory refer to the signs of the quantity responses to a change in some price, with technology being given (in the form a fixed production function). A Hicksian complementarity occurs, for example, when an innovation lowers the cost of some good that is used as an input in several production processes, and more is demanded of other inputs in these varied processes.

Now consider an innovation in one technology whose full benefit cannot be reaped until many of the other technologies that are linked to it are re-engineered, and the makeup of the capital goods that embody them altered. We refer to these as ‘‘technological complementarities’’, defined as occurring whenever a technological change in one item of capital requires a redesign or reorganisation of some of the other items that co-operate with it in its internal makeup and/or in the main technology and/or in the technology systems of which it is a part. The most important point about this type of complementarity is that the effects cannot be modelled as changes in the prices of flows of factor services found in a simple production function. All of the action is taking place in the structure of capital, and the consequent changes will typically take the form of new factors of production, new products and new production functions.

The history of technological change is full of examples of technological complementarities. One important example concerns the introduction of electric power into factories. The consequences could not be modelled as a response to a change in the price of power in a production function designed to reflect the technological requirements of steam. Even if the price of steam power had fallen to zero, the saving would have been relatively small. More importantly, a zero price of steam power would not have led to the radical redesign of the plant which was the major source of efficiency gain under electricity (Schurr, 1990; David, 1991). This redesign depended on the introduction of the unit drive which attached an efficient power delivery system to each machine, something which was impossible under steam.

The automobile industry provides another example. The massive set of adjustments in existing and new capital structures that Fordist mass production brought about could not be modelled as a result of a fall in the price of parts supplied to Henry Ford by his early 20th century suppliers. Even a zero price of non interchangeable parts would have had an impact on the automobile industry that was both quantitatively smaller and qualitatively different from the revolution in the organisation of production that followed from interchangeable parts (which were made possible by the development of machine tools able to cut pre-hardened parts) (Womack, Jones and Roos, 1990).

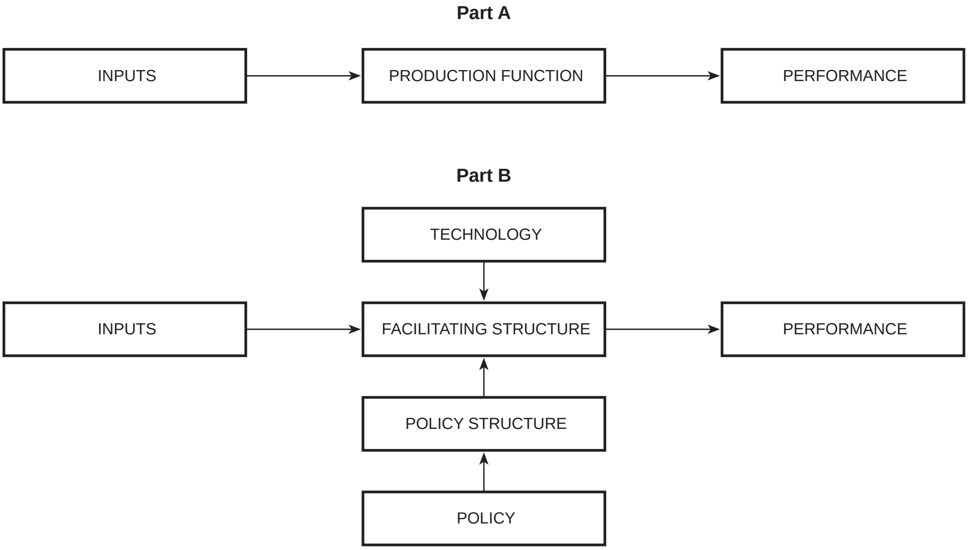
Neo-classical economics has no analytical way of dealing with these structural complementarities which dominate the evidence concerning technological change.

Structure is made explicit

Structure, including institutions, is often made explicit in structuralist-evolutionary models so that its place in the process of technological change can be studied. Here we use a refinement of our own version of what we call a ‘‘*structuralist decomposition*’’ that we originally presented in Lipsey and Bekar (1994), and Lipsey and Carlaw (1996). Its elements are summarised and contrasted with the aggregate neo-classical model in Figure 1. This theory is not meant to be something radically new, nor a substitution of the sociological for the economic, rather it is meant to be a vehicle for summarising and analysing relations that have been well documented by such students of technological change as Paul David, Nathan Rosenberg and Christopher Freeman.

The theory separates technology from the capital goods that embody it, making the latter a part of what we call the economy’s ‘‘facilitating structure’’. At any point in time, the facilitating structure, in combination with primary inputs, produces economic performance. The introduction of any important new technology, or a radical improvement in an old technology, induces complex

Figure 1. **The neo-classical and structuralist approaches**



Notes: Part A shows the neo-classical approach. Inputs of labour, materials and the services of physical and human capital flow through the economy's aggregate production function to produce economic performance, as measured by total national income. The form of the production function depends on the economy's structure and its technology, but these things are hidden in a black box, the only manifestation of which is how much output emerges from a given amount of inputs.

Part B shows our structuralist approach. Technology, the blueprints for the products we make and for the processes by which they can be made, is embodied in the facilitating structure, including the internal organisation of the firm, the geographic location and concentration of industry, the infrastructure and the financial system, to produce economic performance, measured by such variables as total national income, its distribution and the total amount of employment and unemployment. Policies are the blueprints for public activity. The policy structure includes public institutions of all types that embody the policy blueprints and give effect to them. Inputs are transformed by elements of the facilitating structure to produce economic performance.

Changes in technology require accommodating changes in the facilitating policy structure before they can have their full effect on economic performance. Changes in policy working through changes in the policy structure can cause changes in the facilitating structure, as when a change in competition policy allows more national mergers. Changes in policy can also affect technology directly, as when R&D tax credits lead to more R&D and hence to more technological change. Changes in the facilitating structure can also cause changes in the rate of technological progress, as when the reorganisation of an industry leads it to do more R&D.

changes in the whole of this facilitating structure. Ultimately, the performance of the economy is determined by the compatibility of technology, policy and facilitating structure.

Technology is defined as:

- *product technologies:* the specifications of the products that can be produced – where products refer to both intermediate and final goods as well as services;
- *process technologies:* the specifications of the processes that are, or currently could be, employed to produce these goods and services.

The stock of existing technological knowledge (both applied and fundamental) resides in firms, universities, government research laboratories and other similar production and research institutions as well as physical capital.

The facilitating structure: The elements of the facilitating structure are:

- all physical capital;
- the human capital that is embodied in people;
- the organisation of production facilities, including labour practices;
- the managerial and financial organisation of firms;
- the physical location of industries;
- industrial concentration;
- all infrastructure;
- private financial institutions and financial instruments.

The facilitating structure is the embodiment, or realisation set, of the idea set given by technological and organisational knowledge. It is altered by decisions taken by agents in both the private and public sectors.

Public policy: This covers the specification of the objectives of public policy as expressed in legislation, rules, regulations, procedures and precedents, as well as the specification of the means of achieving them as expressed in the design and command structure of public sector institutions from the police force to government departments to international bodies.

The policy structure is the realisation set that provides the means of achieving public policies which are the idea set. These means are embodied in public sector institutions which are a part of the facilitating structure. (Note the parallel with technology and its embodiment in capital goods which are a part of the facilitating structure.) It also includes the human capital related to the design and operation of public sector institutions (institutional competence).

Inputs: These are the basic inputs that are transformed into outputs by the production process which is embedded in the facilitating structure. Our inputs are raw materials and raw labour. Since raw labour and human capital are both embodied in the same persons there is a conceptual and a measurement problem with these two concepts. Arbitrarily, we take the amount of raw labour to be measured in value terms as the quantity of labour multiplied by the minimum wage. The rest is called a return to human capital.

Economic performance: We refer to the system's economic performance rather than just its output since we wish to include more variables than just its GDP. Economic performance includes:

- aggregate GDP, its growth rate, its breakdown among sectors, and among such broadly defined groupings as goods production and service production;
- GNP and its distribution among size and functional classes;
- total employment and unemployment and its distribution among such subgroups as sectors and skill classes;
- ''bads'' such as pollution and other harmful environmental effects.

Behaviour: All of the above is definitional. There is no right or wrong about definitions. They are to be judged by such criteria as clarity, consistency and usefulness. To analyse behaviour, we adopt the heuristic of assuming that all elements of the model are fully adjusted to the existing technologies. This implies that none of the agents who control any of the elements of technology, structure or policy have any incentive to alter what is under their control. We then introduce a single exogenous change in one of the elements of the model and enquire into all of the induced changes. This comparative static equilibrium analysis is used solely for purposes of understanding how the elements of the structure fit together. In practice, we expect the entire system to be evolving continuously and never to reach anything remotely resembling either a static equilibrium or a balanced growth path.

An exogenous change in technology: A change in technological knowledge will cause induced changes in the facilitating structure, in policy and in performance. We take these in turn.

Adjustment of the facilitating structure

To see what is involved in the link from technology to structure we need to establish a number of points.

- First, if elements of technology change, various elements of the facilitating structure will change adaptively. For example, a new method for making steel will have to be embodied in new machines and possibly new plants. This may affect the optimal size of plant and hence the concentration in the steel industry, as well as the location of steel plants. Various elements of the infrastructure may need to be changed. So also will human capital change if the new methods require amounts and types of skills that differ from those required by the old methods. These changes are made mostly by self-interested agents who respond to the price and profit incentives that are created by the changes in technology.

- Second, at any moment in time the facilitating structure may be better or worse adapted to any given state of technology. For example, labour practices with respect to job demarcation which were good adaptations to the Fordist production methods may not yet be adjusted to the new Toyotaist production methods that have already been installed. For analytical simplicity, we assume that there is a unique optimum structure for any given state of technology (an assumption that can be removed whenever it threatens to influence the results).
- Third, we note that there are substantial inertias in most of the elements of the structure. Here are some of the reasons. Much capital is highly durable and will not be replaced by new capital embodying some superior technology as long as its variable costs of operation can be covered. The new pattern of industrial location and firm concentration will not be finalised until all the firms and plants are adjusted to the new technology. The optimal design of plant and management practices may not be obvious after the introduction of a new technology (as was the case with the computer). The understanding of what is needed by way of new infrastructure may take time, as will its design and construction (witness long discussion about the new information highway). New requirements for human capital must be established and the appropriate training devised (both on the job and in school).
- Fourth, this period of adjustment is often ‘‘conflict ridden’’ (Freeman and Perez’s term) because old methods and organisations which worked well, often for decades, begin to function poorly in the new situation and often become dysfunctional. Furthermore, the uncertainty accompanying any radical new innovations implies that there will be many different but defensible judgements of what adaptations are actually needed.

Adjustment of policy and the policy structure

Changes in technology and the facilitating structure can require adaptations in policies and the policy structure that are their instruments. For example, technological changes often turn natural monopolies into highly competitive (in the Austrian sense of the term) industries. For example, the post office once had a natural monopoly in the delivery of hard copy messages but today that can be done by faxes, e-mail, satellite links and a host of other technologies which have made this activity highly competitive. A new technology can also do the reverse by introducing scale economies large enough for natural monopolies to emerge in what was previously an oligopolistic industry in which firms rigorously competed with each other.

Changes in policy and the policy structure tend to happen with long lags. Uncertainty can make it unclear what reactions are needed, giving power to vested interests who would resist the changes. Inertias in political decision taking, plus the resistance of those who are hurt either by the new technologies or by the accommodating changes in policy, can slow the process of adaptation. For example, the US legislators are still arguing over the revision of the Glass Stegal Act, decades after the ICT revolution made prohibitions on interstate banking obsolete.

Not only does policy react to changes in technology and in the facilitating structure, it may also change proactively in an attempt to alter technology or the structure. A policy that directly subsidises research on some new technology is operating directly on technology. (When we say directly we meant through the policy structure; a disembodied policy needs some structure to give it effect and a new policy usually, but not necessarily, requires some amendment in the existing policy structure.) A policy that encourages the establishment of R&D labs or richer links between the private sector and universities is altering the facilitating structure in the expectation that these changes will influence the rate and nature of technological change (as the Canadian IRAP policy has done).

Changes in performance

We have seen above that a change in technology requires a change in structure to make it fully operational, while the changes in structure often induce or require substantial changes in policies and the policy structure. For this reason, economic performance typically continues to change even after the new technology is in place because the facilitating structure and policy are still reacting and adapting to it. For example, it was decades after the introduction of electricity into factories before the technology completed its evolution through the central drive that was typical of steam, through the group drive which was an experiment in partial decentralisation of the power system, to the unit drive which put a power system on each machine tool. The layout of factories could then be altered drastically to take advantage of the flexibility provided by the unit drive. It was only after new factories with the new machines and new layouts replaced the long-lived older ones that the full effects of electricity on industrial output and productivity were felt – this some several decades after the first use of electricity in factories.

II. TYPES OF POLICY

Before we consider the various approaches to policy suggested by the different visions of the economy, we need to distinguish types of policy. For our purposes, two types of classification are useful. The first deals with the object of policy and the second *with the breadth of the policy's focus.*

Targets: Metcalfe (1996) distinguishes between two types of policy:

> The first is ‘‘... concerned with resources and incentives taking the technological possibilities and capabilities of firms as given.... These policies work by changing net marginal returns to developing technology. [They include such things as] ... tax allowances for R&D, specific innovative subsidies, [and] the terms and duration of patent protection.... [The second’s purpose] ... is to change and enhance the innovation possibilities that firms face by improving their access to knowledge and by improving managerial capabilities.’’

We accept the general drift of his distinction but find difficulties with some of its specifics. First, many policies do both. Some of the most successful policies in Canada and the United States have targeted specific technologies, and sometimes even specific firms, while using that support to alter the general conditions under which firms innovate – to alter what we call the facilitating structure. Second, any policy that targets the set of things in Metcalfe’s first category is likely to alter the firm’s technological capacities. Nonetheless, we accept the general distinction which we make in our terms by distinguishing between the objectives of altering the costs and/or returns to inventive and innovative activities, and the objectives of altering the underlying facilitating structure within which technology is embedded at any moment of time and altered over time. Our main caveat is that many policies have both objectives and even those that emphasize one overtly, often have a major effect on the other, sometimes inadvertently.

Focus: We distinguish three major focuses for technology policies. *Framework policies* provide general support for some specific activity across all of the economy. In practice (and usually in principle) they are single-instrument policies. They do not discriminate among firms, industries or technologies but, instead, are generally available to everyone who engages in the covered activity. Examples are support for R&D (which include R&D subsidies and tax credits) and patent protection for the owners of intellectual property. *Focused policies* are policies designed to encourage the development of specific technologies such as nuclear power, particular industries such as software, or particular types of R&D such as pre-commercial research. They are typically not generally available, being narrowly focused on particular client groups. *Blanket policies* incorporate elements of both framework and focused policies. They are more narrowly focused than the former, but less so than the latter. They are designed to accommodate a number of technological objectives at once, usually in the context of pushing a very broad objective such as increasing technological competence in firms. They typically use multiple instruments and have some form of assessment mechanism that enables the administrators to tailor the assistance they provide, at least to a certain degree. As with framework policies, blanket policies are generally available to those engaged in the covered activities. In the past, framework and focused policies have usually sought to influence innovation by changing the costs and benefits of R&D, while blanket policies have often been used in attempts to alter the facilitating structure (as well as directly influencing the payoff from innovative activity).

III. POLICY THROUGH NEO-CLASSICAL LENSES

Market failures

The micro-based neo-classical approach is found in a few disaggregated growth models (such as Helpman and Grossman, 1991), in much of the industrial organisation literature dealing with such subjects as patent races, and in textbook welfare economics. It allows spillovers and other sources of market failures to be examined individually. In these models, the removal of *all* existing market failures leads to an optimum, and policy makers are often advised that the removal of *some* existing market failures will increase welfare.[5]

The neo-classical theoretical literature on the specific issue of technology spillovers usually takes Arrow (1962) as its starting point. He argued that a positive spillover results from any new technological knowledge, due to the existence of indivisibilities, non-appropriabilities and uncertainties. Since R&D is the source of much new knowledge, the social return to R&D greatly exceeds the private return. This basic insight is then inserted into a neo-classical model in which the stock of knowledge is both a homogeneous and a continuous variable which can be added to incrementally. A perfect patent system can be imagined which gives each person a complete and enforceable property right in the knowledge that he or she creates. If we add the assumption of zero transaction costs, each creator of knowledge would act as a perfectly discriminating monopolist. Both the use of existing knowledge and the value of the resources devoted to knowledge creation would then be optimal. In reality, property rights to knowledge are highly incomplete, leading to the prediction that knowledge-creating activities, such as R&D, will be carried on below the optimal rate and should, therefore, be encouraged by public policy. Obvious instruments are more embracing and more enforceable patents that give more return to inventors and innovators, and direct support for R&D in the form of subsidies or tax relief. Notice that in this formulation, there is no distinction between the inputs into the advancement of technological knowledge and the output of the new technological knowledge. Increasing one increases the other. So the policy prescription is indifferent between lowering the costs of generating new technological knowledge and raising the payoff to that knowledge.

Because neo-classical aggregate growth models have no detailed structure, they tend to focus solely on policies that apply across the whole economy. In neo-classical micro models, inputs and outputs are homogenous, everything that is not certain can be expressed as risk, and everything is equated at the margin, including the expected return from a marginal expenditure on R&D everywhere in the economy. In this world, focused policies, which single out particular technologies, industries or firms, distort the allocation of effort from its optimal pattern. If there is a positive externality associated with non-rivalrous technological knowledge, then it is appropriate to offer generalised assistance. For example, if there is a case for subsidising R&D because of its positive spillovers, that case applies equally to all R&D.

Incrementality tests

If an expenditure of government funds leads to no alteration in targeted behaviour, then the funds have clearly been wasted. For example, if firms are given a subsidy to locate in some depressed area and the only firms that accept the money are those that would have gone there anyway, and they do exactly what they would have done without the subsidy, the money has been wasted. If, however, firms go to the depressed area because of the subsidy, what we call the ‘‘weak test of incrementality’’ is passed: something that the policy makers are trying to do has happened as a result of their expenditure of funds. This discussion illustrates that in assessing weak incrementality, we need to know the aims of the policy and be able to measure the relevant results. The structuralist-evolutionary approach accepts this weak incrementality test and measures incrementality against the goals of policy that it recognises and that we study in the next section.

The neo-classical approach goes much further, accepting the goal of maximising income within the context of a static allocation of resources. The ‘‘narrow test of incrementality’’ is that some technology is developed or installed that would not have been produced or installed in the absence of the policy or programme under consideration. No other structural changes are considered. But most neo-classical versions are stricter yet. What we call the test of ideal incrementality is that the policy is in some sense not just a good use but an optimal use of the government expenditure. Usher (1994) defines this test as consisting of four parts.

There is a percentage of the costs of the project that must be provided to the client firm in order to induce it to undertake some level of R&D investment. The project undertaken must be the least costly way to produce the desired level of R&D investment (*i.e.* there cannot be another firm that could undertake the action more cheaply and the subsidy provided must be the minimum necessary to induce the client firm to undertake the activity).

To pass the strong test of incrementality, the anticipated net social benefits from generating the action must exceed the ‘‘subsidy’’ given to encourage the action. The measure of the subsidy must include the transaction costs, dead weight losses and other ‘‘leakages’’ that occur when the government intervenes in the market. Both Tarasofsky and Usher provide some quantitative estimates of these costs as a fraction of a dollar of subsidy spent. These range from a factor of 15 per cent up to 100 per cent or more. So that the total cost of intervention, in their estimation, can be more than double the amount of subsidy given.

The third and fourth points amount to the condition that the total costs of the government intervention (discounted appropriately) must be less than, or equal to, the total anticipated benefits (also discounted appropriately). It is difficult, if not impossible, to measure the direct and full spillover effects of technological change that are needed to apply Usher’s test of incrementality – as is well known to practitioners in this field. In principle, the test could be applied to cover policies designed to alter the structure, but since technology and structure are not explicitly modelled in neo-classical economics, in practice, the test is usually applied to the costs and benefits of the R&D or specific technological changes that are being targeted.

IV. POLICY THROUGH STRUCTURALIST-EVOLUTIONARY LENSES

The evolutionary justification for technology policies

Whatever theory one uses, the case for an active technology policy requires accepting the proposition that it is socially desirable to accelerate the rate of technological change. In this section, we see how evolutionists may come to accept this proposition although not being able to derive it from their theories as a formal proposition. The argument has three main points.

Knowledge externalities

Structuralists accept that the non-rivalrous nature of technological knowledge creates beneficial externalities. Indeed, because of the complex set of complementarities analysed in our structuralist model, the inventor/innovator of any fundamental new technological idea is unlikely to be able to appropriate more than a tiny fraction of the resulting total social benefits.

No optimal level of R&D

We observed in earlier sections that there is no well-defined optimum allocation of resources when technology is changing endogenously.[6] Thus, structuralist theories which seek to incorporate this fact have the following important implication:

> *Because there is no unique optimum allocation of resources when technology is changing endogenously under conditions of uncertainty, there does not exist a set of scientifically determined, optimum public policies with respect to technological change in general and R&D in particular.*

Even if such an optimum amount did exist, we do not know whether agents would produce too much or too little R&D, given that they are making decisions under uncertainty about lumpy investment with lumpy potential payoffs. The market economy encourages innovation by giving rewards to successful innovators, and huge rewards to the really successful, while the unsuccessful suffer losses. There is no existing theory of choice that allows us to predict how agents will react to such uncertain and lumpy possibilities where there are significant differences in both the *ex post* and the *ex ante* payoffs to R&D done by different entrepreneurs.[7]

Policy judgement

Accepting this conclusion has important consequences for how we view economic policy in the area of growth and technological change:

> *If there is no unique optimum rate of R&D, of innovation, or of technological change, policy with respect to these matters must be based on a mixture of theory, measurement and subjective judgement.*

The need for judgement does not arise just because we have imperfect measurements of the variables that our theory shows to be important, but because of the very nature of the uncertain world in which we live. Although a radical idea with respect to microeconomic policy, the point that policy requires an unavoidable component of subjective judgement is commonly accepted with respect to monetary policy. For two decades from the mid-1950s to the mid-1970s, Milton Freidman tried to remove all judgement from the practice of central banking by making it completely rule-based. When his advice was followed by several of the world’s central banks, the monetary rule proved ineffective as a mechanical determinant of policy – just as many of his critics had predicted. Today, the practice of central banking is no different from the practice of most economic policy: it is guided by theoretical concepts; it is enlightened by many types of empirical evidence which are studied for the information that each provides; and, in the end, all of these are inputs into the *judgement calls* that central bankers cannot avoid making.

Because most economists were thoroughly trained in neo-classical welfare economics, many do not like to be told that most policy decisions depend on significant amounts of subjective judgement, rather than solely on scientific analysis. For obvious reasons, many economists prefer models that provide precise policy recommendations, even in situations in which the models are obviously inapplicable to the world of our experience. Our own view is that, rather than using neo-classical models that give precise answers that do not apply to situations in which technology is evolving endogenously, it is better to face the reality that there is no optimal policy with respect to technological change. In the world described by structuralist models, dynamic efficiency is as inapplicable a concept as is static efficiency.

By rejecting Arrow's argument, we are not rejecting the possibility that it would be socially desirable to accelerate the rate of technological change. Most economists, the present authors included, believe that innovation and economic growth improve human welfare on average so that innovation is correctly judged to be socially valuable. But what we cannot do is to determine that the current amount of innovation is too much or too little by comparing the actual amount against some criteria of optimality. Where then does this leave us?

In the final analysis, as we have said, it is a matter of judgement that all of the forces surrounding technological change add up to net positive externalities so that there is a case for active innovation policies designed to accelerate the rate of technological advance above what the unaided market would produce. This is a judgement that virtually all governments are revealed to make – by virtue of their many technology enhancing policies.[8]

The need to encourage technological advance through public policy can be thought of as a response to a *market failure.* There is no need to ban this concept from structuralist-evolutionary theories. Whereas in neo-classical theory the market fails when it does not achieve the unique optimal equilibrium, it fails in structuralist-evolutionary theory when it does not lead to some desired and attainable state.

Structural-evolutionary roles for policy

Showing that a policy thought to follow scientifically must depend on some irreducible element of judgement is not an insignificant accomplishment. But if that was all that the structuralist-evolutionary theory accomplished, it might not be of great practical value. Fortunately, *structuralist decompositions* also shed much light on ways of accomplishing the ultimate goal of accelerating technological change – ways that supplement, and sometimes differ from, those suggested by neo-classical theory. Structuralist theory reveals roles for policy in addition to responding to externalities. Many of these are in Metcalfe's second category of policies that try to alter the structural conditions under which technological advance occurs rather than merely altering the costs and payoffs associated with research and development. First, as we have seen earlier, technological interrelationships that cause positive externalities are extremely rich, making most externalities context-dependent, both sectorally and temporally. A structuralist decomposition reinforces this. Second, there is a major trade-off between innovation and diffusion that complicates technology policy. Third, there are many roles for technology policy beyond internalising spillovers. Fourth, institutional competence to administer programmes and policies becomes a much more complex issue than it is in neo-classical principal-agent analysis. These issues are considered separately in the four sub-sections that follow.[9]

Specific externalities

An important way in which structuralist theories assist in motivating and directing innovation policies is by identifying a much more complex set of spillovers than is found in neo-classical theory. The spillovers associated with each invention can be both positive and negative; they differ both among inventions and the structures into which they are introduced; and costs and benefits have a temporal sequence, with costs tending to be front-loaded and benefits extending into the indefinite future.[10] So, even if the expected private returns to various lines of R&D were equated, as they are in the neo-classical model, the net externalities, and hence potential social returns, would show enormous variations across micro margins. In addition, the structuralist decomposition highlights an additional set of externalities associated with the relation between technology and the facilitating structure.

The classes of spillovers suggested by structuralist theories cover spillovers: *i)* between technology, facilitating structure, and performance; *ii)* within technology; and *iii)* within facilitating structure. (Because economic performance is defined as the final outcome of economic activity there are no spillovers within performance.) A detailed knowledge of these externalities suggests policy opportunities that tend to be either rejected or ignored by the neo-classical model. Many of the specific policy lessons that we use later are related to these spillovers, both as they create opportunities for useful policy interventions and as they create pitfalls for policies that ignore them.[11]

Spillovers within technology: As we observed earlier, developments that improve the efficiency of one technology are often useful in many other technologies. Such was the case, for example, in the 19th century when improvements in machine tools used in very specific applications turned out to have wide application in the machine tools used in other industries (Rosenberg, 1976). The value of many of these indirect effects cannot be appropriated by their initiators, thus giving rise to inter-technology externalities. This creates a potential role for policy which we consider in detail below.[12]

Spillovers between technology and structure: A change in any element of technology typically affects the values of many elements of the structure. Spillovers arise because innovators do not usually take account of the structural effects that they induce. A new technology will typically affect the values of most elements of the facilitating structure, such as exiting capital, firms, contracts, locations and elements of the infrastructure. As the structure changes, this will in turn affect the values of many other existing technologies and R&D programmes. The potential roles for policy are obvious.

Spillovers within facilitating structures: The facilitating structure is composed of a set of interrelated elements. A change in one of them affects the value, or efficiency, of many others. The externalities arise because agents who change those elements of structure that are under their control typically do not take account of induced changes in the values of other elements. For example, changes in the nature of physical capital often require changes in human capital, in the physical location and organisation of firms, and in the infrastructure, before they can achieve their full potential. The policy implication is that there is a potential role for government to assist the full adjustment of that structure where private incentives are lacking.

Spillovers from performance to structure and technology: Experience with the use of evolving technologies often alters the value of some elements of the existing technology and/or structure. Spillovers occur when agents who use the technology cannot capture the value of their experience. The Schumpeterian model of innovation saw technology developing in a one-way flow from pure science, to applied work, to the shop floor, to the sales room. Modern research shows a two-way flow of information running backwards and forwards among every stage of the value-added chain. Von Hipple (1988) shows that some innovations are derived from the initiative of producers, some from downstream users and some from upstream suppliers. New technologies typically have many imperfections that can only be identified through ‘‘learning by using’’, causing users to face significant amounts of uncertainty (Rosenberg, 1982, Chapter 6). The experience of these new users often generates non-appropriable new knowledge that benefits producers and, through product improvements, other users. The two obvious places where policy has the potential to assist are in solving the co-ordination problem between producers and users and in inducing users to create this knowledge.

Spillovers and diffusion

Major radical innovations never bring new technologies into the world in a fully developed form. Instead, these technologies first appear in a crude embryonic state with only a few specific uses. Improvements and diffusion then occur simultaneously as the technology is made more efficient and adapted for use over an increasingly wide range of applications through a series of complementary innovations. The more fundamental is the new technology, including what the literature now calls ‘‘general purpose technologies’’, the more marked is this process of long and slow evolution from crude prototypes with narrow use, to highly efficient products with a vast range of applications. Furthermore, there is enormous uncertainty with respect to the range of applications that a new technology may have. Although this process is usually called ‘‘diffusion’’ because some original generic idea, such as how to generate electricity, is diffusing through the economy, the process bears no relation to diffusion defined as the use of some unchanged piece of knowledge by more and more agents. Rather, the generic idea is added to, mutated and refined as more and more agents adapt it to their own uses.

In a neo-classical world with perfect foresight, no transaction costs and comprehensive airtight patents, the patent holder, and all possible ancillary inventors/innovators, would make contracts to share profits. In reality, this is impossible. Typically, inventors/innovators have no conception of the final range of applications for their new ideas – nor of the major and minor improvements and complementary technologies that will be developed along the way. Under these circumstances, granting airtight patents to inventors/innovators of generic technologies puts them in the position of central planners who manage innovations while having very imperfect knowledge. So, in making policy decisions on the amount of internalisation that it is desirable to create, there is no presumption that the first-best solution would be to give all of the benefits to the original inventor/innovator. One documented example of a patent drastically slowing the diffusion and evolution of a generic technology is Watt’s patent on the basic process of the steam engine. Until the patent expired in 1800, new uses of the steam engine were curtailed because complementary inventions could not be made, in particular those associated with the high-pressure engines needed for mobile uses.

Even if, by some miracle, property rights were such that the inventor/innovator could control his invention long enough to internalise all the externalities, there would still be a place for public policy in this area. The best policy would then be to intervene to *create an externality* by reducing the effectiveness of property rights, and hence the reward going to the original inventor or innovator. This tips the trade off in the direction of more diffusion. A documented example of major differences in judgement over this trade off is found in pharmaceutical patents. The US position is that 20 years is the patent life required to provide sufficient incentive for drug companies to engage in a satisfactory level of R&D. A Canadian Royal Commission conducted by the eminent Canadian economist, Professor Harry Eastman, argued on the basis of considerable evidence that a five-year patent life was quite enough, and that the remaining 15 years only served to create massive rents for the drug companies. This is no small difference in judgement!

Roles beyond internalising spillovers from technological knowledge

Structuralist models emphasize several features that provide scope for technology-enhancing policies in addition to internalising the spillovers that arise from new technological knowledge.

Induced changes in structure: Changes in technology typically require accommodating changes in the facilitating structure. Public policy can respond helpfully in two ways. First, those elements of the structure that are directly determined by policy can be altered. An example is the regulation of the telecommunication industry after the ICT revolution. In this case, changes came all too slowly in many countries. Second, public policy can assist those structural adjustments that are under private sector control but are also subject to major externalities, such as altering the education system to produce skills required by the new technology. (Of course, policy can, and often does, respond in the unhelpful way of slowing down the necessary adjustments to the structure. This can be done by errors of both omission and commission.)

Proactive changes in structure: Policies may also indirectly target technological change by altering elements of the facilitating structure. Examples of such policies include attempts to integrate some university, government and private sector research activities, attempts to create technology information networks, and attempts to change private sector attitudes toward adopting new or different technologies. Furthermore, a government can give funds to firms to develop technologies that they would have developed anyway but then attach structural conditions. This has been done by more than one government to encourage the development of long-range research facilities. All of these initiatives would fail the standard narrow incrementality test that measures only direct changes in specified technologies. But they would pass a wider incrementality test that considers alterations in the structure which would not have happened without the government pressure. A prime example is US military procurement policy, which, to a great extent, created the US software industry and then developed and imposed consistent standards on it (see Lipsey and Carlaw, 1996, p. 311).

Sunk costs: Sunk costs and path-dependent technological trajectories play a prominent role in structuralist theories. Lumpy sunk costs are important for the development of new products and processes, and for the acquiring of codifiable knowledge about new technologies, as well as tacit knowledge of how to operate given technologies. One major policy implication is that government bodies can disseminate technological knowledge by operating on a scale that makes the sunk costs bearable, even trivial, where they would be prohibitively high for small firms.

Path dependency: The knowledge that technologies evolve along path-dependent trajectories suggests that the encouragement of generic technologies in their early stages of development is more likely to produce socially valuable externalities than the encouragement of highly specialised technologies at later stages in their development.[13] However, as Paul David has emphasized, the early stage of many technological trajectories (when government assistance can have most impact) is where exposure to uncertainty is greatest. What looks like a sure winner, such as lighter-than-air craft, or hovercraft, or atomic energy, may turn out later to have totally unforeseen problems that severely limit its commercial success.

One important lesson is that policy opportunities vary over the stage of a particular technology's development. Expectations of large spinoffs from a new generic technology must be balanced against the uncertainties inherent in its early development. Assistance is often best applied after it becomes clear that the technology has major potential, but while it is still in a relatively generic state.[14]

A cautionary lesson is suggested by the theory and evidence on competition among firms who are working on the same technological trajectory. Procurement decisions may lock the economy into one version of the competing technology before the relative merits of the alternatives have been seriously explored (an issue that would not matter if everything was reversible as in neo-classical theory). Arthur (1988) gives several examples where this appears to have happened.

Institutional competence

The neo-classical model gives optimal policies that do not depend on any specific institutional structure. In reality, as emphasized in structural approaches, various public sector institutions have different institutional capabilities. The behavioural differences are partly based on constitutional differences, partly on the different power relations among various special interest groups, partly on the differences in the quality of recruits and the subsequent training of civil servants, and partly on differences in accumulated learning-by-doing in operating each country's specific policy instruments.

The issue here is analogous to that of the difference between technology and capital structure. Technology, which is the blueprint for doing things, is embodied in physical capital which is part of the facilitating structure. Good technology may be embodied in poor capital if its production is beyond the capability of the capital goods producers (as it sometimes is when capital goods designed in the West are produced in less-developed nations). Similarly, public policies are blueprints for public-sector actions which are given effect by institutions and their bureaucracies. A policy that is good in the abstract may work poorly in one particular country because it is beyond the competence of that country's bureaucracy to administer, or because it runs afoul of other incompatible elements in that country's facilitating or policy structures. Many things may be the culprit, including the routines of government agencies, the mind set of the delivery officers, or the lending and project approval procedures. The obvious, but important lesson, is that the success of policies is not determined solely in the abstract. Instead, it partly depends on the specific context in which it is implemented. Potentially good policies are designed to operate within the institutional competences of the organisations that will administer them.

V. HOW THE TWO VIEWS RELATE TO EACH OTHER

The OECD seems to view the neo-classical and the evolutionary policy advice sets as complementary.

> ''In sum, both approaches offer useful frameworks for policy recommendations. Each has its specific strengths and weaknesses in providing a basis for policy intervention. While their emphasis differs, the rationales are not mutually exclusive.'' (''Technology, Productivity and Job Creation: Towards Best Policy Practice – Interim Report'', March 1997, para. 30).

Although we would not wish to argue the opposite case, that the two approaches offer exactly contradictory advice, we would stress that they are very often in conflict and that this conflict leads to strong differences in policies advocated by economists working from the assumptions of each tradition. Below are some important illustrations of differences.

Framework policies and programmes

We have seen in Arrow's version of the neo-classical model, where knowledge is a single, homogenous, continuous variable which produces a single positive externality, that there is an optimum amount of innovation. Given the externality, this optimum amount can be achieved either by lowering the cost of the inputs to R&D or by increasing the value of the technological advances that are its outputs.

In contrast, what is specified in Arrow's model as a smooth accumulation of knowledge is seen, in a structural decomposition, to be the net result of many failures and many successes. We have already observed that in a neo-classical world in which risk analysis fully applies, the expected values of a marginal unit of expenditure on R&D would be the same everywhere, so that lowering the cost of inputs or raising the payoff to outputs would have similar effects. However, in a structuralist model with uncertainty and non-convexities, the calculation that equates expected payoffs to R&D across the economy cannot be performed. Furthermore, knowledge does not always arrive in continuous amounts. It comes instead in discrete packages, the benefits and costs of which also are discrete lumps. The technology that is generated by new knowledge is heterogeneous and its value is often context-specific. Thus, expected values cannot be rationally calculated in advance, are often miss-assessed even after initial breakthroughs have occurred, and are certainly not equated at the margins of different activities.

One implication is that various instruments of framework policies will have different effects on the amount of R&D performed, depending on both the technological and the structural contexts within which they operate. Here are some illustrations.

R&D vs. intellectual property protection: Patents only reward those who succeed, while R&D support is independent of results. Since expected values of a marginal addition to R&D often cannot be rationally calculated, and would not necessarily be equated at every margin, an across-the-board subsidy to costs will have different effects from an across-the-board increase in the security of intellectual property. Furthermore, the ability to extract value from patents varies greatly across types of innovation. Thus, the same amount of aggregate R&D will be distributed differently among firms when it is induced either by an effective patent system or by an R&D subsidy.

Context-specific externalities: What looks at the macro level like a single homogeneous externality associated with the accumulation of technological knowledge is seen under a structuralist decomposition to be an aggregate of many different and complex externalities, some of which are negative. From this point of view, equal assistance to all technological advancement is a blunt weapon. Aggregation, or its equivalent micro homogeneity assumption, does not just suppress a few second-order details, it gives many policy conclusions that are diametrically opposed to those arising from a structuralist decomposition.

For example, the structuralist decomposition suggests that one major undesirable effect of framework policies arises because they benefit all firms, whether or not they are otherwise able to internalise the benefits of their activities. Firms in industries such as pharmaceuticals, where patents are effective, are able to internalise enough of the value that they create to provide strong incentives to innovate. So these industries gain double benefits from R&D support because their profits are already protected by patents.

A second important example is routed in the upstream-downstream complementarities of technology. As argued in more detail in Lipsey and Carlaw (1996), the inability to keep the results of pre-commercial research secret in some activities may lead to too little of it, while ability to keep it secret in other activities may lead to too much of it that is overly duplicative. An R&D subsidy in sectors where firms are hoarding, and thus duplicating, pre-commercial R&D efforts only aggravates what is often wasteful behaviour. A focused policy that discriminates between situations where the free market produces too much and where it produces too little pre-competitive research is potentially superior to a framework policy that merely encourages more of whatever is already being done. For example, focused or blanket policies can create commitments among firms that encourage them to do pre-commercial research in which they all share. (The Japanese Ministry of International Trade and Industry, MITI, has been quite successful in creating commitment mechanisms that allow firms to create, and share, pre-competitive research.)

Third, not only will a framework policy cover some activities that do not need support, it will miss some that do. For example, because there is no clear distinction between innovation and diffusion, much activity that is related to the development and use of new technologies may not appear to be basic R&D. Baldwin (1996) has shown that small firms do little recognisable R&D, but spend a lot of time monitoring what larger firms are doing and adapting these things to their own uses. Although this activity may be just as important as upstream R&D, it will not be covered by such framework polices as R&D tax credits.

Conclusion: Insofar as the object of technology policy is to provide adequate incentives, ideal public assistance would vary inversely among agents according to their ability to capture the returns of invention and innovation; assistance would not vary with either their R&D or their invention and innovation. From a structuralist point of view, therefore, the ideal framework policy would be to give a lump-sum payment to each inventor/innovator sufficient to provide the appropriate incentives, and then to make the resulting technological knowledge freely and immediately available. However, out of the feasible set of instruments, structuralist theories do not preclude such framework policies as patents and R&D subsidies or investment tax credits *per se.* Rather, they provide an explanation for their effects and a method of going beyond them. In contrast to Arrow's theory, therefore, structuralist theory argues for a context-specific view of R&D policy because new technologies are embodied in specific structures.

Focused policies and programmes

Unlike framework policies which are typically embodied in several programmes and projects, focused policies are typically embodied in a single programme or even a single project. In an ideal world, focused policies could target exactly where assistance was needed, striking the right balance between encouragement of innovation and diffusion in each particular context, on the one hand, and encouraging changes in the facilitating structure at a rate which is well adapted to the existing pattern of technological change, on the other hand. But, many of the conditions of an ideal world are not met in our world. This causes problems when heavy reliance is placed on focused policies:

- it is easier for its clients to capture a policy or programme the more it is focused on small groups;

- the more focused a policy the more likely is it also to be captured by politicians who have a self-interest in the projects that are accepted and rejected;
- masses of detailed information are required to calculate the externalities associated with each potential innovation in order to design the appropriate, context-specific, focused assistance;
- the transaction costs in calculating those externalities that can in principle be located, and in designing and administering the large set of required focused policies, would be prohibitive;
- even if such a set of policies could be designed and instituted at zero transaction costs, their administration would require a highly sophisticated bureaucracy at all levels from head office to the field;
- focused policies carry the risk of trade sanctions, since subsidies must be generally available to be exempt under WTO rules.

The above points show the undesirability of providing support to technological change *exclusively* with focused policies.

Where specific needs and major externalities can be identified, while capture and other pitfalls can be avoided, focused policies can provide effective assistance to specific technologies, industries and even firms. Lipsey and Carlaw (1996) provide several examples. Such focused assistance can be used to complement blanket and framework policies.

Blanket policies

Third of our three major policy classes, blanket policies is intermediate between focused and framework policies. From a structuralist-evolutionary point of view, these policies have much to recommend them, given the general objective of encouraging technological change and the problems that are associated with framework and focused policies. First, blanket policies can be used to push a policy objective without being tied to a particular generic instrument. In contrast, framework polices are typically associated with specific instruments such as tax credits for R&D and investment, intellectual property protection and broad-based subsidies. Second, blanket policies can accommodate some context-specific tailoring (condemned by neo-classical theory but supported by structuralist-evolutionary theory) that does not encourage capture, because they can be made conditional on the general objective. Third, where blanket policies contain an element of subsidy, they can be made generally available and so avoid the risk of trade sanctions.

IRAP: A case study of a blanket policy

The difference between the neo-classical and the structuralist approaches to policy is well illustrated by the different evaluations of the Canadian Industrial

Research Assistance Program (IRAP). We choose IRAP as a case study that illustrates the differences that arise in many evaluations. What follows is based on Lipsey and Carlaw (forthcoming).

Objectives and performance: While assisting firms with specific technological advances (Metcalfe's first type of policy), IRAP has induced changes in the facilitating structure that are highlighted as desirable by our structuralist theory (Metcalfe's second type of policy). Students of technological change argue that great benefits were reaped by those countries in which linkages among universities, government research laboratories and private sector firms were strong and were able to evolve as technologies changed. This was particularly true of Germany and the United States (Rosenberg, 1994; Nelson, 1995). IRAP's attempts to strengthen these linkages in Canada, where they had always been weaker than in the United States, must be judged as potentially highly valuable. The linkages that have been forged by IRAP and by some highly innovative university administrations – taking their lead from Waterloo University – shows that what IRAP set out to do was also within the realm of feasibility.

Our assessment: IRAP has tried to induce important structural changes and it appears to have succeeded:

1. IRAP has consistently maintained its overall objective of increasing technological capacity and developing the tools to realise it as their need became apparent;
2. IRAP has been flexible in recognising its own design shortcomings and evolving solutions;
3. IRAP's administrative expertise that gives it overall institutional competence, its market focus, its relatively small contributions often on a shared basis and its lack of capture are fundamental contributions to the programme's success.

Many of the changes in structure that IRAP has pursued are in line with several of the successful policies noted in other countries by Lipsey and Carlaw (1996). In the early 1950s, the US military helped to create the software industry in the United States and helped to set its standards. The government of Chinese Taipei created the microelectronics sector by building up a publicly owned company for which foreign licences were purchased and then handing the company off to private industry as production became internationally competitive. Korea's electronics sector was developed in a manner similar to Chinese Taipei's, where again the government played an active role in inducing private firms to alter the facilitating structure to accommodate the new industry.

Neo-classical assessments: In contrast to our assessment, those who used neo-classical approaches have been critical of IRAP. Usher (1994), in particular, argues that IRAP money would have been better spent on a framework policy such as a generalised investment tax credit, and that many of IRAP's projects fail his incrementality test. At the end of a long study of five of what he calls ‘‘firm-specific’’ programmes, which include IRAP, he concludes:

> ‘‘The potential benefits of firm-specific investment grants are too speculative and uncertain, and the potential costs are too large, to justify the inclusion of firm-specific investment grants among the instruments of economic policy.’’ (Usher, p. 378).

Reconciliation: We reconcile our conclusions with those of the critics by noting that their definition of incrementality is narrow; they require the definition to be imposed rigorously in all cases of subsidy; they do not apply a similar definition to the framework policies they advocate; and there is some question as to their calculation of the relevant costs of each type of programme. We also note that these assessors do not take account of the types of non-linearities that characterise systems of endogenous technological change, nor do they take account of diffusion. We take these points in turn.

As suggested by neo-classical theory, Usher urges that: ‘‘Specific investment grants are intended to promote projects that would not be profitable otherwise’’ (Usher, p. 319). By assuming that IRAP’s objectives are focused exclusively on specific changes in targeted technologies, the critics miss IRAP’s major objective of incrementally changing the facilitating structure. IRAP has placed particular emphasis on changing research and technological capabilities within firms and on creating new channels for information flows between private industry, university and government researchers.

For another illustration of how the critics ignore structural aspects, consider Usher’s observations that ‘‘since a substantial proportion of the grants go to big firms with large research labs, it is difficult to claim that the project for which the grant is applied would not be undertaken if the grant were refused’’ (Usher, p. 318). This ignores the early objective of IRAP (and the Defence Industry Productivity Program, DIPP) of altering the research capacity of large Canadian firms, particularly in aerospace. The lever for doing this was to offer assistance on projects that were in accord with private industry’s research agenda, and to add riders concerning the creation of more permanent R&D capacity.

To look solely at funded projects as its critics have done ignores, for example, the ‘‘more than 11 000 significant client interactions’’ in 1993/94 alone, undertaken by IRAP in providing technical assistance, information and referrals with a view to improving the ‘‘technical competency’’ of Canadian firms as well as ‘‘changing their behaviour and attitudes... toward technology’’ (NRC, 1994, pp. 8 and 16). In 1991/92, ‘‘up to 67 per cent of all requests within a geographical region, [were] for non-funded assistance’’ (Goss Gilroy Inc., 1993, p. 22). Even where ‘‘money is the primary motivating factor in contacting IRAP’’, technical advice and assistance is provided in the preliminary definition and design stages as well as throughout the project (Siddiqi *et al.,* 1983, p. 10). Normal incrementality tests are not fully appropriate in relation to these rather general objectives and the multiple and interdependent instruments used to achieve these ends, many of which resist quantification and aggregation.

Most of the critics make the correct observation that focused and blanket policies, including IRAP, will support some firms and technologies that would not pass a narrow incrementality test. However, they seldom ask how many of the initiatives assisted by the types of framework policies that they advocate, such as R&D tax subsidies, would also fail a similar test. Because framework policies are generally applicable, they necessarily support everyone. In contrast, it is in the nature of focused and blanket policies to customise their assistance to the particular structural characteristics of the firm or industry being assisted. For example, focused and blanket policies can exclude broad classes of firms, industries and types of R&D activities that clearly have few externalities (such as pharmaceuticals which can capture quite enough of the benefits that they create). It seems more likely to us, therefore, that framework policies would fail any incrementality comparison with focused or blanket policies.[15]

In another part of his criticism, Usher asserts that framework policies can do anything that IRAP can do. Although this is true in a neo-classical model, it should be clear from our discussion of IRAP's targeting of several important aspects of the facilitating structure that this is not in fact correct. Nonetheless, it may help to enumerate some of the further reasons why we disagree with Usher on this point.

First, Usher argues that the five programmes that he reviews are the equivalent of a 2.8 per cent investment subsidy. The overall effects of IRAP's contribution would thus be extremely small in a neo-classical model in which everything is marginally variable. IRAP's expenditures are indeed small by comparison with other Canadian programmes, to say nothing of those in other industrialised countries. But this is in keeping with a mandate to alter structure in ways that will encourage invention, innovation and diffusion, rather than to directly alter the overall volume of investment. In theory, the type of non-linear dynamics that characterises systems with endogenous technological change is full of situations in which small causes have large effects. Given these non-linearities, IRAP's small focused expenditures can have large impacts.

Second, in its efforts to assist small firms, IRAP has played a major part in diffusing technologies and adapting them to firm-specific uses. By ignoring the issue of diffusion, many of the critics implicitly accept the usual neo-classical assumption that new knowledge diffuses instantaneously throughout the entire economy. This is manifestly wrong. Studies show that technological knowledge diffuses slowly within one country, to say nothing of internationally. One reason is that the acquisition of knowledge is a fixed and sunk cost at any moment in time, while over time, as more and more knowledge accumulates, these costs are rising. The costs of acquiring existing knowledge are thus an increasing burden on small firms, more and more of whom are unable to bear them.

Third, many critics associate incrementality with high-risk projects, implicitly arguing that risk is the main reason why socially valuable projects will not be undertaken by private firms. For example, Usher reports: ‘‘What is claimed is that... IRAP... may be incremental in some especially risky projects’’. While we agree that pushing high-risk projects is usually incremental, we note that such projects often fail and we do not believe that this should be IRAP’s main justification. Instead, its justification is to be found in the mechanisms it has used to deal with some of the additional reasons why socially desirable technological activities may not be undertaken by unaided private firms. These reasons include hostile attitudes to R&D, ignorance of existing technologies, high private fixed costs of acquiring knowledge about existing technologies, and network externalities in R&D which increase with the number of researchers and with the ease of communication among them.

Fourth, a common argument of the critics is that the costs of firm-specific and blanket programmes are higher than those of framework programmes. Let us grant this point for purposes of argument. However, since both types of policies support projects that would not pass even the weakest of incrementality tests, the relevant comparison is in cost per effective dollar – per dollar that goes to support *incremental* activities. We have already noted that framework programmes such as R&D tax credits distribute many rents to firms whose behaviour is not altered in any significant way, while focused and blanket policies can in principle direct their spending to areas where the incremental effect is large. For this reason, the cost per effective dollar may be higher for framework policies compared to focused and blanket policies. We have no way of knowing if this is true in practice, but the view presented by IRAP’s critics that the costs of focused and blanket programmes must be higher than framework policies is misleading.

In the end, judging IRAP along with most other blanket policies is largely a matter of judgement. While the major critics, Tarasofsky (1984), Usher, and the ECC (1983), outline some of the key issues with respect to incrementality, and suggest that IRAP is non-incremental or that its costs likely exceed its benefits, no conclusive proof that IRAP is throwing money away is offered. Based on the assessments of others, as well as IRAP’s own modest expenditures, one might argue that the burden of proof lies with the programme’s detractors.

We conclude, first, that no strong case for failure has been established by others and, second, that there is a very strong case, on our criteria, for regarding IRAP as a success in terms of the desirability of its objectives and its performance in reaching them (which is not of course to say that it could not be improved). Here, as we said at the outset, is a case that sharply contrasts the differences between the policy implications of the neo-classical and the structuralist-evolutionary world views.

VI. POLICY EVALUATIONS

In this final section, we say a little about how structuralist theory may help us in evaluating the chances of success or failure of specific policies, programmes and projects *on the basis of their specifications.*

Focused policies

Given the clear advantages in principle, but the large set of disadvantages in practice, and given that in the final analysis policy assessment must contain a large element of judgement, how can we assess the effectiveness of specific focused policies? In an attempt to assist in this matter, Lipsey and Carlaw (1996) studied some 30 mainly focused policies which were drawn from around the world and for which reasonably reliable indications of success or failure seemed to exist. With the types of focused policy that they considered, it is usually possible to assess whether the policy did or did not achieve its stated goals. They then looked at the successes and the failures as two groups, searching for characteristics that distinguished them.

They began by classifying their cases according to the changes in technology (T) and in structure (S) that were required by the policies (either explicitly or implicitly). First, consider technology. The change in technology refers to the number and extent of the changes in the elements of existing product and process specifications that are needed to effect the targeted overall change in technology. They observed that: ‘‘Making this measure operational, in a detailed way, and relating the required changes in product and in process specifications is an important part of our ongoing theorising about technological change’’ (pp. 269-270). For purposes of their 1996 paper, however, they relied on an impressionistic metric of ‘‘incremental’’ and ‘‘large-leap’’ technological advances. Within each of the categories of incremental or large leap, they distinguished whether the policy was to ‘‘catch up’’ or to push on the ‘‘leading edge’’ of new technologies. Since studies of technological change show that the vast bulk of private sector R&D activity is to accomplish incremental changes in technology, their category ‘‘incremental’’ must not be taken to mean ‘‘unimportant’’. Although governments frequently attempt big leaps, these are much less common in private sector innovative activity.

Second, consider structure. A fully operational treatment of the changes required in the facilitating structure calls for consideration of both the type and the magnitude of the structural change entailed by the attempted innovation: small, medium and large changes in each of the firm level, industry level and economy-wide level of the facilitating structure. In their preliminary treatment, they used the impressionistic classification of the structural changes required by each policy as being ‘‘small’’, ‘‘medium’’ or ‘‘large’’. Large structural changes are usually registered at the industry and firm levels, while medium or small changes may be registered only at the firm level. Table 1 duplicates their Table 1 on their page 286

Table 1. **Technology**

	Incremental		Large leap	
Structural	Catch-up	Leading edge	Catch-up	Leading edge
Large	**Korean electronics**	**US military software procurement**	*Japanese commercial aircraft – phase 1*	**Japanese automobiles**
	Chinese Taipei electronics			*AGR*
Medium	Japanese commercial aircraft – phase 2	SEMATECH (M)	*Concorde*	
		US military semi-conductor procurement		*SST*[1]
	Early Japanese semi-conductors			*Alvey*
		NACA		
		Korean industrial policy	**Airbus (M)**	
		Indian industrial policy		
			French microelectronics	
			British computers	
Small	**Indian trading companies**	**Stoves in Kenya, Boats in India, Electricity In Nepal**		**VLSI**
				US aircraft procurement
		MITI: supporting networks, research labs, finance		*Japanese 5G*[1]
		Consolidated computers		
		Caravelle		
	IRAP			
	West German SMEs			

Key: Failure = *Italic*; Success = **Bold;** Marginal success = (**M**).

[1] Although these programmes were Type 1 failures in that they did not achieve their objectives, they were Type 2 successes in that the programmes were halted when they appeared to be failing.

(Lipsey and Carlaw 1996). It shows their classificatory scheme made up of 12 cells which combine catch up, leading edge, large and small technological advances, with small, medium and large structural changes. The items in the body of the table refer to the cases that they studied. Notice that, with the exception of the Japanese car industry, pushing for innovations that require large changes in both technology and structure tends to produce failures while those that require only small changes in both more often produce success.

From their comparisons, they developed a set of policy lessons which refer to the design and operation of policies and programmes. Following these lessons does not guarantee success, but the lessons do suggest some conditions that increase the likelihood of creating successful focused policies. The policy lessons that follow are a refinement of those which Lipsey and Carlaw drew from their study. Although some of the items may sound trite, *each one of them is based on one or more real cases, with the ''don't'' items all being cautionary tales drawn from failures in real policies, programmes or projects.* The italicised captions are for easy reference. They do not, however, stand alone, except as labels; the full statement of each lesson is given in the paragraph attached to the caption.

We have grouped these lessons into four categories: those that relate primarily to uncertainty, those that are primarily concerned with design pitfalls, those that are primarily concerned with structural relations, and those that are primarily related to market forces and information. We say ''primarily'' in each case because many of the lessons concern more than one category. While being a convenient way to group our lessons, these four categories are not used for further analytical purposes.

Uncertainty

1. Large leaps are dangerous: Attempts at large technological leaps involve major exposures to uncertainty because they require many changes in some main technology and its various sub-technologies, as well as the accumulation of the tacit knowledge that is required to operate it efficiently. Large leaps in technology for which the facilitating structure already exists are extremely difficult to accomplish; large leaps in technology that also require large leaps in the facilitating structure are nearly impossible to accomplish successfully. The history of focused policies is replete with failed programmes that attempted large technological leaps (of either the catch-up or leading-edge variety) that required major accommodating changes in the facilitating structure.

2. Successful policies and programmes often pursue incremental innovation and (where possible) aid in the acquisition of tacit knowledge: Policy makers can reduce exposure to uncertainty by pursuing incremental innovation, by assisting firms to acquire tacit knowledge about established technologies and by targeting niche developments. This parallels the incremental focus that characterises much private sector activity.

3. Pushing the development of a technology off its established trajectory is dangerous: Exploiting the potential of technologies within their established trajectory involves less exposure to uncertainty than trying to alter the trajectory or establish a wholly new one.

4. Flexibility is important: In the uncertain world of technological advance, almost the only thing that is certain is that something unexpected will happen. There are many uncertainties related both to technological change and to the design and operation of new projects, programmes and policies. Because coping with this kind of uncertainty requires learning from experience, policy designers and programme administrators must be able to change course or cancel any venture as unfavourable experience accumulates. Many programmes and projects have failed because their procedures and objectives could not be changed as experience accumulated about what was and was not possible. To be able to do this, procedures must be put in place for reviews, amendments and/or cancellation of projects, programmes or even whole policies. We refer to the ability to revise the internal structure of policies and programmes as programme *design* flexibility and the ability to change course or cut off particular projects as *delivery* flexibility.

5. Diversity is one of the best protections against uncertainty: Because technological advance is uncertain, diverse experiments are often more productive than one big push along what appears to be the most likely path at the outset.

6. Exposure to uncertainty can be reduced by exploiting the interrelation between users and producers: Users of a technology can provide producers with information about the desired characteristics of a technology, problems with past and present designs, and can give some indication of market demand for innovations. At the same time, producers can provide users with possibilities of which they were unaware. This lesson was stressed in our earlier discussion of spillovers.

Design pitfalls

7. Multiple objectives are dangerous: When policies and programmes have multiple objectives, the uncertainties involved in technological advance make it likely that the non-technological objectives will predominate *and the prediction about the future commercial viability of the technological advance will be whatever is needed to justify the decision to proceed.* To get technological objectives mixed up with political prestige, regional development or any other policy objectives is almost to guarantee that the technology objectives will be made subservient to other ends. The history of technological programmes shows many instances where favourable technological judgements continued to be held in the face of accumulating unfavourable evidence because of fear about the employment, or regional or other non-technological consequences of cancellation. The implication is that, wherever possible, technology advancement policies and programmes should not be given additional non-technological objectives.

8. Multiple objectives may be sustainable if there are multiple tools: Lesson 7 relates mainly to focused policies. More complex policies and programmes may successfully employ multiple objectives if they assign separate policy tools to each objective.

9. Multiple objectives may be sustainable if they are clearly prioritised: Given that we are considering policies designed to advance technology, whenever there are multiple objectives to be served by the same instrument, priority must be given to the technological objective for the reasons outlined in lesson 7.

10. National prestige should be an outcome, not an objective: Policies and programmes that have national prestige as up-front objectives, whether stated or just implicit, are handicapped relative to ones that are chosen for potential commercial viability. These policies and programmes tend to bring the opposite of international prestige and commercially viable innovation. Furthermore, they often hinder technical progress when they introduce inferior technologies that are widely used by many domestic industries.

11. Policies and programmes should avoid capture: Capture can come from two directions, the clients in the private sector and those politicians who would use policies and programmes as political pork barrels. Both types of capture are likely where a policy provides significant funded assistance to a select or limited number of firms. They are made more likely where contributions are allocated on a discretionary basis and where policy objectives and project selection criteria are ill-defined. Political capture also becomes more likely the more the publicity that surrounds the creation and operation of the policy or programme and the more that political concerns are allowed to influence the selection process.

Structural relationships

12. Attention needs to be paid to the interrelation between technology and structure: Changes in either technology or structure typically induce changes in the other. If policy makers target only one of these, there will be induced consequences in the other which will affect the overall performance of the policy or programme, *e.g.* by imposing unforeseen costs or by retarding the targeted developments. If policy makers target technology and structure in ignorance of the interrelations, they may target an inconsistent set of changes that will inhibit attaining their main goals. However, as pointed out in lesson 1, policies and programmes that require large leaps in both technology and structure are prone to failure.

13. Policies and programmes can play a useful role in inducing and co-ordinating pre-commercial R&D efforts: Policies and programmes can assist in gathering and disseminating non-appropriable technical information. They can also provide mechanisms through which firms can credibly commit to jointly conducting pre-commercial R&D, thus reducing the hoarding of such knowledge and minimising costly duplication.

14. Policies and programmes should seek to maximise positive spillovers: We have seen that different technological advances have different spillovers. These depend, among other things, on the current stage in the development trajectory and the number of complementarities both within the sub-technologies of a main technology, and across technology systems.

Market forces and information

15. Market forces and the market expertise of private sector agents should be utilised wherever possible: Policy makers can successfully intervene to aid innovators provided commercial and competitive objectives guide the intervention. This implies that market concentration and protection must be balanced against competition in innovation, and policy must respond to commercial signals reflecting viability. Policy makers are ill-advised to dictate business decisions (*i.e.* they should avoid micro-management and the suppressing or ignoring of market signals).

16. Information co-ordination and dissemination is important: Not all firms are aware of the current and evolving best practice technologies that may be of use to them. Policies and programmes that assist in spreading existing technological knowledge can cover the discrete sunk costs of acquisition that are often too high to be taken on by individual firms, especially small ones.

17. Commercial viability should be sought: Technology for its own sake, commonly called ‘‘technology push’’, has frequently produced technological marvels that are commercial failures.

18. Policies should exploit as much expertise as possible: Although this good advice is obvious, it has been ignored repeatedly in many policies and programmes in many countries. Administering any even moderately complex policy or programme requires a wide variety of expertise, including technological, commercial, financial and administrative. As much as possible, these should be developed in-house. Where this is not possible, or is excessively expensive, mechanisms must be developed to tap outside expertise.

19. Stakeholder participation should always be sought. For many focused policies there is no market test until after the event, but willingness of stakeholders to invest some of their own money is an excellent restraint on unrealistic public sector behaviour. Most of MITI’s mistakes have occurred in programmes where

MITI pushed ahead in spite of private sector reluctance to commit any significant amounts of money. Most of its successes occurred where the private sector backed MITI's judgement with its own funds.

20. Competition-inducing mechanisms increase the chances of success: Policies and programmes designed to produce inter-firm competition in innovation increase the likelihood of commercial success. Such competition also induces a variety of diverse experiments by profit-seeking firms which often produce a cluster of innovations. This stands in contrast to policies that suppress competition by choosing and backing a national champion in terms of a firm or a technology.

Blanket policies and programmes

In Lipsey and Carlaw (forthcoming), we consider blanket policies, asking how their potential can be evaluated before success indicators become available (*e.g.* at the design and early implementation stages).

With blanket policies and programmes, the direct approach of measuring outputs is seldom easy and is often impossible. This forced them to employ an indirect approach that uses the set of policy lessons outlined above. To do this, these lessons are used as design and operation *criteria.* The procedure is as follows:

- *Step one:* We examine the available assessments that have been made by others. These concentrate mainly, but not exclusively, on outputs. They are often highly suggestive of success or failure but seldom, if ever, conclusive. This will not surprise someone with the structuralist perspective that policy assessment must contain some element of judgement that cannot be *wholly* resolved by scientific measurement.
- *Step two:* We compare the design of the policy or programme in question with Lipsey and Carlaw's design and operation criteria, using them to judge the potential for success or failure.
- *Step three:* Where there is agreement between the judgements reached under both of the above procedures, we conclude that there is a strong case for either success or failure.
- *Step four:* If the judgements resulting from the two procedures disagree, we seek to reconcile the differences.

The procedures alluded to in the second bullet point are as follows. First, we judge, in the light of available evidence, how each policy rates with respect to each of our design and operation criteria, assigning a grade of success (S), qualified success (QS), uncertain (U), qualified failure (QF) or failure (F). Qualified indicates either mixed results (leaning towards S or F) or only minor applicability of the criterion in question. Where the criterion is not applicable to the programme in question, it is graded not applicable (NA). Second, we accumulate these grades mechanically, showing for the policy or programme being studied, the number of criteria obtaining each of the grades. Third, we form a final judgement that the overall performance of the policy or programme passes or fails our criteria test. In doing this, a further element of judgement is required because all criteria are not equally important – and a few are so important that they provide necessary conditions for success. Avoiding large leaps in both technology and structure is one of these. Others come close to being necessary. Examples are avoiding such things as capture, extremely rigid design and execution, technology push and domination by considerations of national prestige.

Where our judgement on the programme differs significantly from the other assessors, we seek to reconcile these differences (step four). We do this by comparing the theoretical perspectives adopted by ourselves and the other assessors, seeking to identify the source of the differences between the assessments. In the cases studied so far, the sources are found in the different assumptions that characterise the theories being employed. In both the cases of IRAP, considered above, and the Defence Industry Productivity Program (DIPP), which was cancelled without a major review, Lipsey and Carlaw's favourable structuralist assessments are at odds with those of neo-classical economists who have condemned both policies.

As this analysis of our case studies illustrates, there are major differences in the policy implications of the neo-classical and the structuralist-evolutionary ‘‘world view’’. While in some cases their advice sets may supplement each other, in other significant cases, they are in conflict. In these cases, a choice of world view is needed if policy assessments are to be made. We have no doubt ourselves that in these conflict cases the evidence and the theories that are consistent with the evidence support a preference for the structuralist-evolutionary set of policies.

NOTES

1. Of course, these two alternative visions have some degree of overlap, suggesting some common views on behaviour and some common policy recommendations.
2. For a recent statement of these different conceptions of competition see Blaug (1997).
3. We use interchangeably the terms ‘‘structuralist’’, which emphasizes all the structural relations which are not included in the neo-classical model, and the term ‘‘evolutionary’’, which emphasizes the Austrian view of competition. Either shorthand will do, but ‘‘structuralist-evolutionary’’ captures the key aspects of the differences from ‘‘neo-classical’’.
4. The following two sections briefly allude to material covered in more detail in Lipsey, Bekar and Carlaw (forthcoming 1998).
5. Such piecemeal welfare recommendations ignore the theory of the second best which shows that the removal of some market imperfections, in a world in which others must remain, will not necessarily, or even probably, increase welfare (Lipsey and Lancaster, 1956). Second best remains a skeleton in the policy advisor’s closet. Although there are some rare exceptions, such as customs union theory where the trade-diverting effects are taken into account, piecemeal advice is typically given with few attempts to study second best reactions.
6. In Lipsey (1994), I have analysed in more detail why endogenous technological change at the micro level destroys the concept of an optimum allocation of resources.
7. There is nothing in theory to rule out the possibility that, in retrospect, the aggregate return to R&D and innovative activity will be below the desirable social rate of return, or even negative. To someone raised in neo-classical theory, it seems paradoxical that there should be an activity that confers substantial benefits that cannot be appropriated by the active agent but which, nonetheless, is overproduced.
8. We give here a few of our reasons for concurring with this judgement. Technological change is desirable because it is the engine of growth, and policy makers view growth as being desirable. Because we are in a world of uncertainty where technological change is endogenous, where small causes can have a big effects, where externalities are massive, and where there is often no unique equilibrium, it is appropriate to promote technological change through public policy. Furthermore, a case can be made that the gains to those agents who are successful in terms of generating much social value (whether or not they appropriate it) outweigh the losses to those who are

not. Indeed, many (although not all) of the innovative failures are successes in terms of the knowledge they contribute about the difficulties encountered in certain paths to advancing technological knowledge.

9. Sulzenko (1997) discusses a major restructuring of the Canadian department, Industry Canada, that is much in line with this structuralist perspective, and in which he, as Assistant Deputy Minister for Industry and Science Policy at Industry Canada, played a major part.
10. This temporal sequencing of gains and losses is one major reason why we cannot be completely confident about the case for encouraging technological gains. It is possible, for example, for a new technology to be introduced in spite of conferring a net social loss, as long as the agents responsible for introducing the technological change are net beneficiaries. They rationally introduce the technology in spite of the net social losses which might partly show up as various forms of macro slowdowns. Furthermore, the costs of structural change tend to be up front while the benefits are enjoyed by some in the present and everyone in future generations. Thus, although a cost-benefit analysis showed that some proposed new technology should not be introduced because it conferred a net social loss, a second cost-benefit analysis, made after it is in place, might show that the technology should not be removed. This allows for a sequence of GPTs, each one of which has a negative net present social value and causes an initial slowdown, but which are nonetheless accepted later in their evolutionary path as socially valuable.
11. We discuss these spillovers in more detail in Lipsey, Bekar and Carlaw (forthcoming 1998).
12. One of the major shifts that Sulzenko (1997) discusses is in line with this point: ‘‘It was recognised that innovation is non-linear and has to be holistic [and is to a great extent]... a function... of the relationships and networks between institutions.’’
13. In the interwar years, 1918-39, publicly funded research in the United States played an important part in the development of many basic technologies for the emerging aircraft industry, such as the retractable landing gear. Later, in the early development of jet aircraft, there were large externalities as airframes and engines developed for US military aircraft had civilian applications (the airframe for the 707 and the engines for the 747). The spinoffs from the stealth bomber were, however, quite small, since the highly sophisticated and specialised new technology developed for it had fewer outside applications.
14. By this criteria, US policy was correct in not offering major support to the aircraft industry before 1914 when its potential was still unclear and then giving substantial public assistance between the two World Wars when aircraft were evolving rapidly and coming into more general use. (The evidence from other technology-support policies suggests that this advice is much easier to give than to follow.)
15. In a neo-classical model with continuous, negatively sloped functions relating expected payoffs to R&D in each line of activity, a general R&D subsidy produces *incremental* R&D expenditure in all lines of activity. This result is an artefact of the model’s assumptions and is found neither in structuralist models nor in the real world.

BIBLIOGRAPHY

ARROW, K. (1962), ‘‘Economic Welfare and The Allocation of resources for Invention’’, in *The Rate and Direction of Economic Activity: Economic and Social Factors,* NBER, Princeton.

ARTHUR, B. (1988), ‘‘Competing Technologies: An Overview’’, in G. Dosi *et al.* (eds.), *Technical Change and Economic Theory,* Pinter, London.

BALDWIN, J. (1996), ‘‘The Importance of Research and Development for Innovation in Small and Large Canadian Manufacturing Firms’’, Draft, 8 April, for the Six Countries Programme Conference, R&D Subsidies at Stake.

BLAUG, M. (1997), ‘‘Competition as an End-state and Competition as a Process’’, in *Trade Technology and Economics, Essays in Honour of Richard G. Lipsey,* B. Curtis Eaton and Richard G. Harris (eds.), Edward Elgar, Cheltenham UK.

DAVID, P. (1991), ‘‘Computer and Dynamo: The Modern Productivity Paradox in a Not-too-distant Mirror’’, in *Technology and Productivity: The Challenge for Economic Policy,* OECD, Paris.

ECONOMIC COUNCIL OF CANADA (1983), ‘‘The Bottom Line: Technology, Trade, and Income Growth’’, The Council, Ottawa.

GILROY, G. (1993), ‘‘Industrial Research and Assistance Program (IRAP): Report on the Delivery Process’’, paper prepared for Industry, Sciences and Technology Canada.

GROSSMAN, G. and E. HELPMAN (1991), *Innovation and Growth in the Global Economy,* MIT Press, Cambridge.

LIPSEY, R.G. (1994), ‘‘Markets, Technological Change and Economic Growth’’, Quaid-I-Azam Invited Lecture, in *The Pakistan Development Review,* Winter, Vol. 33, No. 4, pp. 327-352.

LIPSEY, R.G. and C. BEKAR (1994), ‘‘A Structuralist View of Technical Change and Economic Growth’’, in *Bell Canada Papers on Economic and Public Policy,* Vol. 3, Proceedings of the Bell Canada Conference at Queen’s University, John Deutsch Institute, Kingston.

LIPSEY, R.G., C. BEKAR and K. CARLAW (forthcoming 1998), ‘‘General Purpose Technologies: What Requires Explanation’’, Chapter 2 in E. Helpman (ed.), *General Purpose Technologies and Economic Growth,* MIT Press, Cambridge, MA.

LIPSEY, R.G. and K. CARLAW (1996), ‘‘A Structuralist View of Innovation Policy’’, in *The Implications of Knowledge-based Growth,* Peter Howitt. (ed.), University of Calgary Press, Calgary.

LIPSEY, R.G. and K. CARLAW (forthcoming 1998), *Assessing Innovation Policies: Taking Schumpeter Seriously on Innovation Policy,* a monograph to be published by Industry Canada.

LIPSEY, R.G. and K. LANCASTER (1956), ‘‘The General Theory of Second Best’’, *The Review of Economic Studies, 24,* pp. 11-32.

METCALFE, S. (1996), ‘‘Science Policy and Technology Policy in a Competitive Economy’’, paper presented to the British AAS, September 1955, manuscript.

NATIONAL RESEARCH COUNCIL OF CANADA (1984), *NRC-CNRC Industrial Research Assistance Program Annual Report 1983/84,* April, NRC, Ottawa.

NELSON, R. (1995), *The Agenda for Growth Theory: A Different Point of View,* IIASA Working Paper.

ROSENBERG, N. (1976), *Perspectives on Technology,* Cambridge University Press, Cambridge.

ROSENBERG, N. (1982), *Inside the Black Box: Technology and Economics,* Cambridge University Press, Cambridge.

ROSENBERG, N. (1994), *Exploring the Black Box: Technology, Economics, and History,* Cambridge University Press, Cambridge.

SCHURR, S. *et al.* (1990), *Electricity in the American Economy,* Greenwood Press, New York.

SIDDIQI, K.U., B.A. McINTOSH and J. ATACK (1983), *Program Evaluation Assessment Report, Industrial Research Assistance Program (IRAP) Component,* The Program Evaluation Office, National Research Council, Canada.

SULZENKO, Andrei (1997), ‘‘Technology and Innovation Policy for a Knowledge-based Economy: The Changing Views in Canada’’, see this volume.

TARASOFSKY, A. (1984), ‘‘The Subsidization of Innovation Projects by the Government of Canada’’, Economic Council of Canada, Ottawa, Ontario.

USHER, Dan (1994), *The Collected Papers of Dan Usher,* E. Elgar Publishing, Aldershot, England.

VON HIPPEL, E. (1988), *The Sources of Innovation,* Oxford University Press, New York.

WOMACK, J.P., D.J. JONES and D. ROOS (1990), *The Machine that Changed the World,* Rawson Associates, New York.

EQUILIBRIUM AND EVOLUTIONARY FOUNDATIONS OF TECHNOLOGY POLICY

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This article was written by J.S. Metcalfe and L. Georghiou of the ESRC Centre for Research on Innovation and Competition and PREST, University of Manchester. The authors are grateful to Sharon Boardman for help in preparing this draft, and to Andrew James who has collaborated in the development of the ideas on complex adaptive policy making.

SUMMARY

Mainstream economic theory has provided a by-now well-known approach to the formulation of technology policy, an approach built around the related concepts of equilibrium and intervention to correct for market failure in the allocation of resources to innovative effort. In this regard the policy maker acts as if (s)he were an optimising social planner wielding a calculus of marginal costs and benefits to improve the behaviour of firms. Our intention in this paper is twofold: to make a case for the adaptive technology policy maker in contradistinction to the optimising technology policy maker, and to relate this distinction to recent developments in thinking about a systems perspective on innovation, taking as an example innovation policy developments in Europe, which include support for finance, networking, advice and foresight. This is no small matter since it involves, we believe, a fundamental appraisal of the purpose of and limitations to policy action. The foundation for the discussion is an evolutionary perspective on economic change, with its emphasis on variety of behaviour and selection process: the latter to produce co-ordination and coherence; the former to provide the basis for all economic change and development. Central to this approach is an awareness of the division of labour, not only in relation to its traditional role in regard to the production of goods and services, but equally in relation to the production of knowledge and skill.

I. ECONOMIC EVOLUTION

Capitalism and equilibrium are fundamentally incompatible concepts. This is the legacy left by Schumpeter to guide generations of scholars interested in answering the question: ‘‘Why does the economic world change?’’ and, indeed one might add, change in such an unpredictable manner. For a central paradox of modern capitalism is its combination of highly decentralised and loosely co-ordinated institutional mechanisms to tap individual creativity, with strongly co-ordinating market mechanisms which resolve the results of individual creativity into patterns of economic change. Thus the process of economic growth and development proceeds simultaneously with the creation of new activities, the elimination of those which are obsolete and the continual resifting of the importance of existing activities. Whether we look into the broad division of activity between agriculture, manufacturing or services, or into the sectors within each broad division, or, *a fortiori,* between the firms within each sector, the picture is always one of ongoing and pervasive structural change, the outcome of which is a strong development trend. The more we aggregate, the less apparent are these essentially capitalist phenomena and, while it is often fruitful to measure at the macroeconomic level, our understanding comes from comprehension of the emergence of endogenous innovations and responses to micro level variety. To provide such an understanding an evolutionary perspective is wholly appropriate since it deals naturally with the interaction between qualitative and quantitative change: novelty provides the material for change; co-ordination, through market *and* other non-market processes, resolves that material into the patterns of change we recognise as economic evolution.

Innovation and evolution as a three-stage process

The classical model of evolutionary change is often presented as a two-stage process: there are stages for generating variety and stages for selecting across that variety to produce patterns of change. Several aspects of this standard evolutionary dynamic need to be stressed. First, the focus of analysis is upon populations of interacting entities and it is the difference in behaviour between the members of the population which is the crucial factor in evolution. A perspective based upon the notion of representative or uniform behaviour is quite incompatible with this approach. Secondly, an evolutionary perspective makes an important operational distinction between two modes of change, that within the relevant entities and that between those entities. The former is sometimes called *transformational* change and the latter *variational* change; that is, change in terms of the relative importance of those entities in the population. A selection process is naturally dynamic, explaining why the entities grow at different rates and thus how their weight in the population changes. In modern analysis these dynamic processes are described by replicator mechanisms in which the changing relative importance of an entity depends upon how its behaviour compares with average behaviour in the population (Metcalfe, 1998). Here there is a close connection with the evolutionary notion of fitness – provided we equate fitness with differential growth and remember that fitness is not a cause of evolution but a consequence of evolution (Metcalfe, 1998). Developmental change is, of course, closely related to innovation and the consequential differential behaviours of competing firms. Novelty, and the creation of novelty, is the central feature of an evolutionary framework. Such variation is necessary to maintain diversity in the population and it is diversity which makes selection possible. Thus, evolutionary models naturally incorporate two central phenomena relevant to technology policy, namely innovation and the diffusion of innovation. In this regard economic evolution is open-ended and largely unpredictable in its consequences over the longer term.

Finally, it is important to emphasize that evolutionary thinking is a style of reasoning which can be applied quite independently of any connection with biological and related sciences. The biologists simply got there first. Thus, within the economic and social sphere we must pay close attention to the intentional nature of innovative activity, its dependence on hopes and expectations and its relation to the memory of past experience. Innovations are necessarily blind variations in that their consequences cannot be known in advance, and their consequences cannot be known in advance in part because they depend on the behaviour of individuals and entities beyond the control of the innovating firm. It is almost axiomatic that innovations as unique events cannot be treated in terms of a calculus of probability distributions. The point is simple, we cannot close the list and therefore do not know what weight to assign in probabilistic terms to those items which we do believe we can list.

The questions which naturally flow from the evolutionary perspective are questions about the world of change: What are the origins of different behaviours? What are the constraints limiting differentiation of behaviour? What are the selection mechanisms which resolve differences of behaviour into patterns of change? Is there any natural limit or attractor to the evolutionary process? Putting the questions in this way, it is easy to comprehend why economists whose primary interest was the study of technological change have found the evolutionary framework highly productive. Different behaviours correspond to innovations whether radical or incremental, and our concern is with the origins of innovation and the constraints by which it is shaped. Selection mechanisms correspond to a range of market and non-market processes in which the division of labour between organisations and individuals is co-ordinated to produce patterns of change.

As far as innovation is concerned many scholars emphasize the inherent unpredictability of outcomes and the interrelatedness between different innovations and innovating organisations. For present purposes we may summarise our understanding if we emphasize that technological and organisational innovations are not random events; rather they are guided and constrained by cognitive frameworks and the embedding of those frameworks in institutional rules and practices. Patterns of innovation reflect constrained variation limited by the sunk intellectual and institutional capital built up in their development. Innovation processes contain a strong sense of commitment and inertia which implies that radical innovations are comparatively rare, that development is cumulative, and that most innovations emerge as a process of trial and error experimentation within previously accepted boundaries. Just as in biology, most innovation experiments fail and the process necessarily appears to be wasteful and to encourage a belief that the intelligent social planner can improve the process by eliminating wasteful duplication. But, in general, this would be a mistaken belief; unpredictability means generic uncertainty, not calculable risk, and what appears wasteful *ex post* is in reality valuable information on where not to search in the design space of possible innovations. It is particularly important to recognise that innovations flow from joint conjectures about technological and market knowledge and that the appropriate choice of market application is at least as important as the appropriate choice of technology in the narrow sense. In this case it as is important to understand the evolution of demand and market knowledge as it is to understand the development of underpinning technology. Usually the two proceed in concert and reinforce one another and so technology policy in the narrow sense can only be one element in innovation policy more generally. Of course, this is what is implied in the old debate between technology-push and market-pull, but the lesson is all too easily ignored: technological conjectures alone are not sufficient for innovation to succeed. The corollary is clear, it is the firm that typically draws together entrepreneurial conjectures about market and technology, and in this regard the firm is unique.

The final important point about innovation is that it is the kind of experimental, trial-and-error activity one would expect to find in complex adaptive systems. One reason behind the apparent complexity is that innovating organisations rarely innovate in complete isolation. Either formally or informally, they draw innovation inputs from a wider matrix of institutions to take advantage of a division of labour in the generation of knowledge and skills. We will have more to say about this below.

Let us consider further the role of selection mechanisms in the process of innovation-driven evolution. Central among these are market institutions by which suppliers and users of innovations interact: institutions which are not to be judged by their optimality but by their facilitation of adaptation and change. Indeed, the market process is essential in ensuring the spread through the economic system of new technology, provided that that technology is judged to be ‘‘superior’’ to the prevailing alternatives. Markets co-ordinate the development of demand, investment and the growth of productive capacity together with the processes of learning which take place jointly between users and suppliers. But this is what we understand by competition not as a state of equilibrium but as a process of rivalry-driven change in economic structures and the relative positions of individual firms and whole sectors. As such, market competition is synonymous with the process of diffusion of innovation whether product or process: competition defines the pathways by which innovation comes to have its economic consequences for employment, trade and the standard of living. Moreover, since innovation is more or less continuous in the aggregate we have a process of open-ended development which in relatively short periods of time can completely transform the prevailing patterns of economic activity. Market-based diffusion is not the only source of relevant change. Processes of imitation must also be given due weight as facilitating the spread of technology through non-market moderated exchanges: the copying, legal or otherwise, direct or indirect, of existing practice. Clearly this matter is closely related to intellectual property rights and the ability to maintain a degree of secrecy about particular developments.

So far we have followed the traditional route of presenting evolution as a two-stage process, variation and selective retention. However, in economic terms there is a third stage which is particularly interesting from a technology policy viewpoint, namely, feedback from the selection process to the development of further variation. This is a theme which we would rightly emphasize as endogenous innovation and it is this dimension which creates the apparent inevitability of the history of technology in which those technologies that get ahead appear to stay ahead. Of course, nothing remotely inevitable was involved: in an open-ended fashion that was how events worked out.

What endogeneity does is to create a close link between market co-ordination and innovation from the reverse direction to that traditionally implied by competition. Technologies normally develop as sequences of innovations within a cognitive framework of design concepts and constraints. How the sequence develops is surely shaped by the growth of the scale and range of application; by the inducements which user/supplier interaction provides to improve and apply in certain directions; and by the profit streams through which much of the development work is typically funded. Thus, market mechanisms become devices not only for adapting to new opportunities but also devices for stimulating the development of new opportunities to create variety. This is of vital importance to what follows. Innovations require much more than scientific knowledge and technological conjectures. They also require conjectures as to what will be valued in the market-place, an immensely subtle and detailed kind of knowledge.

Finally, we should note that the direct consequence of evolutionary competition is to destroy the variety which makes change possible: left to itself, average practice converges on best practice and all other options are eliminated, whence change dries up. To keep evolutiongoing, variety needs to be replenished by further innovation, partially endogenous but also exogenous. The policy question is then obvious, can intervention, broadly or narrowly defined, improve on this evolutionary process?

Adaptive policy making

Corresponding to our view of market processes as adaptive constructs, there follows a view of the policy maker as an adaptive agent. Unlike the social planner blessed with Olympian rationality, the technology policy maker is little different from the individuals and firms (s)he seeks to influence. Bounded rationality and limited knowledge provide his/her domain and the only distinctive characteristic (s)he possesses is political legitimacy and superior co-ordinating ability across a range of institutions. In all important aspects adaptive policy making is about facilitation. Operating in the context of complex innovation systems the policy maker must accept a considerable degree of indeterminacy and unpredictability in the consequences of policy initiatives. Complex systems are of necessity governed by ambiguity so that there is a strong case for policy experimentation and policy learning. As two of our former colleagues have put it, the wise policy maker uses many instruments and none to excess (Carter and Williams, 1957).

It follows from our previous discussion that the focus of policy can entail any combination of the three stages of evolution: innovation, diffusion and feedback. Mostly the emphasis is upon influencing the innovation behaviour of firms as producers of innovation, but there is no need to be so limited: a wide range of institutions typically contribute to the innovation process. It is particularly important in this regard to recognise the role played by intelligent, advanced users in developing valuable improvements in technology. Then obvious questions arise. Is the policy about firms in general or about specific firms in specific sectors? Should the policy be about specific technologies, conceived as bundles of knowledge skill and artefacts, or general R&D programmes. If specific technologies, is the emphasis to be on skills, knowledge or artefacts or permutations of the three basic dimensions of technology? Questions such as these are central to the policy debate.

It will be noted that little emphasis is placed in the above discussion on market failure as a rationale for policy except in the broadest sense, and this requires more detailed explanation.

The market-failure framework has served well the economist interested in technical progress. However, it is not at all clear that it has done the same for the technology policy maker as a practitioner. While market failure provides a general rationale for policy intervention, it is inherently imprecise in its detailed prescription: a firm may spend too much or too little on innovation, it may innovate too quickly or too slowly, it may undertake excessively risky projects or be too conservative. The appropriate policy therefore depends on the specifics of the situation and requires the policy maker to have a detailed knowledge of what are necessarily *conjectures* held by firms. If one is not careful, the firm and the Olympian policy maker become inseparable, a scarcely desirable situation, at least within the Anglo-Saxon tradition of political economy.

If we take an evolutionary perspective on the traditional sources of market failure, the analysis changes in subtle but important ways. Consider first the matter of asymmetric information, a potent source of moral hazard and adverse selection problems in the equilibrium theory of competition. Far from constituting failures, they are essential if the competitive process is to work in an evolutionary fashion. Without asymmetry there can be neither novelty nor variety. Indeed innovations and information asymmetries are proper synonyms and it should not be forgotten that a profit opportunity known to everybody is a profit opportunity for nobody (Richardson, 1960).

Closely related, of course, is the matter of spillovers which only makes sense in a world where firms are fundamentally differentiated with respect to what they know. If Firm A is as knowledgeable as Firm B, a spillover is a contradiction in terms. Of course, spillovers are important and relate fundamentally to imperfect property rights in information. But information is not knowledge and there is no reason to believe that if spillovers were multilateral they would dull excessively the incentives to innovate. If they flow in one direction only, that is another matter and ultimately an empirical question (Liebeskind, 1996).

Similarly with the public-good aspects of knowledge. Knowledge is unique in that it is used but not ‘‘used up’’, but this in no sense implies that it is a free good. With respect to the dissemination of knowledge there are reception costs and transmission costs and it is a consequence of the intellectual division of labour that firms have to invest in their own knowledge before they can make sense of the information flow from external sources. The point is simple, only if the transmitter and recipient have similar background knowledge is ‘‘foreground’’ knowledge transferred easily. Of course, this in no way ensures that the two parties derive the same ‘‘increment’’ to their respective knowledge bases from the same information flow. The value to the firm of the acquired knowledge clearly depends on how complementary that knowledge is to the firm’s existing knowledge base. The public-good perspective is simply not refined enough to comprehend these important distinctions. This is particularly so when we recognise the subtlety and the tacitness of much innovation-related knowledge. This kind of knowledge is not like the scientific knowledge which is the paradigm of the public-good perspective. The most one can say of science is that it provides boundary constraints on innovation, not knowledge of specific innovations (Vincenti, 1991).

From this, the evolutionary economist draws two broad lessons. The first is that private firms will willingly generate innovation-related knowledge if it provides for them a differential advantage over competitors. Imperfect property rights may do little to undermine this in practice. Anyone who wishes to argue otherwise must confront history and the long sweep of private innovation since the industrial revolution. The second is that there is a strong presumption in favour of widespread innovative experimentation in the economy. The blindness of innovation means that its origins and content cannot be predicted: hence it should be stimulated on a wide front and often in unwonted places. It is this which gives the foundation for public support of generic knowledge and skills, a necessary condition for innovation but not of itself sufficient.

A policy dichotomy

It is clearly sensible to put firms at the centre of technology and innovation policy initiatives, but this is only the first step. If the policy is to influence the rate of innovation, it follows that innovation must be an endogenous phenomena and this implies that there are technical progress functions or innovation possibility frontiers confronting firms. These are assumed and idiosyncratic relations between innovation inputs and expected outputs which guide a firm’s decision making. Without this step it is impossible to understand innovations as conscious decisions or to understand the allocation of resources to innovation. Thus, relationships of this sort, naturally specific to individual firms, must be presumed if policy is to be effective. One useful way to think of innovation-opportunity functions is to locate them in the context of the particular design configurations which underpin a particular activity; that is to say, those principles which define the purpose of a product or service, its method of manufacture and its method of use or application. Design principles reflect knowledge, some of it scientific in the conventional sense, some of it technological, about how rather than why a particular result is achieved, some of it codifiable, much of it tacit. It is rarely the case in modern terms that design knowledge is drawn from single knowledge disciplines, rather we see increasingly the fusion of knowledge across traditional boundaries as the underpinning for new design possibilities (Kash and Rycroft, 1994). This is an issue which bears greatly on the technology infrastructure of an economy, as we shall see below.

One way to view design configurations is as sets of latent opportunities for particular innovations through which sequences of products *and* applications emerge. Unless the set of principles is changed, one must expect a limit to what can be achieved, hence the emphasis upon sigmoid trajectories of development *within* specific design configurations (Georghiou *et al.,* 1986).

At any point in time a firm will have accumulated a level of skill and body of knowledge specific to the articulation of a particular configuration. If it devotes resources to further innovation in that particular design, that body of knowledge acts ‘‘as if’’ it were the traditional fixed factor producing diminishing returns to innovative effort. Of course, to the extent that further effort leads to advances in knowledge, this changes the constraining ‘‘fixed factor’’ and opens up a new but limited set of opportunities, the exploitation of which is also subject to diminishing short-run returns. Ultimately, of course, the sources of knowledge latent in the configuration are exhausted and progress on this particular design becomes infeasible (Machlup, 1962).

This granted, the range of innovation policies may then be divided into two broad camps:[1]

- policies which encourage firms to exploit their existing innovation-possibility frontiers, given their prevailing knowledge, more intensively; and

- policies which enhance those innovation possibilities by adding to the firm's knowledge and capabilities so that the same effort provides greater innovative outputs (we are here begging a number of difficult questions about the measurement of innovative output and input).

In the first group of policies fall schemes to lower the cost of R&D through innovation grants, R&D subsidies and R&D-based tax-breaks, together with public procurement policies which increase the demand for innovation outputs, and policies, such as technology demonstrators, which subsidise user firms to adopt new technology. Each of these can have positive effects on the returns and the incentives to innovate, although their magnitude remains contentious (Metcalfe, 1995). From the policy viewpoint the key issue is additionality which in turn relates to the question of how quickly the *conjectured* marginal returns to innovation decline with extra effort; an issue that will be sectorally specific and dependent on the richness of the underlying knowledge base. In relation to marginal returns, it must not be forgotten that the relevant divergence between private and social returns to innovation is a divergence *ex ante,* which exists only in the minds of the relevant decision makers. It can be measured *ex post* but by then it is too late. Equally problematic in this field is the question of which firms to support, if it is not to be firms in general, and how the innovative capabilities of the chosen few are to be assessed. For firms with good innovative ideas but little track record at managing innovation projects, this may be particularly troublesome.

The second group of policies are quite different in nature. Rather than taking the innovation possibilities as given, they seek to enhance them and to do so by bringing a greater degree of access to external knowledge to bear upon the firm's innovative efforts. These are policies to enhance capabilities at innovation. Closer connection with the science base, general research and development initiatives relevant to a particular sector and collaborative initiatives of various kinds are the hallmark of this policy group. In the main such policies recognise the division of labour in the generation of innovation-relevant knowledge, that no individual firm is self-sufficient in its knowledge and skills and that there are corresponding gains from linking firms with the wider matrix of knowledge-generating institutions. They constitute policies for compound learning in which the rate at which a firm can learn depends upon the rate of learning in other supporting institutions, and *vice versa.* This is the considerable insight contained in the innovation systems literature, with the emphasis on the bridging between institutions and the consequences of the resulting patterns of connection upon the mutual accumulation of knowledge. This sets a quite different agenda for policy making, to design and create organisations and institutional structures which support and enhance the innovation process (Justman and Teubal, 1995; Teubal, 1997; Freeman, 1987; Lundvall, 1992; Carlsson, 1997).

II. EUROPEAN INNOVATION POLICIES

Boundaries, diagnoses and broader trends

To discuss innovation policy in Europe, it is first necessary to define some boundaries. In geographical and political terms, the concern of this paper is with Western Europe, and within that, largely with the 15 Member States of the European Union (EU). These distinctions are reinforced by economic criteria, as the countries of Central and Eastern Europe, despite rapid progress in some cases, are still well behind their Western counterparts in terms of economic development. Beyond that, the Members of the EU have achieved a substantial degree of economic integration and have in common those innovation policies administered by the European Commission, principally the Framework Programme, a large multi-annual funding scheme which provides 50 per cent of the costs of collaborative R&D projects, but also including a variety of measures seeking to transfer experience and achieve network benefits in more downstream aspects of innovation policy and infrastructure.

The convenience of this delineation should not obscure the substantial diversity which persists within the EU in terms of scientific and innovative capacity. The three largest countries, Germany, France and the United Kingdom, accounted for 74 per cent of the EU's R&D expenditures in 1992 (European Union, 1994) and 80 per cent of US patents granted to EU Members in all industries in 1993. Other countries such as the Netherlands and the Nordic Members have smaller but highly developed economies, while the Southern Members (with the partial exception of Italy) have been principally concerned with building up their R&D and innovation infrastructures from a relatively low base. During a period of economic austerity, reinforced by efforts to meet the criteria for entering a single European currency, these countries have been unusual in raising their government R&D appropriations as a percentage of GDP in the past decade, but the degree of convergence achieved remains limited and they remain well behind the average for the Union as a whole.

This diversity has not prevented a number of analyses of the position of Europe relative to the United States and Japan. Two significant policy documents from the European Commission summarise recent thinking. The first, the *White Paper on Growth, Competitiveness and Employment* (European Commission, 1994) drew together the views of Member States on the problem of unemployment and drew attention to the EU's long-term unfavourable position relative to the United States and Japan in terms of unemployment, shares of export markets, R&D and innovation and its incorporation into goods brought to the market, and the development of new products. Innovation policies, notably in the environment, health and the media, are seen as having the potential for moderate but positive impacts upon employment.

A consistent tendency in Commission thinking has been to couch the central problem of innovation policy in terms of Europe's ''comparatively limited capacity to convert scientific breakthroughs and technological achievements into industrial and commercial success''.

The second significant document, the *Green Paper on Innovation,*[2] couches this analysis as the ''European paradox'' arguing that, compared with the scientific performance of its principal competitors, that of the EU is excellent, but over the last 15 years its technological and commercial performance in high-technology sectors has deteriorated. This line of argument may be criticised on several grounds, including wide variability between sectors, but the main problem inherent in this analysis is that it embodies in policy terms a linear or sequential model of innovation. The Commission shares this position with other bodies whose principal policy instrument is funding of research. In this paper we shall argue that the major advance in European innovation policy in the 1990s has been a recognition that support for R&D is only one part of a necessary portfolio of policies. To be fair, the *Green Paper* goes a long way towards embodying this broader perspective, emphasizing the importance of strategic and organisational skills within innovative firms and of the regulatory, legislative and fiscal environment in which those firms operate, including intellectual property and the public infrastructure for research and innovation support services.

Analyses of this type have become increasingly common at national level. In the United Kingdom an annual *White Paper on Competitiveness* is published by the government containing analyses of aspects of the business environment (Department of Trade and Industry, 1994); Ireland conducted a major review of its science and innovation policies through a specially convened body, the Science, Technology and Innovation Advisory Council (Science, Technology and Innovation Advisory Council, 1995); in France, the national innovation agency, ANVAR, has been reviewed in the light of the changing environment for innovation (Chabbal, 1994); and in Germany a series of reports have raised concerns about the country's technological position (NIW/DIW/ISI/ZEW, 1995). The proliferation of these high-level analyses in these and other European countries is symptomatic of several important trends. They reflect strong political concerns with perceived declining industrial competitiveness and high levels of unemployment. Technology and innovation are seen as key elements in addressing these problems. At the same time, Europe has seen structural changes impinging directly upon innovation systems in all three major sectors. At the corporate level three trends have been significant over the decade. The first of these, globalisation of technological activities, has had a varied effect in Europe. On the positive side there has been substantial inward investment, particularly by companies from the Far East (with 250 Japanese R&D laboratories in Europe in 1994), but this has been uneven, with the United Kingdom the principal beneficiary. On the other side of the coin, the relatively high cost of performing R&D in Europe has created incentives for companies to relocate their laboratories to cheaper locations. Two high-cost countries, Germany and the Netherlands, have instituted specific incentives to persuade firms not to move. Even in more competitive European locations such as the United Kingdom, the threat of relocation by multinationals has become a part of the national science policy debate, with a recent report on the (poor) state of academic research equipment exposing some relocation by pharmaceutical majors motivated by the desire to be close to high-quality and well-equipped academic collaborators (Georghiou, Halfpenny *et al.,* 1996). The globalisation of large companies may also be a partial explanation (along with their employment-generating capacity) for another innovation policy trend, a focus on small and medium-sized enterprises (SMEs).

The second corporate trend, in common with other parts of the world, has been the decline of centralised laboratories, with research typically organised on a contract basis with most of the budget held by operating divisions. The consequence of this has been a focus of research upon current business problems, with a substantial reduction in longer-term strategic research. Some major companies have contracted out their strategic programmes to universities (showing a remarkable lack of understanding of the externalities involved in performing research). The former corporate laboratories have become increasingly detached from their former parents, with many willing to undertake external contract work to survive. Their plight has been exacerbated by the third major trend, a decline in defence-related contract R&D following the end of the Cold War.

In the public sector, national laboratories have been subject to widespread reforms and restructuring throughout Europe. In some cases this process has been driven by expiry of the laboratories' original missions (for example, the development of civil nuclear power), but they have also been subject to wider reforms in government, often collectively termed ''New Public Management'' (Hood, 1995). This has involved changes such as the introduction of contract-based competitive supply, private sector management styles and an arm's-length relationship with the government departments formerly responsible for them. In virtually every case these changes have been part of a drive towards commercialisation, with a demand for an increasing proportion of resources to come from external contract-based work, often paralleled by a requirement to compete for the work for government which was previously theirs by right. In some countries, notably the United Kingdom, this process has gone further to full privatisation. Innovation policies in several countries have sought to reinforce and exploit these changes by attempting to stimulate these laboratories to play a more effective role in support of industrial innovation.

In the third major technological sector, universities, the 1980s saw a strong move towards research collaboration with industry, through a succession of models (Georghiou and Metcalfe, 1990), culminating in jointly performed research projects with partial public funding. These models were still essentially superimposed upon traditional academic structures, epitomised by the proliferation of ‘‘technology-transfer offices’’ which sought to take the outputs from universities and to find applications for them. In the 1990s the model has progressed to the extent that universities are an explicit component of national innovation policies and research funding is increasingly expected to yield exploitable benefits. Gibbons *et al.* (1994) have described this as a transformation from knowledge generated in a disciplinary, cognitive context to knowledge created in broader transdisciplinary social and economic contexts.

It is possible to identify several weaknesses in innovation systems as a consequence of the changes described above, including a convergence between the main classes of R&D performers towards an increasingly overcrowded contract research market. At the same time, the original missions of the three performers are at risk, with a loss of strategic capability in firms, a loss of competence-building capability to underpin independent advice in the public sector and, for universities, the question of how much externally driven research can be performed without losing the directions arising from the dynamics of knowledge generation. One policy diagnosis is that the fragmentation involved in these changes requires new channels of connection to be put in place.

However, these changes may also be seen as forces conditioning the development of innovation policy in Europe and as part of a broader effort to harness the science base and technological development to the pursuit of economic and social goals. In the next section we review some key recent innovation policy developments in Europe.

Innovation policies

There have been several taxonomies of innovation policies, seminally that of Rothwell and Zegveld (1981), recently brought up-to-date by Dodgson and Bessant (1996) in the light of research on learning and capabilities. For the purposes of this paper we shall discuss specific policy measures using a simple approach which distinguishes between our two broad camps of policies:

- assisting firms to exploit their existing innovation possibilities more intensively; and
- creating or enhancing innovation possibilities by adding to the firm’s knowledge and capabilities such that the same effort produces greater innovative outputs.

These characteristics are concerned with the effects of policies and hence may co-exist within a single policy measure. Nonetheless, we shall argue that the trend in European innovation policy has been from the first to the second of these categories. Let us consider then some of the main policy measures.

Provision of finance for innovation

Traditionally, this policy is treated as having two major variants, provision of *direct* support through grants or loans for individual projects and *indirect* support through fiscal concessions for R&D or other innovative activities (although in Germany there is also a concept of ‘‘indirect-specific’’ support, whereby all eligible applications for grants are accepted until the budget is exhausted). The argument for these policies rests largely upon the familiar market failure rationale, essentially that left to themselves firms will underinvest in innovative activities because of their inability to appropriate all of the benefits arising from these. When social returns are taken into account, the argument goes, public provision of resources is justified. A key aspect of these measures is the question of additionality, that is the extent to which the subsidy given to firms represents additional expenditure rather than substitution for expenditure which would be made anyway. Fiscal incentives tend to concentrate on rewarding incremental expenditure, while direct support is normally accompanied by appraisal procedures which examine each project in these as well as other terms.

During the 1970s direct financial support for innovation projects was relatively common. The trend towards more conservative policies in the 1980s moved away from single company support and tended to restrict financial aid to inter-firm and academic-industrial collaborative programmes (except for SMEs as described below). The rationale here was that collaboration offered many benefits [cost and risk-sharing, complementarity, development of standards, strategic learning (Georghiou and Barker, 1992)], but that collaborative research was more expensive, particularly to newcomers, and therefore financial assistance was justified. It was also argued that collaborative research was inherently more ‘‘leaky’’ and hence that appropriability arguments applied *a fortiori.* Collaborative R&D could also be reconciled more easily with conservative ideology by arguing that firms would only willingly collaborate on ‘‘pre-competitive’’ projects, from which they would subsequently exploit the results separately and in competition with each other.

Collaborative R&D has been a feature of national programmes in Europe but has achieved its greatest prominence as the principal instrument of the European Commission’s Framework Programmes and of a separate, nearer to the market scheme, the EUREKA Initiative. In both of these cases, the arguments above are reinforced by a desire to use R&D as an instrument of European integration. Rather paradoxically, while the availability of finance has been an important motivation for firms to enter these programmes, evaluations have shown that their most durable effects have been in terms of the behavioural changes they have induced in participating firms in terms of developing strategic linkages (termed ‘‘behavioural additionality’’) (Buisseret, Cameron and Georghiou, 1995). Not surprisingly, the least fertile ground for this type of effect is one which meets the original ‘‘pre-competitive’’ criteria by bringing together competitors. Firms have tended to avoid such projects except in unusual circumstances (pre-normative research for standards development or competitively peripheral activities such as safety) in favour of projects which are structured upon vertical collaborations between suppliers and customers, with additional participation from academics (Ormala *et al.,* 1993). As the programmes have moved into new areas such as biotechnology research, concern from industry about protection of intellectual property is leading to pressure for projects which have only one firm involved (along with academic collaborators) (Commission of the European Communities, 1997).

At a national level there has been a gradual move away from support for industrial collaborative R&D, partly because this is already being catered for by the European schemes (though this is problematic for EUREKA which does not have a dedicated budget, relying on each participating government to fund its own nationals through domestic schemes – many EUREKA participants do not receive public funding). The national focus is upon providing finance for R&D and innovation for SMEs, often through reinforcement of venture capital schemes. Thus, Sweden has the Swedish Industry Fund (a government-controlled foundation) which operates a risk capital operation targeted at small innovative firms in their early development stages; similar funds in Finland subsidise R&D in SMEs in the form of equity-based development loans; in France substantial funds are available to promote the uptake of key technologies by SMEs; Germany is launching a programme of support for patent applications by SMEs, covering the legal and associated registration costs of patenting; the United Kingdom operates competitive awards for SMEs in its SMART and SPUR schemes. For the first time, a European equivalent to NASDAQ (EASDAQ) has become a reality.

Support for networking

Policies to promote networking have focused principally upon improving the relationships between firms, on the one hand, and public sector laboratories and universities, on the other. Perhaps the strongest expression of this is in the United Kingdom where the 1993 *White Paper on Science, Engineering and Technology* (the first since the 1960s) redefined the role of all publicly funded research as being to support wealth creation and quality of life. Apart from giving research councils mission statements which link them to specific user sectors, the effect of this injunction has been for grant-holders to be expected to demonstrate user interest even for basic research. Increasingly, funding has been concentrated upon researchers who are able to raise industrial contributions, the argument being that this will mean that exploitable research is performed. Virtually every European country has schemes to promote networking: the Swedish innovation agency, NUTEK, has invited businesses to form local groups with a joint purpose to support the use of new technology in order to build networks between firms, technology advisers and universities; the Dutch Ministry of Economic Affairs has rationalised its collaborative schemes into a single instrument aiming to increase co-operation between businesses and between the private sector and research institutes in a range of technology fields; Spain operates a network of research transfer offices (OTRIs); Greek universities and research centres receive funding to create industrial liaison offices; Germany is strengthening its already impressive infrastructure with a new programme of *innovations-kollegs* in which university-based research teams drawn from academic and private sector sources will be half-funded for a period of five years. Industry-only networks are also a growing phenomenon, often with the aim of using benchmarking to stimulate performance improvements.

Policy measures in this category are clearly intended to enhance opportunities for firms: in linear mode they can be seen as bringing firms into contact with exploitable results and thus turning knowledge into opportunities. If an interactive perspective on innovation is applied, the resulting relationships appear more complex but nonetheless valuable. A typical pattern of collaborative innovation places the main thrust of development with the company while the partners in the science base raise the technological level, solve problems and test and evaluate the outcomes. In less developed regions and for SMEs there is also a resource factor in that the external research input is one they could not perform for themselves and probably could not afford to pay for on full commercial terms. For large companies the motivation is different – they see the benefits of networking with the science base as providing them with a window on the latest developments in their fields. This has led to a policy dichotomy for the Framework Programme, with large firms currently pressing for the next iteration to place the emphasis on longer-term strategic research, while small firms lobby for an instrument which supports work much closer to the market.

Advice, information and infrastructure

A strong growth area in innovation policy has been the provision of information to companies. This is not necessarily a distinct category from the other policy measures discussed in that advice is often intended to guide firms towards suitable partners or to assist them to acquire funding from public or private sources. Other forms of advice are directed at assisting firms to make decisions about the acquisition of technology (as knowledge, skill or artefact), to improve their capabilities to manage innovation or to guide them through regulatory issues. In this mode government (or its agents) become brokers rather than providers.

In the United Kingdom at least, the rationale for a strong shift of emphasis away from national schemes to support collaborative R&D in high-technology sectors and towards information-based support has been based upon analyses which demonstrated that aid was mainly going to a small group of large firms in a narrow range of sectors. The great majority of firms, SMEs and those in traditional sectors, were largely excluded. In these sectors solutions would more typically involve acquisition of technology developed elsewhere (including outside the country). A new infrastructure has been developed to deliver these measures, based upon a network of ‘‘Business Links’’, so-called one-stop shops in most cities and towns where firms are directed by specialist counsellors towards the source of expertise which an initial diagnosis indicates they require. A cynic might remark that these policies have the attraction of being considerably cheaper than direct project support, especially as most services have to be paid for, albeit at subsidised rates. It is too early to judge the success of the shift in UK policy (which coincided with the *White Paper*), but earlier experiments with this type of approach have shown that the principal difficulty is likely to be in persuading firms to become used to paying for this type of information.

Other countries are also developing activities in this direction. In France a new measure allows organisations to be accredited as ‘‘Centres de resources technologiques’’ and provide technological services to SMEs. Several countries have sectoral schemes, notably to promote the development of the ‘‘information society’’ through the uptake of relevant technologies and services. Another trend in this direction lies in the supporting infrastructure, whereby science and technology parks are increasingly providing a range of accompanying services to incubate start-up firms. The European Commission has been active in this sphere, using its SPRINT and INNOVATION programmes to provide a transnational dimension to these networks and to facilitate transfer of expertise.

Broader infrastructural issues affect innovation directly or indirectly. The *Green Paper* pointed out educational deficiencies, barriers to mobility and cumbersome administrative procedures involved in establishing new companies. More directly connected to the innovation system are regulations governing intellectual property and standards.

Foresight and critical technologies

Perhaps the most prominent of the new innovation policies has been the rise of technology foresight programmes in Europe during the 1990s. Some countries, notably France, had a tradition of planning and prospective studies, but foresight has also taken root in countries without such a tradition, notably Germany, the United Kingdom and the Netherlands. In some cases the aim of foresight has been to establish priorities for funding of technological research. France ran a panel-based exercise to identify ‘‘key technologies’’ (ministère de l’Industrie, 1995); these now provide the basis for measures to promote their uptake and are being used to guide research priorities more generally. In the United Kingdom, the Technology Foresight Programme had two aims, to establish priorities for public expenditure on R&D and to promote networking between industry and the science base (Office of Science and Technology, 1995). Fifteen panels were supported by widespread consultation, including a Delphi survey. The resulting priorities have been applied to strategic research across government and the research councils, while a specific follow-up scheme supports academic-industrial collaborative projects aligned with foresight priority themes. Dutch foresight activity has stressed the networking aspects rather than priorities, while in Germany large-scale Delphi surveys undertaken in collaboration with Japan aim to inform rather than direct policy.

It has been argued that the rise of foresight activity, and in particular the enthusiasm with which it has been embraced by industry, can be explained in terms of the transformation of the innovation system (Georghiou, 1996). The development of the network economy, described above, means that innovations are now frequently undertaken in collaborative mode and almost always involve external interactions with customers, suppliers, regulators, knowledge providers, etc. This is particularly the case for the type of complex systems discussed in Section III of this paper. In these respects, part of the strategy-making process which was previously internal to the innovating firm is now in a semi-public domain. Foresight provides an arena in which a common strategy can be formed, restoring some stability to the firm’s environment. In this respect the key element of foresight is not its ability to predict accurately the future (no-one can do that) but rather to inform participants what their collaborators (and competitors) believe the future will be. Thus informed, all concerned are likely to be in a better position to exploit opportunities when they emerge.

III. TECHNOLOGY POLICY MAKING IN A COMPLEX EVOLUTIONARY WORLD

The developments outlined above can be summarised in the following broad terms. The traditional policy approach of taking the innovation opportunities of firms as given and using policy instruments to encourage the more effective exploitation of these given relationships has been augmented by a policy focus aimed at improving the opportunities faced by firms and their capability to exploit them. This broad shift from a ‘‘grants and subsidies’’ based approach to an ‘‘infrastructure building’’ approach has been particularly noticeable in the United Kingdom, but the trend is more general (Kash and Rycroft, 1993; Galli and Teubal, 1996; Sulzenko, 1998, see this volume). It is naturally systemic in outlook. While the role of market failure in the rationale for technology policy is still accepted, the policy maker is no longer seen as a surrogate for a perfectly informed social planner: correcting imperfect market signals to guide private decisions toward more desirable outcomes. Recognition of the complex systems characteristics of the innovation process takes us to a different rationale for policy, a rationale which recognises the ambiguity and uncertainty of the policy environment and the futility of picking winners as distinct from encouraging winners to emerge by strengthening the innovation process in general. The primary concern of the new policy focus is to promote the generation of novelty and to do this by the principle of connectivity – the bridging together more effectively of the different actions and institutions involved in the innovation process. It is about innovation infrastructure and not directly about specific innovation outcomes. Consequently, a prime task for the policy maker is to map and appraise the particular innovation systems and communities of practitioners through which policy initiatives are to have their influence.

From an evolutionary systems perspective the policy maker needs to ask a number of questions to identify the institutions involved and the mechanisms which bridge between them. The key question is where do the capabilities for knowledge generation lie? It is widely accepted that firms have to look beyond their own boundaries for the solution of innovation-related problems. Establishing such connections can involve a number of mechanisms ranging from the passive, general dissemination of information in an unfocused way, to the development of joint programmes in which the knowledge-generating activities of the participating institutions are co-ordinated. In between will be more formal attempts to transfer technology often involving the transfer of people across different institutions within the system. If these connecting mechanisms are weak, the plans of the different institutions will be unco-ordinated and the ability of an institution to improve the innovative contribution of another may reduce to happenstance – something which is not necessarily to be dismissed lightly, but which of itself is unlikely to bear much fruit. The policy question is whether unfocused, random bridging can be improved upon, and the answer to this clearly appears to be in the affirmative, as recent European experience indicates. This improvement is not easily achieved. The different internal communication patterns and incentive structures of different, independent institutions do not help when institutions as diverse as universities and private firms seek to align their innovative activity across their different kinds of knowledge-generating activities. Moreover, only non-proprietary knowledge can be shared effectively in such circumstances, which puts a premium on the development of generic knowledge, knowledge which is not the defining element in the generation of competitive advantage. As many authors have recognised, there are natural limits to collaboration between competing organisations, not only rival firms (Metcalfe, 1992).

The attempt to shape the research agenda of universities, for example, by introducing external criteria in the research-funding process is bound to create friction especially when the overall volume of public funding for research is in decline. It may be that the alignment of behaviour can only be achieved by creating specialist bridging institutions, linked to the academic base but otherwise setting their agenda separately. Note carefully that such institutions may still do fundamental work, but it is fundamental work chosen in relation to wider objectives. The trend to collaborative work, foresight analysis and the creation of specialist bridging institutions are all supportive of our systems perspective.

There is, of course, a drawback to this emphasis on joint learning, in that, while it may speed advance along agreed, established lines, it may also be very conservative with respect to major shifts in innovative direction. Since knowledge accumulation is a positive feedback process there is always a danger of ‘‘lock-in’’ to specific design configurations. Inertia is a fundamental evolutionary constraint and the issue becomes one of trading off the support for established lines of technological advance against the open-ended encouragement of new and potentially competing lines of development. Innovation infrastructures are likely to be good at incremental innovation, less good with radical innovation unless this is explicitly encouraged. Of course, this raises particularly interesting questions about innovation systems for newly emerging technologies and how those new institutional structures emerge.

The second aspect of the policy shift to be emphasized is the implicit change from the optimising policy maker to the adaptive policy maker. Policy is no longer about correcting imperfect incentives for private agents, it is rather about facilitating the emergence of new opportunities by building innovation infrastructure. Here the emphasis is upon the co-ordination of actions leading to innovation by non-market methods recognising that once innovations occur they will be co-ordinated by the market process.

In a world of immense micro complexity, the adaptive policy maker can make no claim to superior knowledge, operating rather within the constraints of localised, imperfect knowledge just as do the firms and individuals that are trying to innovate. What the policy maker does enjoy is superior co-ordinating ability across a diverse range of institutions. Policy may not work, just as complex strategy may not work, and the concern is how will the policy maker learn and adapt in the light of experience. The agenda for adaptive policy is a demanding one since it can only be formed and implemented in the light of judgements about the working of the system as a whole. From the systems perspective, it follows that individual firms are unlikely to be the focus of policy, rather the emphasis will be, as we have seen, upon all the co-operating groups of institutions defining a particular innovation system.

Finally, one may sum this up by saying that technology policies, like innovations, are trial and error experiments. Hence if the policy maker is to learn and adapt, considerable emphasis must be given to policy trials and their evaluation. In most parts of Europe evaluation of technology policy has been institutionalised since the 1980s, albeit in diverse ways which reflect the different administrative cultures (Georghiou, 1995). It also seems clear that learning is a strong motivation for evaluation; evaluation resources have clustered around new policy instruments. Thus, collaborative R&D programmes were for several years a major focus for evaluation but, as this instrument has become better understood, there has been a tendency to routinise evaluation, reverting to a monitoring mode and with an increasing use of performance indicators. The emergence of the new innovation policies discussed in this article is likely to create a new demand for innovative and detailed evaluations which in turn allow the policy maker to learn and adapt.

IV. CONCLUSIONS

In summing up we simply draw attention to the principal themes of the evolutionary and systemic perspectives on technology and innovation policy. We list them *seriatim:*

- While policy may usefully distinguish between the promotion of innovation and the spread of innovation, in reality the two are closely intertwined such that feedback from the diffusion process shapes considerably the development of a technology.
- Technologies typically develop through sequences of related innovations in which a major stimulus is often the extension of the technological principles to new market applications. Market conjectures are at least as important as knowledge conjectures. Consequently, intelligent users are as important as intelligent, innovating suppliers in the innovation process: if users learn slowly this must limit the rate at which suppliers can innovate profitability. Technology and innovation policy should not privilege the supply side to the detriment of the demand side of the innovation process.
- Policy can influence the development of novel devices and concepts either through subsidising the pay-offs to innovation or through enhancing these pay-offs. This latter has been a noticeable feature of recent policy initiatives which emphasize innovation infrastructure and an innovation systems perspective. The issue here is building connections between firms and their wider knowledge base.
- Important dimensions of innovation systems will be inherently sectoral in focus and likely to spill over natural boundaries through the operation of transnational companies and user-supplier linkages. This being so, a question of co-ordination of different national policies will arise, together with the intriguing question of transnational bridging institutions.

- Difficult questions for policy makers relate to whether their policies are to be general in terms of firms and technologies, or specific. If so, which firms and which technologies? This comes uncomfortably close to picking winners.
- Policy will have its impact by changing the behaviour of firms which are constrained by the relevant innovation system. This raises the matter of whether the ‘‘design’’ of the system should itself be a matter for policy initiative. In the case of newly emerging technologies, or existing technologies experiencing rapid change, it may well be that different institutional components are neither being created nor reacting appropriately to the new opportunities.
- Evolutionary processes are inherently wasteful *ex post* and involve considerable degrees of trial and error. Any policy to promote the generation of novelty on a broad front is then open to obvious objection. However, it is not at all obvious in a complex world that we can do better.

NOTES

1. Lipsey and Carlaw (1998, this volume) are right to point out that many policies will involve both camps simultaneously. I make the distinction simply to enhance conceptual understanding. Their article contains a very valuable discussion of different ways to present policy options, *e.g.* their distinction between focused programmes and blanket programmes.
2. European Commission (1995), *Green Paper on Innovation,* ECSC-EC-EAEC, Brussels, Luxembourg, subsequently followed up by *The First Action Plan for Innovation in Europe,* 1996.

BIBLIOGRAPHY

BUISSERET, T., H. CAMERON and L. GEORGHIOU (1995), ‘‘What Difference does it Make?’’, *International Journal of Technology Management,* 10, pp. 587-600.

CARLSSON, B. (ed.) (1997), *Technological Systems and Industrial Dynamics,* Kluwer Academic Publishers.

CARTER, C.F. and B.R. WILLIAMS (1957), *Industry and Technical Progress,* Oxford University Press.

CHABBAL, R. (1994), *Le financement de l’innovation dans les PMEs,* ministère des Entreprises et du Développement économique.

COMMISSION OF THE EUROPEAN COMMUNITIES (1997), *Evaluation of the Biotechnology Programme.*

DEPARTMENT OF TRADE AND INDUSTRY (1994), *Competitiveness: Helping Business to Win,* (CM2563), HMSO, London, May.

DODGSON, M. and J. BESSANT (1996), *Effective Innovation Policy: A New Approach,* International Thomson Business Press, London.

EUROPEAN COMMISSION (1994), *Growth, Competitiveness and Employment – The Challenges and Way Forward into the 21st Century,* White Paper, ECSC-EC-EAEC, Brussels, Luxembourg.

EUROPEAN COMMISSION (1995), *Green Paper on Innovation,* ECSC-EC-EAEC, Brussels, Luxembourg.

EUROPEAN UNION (1994), ‘‘EUROSTAT/OECD’’, in *The European Report on Science and Technology Indicators 1994,* European Commission, EUR 15897.

FREEMAN, C. (1987), *Technology Policy and Economic Performance: Lessons for Japan,* Pinter, London.

GALLI, R. and M. TEUBAL (1996), ‘‘Paradigmatic Shifts in National Innovation Systems’’, mimeo, Jerusalem University Institute.

GEORGHIOU, L. (1995), ‘‘Research Evaluation in European National Science and Technology Systems’’, *Research Evaluation,* Vol. 5(1), April.

GEORGHIOU, L. (1996), ‘‘The UK Technology Foresight Programme’’, *Futures,* Vol. 28, No. 4, May, pp. 359-378.

GEORGHIOU, L. and K. BARKER (1992), ‘‘Management of International Collaboration’’, in J.P. Swann (ed.), *New Technologies and the Firm,* Routledge, London.

GEORGHIOU, L., P. HALFPENNY *et al.* (1996), ‘‘Survey of Research Equipment in United Kingdom’’, Committee of Vice-Chancellors and Principals, London.

GEORGHIOU, L. and J.S. METCALFE (1990), ‘‘Public Science, Intellectual Property Rights and Research Administration’’, in J. De La Mothe and L.M. Ducharme (eds.), *Science, Technology and Free Trade,* Pinter, London.

GEORGHIOU, L., J.S. METCALFE, M. GIBBONS, J. EVANS and T.E. RAY (1986), *Post-Innovation Performance,* Macmillan, London.

GIBBONS, M., C. LIMOGES, H. NOWOTNY, S. SCHWARTZMAN, P. SCOTT and M. TROW (1994), *The New Production of Knowledge,* Sage, London.

HOOD, C.,(1995), ‘‘The New Public Management in the 1980s – Variations on a Theme’’, *Accounting Organisations and Society,* Vol. 20, No. 2/3.

JUSTMAN, M. and M. TEUBAL (1995), ‘‘Technological Infrastructure Policy (TIP): Creating Capabilities and Building Markets’’, *Research Policy.,* Vol. 24, pp. 259-281.

KASH, D.E. and R.W. RYCROFT (1993), ‘‘Two Streams of Technological Innovation: Implications for Policy’’, *Science and Public Policy,* Vol. 20, pp. 27-36.

KASH, D.E. and R.W. RYCROFT (1994), ‘‘Technology Policy: Fitting Concept With Reality’’, *Technological Forecasting and Social Change,* Vol. 47, pp. 35-48.

LIEBESKIND, J.P. (1996), ‘‘Knowledge, Strategy and the Theory of the Firm’’, *Strategic Management Journal,* Vol. 17, pp. 95-107.

LIPSEY, R.G. and K. CARLAW (1998), ‘‘Technology Policies in Neo-classical and Structuralist-Evolutionary Models’’, see this volume.

LUNDVALL, B.Å. (1992), *National Systems of Innovation,* Pinter, London.

MACHLUP, F. (1962), ‘‘The Supply of Inventors and Inventions’’, in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors,* NBER, Washington.

METCALFE, J.S. (1992), ‘‘Competition and Collaboration in the Innovation Process’’, in M. Bowen and M. Ricketts (eds.), *Stimulating Innovation in Industry,* Kogan Page, London.

METCALFE, J.S. (1995), ‘‘The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives’’, in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change,* Blackwell, London.

METCALFE, J.S. (1998), *Evolutionary Economics and Creative Destruction,* Routledge, London.

MINISTÈRE DE L’INDUSTRIE (1995), *Les technologies clés pour l’industrie francaise : A l’horizon 2000.*

NIW/DIW/ISI/ZEW (1995), ‘‘The Technical Capability of Germany’’, Report to BMBF.

OFFICE OF SCIENCE AND TECHNOLOGY (1995), *Progress through Partnership,* Report from the Steering Committee of the Technology Foresight Programme.

ORMALA, E. *et al.* (1993), *Evaluation of EUREKA Economic and Industrial Effects,* EUREKA Secretariat, Brussels.

RICHARDSON, G.B. (1960), *Information and Investment,* Oxford University Press.

ROTHWELL, R. and W. ZEGVELD (1981), *Industrial Innovation and Public Policy,* Frances Pinter, London.

SCIENCE, TECHNOLOGY AND INNOVATION ADVISORY COUNCIL (1995), *Making Knowledge Work for Us,* The Stationery Office, London.

SULZENKO, A. (1998), ''Technology and Innovation Policy for the Knowledge-based Economy: The Changing View in Canada'', see this volume.

TEUBAL, M. (1997), ''A Catalytic and Evolutionary Approach to Horizontal Technology Policies (HTPs)'', *Research Policy,* Vol. 25, pp. 1161-1188.

VINCENTI, W.G. (1991), *What Engineers Know and How They Know It,* Johns Hopkins University Press.

MARKET FAILURE OR MARKET MAGIC? STRUCTURAL CHANGE IN THE US NATIONAL INNOVATION SYSTEM

TABLE OF CONTENTS

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I. INTRODUCTION

A ‘‘new wave’’ of thinking and policy in science and technology policy has emerged from a combination of several factors, notably: *i)* academic research, including contributions by Nelson, Romer, Metcalfe, David, and Foray;[1] *ii)* the end of the East-West military and political confrontation; *iii)* slower economic growth and intensified competitive pressure within the G7 economies; and *iv)* slower growth in the budgets of G7 central governments, which has placed severe constraints on spending on discretionary programmes such as R&D. Some elements of this new approach to science and technology policy are articulated in the recent OECD report on ‘‘Best Policy Practice’’ (OECD, 1998), which emphasizes the need to move beyond the ‘‘market failure’’ foundation for policy making and advocates a focus on ‘‘institutional systems’’ for the support of innovation at the national and regional levels. A key prescription of this new framework is the use of policies to encourage interactions among institutional actors within innovation systems, based on the recognition that the linear model of the innovation process has lost much of any validity it once had.

The OECD document is intended to distil ‘‘best practices’’ from the experiences of OECD Member nations in restructuring science and technology policies. But few of these initiatives have been the focus of rigorous evaluations, and the feasibility and effectiveness of these ‘‘best practices’’ therefore remain open to question. Such evaluations are essential, in large part because the ‘‘new thinking’’ in the economics of innovation cited above does not always yield precise prescriptions for policy, and many of its prescriptions require conceptual taxonomies or data that do not presently exist.

This article examines recent experiments in US science and technology policy that have relied on the creation of markets in intellectual property to encourage the types of inter-institutional interactions and technology commercialisation that the ‘‘new thinking’’ in policy prescribes. These US policy initiatives depart in important respects from the prescriptive advice of the scholars cited earlier. In particular, some of them provide encouragement for technology commercialisation and inter-institutional collaboration by restricting other channels for knowledge distribution within the US and global innovation systems.

The key question is whether the vehicle employed for promotion of these collaborations is appropriate. The heavy emphasis in recent US initiatives on the creation of markets for intellectual property paradoxically may discourage or impede some desirable forms of interaction, while emphasizing others that are less effective for system-wide performance. Such policies raise at least two types of hazards for the institutions they seek to influence. Some institutions, such as government laboratories, are insufficiently responsive to the market-based incentives provided by current programmes. But other institutions, such as US research universities, may be too responsive to such incentives, and the resulting changes in internal norms and behaviour could impair the research and training roles that these institutions have performed effectively during the post-war period.

The next section briefly surveys the intellectual foundations for new approaches to science and technology policy, focusing on the limits of their guidance to policy makers. Section III describes the changes in the US innovation system since the early 1980s, and presents a summary comparison of structural change in the US R&D system with that in other major OECD economies. The fourth section discusses post-1980 US government efforts to strengthen protection for the intellectual property created with public research funding, and presents some preliminary evidence on their implementation and effects. Concluding remarks are in Section V.

II. ‘‘NEW THINKING’’ ON THE CHARACTERISTICS OF KNOWLEDGE AND NATIONAL INNOVATION SYSTEMS

In several recent papers, Richard Nelson and Paul Romer have jointly and separately stressed the need to distinguish among different bodies of knowledge within the process of scientific and technological change. Nelson (1992) argues that both public and private R&D performers in capitalist economies produce ‘‘public’’ and ‘‘private’’ knowledge. Basic research produces quintessentially public goods, for which the creation of private property rights is difficult and undesirable. Although much technological innovation occurs in the absence of a strong science base, the results of basic research inform and can improve the productivity of applied research efforts. Even the results of unsuccessful experiments are useful in this context, since they can guide other researchers away from ‘‘dry holes’’ (David, Mowery and Steinmueller, 1992). But Nelson argues that the applied research efforts of both public and private institutions also produce important ‘‘generic’’ knowledge that is best kept in the public domain, because it aids and accelerates the innovation process. Examples of such generic knowledge include information on materials properties or standards, manufacturing process know-how, information disclosed in patent grants, and basic scientific research findings that underpin technological innovation in many sectors.

Romer (1997) and Nelson and Romer (1997) extend and refine this argument, drawing on Romer's distinctions between ''rival'' and ''non-excludable'' goods. Rival goods are those for which the use by one consumer degrades or eliminates the possibility of use by another – these are typically tangible objects (or natural resources), and are differentiated from goods such as information or software, where one individual's use does not degrade or eliminate the possibility of use by another. This distinction recalls Arrow's classic 1962 analysis of ''market failure'' in R&D investment. But Romer and Nelson point out that the ''excludability'' associated with goods of varying degrees of ''rivalrousness'' is in many cases determined by policy. Software and many forms of information (including basic research results) can be rendered more or less excludable by the private actions of their authors, and by the forms of protection extended to intellectual property by governments. The critical challenge in the Romer-Nelson view, which broadly resembles Nelson's earlier formulation, is in setting the ''excludability fence'' at the right point and height, enabling some types of non-rival goods to be protected and others to be used at low or no cost. The authors suggest that such protection should be afforded to ''applications'', but not to the basic ''concepts'' underlying them, and recommend that patent examiners deny generic, broad claims that go beyond the specifications of the invention in the application. Although this recommendation is appealing, its implementation requires deep understanding of the highly idiosyncratic characteristics of different bodies of knowledge. The data to establish such distinctions do not exist, which makes the analysis an important consideration, but thus far an inapplicable prescription, for policy.

Other work by Nelson (1993), David and Foray (1996) and Metcalfe (1995) on national innovation systems raises similar considerations for the design or reform on national R&D systems. David and Foray stress the importance of the distribution of the results of R&D among various actors within these systems. Like Nelson and Romer, David and Foray argue that more widespread distribution and access of knowledge and know-how can improve the performance of national R&D systems, since such information improves the priors of would-be inventors about promising avenues for exploration and can reduce unwarranted duplication of inventive effort. The prescriptive advice of David and Foray supports a sceptical attitude towards broad or exclusive grants of intellectual property rights to individual inventors and favours a requirement that any grants of exclusive ownership of intellectual property be accompanied by significant requirements for disclosure of the technical content of such advances. At present, however, implementation of these policy prescriptions, like those of Nelson and Romer, remains infeasible without detailed data that are not available to policy makers or others. Indeed, David and Foray propose an ambitious data collection project to improve such information for policy making.

Metcalfe (1995) emphasizes the importance of analysing national innovation systems as systems, rather than focusing on individual institutions in isolation from one another. Thus, policies intended to improve systemic performance should focus on the interactions among the institutions typically included in most definitions of national innovation systems, as well as the interactions between these institutions and others (*e.g.* regulatory or competition policy bodies) not typically included in such definitions. The robustness, efficiency, adaptability and likely future path of the system are as important as the behaviour of individual parts. But here too, prescriptive advice is lacking, because of the high level of aggregation of the analysis and the absence of reliable data on which to base assessments of system-wide performance or dynamics.

All of these contributions to the economics of science and technology policy reject simplistic ‘‘linear models’’ of the interaction between scientific and technological knowledge within the innovation process. In varying degrees, they also emphasize the importance of differences among industries in the structure of innovation processes, in these industries’ reliance on different bodies of knowledge, and in the importance of different institutional performers and funders of scientific and technological research. All of these analyses also are wary of comprehensive policies to strengthen intellectual property rights and express scepticism about the feasibility or desirability of exclusive reliance on market mechanisms for the distribution of knowledge or for the governance of collaborations among institutions. This last point is worth emphasizing, in view of the contrary trend that is apparent in recent policy developments in the United States, and the possibility that US developments could prefigure similar trends in other OECD nations.

III. STRUCTURAL CHANGE IN THE US NATIONAL R&D SYSTEM, 1980-95

Introduction

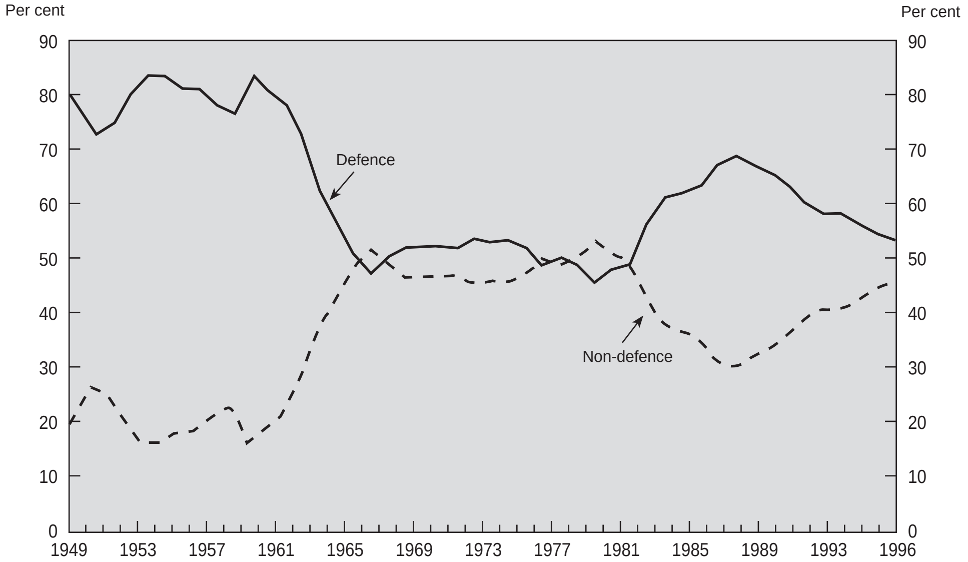
The foundations of the structure of the post-war US ‘‘national innovation system’’ were largely put in place during 1945-50, as demobilisation for peace was replaced by Cold War rearmament. The federal government assumed a role as a financial supporter of R&D that dwarfed its pre-1940 presence – the federal share of national R&D spending rose from roughly 20 per cent in 1939 to more than 50 per cent by 1962. Federal spending supported R&D activity in industry and universities, rather than being concentrated in federal government laboratories; as of 1988, arbitrarily chosen as the last year of the Cold War, 11 per cent of R&D performance was located in the public sector, 14 per cent took place in universities and 73 per cent was located in industry.

Federal R&D spending was dominated by basic research (especially in the biomedical sciences), and research in defence-related technologies. During the late 1950s (see Figure 1), defence-related spending accounted for as much as 80 per cent of federal R&D outlays. Federal and state governments invested little in programmes designed to assist firms in adopting technology, which may have contributed to the relatively slow adoption by US manufacturing firms of advanced manufacturing technologies (Mowery and Rosenberg, 1993; Edquist and Jacobsson, 1988). US agriculture, of course, was a prominent exception to this characterisation, with its elaborate network of federal and state-funded extension agents (see Evenson, 1982).

The dramatic transformation in the scope and sources of funding for R&D activity within the post-war US economy (along with the migration of a number of leading European scientists to the United States during the 1930s and 1940s) aided the emergence of the United States as a leading source of basic scientific

Figure 1. **The conduct of federal R&D: defence and non-defence shares**

Fiscal years 1949-96[1]



1. Outlays for FY 1995 are estimates. Outlays for FY 1996 are proposed.

Source: US Office of Management and Budget, 1995.

research, a characterisation that could not have been applied to the US innovation system of the 1930s. From an inter-war position of parity at best in some fields and considerable lags behind the scientific frontier in others, US scientists during the post-war period have come to dominate scientific publications and major awards such as the Nobel Prize.[2] This shift in the standing of US scientific research was associated with the emergence of several other distinctive features of the US national innovation system. Defence-related R&D and procurement programmes provided a powerful impetus to the development and commercialisation of new civilian technologies in commercial aerospace, semiconductors, computers, and computer software (such defence ‘‘spillovers’’ proved to be far less beneficial for civilian firms in nuclear power). In almost all of these industries other than commercial aerospace, new firms played a prominent, and in some cases dominant, role in the commercialisation of important technological advances. The important role of these new firms appears to be unique among the major post-war industrial economies, and reflects the unusual conjunction of defence procurement policies with US antitrust policy and a domestic financial system that aided the formation of new enterprises in high-technology industries (Mowery, 1997*a,* provides additional details).

Change in public and private R&D spending, 1980-95

The most dramatic shift in spending trends within the US R&D system during the past 15 years is the decline in R&D spending by the federal government. Having grown at an average rate of 6 per cent per year in real terms during 1980-85, inflation-adjusted federal R&D spending declined at an average rate of roughly 1 per cent per year during 1985-95.[3] The other major source of R&D spending within the US system is industry, which accounted for 59 per cent of total R&D spending in 1995. Industry-financed R&D scarcely grew in real terms during the early 1990s, but this trend was reversed sharply in 1993, and National Science Foundation data for 1993-95 reveal that real industry-funded R&D spending grew at an annual rate of nearly 10 per cent during the period (National Science Foundation, 1998).

These shifting growth trends in industry- and government-funded R&D have produced wide swings in the rate of growth in overall US R&D spending since 1980. Total national R&D spending grew by nearly 7 per cent annually in constant-dollar terms during 1980-85, but during 1985-93, the average annual rate of growth in total constant-dollar R&D spending declined to 1 per cent. More recently, however, total US R&D spending has grown in real terms at an average annual rate of almost 3 per cent between 1993 and 1995.

Declines in federal R&D spending are largely due to reductions in defence-related R&D spending, which increased from 50 per cent of federal R&D spending in 1980 to almost 70 per cent by 1986, a level from which it has declined once again to approximately 52 per cent of total federal R&D spending (Figure 1).[4] Further reductions below this share of the overall federal R&D budget appear to be unlikely, although pressure for increased procurement spending may increase the share of development activities within the defence-related R&D budget. The long-term outlook for growth in federal civilian R&D spending is uncertain. Legislative actions by the Senate and House of Representatives increased the federal R&D budget for fiscal 1998 by more than 4 per cent above its prior-year levels, and more recent forecasts of budgetary surpluses may result in further increases in federal R&D spending, especially in biomedical research. Longer-term trends, however, are less favourable for civilian R&D spending growth. In the absence of political agreement on reductions in entitlement spending for the elderly and health care, growth in these items will constrain growth in federal R&D spending. Even in the context of a balanced overall federal budget – a state of grace that is likely to be temporary at best – it is unlikely that federal R&D spending will increase significantly above its 34 per cent share of total US R&D spending for 1995.

Another important shift in the profile of US R&D spending growth during the 1990s is the reduction in the share of ‘‘research’’ within overall ‘‘R&D’’. During 1991-95, total spending on basic research declined at an average rate of almost 1 per cent per year. This decline reflected reductions in industry-funded basic research from almost US$7.4 billion in 1991 to US$6.2 billion in 1995 (in 1992 dollars). Real federal spending on basic research increased slightly during this period, from US$15.5 to almost US$15.7 billion. Industry-funded investments in applied research scarcely grew during this period, while federal spending on applied research declined at an annual rate of nearly 4 per cent. In other words, the upturn in real R&D spending that has resulted from more rapid growth in industry-funded R&D investment is almost entirely attributable to increased spending by US industry on development, rather than research. Indeed, the National Science Foundation reports that industry-funded real spending on ‘‘development’’ grew by more than 14 per cent during 1991-95, from US$65 billion to US$74.2 billion (federal development spending declined during this period, reflecting the cutbacks in defence-related R&D spending).

Extrapolation of future trends from recent data that cover only four years is hazardous. Nevertheless, if the trends of the early 1990s continue unabated, US R&D spending could change its profile and pattern of growth significantly. The reduction in the federal government’s share of overall R&D means that increased federal R&D spending will do less to offset the effects of any future reductions in the rate of growth in industry-financed R&D spending on overall US R&D spending levels. Since industry-funded R&D investment tends to move procyclically, future trends in total US R&D spending are likely to be more sensitive to the domestic business cycle. In addition, the reduction in the federal government share of total R&D spending and the apparent shift in the profile of industry-funded R&D spending to favour development more heavily than ‘‘upstream’’ research activities (basic and applied research) could shorten the time horizon of overall US R&D investment, with important consequences for both national and international scientific and technological advance.

Promoting the ‘‘privatisation’’ of R&D results

Shifts in US policy toward intellectual property rights began in the early 1980s, and produced action in a number of different spheres. In 1982, Congress established the Court of Appeals for the Federal Circuit, which strengthened the protection granted to patentholders.[5] The US government also pursued stronger international protection for intellectual property rights in the Uruguay Round trade negotiations and in other bilateral venues. The faith in intellectual property rights as a critical policy tool in improving US competitiveness was exemplified in two other statutes of the 1980s that sought to encourage closer links between US industrial firms and other key institutions in the US R&D system. The Bayh-Dole Patent and Trademark Amendments Act of 1980 permitted performers of federally funded research to file for patents on the results of such research and to grant licences for these patents, including exclusive licences, to other parties. The Federal Technology Transfer Act of 1986 and amendments passed in 1989 authorised federal laboratories to conduct co-operative research and development agreements (CRADAs)[6] with private firms, and allowed the assignment of any resulting patents to these firms.

This broad shift in policy toward intellectual property rights reflected growing concern by policy makers and managers in the private sector that intensified foreign competition necessitated tighter protection of intellectual assets. The policy shift also was influenced by the increased saliency of competitiveness and economic growth in domestic political debate after 1980. Growing concern over domestic economic performance intensified political demands for tangible economic benefits from public R&D spending. As Eisenberg (1996) notes, policy makers believed (on the basis of modest evidence) that stronger protection for the results of publicly funded R&D would accelerate their commercialisation and the realisation of these economic benefits by US taxpayers. Finally, and of considerable importance, these new policies of support for patenting of the results of public R&D programmes held out the promise of increased economic returns for little additional investment of public funds, an enormously attractive feature for policy makers dealing with severe fiscal constraints. This last characteristic of the ‘‘intellectual property markets’’ policy is likely to enhance its appeal to other OECD governments that face similarly binding spending constraints.

Although this shift in policy towards the protection of the results of public R&D programmes arguably is consistent with the ‘‘market failure’’ analysis of R&D described in the OECD ‘‘Best Practices’’ report, it upends the classic market failure analysis of Arrow (1962) and Nelson (1959). Both of these scholars, especially Arrow, argued that the ‘‘non-excludable’’ characteristics of the results of fundamental research meant that pricing these results at a sufficiently high level to reward their discoverer was socially inefficient. In addition, Arrow noted that the market for inventions itself was prone to failure, because of the paradox of information, uncertainty and other problems.[7] The Bayh-Dole Act and its various modifications adopt the opposite view – unless the discoverer can establish property rights to these results, mechanisms for their distribution and transfer will fail, preventing the commercialisation of these results and the realisation of a return to investments of public funds.

Rather than emphasizing public funding and relatively liberal disclosure and dissemination, the Bayh-Dole Act assumes that restrictions on dissemination of the results of many R&D projects will enhance economic efficiency by supporting their commercialisation. In many respects, the Bayh-Dole Act is the ultimate expression of faith in the ‘‘linear model’’ of innovation – if basic research results can be purchased by would-be developers, commercial innovation will be accelerated. But, as Nelson and Romer or David and Foray point out, the effects of raising the private returns to invention are likely to differ from the effects of subsidising R&D, the Arrow recommendation.[8]

Comparing the US and other OECD economies

Data on similar changes in the treatment of the results of publicly funded R&D in other OECD economies are difficult to obtain. It nevertheless seems likely that US policy has moved further in extending formal intellectual property protection to the results of publicly funded research than has occurred in other large OECD economies. Indeed, the overall growth in the use of formal intellectual property protection in the United States since the early 1980s contrasts with trends in other large OECD economies. Patent applications from US inventors in the United States have soared since the mid-1980s,[9] and patenting by US universities has grown even more dramatically (see below). Patent applications by domestic inventors in Germany, France, Japan and the United Kingdom display no comparably sharp surge in growth from the mid-1980s (Kortum and Lerner, 1997).

Structural change in other, more easily measured features of the US R&D system, however, seems to follow trends in other OECD economies more closely. Table 1 contains data on trends during 1971-93 in the distribution of R&D performance and funding among government, academia and industry in the largest OECD economies. These indicators suggest that the post-1981 restructuring of the sources of funding in the US R&D system is proceeding along lines that closely resemble those of the other four largest OECD Member States (the United Kingdom, France, Germany and Japan) – the share of public funding of

Table 1. **Structural change in the five largest OECD national R&D systems, 1971-93**

	Sources of R&D finance (percentage)											
	Industry				Government				Other national sources			
	1971	1981	1991	1993	1971	1981	1991	1993	1971	1981	1991	1993
United States	39.3	48.8	57.5	58.7	58.5	49.3	40.5	39.2	2.1	1.9	2.0	2.1
Japan	64.8	67.7	77.4	73.4	26.5	24.9	16.4	19.6	8.5	7.3	6.1	7.0
France	36.7	40.9	42.5	46.2	58.7	53.4	48.8	44.3	0.9	0.6	0.7	1.3
Germany	52.0	57.9	61.7	60.2	46.5	40.7	35.8	37.0	0.6	0.4	0.5	0.5
United Kingdom	43.5	42.0	50.4	52.1	48.8	48.1	34.2	32.3	2.3	3.0	3.6	3.9
	Shares of total R&D performance (percentage)											
	Industry				Government				Other national sources			
	1971	1981	1991	1993	1971	1981	1991	1993	1971	1981	1991	1993
United States	65.9	70.3	72.8	71.2	15.5	12.1	9.9	10.2	15.3	14.5	14.1	15.2
Japan	64.7	66.0	75.4	71.1	13.8	12.0	8.1	10.0	19.8	17.6	12.1	14.0
France	56.2	58.9	61.5	61.7	26.9	23.6	22.7	21.2	15.6	16.4	15.1	15.7
Germany	63.7	70.2	69.3	66.9	14.2	13.7	13.9	14.8	21.6	15.6	16.3	18.1
United Kingdom	62.8	63.0	65.6	65.9	25.8	20.6	14.2	13.8	8.7	13.6	16.3	16.5

Source: OECD, *Science, Technology and Industry Outlook,* 1996.

R&D has dropped and industry R&D funding has grown (although the Japanese government made a public commitment in 1996 to significantly increase public R&D spending, slow economic growth may constrain growth in public R&D spending – see Normile, 1997). The sharpest decline in public-sector R&D funding among these five nations during 1981-93 has occurred in the United Kingdom, where the share of national R&D spending funded by public sources has dropped by roughly one-third. In both the United States and France, public funding has declined by approximately 10 per cent of R&D spending, a decline in the public share of roughly one-fifth. The data for Germany and Japan reveal smaller declines in the public share through 1993.

The shifts during 1981-93 among universities, industry, and government in the performance of R&D within these five economies are less significant (again, with the exception of the United Kingdom, where a number of public research laboratories have been privatised). The data for the United States reveal very small increases (a shift of less than 1 per cent in the share of *each*) in the share of R&D performed by industry and universities, and a slightly larger decline (of nearly 2 per cent) in the share of R&D performed in government laboratories. The share of publicly performed R&D in both Japan and France declined by comparable or slightly larger amounts, while the German data (which include the effects of unification) rise modestly. The United Kingdom data, however, reveal a decline of nearly 7 per cent in the share of R&D performed in government facilities.

If there is an ‘‘outlier’’ in these measures of structural change since the early 1980s in national R&D systems, it is the United Kingdom, rather than the United States. In general, the shifts in funding sources in the United States and the other largest OECD economies are slightly larger than the shifts in performance. Indeed, the contrasting magnitude of these trends in structural change reflects the difficulties of undertaking radical structural changes in national R&D systems of the sort illustrated by the United Kingdom. The highly visible political costs of closing or privatising large public research establishments vastly outweigh those associated with the gradual shrinkage of such facilities through incremental shifts in the shares public and private R&D spending. Nevertheless, the United States appears to differ from other large OECD economies in its policy initiatives affecting the ownership of the results of research performed with public funds.

IV. ASSESSMENT

This section presents detailed evidence on the operation and effects of two policies for the support of inter-institutional collaboration in the US R&D system, both of which have been influenced by the Bayh-Dole and Federal Technology Transfer Acts. The first policy has encouraged collaboration between US research universities and industry in technology development and licensing. The second case focuses on the use by federal laboratories of Co-operative Research and Development Agreements (CRADAs) to support collaboration with industry. Both of these policies have relied on strengthened domestic and international enforcement of intellectual property rights, increasing the ‘‘excludability’’ of research results while simultaneously making it possible for the results of publicly funded research to be patented and licensed to industry by university and laboratory performers of this R&D.

These cases also suggest some limitations to domestic inter-institutional collaboration: without the creation of new ‘‘bridging’’ institutions between universities and industry, or the imposition of much more far-reaching structural and budgetary reforms on federal laboratories, these efforts at structural reform may have limited benefits. In the case of universities, these new policies may produce significant change, restricting the operation of important channels for knowledge dissemination that enhance the social returns to academic research. In the federal laboratories, these policies are too modest in scope to enhance meaningful collaboration, even as they impose substantial administrative burdens on such collaboration and (as in the university case) restrict other channels for collaboration.

A changing role for university research?

A defining characteristic of the post-war US innovation system is the central role of research universities in the performance of fundamental research. Increased federal R&D spending during the post-war period transformed the position of US universities within the domestic innovation system. Universities’ share of total US R&D performance grew from 7.4 per cent in 1960 to nearly 16 per cent in 1995, and universities accounted for more than 61 per cent of the basic research performed within the United States in 1995 (National Science Foundation, 1996). The federal government’s contribution to university research has declined since the early 1970s, when federal funds accounted for more than 65 per cent of university-performed research and industrial support accounted for 2.3 per cent. By 1995, federal funds accounted for 60 per cent of total university research, and industry’s contribution had tripled to 7 per cent of university research. The major growth in industry’s share of university research, however, occurred during the 1980s, and since 1990 this industry share has remained roughly constant.

The increased importance of industry in funding university research is reflected in growth in the number of research institutes at US universities seeking to support research on issues of direct interest to industry. By 1992, more than

1 050 of these had been established, and data from Cohen, Florida and Goe (1994) indicate that 57 per cent of all such institutes in existence as of 1992 were established during the 1980s. Nearly 45 per cent of these institutes involve 1-5 firms as members, and more than 46 per cent of them rely on government funds for support in addition to (or in some cases, in lieu of) support from industry.

Of particular interest for the analysis of ‘‘best practice’’, especially in light of the criteria for policy reform suggested by David and Foray (1996), is the apparent willingness of some US universities to accept significant restrictions on the publication of the results of research undertaken with industry sponsorship. The survey of university-industry research centres by Cohen *et al.* (1994) found that 35 per cent of these centres allow participating firms to require that information be deleted from research papers before submission for publication, 52.5 per cent of the centres allow participating firms to delay the publication of research findings, and 31.1 per cent of the centres allow participating companies to require both the deletion of information and delays in publication. Cohen *et al.* (1994) point out that their data indicate only the fraction of centres that allow participating firms to impose such restrictions; these data do not capture the frequency with which sponsor firms actually request publication delays or deletion of information. The study also provides no information about the prevalence of publication restrictions at the leading US research universities that account for the bulk of the publicly financed research performed within the United States.

Restrictions on the publication of university research results are not new within the United States – during the 1950s and 1960s, defence-related research funding occasionally included restrictions on publication. Nevertheless, the apparent willingness of a large number of US universities to accept restrictions on the dissemination of research findings should be a cause for concern and may represent a major shift from the relatively ‘‘open’’ norms of university research that typified US universities during much of the post-war period. Liberal disclosure and dissemination of university research results (through publications, conferences and numerous other channels, including the foundation by faculty of ‘‘spinoff’’ firms) enhance the efficiency of the overall innovation system by expanding the pool of knowledge available to other would-be innovators (David, Mowery and Steinmueller, 1992; David and Foray, 1996).[10] Delays or restrictions on disclosure could have negative consequences for the innovative and economic performance of the US national innovation system that might outweigh the benefits derived from closer university-industry R&D relationships.

Another policy development with significant implications for the role of universities within the US innovation system is the growth of university patent licensing and ‘‘technology transfer’’ offices since passage of the Bayh Dole Act. These policies also have increased the ‘‘excludability’’ associated with much university research. The number of US patents awarded to the 100 leading US research universities (measured in terms of their 1993 R&D funding) grew from 177 in 1974 to 1 486 in 1994 (Table 2). The data in Table 2 reveal a sharp increase in university patenting after the passage of the Bayh-Dole Act in 1980 – the number of patents issued to these 100 universities more than doubled between 1979 and 1984, and more than doubled again between 1984 and 1989. Trajtenberg, Henderson and Jaffe (1994) noted that the share of all US patents accounted for by universities grew from less than 1 per cent in 1975 to almost 2.5 per cent in 1990. Moreover, the ratio of patents to R&D spending within universities almost doubled during 1975-90 (from 57 patents per US$1 billion in constant-dollar R&D spending in 1975 to 96 in 1990), while the same indicator for all US patenting displayed a sharp decline (decreasing from 780 in 1975 to 429 in 1990). In other words, universities increased their patenting per R&D dollar during a period in which overall patenting per R&D dollar was declining significantly.[11]

Table 2. **Number of US patents issued to 100 US academic institutions with the highest 1993 R&D funding, 1974-94**

	Number of US patents
1974	177
1979	196
1984	408
1989	1 004
1994	1 486

Source: National Science Board (1996).

In addition to increasing their patenting activities, US universities expanded their efforts to licence and reap revenues from these patents. The Association of University Technology Managers (AUTM) reports that the number of universities with technology licensing and transfer offices increased from 25 in 1980 to 200 in 1990, and licensing revenues of the AUTM universities increased from US$183 million to US$318 million in the three years from 1991 to 1994 alone (Cohen *et al.,* 1997). Data for the largest single institutional recipient of licensing income, the University of California, indicate that total income grew from US$22.5 million in fiscal 1991 to nearly US$75 million in fiscal 1997 (Office of Technology Transfer, 1997). The majority of this income stream derived from a very small number of patents – the ‘‘top 5’’ patents within the University of California’s portfolio (all of which are based on biomedical research) accounted for 74 per cent of the University’s fiscal 1997 licensing income, and the distribution of profits from other universities’ patent portfolios is likely to be similarly skewed.

The rapid growth in patenting and licensing by universities need not inevitably constrict the channels of knowledge transmission within the US economy. The issue of a patent in the United States requires the disclosure of the technical details of an invention, which disseminates the codified knowledge that is specific to that invention. Moreover, in some instances (*e.g.* the Cohen-Boyer patent on gene splicing techniques), widespread commercial application of a major university research advance does not appear to have been obstructed by the issue of a patent and its extensive dissemination through non-exclusive licences.

Nevertheless, like publication restrictions within university-industry research institutes, the rapid growth of university licensing programmes, many of which involve restrictions on publication before patent applications are filed, could limit the diffusion of important scientific and technical knowledge within the US innovation system. For example, restrictive licensing terms (*e.g.* exclusive licences that cover a broad array of possible fields of use) could reduce the speed and coverage of ‘‘knowledge distribution’’ within the US national innovation system and within the international innovation system (David and Foray, 1995). Bayh-Dole and related initiatives that seek to strengthen the contributions of research universities to economic growth are based on a narrow view of the channels through which universities and faculty interact with industry and affect the innovation process. Not only publishing, but conferences, consulting, graduate education and service on scientific advisory boards all operate to transfer academic research results to industry and *vice versa.* The incentives created by Bayh-Dole may lead to one channel being favoured at the expense of others – emphasis on patenting, rather than publishing, the results of research may well reduce the volume of information flowing through conventional channels of dissemination in favour of market-based transactions.

Paradoxically, in view of the Congressional origins of the policy that has given renewed impetus to their efforts in this area, US universities’ use of federal funds to ‘‘privatise’’ research results for profit could threaten the historically strong political support for federal support of basic research. For example, industry support for public funding of academic research may be undercut if universities adopt a very restrictive approach towards protection of the intellectual property resulting from publicly funded research. Restrictive policies, such as extensive use of exclusive licensing contracts, create a risk that firms will protest the use of general revenues to benefit their competitors, an issue that has arisen in the collaborative research activities of the Department of Energy laboratories. Licensing and other agreements with non-US corporations create similar risks and potentially greater political controversy.

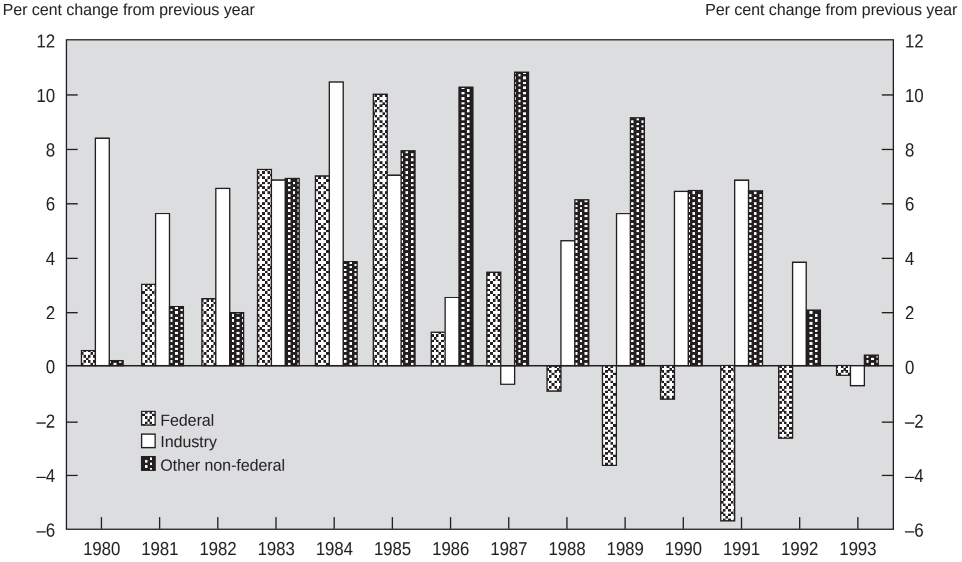
An assessment of the effects of increased ‘‘connectivity’’ and collaboration between US universities and industry must consider the effects of such collaboration on the process of academic research, including the commitment of academic researchers and administrators to the free dissemination of the results of research. The above discussion suggests some basis for concern over these effects, although recent ‘‘horror stories’’ of restrictions on disclosure (see the collection of articles in *science,* 25 April 1997) may not be representative. An equally reasonable basis for concern, however, is the possibility that the intellectual property that is being protected through these expanded university efforts is not particularly valuable. In their analysis of post-1980 US university patents, Henderson *et al.* (1994) use citations of these university patents in subsequent patent applications as a measure of quality, a procedure employed by other scholars in previous work. Their work suggests that the ‘‘average quality’’ of these post-1980 patents has declined, relative to those in a control sample drawn from all patents issued during the same period.

An analysis of the patenting and licensing activities of the University of California before and after Bayh-Dole

A comprehensive assessment of Bayh-Dole’s effects on university research and licensing activities must separate its effects on universities already active in patenting and licensing from its effects on entry by universities into this activity. The data presented above indicate that a large number of US universities previously not active in patenting and licensing their research results created new offices devoted to such activities after 1980. But a number of other US universities, such as the University of California, Stanford University, M.I.T. and the University of Wisconsin, have patented and licensed inventions for much of the 20th century. Data on these ‘‘incumbent’’ universities’ patenting activities should shed additional light on changes in the quality of the patents issued to universities after 1980.

As a first step in such an analysis, this article presents data on the University of California’s patenting and licensing activities for 1975-79 (prior to Bayh-Dole) and 1984-88, following the passage of the bill. The average annual number of ‘‘invention disclosures’’ during 1984-88, following passage of the Bayh-Dole Act, is almost 237, well above their level (140) for the 1975-79 period.[12] The period following the Bayh-Dole Act thus is associated with significant growth in the number of inventions disclosed to the Office of Technology Transfer (OTT) at the University of California. But a somewhat different view of the effects of Bayh-Dole emerges from Figure 2, which displays a 3-year moving average in the disclosure of ‘‘inventions’’ by UC research personnel, which omits the first and last years in the 1975-88 period. The increase in average invention disclosures in Figure 2 predates the passage of the Bayh-Dole Act; indeed, the largest single

Figure 2. **Annual changes in national R&D spending, by source of funds: 1980-94**[1]
Based on constant 1987 dollars



1. Data are estimated for 1993 and 1994. As a result of a new sample design for the underlying Survey of Industrial Research and Development, data for the years 1988-92 have been revised.

Source: National Science Foundation.

year-to-year percentage increase in disclosures during the entire 1974-88 period occurred in 1978-79, before the Act's passage. This increase in disclosures may reflect the important advances in biotechnology that occurred at UC San Francisco during the 1970s, or other changes in the structure and activities of the UC patent licensing office that were unrelated to Bayh-Dole.

What do these data suggest about changes in the ''quality'' of the larger portfolio of invention disclosures in the UC system after 1980? One measure of such quality is the share of disclosures that yield patent applications, granted patents and licences.[13] Comparison of the 1975-79 and 1984-88 disclosures (Table 3) reveals that all three of these shares are larger for the post-Bayh-Dole disclosures, although the share of disclosures that result in patents being issued increases only slightly.[14] The share of disclosures that result in licences generating royalty income also increases slightly in the second period (from 3.9 per cent

Table 3. **University of California invention disclosures, patents and licences, 1975-79 and 1984-88**

Percentage

	1975-79	1984-88
Disclosures generating patent applications/invention disclosures	24.0	31.2
Disclosures resulting in issued patents/invention disclosures	20.2	21.9
Disclosures licensed/invention disclosures	4.9	12.6
Disclosures generating licences with royalties/invention disclosures	3.9	5.0
Patents issued/patent applications	62.1	43.6
Patents licensed/patents issued	25.1	35.5
Licences with royalties/licences	87.2	59.3

Source: Office of Technology Transfer, University of California.

in 1975-79 to 5.0 per cent in 1984-88). None of these measures indicate a significant decline in the quality of the invention disclosures of the University of California after 1980.

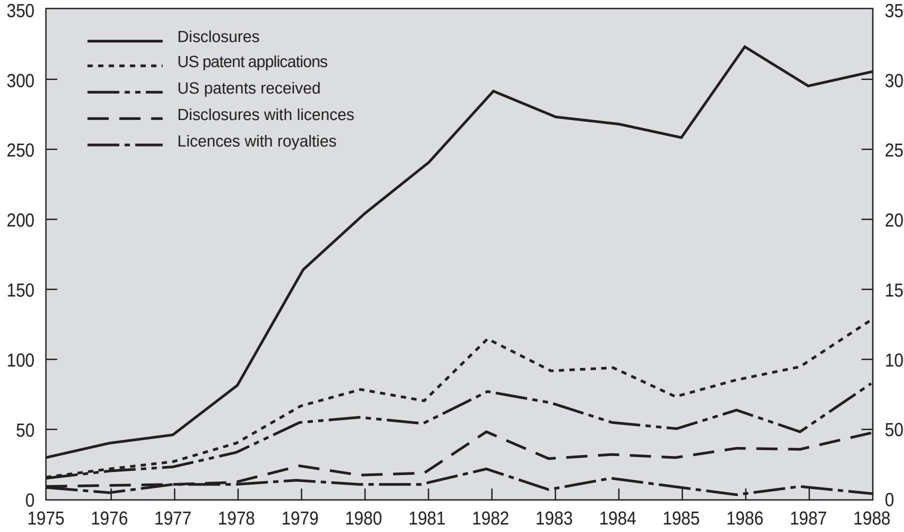
Other measures present a more mixed picture of the trends in the quality of the sub-set of UC inventions for which UC administrators sought patent protection after 1980. The share of patent applications based on these inventions that yield patent grants declines between these two periods (from 62.1 per cent in 1975-79 to 43.6 per cent in 1984-88), suggesting some decline in the novelty or non-obviousness of the applications resulting from the disclosures. This decline may reflect a greater effort by UC administrators to seek patent protection for a broader array of disclosures in the post-Bayh-Dole period. The increase in the share of disclosures that result in licences generating royalties (from 3.9 per cent in 1975-79 to 5 per cent in 1984-88) also is much smaller than the increase in the share of disclosures that result in licences, which more than doubles from 4.9 per cent in 1975-79 to 12.6 per cent in 1984-88. Like the drop in the share of patent applications resulting in patents, these data suggest some decline in the quality of the sub-set of all disclosures that resulted in licensing agreements for the 1984-88 period (149 disclosures from this period produced at least one licensing agreement) from that associated with disclosures produced during 1975-79 (34 disclosures from this period resulted in at least one licence). Indeed, the share of all of the licensing agreements associated with the second period's disclosures that yield positive royalties (59.3 per cent) is lower than this share for disclosures produced during 1975-79 (87.2 per cent).

Overall, then, these data on UC disclosures do not reveal a precipitous decline in the quality of the inventions disclosed to university administrators for possible patenting and/or licensing after Bayh-Dole's passage. These data do indicate that university administrators were seeking patent protection for a broader share of the underlying population of disclosures, and the decline in the share of patent applications resulting in patents suggests that this larger set of applications declined somewhat in quality. The more extensive licensing efforts of the post-1980 period also appear to have produced a decline in the ‘‘productivity’’ of these licences, measured in terms of the share of licences yielding positive royalties.[15] Although these results differ somewhat from those of Henderson *et al.* (1994), a rigorous comparison with this earlier work requires an analysis of citations to the UC patents based on these disclosures. Our results suggest that these scholars’ findings of declines in the quality of university patents after 1980 may reflect the patenting activities of entrants, rather than the incumbents that had long been active in patenting and licensing. Further research on the effects of Bayh-Dole on the patenting and licensing activities of US universities should separately analyse the activities of ‘‘entrants’’ and those of ‘‘incumbents’’.

We noted earlier that the licensing income of the University of California has long been dominated by licences based on biomedical invention disclosures. The 1970s were a period of remarkable scientific and innovative activity in the biomedical sciences, and the University of California, especially the San Francisco campus (UCSF), played a prominent role in these advances. One of the most widely licensed university patents of the 1980s, and one of the most profitable patents in the UC licensing portfolio, the Cohen-Boyer patent for gene splicing techniques, emerged from research at UCSF and Stanford during this period. What role did biomedical inventions play in the steady growth in UC invention disclosures prior to 1980?

Figure 3 reveals that the shares of biomedical inventions within all UC invention disclosures began to grow in the mid-1970s, well before the passage of Bayh-Dole. Moreover, these biomedical inventions have long accounted for a disproportionate share of the patenting and licensing activities of the University of California – during 1975-79 biomedical invention disclosures made up 33 per cent of all UC disclosures, but these disclosures accounted for 60 per cent of patents issued to the University of California for inventions disclosed during that period. The importance of biomedical patents in UC licensing was greater still during this period, as they accounted for 70 per cent of the licensed patents for this set of disclosures. Biomedical inventions retained their importance during the 1984-88 period, as they accounted for 60 per cent of disclosures, 65 per cent of patents, and 74 per cent of the patents from these disclosures that were licensed. Biomedical licences accounted for 59 per cent of the UC licences based on 1975-79 disclosures that generated positive royalties. Their share of this population for the 1984-88 disclosures was higher still – 73 per cent. Biomedical inventions thus account for a disproportionate share of UC patenting and income-generating licences before and after 1980. Moreover, the growth in the number of disclosures in the biomedical area predates the passage of the Bayh-Dole Act.

Figure 3. **University of California: Invention disclosures, patent applications, grants and licences, 1975-88**
Three-year moving average



Source: Office of Technology Transfer, University of California.

The apparent effects of Bayh-Dole on UC invention disclosures, patenting and licensing thus are confounded with those of a nearly simultaneous shift in the underlying research agenda, as biomedical research funding and scientific advances grew rapidly during the 1970s and 1980s.

A summary assessment

The Bayh-Dole Act has enticed many more universities to expand (or begin) ambitious policies to patent and licence the results of federally and industrially funded research, but the economic effects of this major federal policy shift on faculty inventions and patenting have been mediated by a shift in the content of academic research toward biomedical inventions. The data on the University of California suggest that for universities already active in patenting and licensing, Bayh-Dole's effects were modest, especially given the simultaneous shift in the composition of this academic invention portfolio.

The Bayh-Dole Act and the related activities of US universities in seeking out industrial funding for collaborative R&D have considerable potential to increase the ‘‘excludability’’ of academic research results and to reduce the ‘‘knowledge distribution’’ capabilities of university research. The commercial attractiveness of academic research to industry and the ability of formal intellectual property protection to ‘‘exclude’’ others vary significantly among fields of technology – in biotechnology and other areas of biomedical research, patents are relatively strong and industrial interest is high. In other areas, however, such as semiconductor manufacturing technologies, academic research may be well behind industrial practice and formal intellectual property protection is of limited effectiveness. These differences among technologies also mean that different channels for technology transfer and R&D collaboration are likely to vary in importance across technology classes. Yet many US university administrators persist in the belief that fields like biotechnology, more likely the exception, define the rule.

There are no comprehensive data that allow one to determine whether the conduct of academic research and education in fields such as molecular biology or computer science has been significantly compromised as a result of expanded collaboration with industry and any restrictions on disclosure or dissemination of research results that may accompany such collaboration. But these dangers appear to be greatest in the fields where the ‘‘gap’’ between academic research and industrial application is especially narrow. And the US university, populated by entrepreneurial faculty and students with hard-won skills at raising research funds from external sources, is surprisingly responsive to shifts in the environment of research funding opportunities and constraints. In many respects, this very institutional responsiveness is an argument for some insulation of the research university from extensive involvement in R&D collaboration with industry, at least from the collaborative activities that may entail significant restrictions on publication or disclosure. For these types of activities, some sort of ‘‘bridging’’ institution, perhaps resembling the German Fraunhofer Institutes, may have significant advantages. Current policy discussions within the federal government and US universities, however, have scarcely considered such a possibility.

CRADAs and public-private collaboration

The Co-operative Research and Development Agreement, defined earlier, is another important instrument of post-Cold War federal technology policy that relies on markets in intellectual property for the creation of public-private R&D collaborations. CRADAs were created by the Federal Technology Transfer Act of 1986, but government-owned, contractor-operated federal laboratories were allowed to conduct CRADAs with private firms only with the passage of amendments to the Act in 1989. Federal agencies and research laboratories had signed more than 2 000 CRADAs through the end of 1995. Many CRADAs include cost-sharing provisions that provide ‘‘in-kind’’ support (typically, laboratory facilities staff, or equipment) for up to 50 per cent of total project costs.

Like the extension of licensing rights to universities, CRADAs were developed to encourage private investment in the commercial development of technologies whose initial discovery was wholly or partly financed with public funds. The CRADA’s assignment to a private party of the intellectual property rights to these technologies is intended to provide incentives to commercialise the technologies. As in the Bayh-Dole Act, the CRADA policy assumes that a critical impediment to the commercial exploitation of publicly funded research advances is the ‘‘non-excludability’’ of such research advances. The CRADA, which seeks to establish clear private property rights to these advances, is premised on an inversion of the Arrow-Nelson market failure analysis that is very similar to that underlying the Bayh-Dole Act – increased excludability for non-rival goods is expected to raise the private returns to commercial exploitation, thereby increasing the social returns to public research investments.

But the institutions involved in CRADAs, the federal laboratories, bear little resemblance to US research universities. With few exceptions, these organisations have been funded through programmatic budgets associated with the missions of their parent agencies. Researchers rarely rely for support on project funds that are awarded through peer-reviewed competition. The scientific and technological capabilities of these laboratories are closely linked to agency missions, rather than to industry concerns, and research personnel have fewer incentives to pursue funding from competitive sources. The modest incremental financial incentives provided by most CRADAs thus are likely to have less influence on the research agenda of federal laboratories than the Bayh-Dole initiatives could have on university faculty.

Case studies of CRADAs at a US weapons laboratory

CRADAs have received a good deal of attention but little evaluation. Indeed, very little is known about even the magnitude of federal spending on those CRADAs for which federal funds defray a portion of the costs of joint R&D.[16] One study of CRADAs between a large nuclear weapons laboratory operated by the Department of Energy (the Lawrence Livermore National Laboratory, LLNL) and private firms was recently conducted by Ham and Mowery (1995, 1998), and its results are briefly summarised here.

CRADAs have been especially prominent in the post-Cold War activities of the Department of Energy (DOE) laboratory complex, a network of 26 laboratories that in 1996 consumed more than US$8 billion in federal funds for operations, employed more than 50 000 workers, and by the Department’s own estimate, have received more than US$100 billion in public investment funds since their creation in the atomic weapons programme of the 1940s (US General Accounting Office, 1995; Lawler, 1996). The Department of Energy accounts for more than half of the 2 000 CRADAs signed by the federal government through 1995. Many of these DOE CRADAs have involved the DOE nuclear weapons laboratories – Los Alamos, Lawrence Livermore, and Sandia National Laboratories – which together accounted for more than US$3.4 billion in federal operating expenditures in 1996 (Lawler, 1996).

The field research reported here consisted of detailed case studies of five CRADA projects between private firms and Lawrence Livermore National Laboratory (LLNL).[17] The projects ranged widely in size, from budgets of less than US$1 million to more than US$20 million; the participating firms also varied greatly in size. The CRADAs covered technologies that ranged from materials analysis to electronics. Despite the central importance of intellectual property rights in the design of the CRADA instrument, in four of our five cases, obtaining intellectual property rights for the jointly developed results of the CRADA was not of central importance to the participating firms. Rather than estimating a ''return on investment'' from specific pieces of intellectual property created by these projects, firm managers stated that many of the benefits from their LLNL CRADA were generic.[18] The greatest benefit of their CRADAs was felt as much in other product lines and future products as in the specific ''deliverables'' produced by the CRADA. Few if any of these generic benefits are covered by the instruments of intellectual property protection that are at the heart of most CRADAs. Nevertheless, negotiation and approval of intellectual property provisions of these CRADAs consumed an enormous amount of time and delayed the inception of the projects, impeding the collaborative effort.

The creation and assignment to the private sector partner of intellectual property rights in CRADAs thus was of secondary importance, or operated as a hindrance, in a majority of these projects. Although for some collaborative research projects the transfer of intellectual property rights is critical, in those for which intellectual property rights are of secondary importance, simpler instruments for collaboration may be preferable to CRADAs. Indeed, a different approach that supported the dissemination of the ''generic'' knowledge created through the CRADA might yield greater private benefits to the industrial partners and higher social returns.

The radically different histories and operating environments of these private firms and the Livermore nuclear weapons laboratory also influenced the operation and outcome of the projects we studied. Moreover, the power of the CRADA instrument to bridge these differences was limited. LLNL researchers, many of whom had for years been involved in classified research on weapons systems for which performance was the overriding objective, often assigned the highest priority to answering the fundamental research questions within the project. Private sector teams, on the other hand, were most concerned with the completion of critical development milestones as quickly as possible, regardless of their understanding of the underlying science.

Another manifestation of the different ‘‘styles’’ of R&D associated with LLNL and private-firm managers was the disparate levels of familiarity with user needs and market requirements among the firm and LLNL participants in most projects. The CRADA mechanism worked reasonably well in the project in our study that focused on developing a product for which the Laboratory was a major user and manufacturer of previous models for internal use; as a customer, LLNL was able to articulate its needs clearly. Moreover, this project essentially focused on transferring Laboratory-developed technology to a firm, another factor contributing to its success. By contrast, managers from another small-firm CRADA participant felt that misunderstandings between LLNL and firm engineers were fuelled by LLNL engineers’ lack of familiarity with the operating environment within which the product under development would be used. These sorts of problems also reflect the inability of the R&D partners to fully assess the capabilities and likely performance of one another – misunderstandings between LLNL and private-firm personnel over user needs, operating requirements, and the level of fundamental knowledge of the underlying technology and science were common. Such misunderstandings are pervasive in R&D contracts, and overcoming them requires the use of ‘‘higher-powered’’ incentives for laboratory research personnel than are created by CRADAs.

The narrow bounds of the CRADA contract contributed to another problem that emerged at the conclusion of several of these projects, in which LLNL’s activity ceased immediately after the development and demonstration of a laboratory prototype. Rapid termination of the collaboration created problems in ‘‘debugging’’ laboratory prototypes for volume manufacture, a demanding task that often affects the performance characteristics and quality of the product. In one CRADA, this ‘‘post-prototype’’ phase involved the debugging of a complex piece of test equipment for use in materials analysis. Although they eventually succeeded in improving the performance of the equipment developed through their CRADA with LLNL to a level that met their expectations, the firm’s engineers felt that greater interaction with LLNL staff could have accelerated this four-month learning process. Laboratory personnel occasionally worked informally with the firms after the end of CRADA-related funding, but did so with no budgetary support. This situation contrasts with collaborative development agreements between private firms, in which profit-sharing arrangements frequently are designed to ensure that partners remain engaged in a joint product development effort well into the commercial manufacturing stage.

These case studies suggest that the private efficiency, to say nothing of the social returns from such collaborations, requires careful attention to match the requirements of collaboration in a specific area with the capabilities of partners and the policy instruments used to support such collaboration. Although CRADAs may be useful in some technologies or projects, their focus on intellectual property rights proved to be dysfunctional for a majority of the projects considered in this study. The design of CRADAs by Congressional policy makers, as well as their implementation in many federal laboratories, seems to assume that these facilities are ‘‘treasure chests’’, organisations with a great deal of technology that is directly applicable in private industry (Ham and Mowery, 1995). In this view, commercialisation of these technologies requires that their ownership be defined through the assignment of intellectual property rights and that these rights be transferred to the private sector through an agreement between the firm and the laboratory – only modest additional development is required. But the treasure-chest model is an inaccurate characterisation of the laboratories' technological assets and of the processes through which these assets can assist US industry. Few laboratory technologies are in fact ‘‘on the shelf’’, and the necessary co-development and improvement of these technologies for commercial application is a far more uncertain and demanding task than this model implies. Instead, co-development typically is fraught with uncertainty, requires intensive interaction and communication, and extends through the initial stages of large-scale manufacture of products incorporating the technology. A broader portfolio of mechanisms for collaboration, and expanded assessments of their effectiveness in specific fields and projects, would improve project performance.

Yet another impediment to the operation of CRADAs between LLNL and private firms, of course, is the fact that many of the core capabilities of nuclear weapons laboratories may have limited applicability to the technological problems of private firms. Even where such capabilities are relevant, public sector laboratory personnel often find it difficult to operate in the environment of short development cycles and tight budgets that characterises most private-sector projects. In our study, LLNL's role as a major user and prior manufacturer of the product that resulted from one project contributed to a successful outcome. The apparent success of this CRADA further suggests that co-development projects in technologies for which LLNL or other federal laboratories are major users of the results (equipment, ideas or services) are good candidates for the CRADA mechanism. These considerations provide another argument in favour of LLNL and similar facilities focusing their collaborative R&D activities on areas that are related to the Laboratory's historic missions in defence, energy and environmental research. Laboratory researchers will in most cases be far less familiar with user or industry requirements in areas that are far removed from these areas.

In contrast to much of the private sector infrastructure for Cold War defence R&D, reductions in the US defence budget have not produced dramatic cuts in the budgets for the federal defence-related laboratories operated by the Defense and Energy Departments. Indeed, one feature of CRADAs that made them especially attractive in the early 1990s was their promise of ‘‘conversion’’ of these laboratories, which could apply their extensive facilities and scientific and engineering skills to civilian technological challenges. These case studies support considerable scepticism about the ability of CRADAs to effect such a conversion, and their findings tend to corroborate the critical comments in the report of the US Department of Energy Task Force on Alternative Futures for the Energy Department Laboratories (1995; more commonly known as the Galvin Committee) about the feasibility of a broad ‘‘civilian competitiveness’’ role for the Energy Department’s weapons laboratories.

The mere existence of capabilities that are relevant to civilian as well as defence-related production or research activities (see Kelley and Watkins, 1995, for one recent empirical analysis) may be necessary, but is hardly sufficient, to support the application of these capabilities to civilian objectives in a cost-effective fashion. The influence of historical factors and intra-organisational incentives on the behaviour of researchers in Livermore and other facilities is so strong that reorientation of the activities of these research installations will require considerable time, far-reaching changes in their internal management, and much greater financial and other incentives for cost-effective performance of R&D tasks of interest to private firms.

A summary assessment

The creation of a market for the intellectual property resulting from joint R&D projects is insufficient to overcome deep differences in the approaches of public and private R&D personnel to such projects that reflect the contrasting environments of incentives, organisational structure and competitive pressure within which each group operates. Nor does the creation of such a market overcome problems with the transfer of technology through such channels that have been pointed out in earlier work (Arrow, 1962; Mowery, 1983). Indeed, the prominence assigned to intellectual property rights within the CRADAs that were examined in these case studies appeared to obstruct fruitful collaboration at least as often as it facilitated it. The scope for collaboration between defence-oriented laboratories such as LLNL and private firms in areas that are not directly related to LLNL’s historical missions appears to be limited; moreover, even within these mission-related areas, effective collaboration requires a much broader set of changes in budgetary and management policy than the assignment of intellectual property rights can accomplish.

V. CONCLUSION

The US national innovation system for much of the post-war period differed sharply in structure, scale, and operation from those of most other OECD nations

(Mowery and Rosenberg, 1993). At least some of these differences between the US and other national innovation systems may decline in significance as a result of the changes in R&D spending (especially the decline in public R&D spending related to defence) and performance that have taken place since the early 1980s. The broad outlines of post-1980 structural change in the US R&D system, at least, appear to be similar to those of other large OECD economies, with the exception of the United Kingdom. Another important source of change in the structure of the US innovation system about which this article is virtually silent is its internationalisation, which since the mid-1980s has reflected high rates of growth in R&D investment flows to the United States from firms based in other economies (Mowery, 1997*b*). Increased economic interdependence has a complement in growing interdependence between the US and other nations' innovation systems.

Despite the similarities among the large OECD nations in the trends of structural change within their R&D systems, there is little indication that these other nations have experienced a shift toward greater reliance on formal instruments of intellectual property for the results of publicly funded R&D that is comparable in significance to that observed in the United States over the past 15 years. These policy changes (along with other developments) have the potential to transform the role of the research university within the US innovation system, with very uncertain benefits and costs. Although some evidence suggests that the increased university patenting since 1980 covers rather unimportant intellectual property, this effect may reflect the patenting of US universities that became active in this area only after 1980. There is no indication of a sharp decline in the quality of the inventions patented by the University of California after 1980. Other evidence indicates that the increased prominence of university licensing may reflect changes in the academic research agenda that occurred for reasons unconnected with the shift in federal policy. Nevertheless, the concern of university faculty and administrators with patenting has in some instances been associated with restrictions on the free flow of scientific information, a development that should raise concern and merits close monitoring.

Transformation seems less likely, but probably more badly needed, in the federal laboratories that are attempting to create markets for their research through CRADAs. The upsurge in popularity of CRADAs, especially those involving defence-related laboratories, during the early Clinton Administration was based in large part on the potential of this policy to deliver a politically desirable compromise. CRADAs seemed to promise an increase in the economic returns to the large federal investment in defence-related laboratories, while enabling political decision makers in both Congress and the Executive branch to avoid the politically painful alternative of severe reductions in employment and budgets for these installations. But the creation of markets for the results of their research does little to change the internal structure and incentives, as well as the historical legacy of defence-related research, that hamper effective collaboration between these laboratories and private firms. Such collaboration is especially difficult, and inadvisable, in areas that are distant from those pursued historically in these laboratories.

The belief of policy makers from both the Republican and Democratic parties in the ‘‘magic of the market’’ in technology transfer and commercialisation is pervasive, and radically revises the prescriptive diagnosis of the ‘‘market failure’’ analysis of the early 1960s. Moreover, these initiatives appear to conflict with much of the recent work on the role of knowledge and innovation in the growth of modern industrial societies (David and Foray, 1996; Nelson and Romer, 1997). Indeed, the broader faith in intellectual property rights as a solution to ‘‘market failure’’ and as a vehicle to support inter-institutional collaboration deserves much more serious scrutiny and evaluation. Certainly, such initiatives appear to be inconsistent in many respects with the arguments of these scholars for broader distribution and lower levels of ‘‘excludability’’ for knowledge within national innovation systems. Nevertheless, policy makers throughout the OECD Member states, confronting limited public budgets and soaring demands (especially from entitlement programmes) for public spending, are likely to find policies like those of the United States attractive, because of their minimal incremental public costs and promise (however unrealistic) of improved performance, all without undertaking the far more politically painful tasks of large-scale structural reform of national R&D systems, especially public laboratories. The ‘‘market-oriented’’ policies pioneered by the United States thus may be emulated by other governments.

In view of this possibility, another disquieting element of these initiatives on which this article is largely silent concerns their often nationalistic overtones. University licensing of intellectual property to non-US firms has occasionally been the target of political criticism, and participation in CRADAs by non-US firms is permitted only in circumstances in which the foreign participant can guarantee that any results of the project will be ‘‘substantially manufactured’’ within the United States. This ‘‘techno-nationalistic’’ posture of course is consistent with the underlying concern of US policy makers over capturing the economic returns to their public R&D investments. But efforts to erect obstacles to international scientific and technological co-operation are likely to harm the welfare of citizens of the United States and other nations. Moreover, as and if the policy initiatives undertaken in the United States diffuse to other OECD Member nations, the conflict between growing international interdependence in science and technology and the nationalistic efforts of governments to capture the benefits of their R&D investments will become more intense, and the risks of obstructionist policies greater.

This assessment should illuminate some of the limits of inter-institutional collaboration – both its feasibility and in some instances, its desirability, can be overstated. But even more important from the viewpoint of research is the need for much better indicators of the incidence of such ‘‘knowledge privatisation’’ policies among the OECD economies and better measures of the extent to which patenting or licensing *per se* do in fact limit intranational and international knowledge flows. One of the most serious gaps between the emergent conceptual apparatus for assessing the ‘‘design’’ of national innovation systems and the empirical data available to support the application of such theories is precisely the lack of reliable data on the extent, significance and potential effects of changes in the treatment of intellectual property resulting from publicly funded R&D. An initiative worth pursuing on an exploratory basis would construct such measures for a small number of sectors or R&D performers within a few of the larger OECD economies, and test their robustness, coverage and validity. Without better measures of this sort, the promising theoretical apparatus now being developed will not provide the sorts of policy guidance of which it is capable. Recent trends in US science and technology policy indicate that such guidance is badly needed.

NOTES

1. See Nelson (1992, 1993); Nelson and Romer (1997); Metcalfe (1995); David and Foray (1995).
2. A comparison of trends in awards of the Nobel Prize in Chemistry to citizens of the United States and the major European powers before and after 1940 reveals the scope of this transformation in US strength in basic research in one scientific field. Through 1939, German scientists received 15 out of the 30 Nobel Prizes awarded in chemistry, US scientists received only three, and French and British scientists each accounted for six. Between 1940 and 1994, US scientists received 36 of the 65 chemistry Prizes awarded, German scientists received eleven, British scientists received 17, and French scientists received one (*Encyclopaedia Britannica,* 1995, pp. 740-47).
3. R&D spending from ‘‘Other non-federal sources’’ (R&D funded by state and local governments, as well as universities and colleges) grew by 2 per cent in real terms during 1994-95. The National Science Foundation data currently available from the forthcoming *National Patterns of R&D Resources: 1997* provide only estimated levels of R&D spending for 1996 and 1997, and these are less reliable, particularly for industry-funded R&D investment, than the actual spending levels reported (with a lag) by the NSF. In addition, revisions in NSF data collection procedures mean that the data on industry-funded R&D before and after 1991 are not strictly comparable with one another, especially for the disaggregated components of R&D spending and for individual industries (see National Science Foundation, 1996). Accordingly, our discussion of spending trends covers only the period through 1995, and we confine the analysis of trends in the components of industry-funded R&D investment to the 1991-95 period.
4. The economic consequences of this sharp reduction in defence-related R&D spending are difficult to project. Technological ‘‘spillovers’’ from defence to civilian applications of this spending now are less significant than was true of the 1950s and early 1960s, as the requirements for military and civilian applications in such technologies as aerospace and electronics have diverged. In addition, a considerable portion of federal defence-related R&D spending was directed to applied research, such as weapons testing, that generated few civilian economic benefits. Nevertheless, the enormous defence-related R&D budget contained a substantial basic research component, and defence-related R&D accounted for a considerable share of federally funded research in US universities in such areas as electronics. Reductions in spending in these areas could have negative consequences for civilian innovative performance.

5. According to Katz and Ordover (1990), at least 14 Congressional bills passed during the 1980s focused on strengthening domestic and international protection for intellectual property rights, and the Court of Appeals for the Federal Circuit created in 1982 has upheld patent rights in roughly 80 per cent of the cases argued before it, a considerable increase from the pre-1982 rate of 30 per cent for the Federal bench.
6. A CRADA specifies terms under which a private organisation provides personnel, equipment or financing for R&D activities that are consistent with a specific laboratory's broader mission. Most CRADAs include provisions that cover the sharing of intellectual property rights to any technologies resulting from the project.
7. Indeed, these recent policy initiatives rely heavily on the efficiency of markets for licensing intellectual property, despite the extensive scholarly evidence on the transactional and other problems associated with such markets. Inefficiencies or failures in these markets arise from a number of sources, including the Arrow paradox of information, the high levels of uncertainty over the quality of the technology offered for licence and over the behaviour of the licensee, and the small numbers of buyers and sellers in markets for specific technologies (Caves, Crookell and Killing, 1983; Williamson, 1979, 1985; Mowery, 1983, 1988).
8. The internal tensions, not to say contradictions, in this policy posture can be illustrated by reference to the Advanced Technology Program of the US Department of Commerce. ATP was created in 1989 to fund ‘‘high-risk, high-spillover’’ R&D by private firms, providing matching funds to projects that are scrutinised on the basis of their technical and economic merit. Having set out to provide public funds to support the creation of spillovers, however, the architects and managers of this programme also insist that protection of the intellectual property created in the programme is essential for the commercial applications of ATP-funded research results to be achieved. For further discussion, see Yager and Schmidt (1997).
9. Kortum and Lerner (1997) find a significant surge in patenting by domestic inventors in the United States, noting that ‘‘... until the mid 1980's, [patent] applications fluctuated within a band of 40 to 80 000 per year, but in 1995 US inventors applied for over 120 000 patents on their inventions’’ (p. 1). Kortum and Lerner's data reveal a steep increase in patents applied for and granted to domestic inventors in the United States since 1980.
10. Cohen *et al.* (1997) cite data from their 1986 survey of US industrial R&D managers indicating that the most important channels through which these industrial scientists and engineers learn of academic research advances are publications, public meetings and conferences, informal information exchange and faculty consulting. Patents, licences, and co-operative ventures all are ranked by these managers as much less important channels for interaction.
11. Comparable data on university patenting and licensing in other OECD economies are not readily available, but would be very useful for extensions of the David-Foray analysis. The limited information on such policies suggests that US policy allows for a more restrictive approach by universities to patent licensing. For example, publicly funded research in German universities can be licensed on a non-exclusive basis only to industrial partners, and a portion of any licensing income must flow back to the federal funding agency. In general, however, German universities do not appear to be active in developing patenting or licensing programmes.

12. Disclosure to the University of California Office of Technology Transfer of inventions that are potentially of interest to industry or agriculture is required of all UC faculty, students and other research personnel. We therefore believe that the sample of UC faculty and researcher inventions captured by the OTT data is reasonably unbiased and more comprehensive than the data available from many other US research universities.
13. An alternative measure of patent ‘‘quality’’ is the number of citations to a patent in subsequent patent applications; this measure was used in Henderson *et al.* (1994). In future work, we plan to analyse the trends before and after 1980 in citations to UC patents.
14. Filing for patents and negotiating licences are time-consuming processes, often requiring several years and in some cases more than a decade. As a result, some of the invention disclosures from the 1984-88 period have only recently been patented or licensed, while others may still be awaiting the issue of a patent or the final resolution of the details of a licensing agreement. In order to avoid biasing the results of our comparison of the 1975-79 and 1984–88 disclosures, we restricted the period during which we searched for evidence of patents and licensing agreements to the eight years following the date of the invention disclosure.
15. Note that we are analysing changes in the share of licences yielding positive royalties, rather than any change in the average royalty income per licence in the two periods. It is possible that average income per license could have increased in the second period, although the skewed distribution of the licensing income of the Office of Technology Transfer means that any such changes are likely to be small.
16. Cohen and Noll (1995) estimate that the federal government share of funding for the sub-set of CRADAs that involve cost-sharing by public and private parties amounted to roughly US$1 billion in 1993, but this estimate is based on incomplete data compiled by a private analyst.
17. This research was conducted with Rose Marie Ham of the Haas School of Business at UC Berkeley, and was aided by assistance from Hank Chesbrough and Brian Silverman. Additional details on the cases are reported in Ham and Mowery (1995, 1998).
18. Indeed, managers consistently felt incapable of computing precise estimates of the returns on their investments in these projects, like respondents to other surveys of federal technology development programmes such as the Advanced Technology Program (see Solomon Associates, 1993).

BIBLIOGRAPHY

ASSOCIATION OF UNIVERSITY TECHNOLOGY MANAGERS (1994), *The AUTM Licensing Survey: Executive Summary and Selected Data, Fiscal Years 1993, 1992, and 1991,* Association of University Technology Managers, Norwalk, CT.

CAVES, R.E., H. CROOKELL and J.P. KILLING (1983), ‘‘The Imperfect Market for Technology Licenses’’, *Oxford Bulletin of Economics and Statistics* 45, pp. 249-268.

COHEN, L. and R. NOLL (1995), ‘‘The Feasibility of Effective Public-Private R&D Collaboration: The Case of CRADAs’’, CEPR Publication No. 412, Stanford University.

COHEN, W., R. FLORIDA and R. GOE (1994), ‘‘University-Industry Research Centers in the United States’’, Technical Report, Center for Economic Development, Carnegie-Mellon University.

COHEN, W., R. FLORIDA, L. RANDAZZESE and J. WALSH (1997), ‘‘Industry and the Academy: Uneasy Partners in the Cause of Technological Advance’’, forthcoming in R. Noll (ed.), *Challenge to the Research University,* Brookings Institution, Washington, DC.

DAVID, P.A. and D. FORAY (1995), ‘‘Accessing and Expanding the Science and Technology Knowledge Base’’, *STI Review,* No. 16, Special Issue on Innovation and Standards, OECD, Paris, pp. 13-68.

DAVID, P.A., DC MOWERY and W.E. STEINMUELLER (1992), ‘‘Analysing the Economic Payoffs from Basic Research’’, *Economics of Innovation and New Technology* 2, pp. 73-90.

EDQUIST, C. and S. JACOBSSON (1988), *Flexible Automation,* Blackwell, Oxford.

EISENBERG, R. (1996), ‘‘Public Research and Private Development: Patents and Technology Transfer in Government-Sponsored Research’’, *Virginia Law Review* 82, pp. 1663-1727.

EVENSON, R.E. (1982), ‘‘Agriculture’’, in R.R. Nelson (ed.), *Government and Technical Progress: A Cross-Industry Analysis,* Pergamon, New York.

HAM, R.M. and D.C. MOWERY (1995), ‘‘Improving Industry-Government Co-operative R&D’’, *Issues in Science and Technology,* Summer.

HAM, R.M. and D.C. MOWERY (1998), ‘‘Technology Transfer and Collaboration between Industry and National Laboratories’’, *Research Policy* (forthcoming).

HENDERSON, R., A.B. JAFFE and M. TRAJTENBERG (1994), ''Numbers Up, Quality Down? Trends in University Patenting, 1965-1992'', paper presented at the CEPR conference on ''University Goals, Institutional Mechanisms, and the 'Industrial Transferability' of Research'', Stanford University, 18-20 March.

KATZ, M.L. and J.A. ORDOVER (1990), ''R&D Competition and Co-operation'', *Brookings Papers on Economic Activity: Microeconomics 1990,* pp. 137-192.

KELLEY, M.R. and T.A. WATKINS (1995), ''In from the Cold: Prospects for Conversion of the Defense Industrial Base'', *Science* 268, pp. 525-532.

KOIZUMI, K. (1997), ''R&D Trends and Special Analyses'', in Intersociety Working Group, *AAAS Report XXII: Research and Development, FY 1998,* American Association for the Advancement of Science, Washington, DC.

KORTUM, S. and J. LERNER (1997), ''Stronger Protection or Technological Revolution: Which is Behind the Recent Surge in Patenting?'', unpublished MS, Boston University.

LAWLER, A. (1996), ''Grim Budgets Spur Call to Action'', *Science* 272, 26 April, p. 477.

METCALFE, S. (1995), ''The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives'', in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change,* Blackwell, Oxford.

MOWERY, D.C. (ed.) (1983), ''The Relationship Between Intrafirm and Contractual Forms of Industrial Research in American Manufacturing, 100-1940'', *Explorations in Economic History,* 1983, pp. 351-374.

MOWERY, D.C. (1997*a*), ''US Postwar Technology Policy and the Creation of New Industries'', in *Creativity, Innovation and Job Creation,* OECD, Paris.

MOWERY, D.C. (1997*b*), ''Technological Innovation in a Multipolar System: Analysis and Implications for US Policy'', paper prepared for the study group on ''The Globalization of Industrial R&D'', Council on Foreign Relations, New York.

MOWERY, D.C. and N. ROSENBERG (1993), ''The US National Innovation System'', in R.R. Nelson (ed.), *National Innovation Systems: A Comparative Analysis,* Oxford University Press, New York.

NATIONAL SCIENCE BOARD (1996), *Science and Engineering Indicators: 1996,* US Government Printing Office, Washington, DC.

NATIONAL SCIENCE FOUNDATION (1994), *National Patterns of R&D Resources: 1994,* US Government Printing Office, Washington, DC.

NATIONAL SCIENCE FOUNDATION (1996), *National Patterns of R&D Resources: 1996,* US Government Printing Office, Washington, DC.

NATIONAL SCIENCE FOUNDATION (1998), *National Patterns of R&D Resources: 1998,* US Government Printing Office, Washington, DC.

NELSON, R.R. (1959), ''The Simple Economics of Basic Scientific Research'', *Journal of Political Economy,* pp. 297-306.

NELSON, R.R. (1992), ''What is 'Commercial' and What is 'Public' About Technology, and What Should Be?'', in N. Rosenberg, R. Landau and D. Mowery (eds.), *Technology and the Wealth of Nations,* Stanford University Press, Stanford, CA.

NELSON, R.R. (ed.) (1993), *National Systems of Innovation,* Oxford University Press, New York.

NELSON, R.R. and P. ROMER (1997), ''Science, Economic Growth, and Public Policy'', in B. Smith and C. Barfield (eds.), *Technology, R&D, and the Economy,* Brookings Institution, Washington, DC.

NORMILE, D. (1997), ''War on Debt Puts Big Science Under Fire'', *Science* 276, 2 May, p. 670.

OECD (1996), *Science, Technology and Industry Outlook 1996,* Paris.

OECD (1998), *Technology, Productivity and Job Creation: Best Policy Practice,* Paris.

OFFICE OF TECHNOLOGY TRANSFER, UNIVERSITY OF CALIFORNIA (1997), *Annual Report: University of California Technology Transfer Program,* University of California, Oakland, CA.

ROMER, P. (1997), ''Beyond Market Failure'', in A. Teich, S. Nelson and C. McEnerny (eds.), *AAAS Science and Technology Policy Yearbook: 1996-97,* American Association for the Advancement of Science, Washington, DC.

SCIENCE (1997), ''Publishing Sensitive Data: Who's Calling the Shots?'', 25 April, pp. 523-526.

SOLOMON ASSOCIATES (1993), *The Advanced Technology Program: An Assessment of Short-term Impacts,* Solomon Associates, Gaithersburg, MD.

TRAJTENBERG, M., R. HENDERSON and A. JAFFE (1994), ''University Versus Corporate Patents: A Window on the Basicness of Inventions'', CEPR Working Paper No. 372, Stanford University.

US DEPARTMENT OF ENERGY, TASK FORCE ON ALTERNATIVE FUTURES FOR THE DEPARTMENT OF ENERGY NATIONAL LABORATORIES (1995), *Alternative Futures for the Department of Energy National Laboratories,* US Department of Energy, Washington, DC.

US GENERAL ACCOUNTING OFFICE (1995), *University Research: Effects of Indirect Cost Revisions and Options for Future Changes,* US Government Printing Office, Washington, DC.

US OFFICE OF MANAGEMENT AND BUDGET, EXECUTIVE OFFICE OF THE PRESIDENT (1995), *The Budget of the United States Government for Fiscal 1996,* US Government Printing Office, Washington, DC.

WILLIAMSON, O.E. (1979), ''Transaction Cost Economics: The Governance of Contractual Relations'', *Journal of Law and Economics,* pp. 233-262.

WILLIAMSON, O.E. (1985), *The Economic Institutions of Capitalism* (New York: Free Press).

YAGER, L. and R. SCHMIDT (1997), *The Advanced Technology Program: A Case Study in Federal Technology Policy,* American Enterprise Institute, Washington, DC.

POLICIES FOR PROMOTING ENTERPRISE RESTRUCTURING IN NATIONAL SYSTEMS OF INNOVATION: TRIGGERING CUMULATIVE LEARNING AND GENERATING SYSTEM EFFECTS

TABLE OF CONTENTS

This article was written by Morris Teubal of the Hebrew University of Jerusalem (Economics) and the Industrial Development Policy Group (IDPG) of the Jerusalem Institute for Israel Studies. The author is grateful for comments received at the OECD 1997 Vienna Workshop on ‘‘Best Practices in Technology and Innovation Policy’’ as well as those from Seminars given at IMRI (University of Paris-Dauphine), University of Roskilde and the Skagen Seminar of DRUID (Danish Research Unit on Industrial Dynamics). He would also like to thank participants at these seminars, in particular S. Borras, G. Dosi, D. Ernst, D. Foray, B. Johnson, A. Link, R. Lipsey, B. Lundvall, S. Metcalfe, F. Malerba and M. Peneder, for their comments on the paper.

I. INTRODUCTION

The objective is to analyse the time pattern of technological (and industrial) policies required for successful adaptation of a *national system of innovation* (NSI) to changes in the external and internal environment facing the economy of a particular country. The analysis is based on an ‘‘appreciative theory’’ (Nelson and Winter, 1982; Nelson, 1994) model of NSI transition first developed in a previous paper (Teubal, 1997*b*). Appreciative theory is a first step in understanding and conceptualising complex processes involving numerous variables; it may be followed by formal model building which will normally focus on a specific aspect of the broader problem, but with fewer variables. While not in itself formal theory, Nelson emphasizes that it is theory nonetheless since it selects variables and looks at possible relationships among them; and it may be critical for policy purposes in very dynamic environments (complexity and short decision times mean that only informed judgements are able to be made about policy actions, supported by general economic principles and some data (Lipsey and Carlaw, 1997).

The changes forcing adaptation could be visualised as liberalisation of foreign trade, globalisation, the emergence of new technologies such as microelectronics and paradigmatic changes in innovation and its organisation (Freeman and Perez, 1988). The latter include new patterns of co-operation in innovation and in the generation of technological infrastructure (Galli and Teubal, 1997; Justman and Teubal, 1995; Teubal *et al.,* 1996). While this article uses the existing theoretical structure and is also focused on policy and on the restructuring of enterprises in the business sector, it differs in that it further develops the policy implications of the analysis by linking them to the broader neo-classical, structuralist and evolutionary perspectives on technology policy (Arrow, 1962 and other items of economic theory; Lipsey and Carlaw, 1995, 1997; Justman and Teubal, 1986; Smith, 1991; Metcalfe, 1993; Metcalfe and Georghiou, 1997; Malerba, 1997; and Teubal, 1996*a,* 1997*a*).

The ‘‘dynamic’’ framework of this article enables a rich discussion of policy which goes beyond the translation of general principles into a taxonomy of policies/programmes (with each category characterised by its objective, focus and by the types of instruments being implemented). More specifically, it enables an analysis of the policy mix at any moment of time, of programme follow-ups and of the timing and co-ordination of policies in general. Needless to say, neither this article nor others dealing with technology policy seem yet to have come to grips with the notion of the ‘‘policy sub-system’’ – the component of the NSI involved in formulating and executing policies (Galli and Teubal, 1997) – nor with a theory of ‘‘policy learning’’ that may substitute effectively for the implicit ‘‘neo-classical’’ duality between government failure and non-failure.

Finally, the article proposes a distinction between market failure and system failure. Market-failure analysis is the cornerstone of the neo-classical perspective on technological policy. Its limitations have been extensively analysed in the 1980s and 1990s (Nelson, 1983, 1987; Metcalfe, 1993; Lipsey and Carlaw, 1995, 1997), *e.g.* the complexity of the processes makes it very difficult to identify and even to define market failure; it ignores the broader institutional framework that defines how markets work; it implicitly assumes that the market (selection) mechanism has a competitive advantage over other mechanisms in all industrial, technological and interface activities relevant for policy purposes; and it may fail in providing direction and focus to policies when externalities are pervasive. I focus here on a redefinition of the notion of market failure (Teubal, 1997*a*) and of its role and limitations within a broader structuralist-evolutionary-systemic policy framework.

To understand ‘‘system failure’’, it is important to mention that in the model full business-sector restructuring requires the establishment of new ‘‘collective’’ institutions/organisations housing the technological infrastructure required for the supply of new technological inputs previously unavailable in the economy (geographical proximity is important due to the need to customise applications for the new technology). These collective institutions/organisations comprise a new and more complex component of the new (adapted) national system of innovation, one that – to some extent – spearheads its transition (Galli and Teubal, 1997). I would like to reserve the term *market failure* for situations in which enterprises fail to restructure even when this new component of the system is already in place and operating;[1] and use *system failure* for situations in which such new collective organisations have not emerged in a timely fashion. Thus, failure of enterprises to restructure may be the result of market failure or of system failure or of a combination of market and system failure (overcoming a system failure, *i.e.* generation of system effects,[2] is only a necessary condition for enterprise restructuring; there still may be market failure).

The distinction between market and system failure is important because it may be indicative of the root problem blocking the adaptation of enterprises to a changing environment. It may also be indicative of the policy priorities that might have to be undertaken. In our conceptual framework, while new collective institutions/organisations are, to some extent, demand-driven, meaning induced by market forces, the role of policy in setting both new priorities and the broader institutional framework is still assumed to be critical for the emergence of such a new system component. Moreover, non-emergence of such collective organisations is not indicative, in this framework of analysis, of a pure ‘‘market failure’’.

Section II presents the framework of analysis, including a description of restructuring, types of enterprises, categories of policies and phases in the transition of the NSI. A major distinction is made between *horizontal* policies which *directly* promote enterprise restructuring, and *targeted* policies which are aimed at generating the new and more complex collective organisations (the TCs or technology centres) which promote such restructuring through system effects. It also discusses the process of transition of the NSI. The structure follows very closely that developed in Teubal (1997*b*). Section III discusses NSI transition and some policy implications for successful business-enterprise restructuring. A major issue here is how to achieve ‘‘cumulativeness’’ in the restructuring process – an aspect which dictates the timing and sequencing of policies. The final section links the policy discussion with the structuralist and evolutionary perspectives on technological (and industrial) policies as represented by the authors mentioned above. It aims to illustrate how a ‘‘dynamic’’ system of innovation perspective based on appreciative theory and analysis could contribute to the objective of consolidating an overall industrial and technological policy framework which is relevant to current turbulent environments.

II. FRAMEWORK OF ANALYSIS

I will successively refer to the nature of enterprise restructuring assumed in this article; to the types of policy being considered; and to firm categories and phases in the NSI transition process. Our appreciative theorising will focus on what could be termed a full or complete NSI transition trajectory, one involving the restructuring of a significant share of enterprises in the business sector.

Enterprise restructuring

There are both *general* and *specific* aspects to enterprise restructuring. The former could be visualised as involving organisational innovations such as the introduction of R&D or design-related routines into the firm – a process which to a large extent depends on availability of information and experience as to what benefits this would entail and how to go about implementing such a step. The *specific* aspect is the absorption of a new technological input, such as the effective integration of custom-made chips, into the design of existing or new products. These should be available locally due to the need of customisation and due to the fact that ‘‘access’’ and effective utilisation of the new inputs is neither automatic nor trivial. The new input is thus not ubiquitous and cannot be obtained in the world market (at least initially), although the technology to produce it could. Following the example given above, the task of the technology centre is to adopt and absorb such ‘‘generic’’ technologies with the effect of generating the technological infrastructure for designing and producing the various configurations of chips demanded locally.

The successful restructuring of a firm is assumed to depend on implementing both the specific and general aspects of restructuring. Only this will enable enterprises to respond successfully to the changes in the environment facing the economy. Both are related and I will assume that implementation of the general aspect of restructuring (*e.g.* introducing a ‘‘product design’’ function into the activity of an SME) will enhance the ‘‘demand’’ for the specific aspect (awareness of the need and searching for application-specific or custom-made integrated circuits which will enable even better product designs). There are important differences among firms both in the articulation of their need for such inputs and in their capacity to effectively make use of them (but firms may also learn from the experience of others’ restructuring). Moreover only some ‘‘pioneering’’ firms will be involved in creating the conditions for ‘‘local’’ supply of such inputs, an action enabling other firms to benefit once such a source becomes readily available to everyone.

Phases of restructuring and categories of firms

There are three phases and, in the ideal trajectory, one category of firm will join in the restructuring bandwagon at each phase. In Phase 1 an *advanced* category of Schumpeterian firms – *the innovators* – will initiate the restructuring process (some prior to, and others after, the implementation of appropriate policies). Only they are both aware of the need for such a set of actions and have a capacity to act in order to secure, temporarily, local production of the new technological input and assure its effective utilisation within the organisation.

In Phase 2, *imitator firms* initiate their restructuring. These firms may benefit from the experience accumulated in the restructuring of advanced firms. This has enhanced awareness of the need to restructure as well as a capacity to absorb the new technological input. They also benefit from the efforts of the latter group of firms to secure steady sources of supply for such inputs. This is because, while advanced firms in Phase 1 temporarily generated less efficient in-house solutions to their product design needs, they also undertook efforts to co-operate in their collective production. These efforts are complemented by government policy and both lead to the creation of the technology centre which begins operations in Phase 2.

In Phase 3, *laggard* firms join in, but the scope and variety of such firms requires special efforts to diffuse the restructuring process. This brings us to a discussion of government policies (see below).

Table 1 summarises the conditions of supply, demand and ability to use the new technological input (X) by the various types of firms in the three phases. While the new collective organisation (TC) plays a significant role in the supply of X during Phases 1 and 2, the last column of the table reflects the metamorphosis of the TC which occurs during Phase 3: partial substitution by a fully-fledged market for the input, on the one hand; and a downsized and reconfigured organisation which supplies the new input to the sub-category of severe laggards, on the other.[3]

Table 1. **Supply, demand and ability to use the new technological input (X)**

Enterprise segment	D: Demand A: Ability to use	Supply
A. Advanced firms (Phase 1)	D: autonomous awareness and felt ‘‘need’’ A: full ability	Initially only available from in-house effort
I. Potential imitators (Phase 2)	D: awareness and partial articulation of need (learning from advanced firms) A: partial ability	Available from TC
L. Laggards (Phase 3)		
– Mild	D: some awareness of need (learning from others) A: partial ability	Available from the new market
– Severe	D: no awareness nor articulation of need A: weak ability	Residual supply from reconfigured TC

Source: Teubal (1997*b*).

Government policies

Five categories of technological and industrial policies have been analysed in the model:

- anticipated institutional change (AIC);
- horizontal restructuring policies (HRP);
- proactive diffusion policies (PD);
- market building (MB);
- networking policies.

AIC is a package of policies leading to the establishment and initial operation of the technology centre (TC). The main elements are: adaptation of the institutional framework (*e.g.* modification of antitrust laws to enable enterprise co-operation in the absorption and diffusion of technology); assistance to enterprise co-ordination and co-operation; incentives to establish the new technological infrastructures; and support of initial diffusion of the new technological inputs flowing from such an infrastructure (more details of this can be found in Galli and Teubal (1997). This type of policy is classified as *targeted* since it involves a measure of targeting of a new technology or technological input which is critical for the restructuring of the business-enterprise sector. In Lipsey's policy taxonomy, AIC belongs to the focused or blanket policy category rather than to what he terms ''framework policies''.[4]

HRP have been studied systematically in the past in the context of socially desirable technological activities (and associated managerial routines) such as R&D, technology absorption and diffusion, and even technological infrastructure (Teubal, 1996*a,* 1997*a*). The catalytic-evolutionary perspective used there is applicable here in the context of the introduction of new R&D/design-related routines in the business sector (the general aspects of restructuring). HRP comprises a set of programmes, each focused on a specific category of enterprise in the business sector (that focused on laggards could be visualised as an SME support scheme). This implies that the type of activity or function which is horizontally supported across firms may also differ, *e.g.* R&D for advanced firms; and more simple design functions for the others. In Phase 1 an HRP is implemented for advanced firms, to reinforce their autonomous restructuring processes. It makes no sense to implement another HRP for laggard firms in Phase 1 since these firms are not yet ''prepared'' for effective restructuring. *Cumulative learning about restructuring, based on the experience of advanced firms in Phase 1, is assumed to be a critical ingredient for successful restructuring of laggards and also of imitators; it will generate awareness, and will also help them define and articulate their restructuring needs – both in organisational terms and concerning the appropriate configurations of the new technological input.*[5]

An additional reason for not implementing a HRP for imitators and/or laggards early in Phase 1 is the absence of a source of supply for the new input (X). Such a source will only emerge after the restructuring of advanced firms and the associated efforts to create the new, collective organisations. Alternatively, we might say that system effects must be generated before the restructuring of non-innovators is even considered. In the extreme case it may even be that prior to Phase 2 there is no market failure in connection with the restructuring of such firms (the general unavailability of the new input would make the social benefits net of social costs negative.)

PD and MB are policies undertaken by the collective organisation (TC) to promote the absorption and diffusion of the new technological input. Given the limited capabilities of laggard firms and imitators, the process of diffusion is neither trivial nor automatic. Selling and distributing will not do; rather an explicit process of customisation based on a thorough understanding of the needs of the various categories of enterprises must take place (similarly, technical support is required for the effective absorption of X into enterprises). *The main effect of PD is ''creation of demand for X'' or, alternatively, transformation of an abstract and non-articulated need into demand.*[6] PD policies are undertaken during Phases 2 and 3. In Phase 3, however, they become part of a wider set of MB which also includes stimulation of new supply agents for the novel technological input.[7] We have considered these policies as targeted policies although decentralisation of policy making (*i.e.* the fact that implementation is done by collective organisations that are privately owned although publicly supported), may mean that this characterisation is not quite so clear cut. On the other hand, the fact that governments will usually support these policies means that at least one component of the policy might involve targeting.

A final type of policy is *enterprise networking,* which in this article is taken to mean a set of measures promoting clubs of firms with two main objectives in mind: the promotion of awareness about the need to restructure among imitators and laggards; and gathering information and experience from other firms on how to proceed. Such policies have been common in many countries (*e.g.* Chile); they are preparatory to the implementation of other policies.

Table 2. **The deployment of policies: segments and phases**

Segment	A	I	L
Phase 1	HRPa, AIC*	Networking	Networking
Phase 2		HRPi, MB*, PD*	Networking
Phase 3			SME, PD*
			Endogeneous

Symbols:
A : Advanced
I : Imitator
L : Laggard
HRP: Horizontal restructuring policies (HRPa, HRPi, SME)
AIC : Anticipated institutional change
PD : Proactive diffusion policies
MB : Market building
SME: SME support scheme
* : Indicates ''targeted'' policies
Source: Teubal (1997*b*).

Table 3. **Business sector restructuring (R): capacity to access and use new input (X) and policy implications**

	A. Avanced firms (Phase 1)
Capabilities	
1*a)*	Capacity to initiate R with imperfect, in-house substitutes; and a capability to organise co-operative and co-ordinated action to create a TC (necessary but not sufficient for emergence of TC).
1*b)*	Capacity to complete R (after establishment of TC and availability of X).
Policy implications	
1*a)*	Horizontal restructuring policies (HRP) to strengthen autonomous R and to generate collective learning (non-targeted but aimed at advanced firms).
1*b)*	Targeted anticipated institutional change (AIC): changes in the institutional framework, co-ordination efforts, identification and support of relevant new technological infrastructures and stimulating establishment of a TC.
	I. Potential imitators (Phase 2)
Capability	
	Given X from the TC, only a partial ability to absorb the new input and undertake restructuring due to weak technical skills and insufficient ability to articulate or translate specific R ‘‘needs’’ in terms of the new input.
Policy implications	
	Continuation of HRP with a new focus aimed at imitators rather than advanced firms.
	Targeted proactive diffusion policies – strong technical back-up to sales and systematic attempts at building demand (by TC).
	Targeted market-building policies (continuation by TC of demand creation policies and initiation of supply-building policies).
	L. Laggards (Phase 3)
Capabilities	
Mild L:	Given the market for X, a partial capability to restructure due to weak skills and absence of organisational capabilities.
Severe L:	Extremely weak capabilities.
Policy implications.	
	An SME support scheme (instead of a regular HRP).
	Continuation of proactive diffusion by (reconfigured) TC for those firms not effectively reached by market or by market with incentives.

Source: Teubal (1997*b*).

Table 2 summarises the pattern of technological policies and programmes throughout the three phases of an ideal NSI transition. Table 3 integrates policies explicitly with enterprise capabilities at the various phases of the process, summarising and complementing the issues described above.

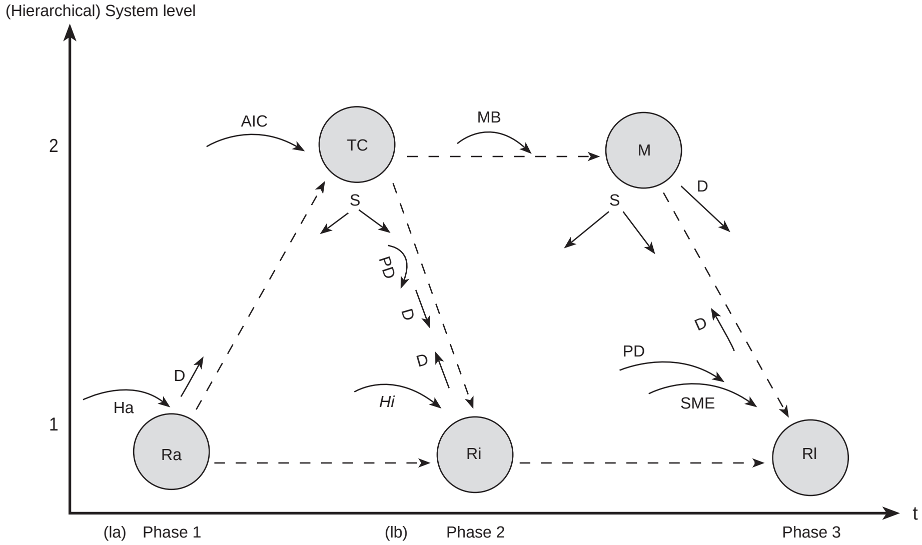
III. NSI TRANSITION AND POLICY IMPLICATIONS

The transition

This is summarised in Figure 1. The initial trigger of NSI transition is the autonomous restructuring of advanced firms (Ra). Ra would include the general aspects of restructuring, but will also indicate a measure of overall restructuring since some of the advanced firms will generate their own supply of X-substitutes. Under our assumptions, and in response to the successful implementation of an HRP for such a segment (Ha in the figure), there will be cumulative learning about restructuring which benefits imitators. Ra, in addition, generates demand for X and pressure to generate a collective organisation to exploit economies of scope in the supply of the input. Once the input is available from the TC (expressed in the figure by the ''S'' with arrows), it will – in conjunction with the above-mentioned learning process and provided that PD policies are followed – promote the restructuring of imitators (Ri). *The combination of system effects and cumulative learning effects leads to Ri.* The lack of restructuring of imitators in Phase 2 may be the result of insufficient learning and insufficient or non-timely system effects. The rest of the figure must be interpreted in a way similar to what occured in the first and second phases. Further details can be found in Teubal (1997*b*) (Section 3.2).

A successful transition of the NSI could be visualised as a process of co-ordinated building of supply and demand of the new technological input which plays a strategic role in the restructuring process of the business-enterprise sector. Certainly, it is not only a process of creation of supply, but also of diffusion and creation of demand. Lack of demand on the part of imitators and/or laggards is due to unawareness of, and/or lack of a capacity to articulate, needs for the new input in the light of changes in the environment.[8] The task of policy is to help create (differentiated) supply or help create (differentiated) demand when a bottleneck exists, and this requires a focus on particular activities or functions, firm categories and/or the new technology. For example, in Phase 1 some demand for X exists or emerges from advanced firms but no regular nor efficient source of supply exists. A targeted anticipated institutional change package will be directed to creating a new source of supply. However, this new source of supply (the TC)

Figure 1. **Dynamic factor and government policy in RBS – The full NSI transition case**



Key:

- - - → Direction of effect of dynamic factors and spillover effect

$\xrightarrow{S}$ $\xrightarrow{D}$ Supply, demand effects (for X)

$\overset{G}{\frown}$ Government (or TC) policy

G = (Ha, Hi, SME, AIC, PD, MB)
Rj = Restructuring of business sector segment J (J = *a*, *i*, *l*)
Ha = Horizontal restructuring policies (aimed at advanced firms)
Hi = Horizontal restructuring policies (aimed at imitators)
SME = SME support schemes (aimed at laggards)
PD = Pro active diffusion policies
MB = Market-building policies
AIC = Anticipated institutional change
M = The new market
TC = The technology centre

Source: Teubal (1997*b*).

not only solves the existing restructuring needs of advanced firms, but also creates a new opportunity for the restructuring of other firms by providing competitively priced inputs. Its implementation, however, requires generating demand for the new input – which is one of the objectives of horizontal restructuring policies directed to this category of firms (and also of proactive diffusion policies). Note that *the building of demand (and, indirectly, of supply) depends on success in generating cumulative learning effects and in the creation of system effects.* While it is impossible for imitator or laggard firms to restructure early in the process, this may be possible later on when both the lessons from the restructuring experience of innovator firms and the new source of critical new inputs are made available to them.[9]

The outcome of a full NSI transition is the *embeddedness of the business sector into a wider NSI, one involving new institutions organisations and markets.* Embeddedness is a *distributed capability* for flexible and rapid adaptation to non-radical changes in the environment (Imai *et al.,* 1988; Lundvall, 1985) as well as a capacity to continuously upgrade existing products (Teubal, 1982).

Policy implications of the model

The policy implications presented up to now should be mentioned or, if mentioned already, summarised, before linking with broader industrial and technological policy framework issues. It is important to recall that our model is based on enterprise heterogeneity – a differential capacity of firms to adjust and act in the face of changes in the environment. It is also based on the assumption that there exists a segment of advanced firms that may trigger the process.

The list will be very compact, and includes:

- *The criticality of initial policies,* because of the path dependency of the processes being promoted and the need to assure cumulativeness in the restructuring process. Thus, providing support initially to SMEs rather than to advanced firms when most SMEs are laggards, will not, in this model, help (lack of a fund of prior restructuring experience and knowledge which may help these firms adjust; and no local source of new technological inputs). At best, it might delay *overall* restructuring due the weak initial impacts and little or no follow-up cumulativeness. At worst it might waste an opportunity to trigger such a process if conditions in the environment continue to deteriorate (*e.g.* further loss of competitiveness due to the entry of new dynamic economies into the world market).
- *Initial policies should reinforce the restructuring of advanced firms and set the stage for the later phase* – restructuring of imitator and laggard firms. Although this seems to follow from the structure of the model, it underlines an important point that policy makers should consider in deciding strategies for NSI transition. Note that advanced firms in this model need not be large firms nor even presently profitable firms. The term *advanced* here should refer to the restructuring objective, and is more likely to be

applicable to enterprises aware of changes in the environment, who are *fast learners,* and who have already made some autonomous adjustments or strategic realignment. There are plenty of large enterprises and even conservative R&D organisations that would not be part of this category.[10]

- *A mix of policies is required* with horizontal restructuring policies aimed directly at restructuring and at generating collective learning (both within and beyond the targeted enterprise segment) and targeted policies aimed first and foremost at generating system effects and, subsequently, new markets. In this model combining the two types of policy will assure the ‘‘cumulativeness’’ of the restructuring process.
- *Policies are* ***demand-creating*** *rather than being exclusively* ***demand-driven*** – and this is consistent with the fact that the acid test of a successful NSI transition is the effective restructuring of the business-enterprise sector. In referring to demand, I mean, in the specific context of this article, demand by business enterprises for those technologies and new technological inputs and those organisational innovations and innovation routines which are critical for successful enterprise restructuring. The demand I refer to here, therefore, relates very closely to a reorientation of the strategy of these enterprises (it is not demand for a specific product having well-known characteristics and under clear budget constraints). Having made that point, what is meant by this statement is that, while some policies may in part respond to existing demand of business enterprises, an important component will always be anticipation and creation of demand.[11] This is a critical aspect of successful NSI transition and, it seems to me, one given insufficient attention in the literature. Horizontal policies, for example, can act in two ways: provision of incentives to those within the focused set of firms who restructure; and promotion of collective learning about restructuring. The former will have a direct impact on those firms with a clear demand for the new organisational and technological aspects of restructuring. The latter ‘‘learning effect’’ not only increases the restructuring efficiency of such firms, but also promotes demand creation through diffusion of restructuring experience/knowledge throughout the non-restructured population of firms.
- *The timing, mix and co-ordination of policies is crucial for a successful NSI transition* since this requires, beyond the general aspects of restructuring, a co-ordinated building of the supply and demand for the new technological input. Both horizontal and targeted policies contribute to supply and to demand for this input, although the direct effect of horizontal policies is to enhance demand while that of targeted policies (especially AIC) is to enhance supply.[12]
- *Successful NSI transition leads to the embeddedness of the business enterprise sector into a wider and more complex system of innovation.*

– *In practice, the desirable scope of ''diffusion'' of the restructuring process may exceed what market forces by themselves may achieve.* There are a number of reasons for this:
  - institutional and system failures;
  - failure of policies to generate strong collective learning (a condition for cumulativeness);
  - non-economic reasons, *e.g.* the need to promote social cohesion, may imply that laggard restructuring policies of Phase 3 may have to go beyond the point dictated by current competitiveness considerations.

IV. IMPLICATIONS FOR A DYNAMIC AND INTEGRATED STRUCTURALIST, EVOLUTIONARY AND SYSTEMS PERSPECTIVE TO TECHNOLOGICAL POLICY

The perspective on NSI transition presented above, with its focus on both enterprise restructuring and technological and industrial policy, is largely consistent with a policy perspective following structuralist and evolutionary approaches. It shows *the possibility for undertaking a dynamic analysis of policy and for doing this in a systemic context.* Despite appearing to be quite specific, the model illustrates the type of theorising and the type of policy recommendations that could appear in a wider class of models. Moreover, by postulating a *structure* for dynamic analysis, the article aims to go beyond general principles (neo-classical, structuralist or evolutionary) and beyond the specification of policy taxonomies. It attempts to *specify the contexts where different policies or policy categories are applicable and how both the contexts and the policies co-evolve.*

As an example of the possible implications of a dynamic approach, I will refer to the time profile of a *single* horizontal technology policy programme such as a programme supporting R&D for all firms, sectors and technologies (Teubal, 1983, 1993). Such a policy could be considered as one of the components of the set of HRP, *e.g.* directed to advanced firms. It was pointed out in previous work that the absence of policy capabilities at the initial phase of policy implementation and a generalised lack of experience in the business sector with the new technological activity being supported might justify the adoption of a neutral incentive scheme (*e.g.* all projects receiving a 50 per cent subsidy towards approved R&D costs). This would have to change in the mature phase of policy implementation as a result of learning by the firms receiving support (including organisational learning) and learning by government. Thus, the previously neutral programme will become more selective in its incentives; a variety of alternative promotion schemes may emerge; and it may even be reasonable to replace the horizontal programme by a small set of targeted programmes aimed at specific sectors and technologies (in Lipsey and Carlaw's terminology, there would be a shift from a framework policy to a small set of focused policies, see below).[13]

The example illustrates ‘‘in the small’’ – that is, within what was initially a *single* programme – possible links between policies through time and between policy and the underlying contexts/reality. The broader NSI structure of this article has a potential to uncover a richer set of policy-relevant dynamic links. In my opinion this is the source of the potential value added of this approach for policy analysis.

The final section of this article will initiate the process of consolidation of the framework for dynamic policy analysis presented in Sections II, III and IV. The *first objective is to integrate the analysis with the broader frameworks of technology policy – neo-classical, structuralist and evolutionary.* I will only accomplish this partially, particularly with respect to the neo-classical and structuralist approaches to technology policy (some connections with evolutionary technology policy will be mentioned in the Conclusions; others are quite straightforward and follow my previous work and that of Metcalfe and Malerba). A *second objective is to contribute to the theoretical or analytical foundations for the various types of industrial and technology policy,* both market failure and other types of analysis. The market-failure notion will have to be redefined for our purposes and, even then, its applicability to identifying and structuring policy will be limited. It will become clear – even without adoption of a full evolutionary approach to policy – that our dynamic and systemic approach to policy should deal with other types of failure, particularly system failures.

The main specific topics to be covered are:

- structure of model and types of technology policy;
- towards a redefined market-failure analysis;
- market failure and system failures;
- other limitations of market-failure analysis.

Structure of model and types of technology policy

This article presupposes that NSI transition depends both on *enhancing innovation* and on *diffusion* in the business sector (‘‘enterprise restructuring’’ in the model) and on extending or *reinforcing the ‘‘facilitating structure’’.*[14] Implementing only one of these is insufficient and will not enable a successful transition trajectory. This is the fundamental reason why a successful transition trajectory requires the presence of both targeted and horizontal policies; as we will show, these categories roughly correspond to the policy categories proposed by

Justman and Teubal (1986), Lipsey and Carlaw (1997) and Metcalfe (1996). Moreover, the need to prioritise both aspects of innovation is the reason why the model specified here has, I believe, potentially broader significance. It would seem to reflect the adaptation requirements of all systems of innovation facing rapidly changing and turbulent environments. Such adaptation generally requires new policies, particularly targeted policies, in order to bring about the required changes in structure. In this model the new structure is reflected in the greater level of complexity of the system which comes about through the establishment of new, collective, infrastructural organisations. *What is required is both new institutions/organisations* ***and*** *new generic capabilities, and not solely the latter. This, in fact, is the meaning of the anticipated institutional change (AIC) package of policies.*

These requirements for successful NSI adaptation (and indirectly the need for ‘‘targeted’’ policies) derive from the fact that globalisation and the technological revolution are creating an increasing array of new technologies and new technological inputs which have to be accessed by enterprises in order to maintain competitivity. Despite the growth of markets these assets are not fully tradable nor easily replicable by individual firms, at least in the short run. Moreover, not only their development, but also their access, is subject to economies of scope. While individual firms in some cases access some of the technologies required on an individual basis, wide and fast access – under the conditions mentioned above – to technologies of strategic importance requires targeting them and housing them in new collective organisations.[15] It is well known that some of these generic capabilities may, eventually, be ‘‘transferred’’ to market agents (see Teubal *et al.,* 1996, Introduction).[16]

Concerning issues of taxonomy, Lipsey and Carlaw (1997 and previous work) classify policies according to their technology, sector or firm focus. Their *framework policies* accord very much to my horizontal policies (the HRPs of the model) since they ‘‘provide general support for some specific activity across all of the economy ... and do not discriminate among firms, industries or technologies... and are generally available to everyone who engages in the covered activity’’.[17] On the other hand, my targeted policies, and especially anticipated institutional change, are closely related to both their focused and their blanket policies, particularly to the latter. To *focused policies* since they support a particular technology; and to *blanket policies* since they can be tailored or customised and are ‘‘generally available to all those engaged in the covered activities’’. Another reason why my targeted AIC is really a blanket policy is its aim of creating and stimulating the collective organisations generating critical inputs for restructuring, which is the model’s counterpart to Lipsey and Carlaw’s innovation facilitating structure.

The two main categories – horizontal and targeted – also roughly correspond to Metcalfe’s categories: *i)* supporting innovation by changing incentives while maintaining existing technological capabilities; and *ii)* policies aiming directly at increasing technological capabilities or the innovation possibilities frontier (Metcalfe, 1996). The meaning or counterpart of ‘‘innovation’’ in my model is enterprise restructuring, involving both its organisational and technological components. HRP directly affects the incentives to restructure within business enterprises while not changing directly the underlying capabilities to do so (over and above the learning effects generated by implementation of the programme). By contrast, AIC enhances the underlying capabilities for restructuring by enabling production at ‘‘competitive prices’’ of new technological inputs which cannot be accessed in the world market and which are critical for ‘‘innovation’’.[18]

Towards a redefined market-failure analysis

Several of Nelson’s papers of the 1980s and earlier have emphasized the limitations of market-failure analysis as a basis for the identification and implementation of technological policies (Nelson, 1983, 1987). He emphasizes:

- the (implicit) assumption in market-failure analysis that the market mechanism is the best mechanism to undertake innovation and technological change activities;
- in many contexts externalities are pervasive and therefore no clear policy guidance is achieved with such an analysis; and
- problems of identification of projects where market failure is present (*e.g.* issues of revelation of relevant information by firms).

With the consolidation of evolutionary approaches, other types of criticism were raised:

- the economic system is not in equilibrium, but rather in flux (Metcalfe, 1993; Nelson, 1994);
- there is no way to identify an ‘‘optimum’’ amount of R&D (Lipsey and Carlaw, 1995, 1997); and policy making is ‘‘adaptive’’ rather than optimising (Metcalfe, 1993);
- any innovation in a perfectly competitive equilibrium framework should be considered as a ‘‘market failure’’ since any innovation inherently implies asymmetric information – with the implication that market failure is not a useful concept in technology policy (Dosi, 1988; Metcalfe, 1993);
- *complexity and fundamental uncertainty:* it is impossible to identify and even to define market failure in innovation due to the complexity, interactivity and co-evolution of the processes involved and the fundamental uncertainty surrounding the sources and impacts of innovation (Metcalfe, 1993; Malerba, 1997).

The second group of criticisms (excepting the last point) take as their point of departure the standard market-failure analysis based on the perfectly competitive model, which resposes on very simplified assumptions about reality [a good discussion and analysis is found in Lipsey and Carlaw (1997)]. In previous work I mentioned that the importance of ‘‘market-failure analysis’’ for technology policy need not be restricted to such a narrow definition. Even if we refuse to define ‘‘failure’’ by referring to such a situation, there remains a genuine problem of establishing the role of market forces in innovation and technological development given the fact that other mechanisms exist – bureaucratic/institutional/professional/political – some being substitutes and others complements (in a dynamic sense) to market forces (see Nelson, 1994; Teubal 1997*a*; Galli and Teubal, 1997).

An alternative basis for market-failure analysis

There are three conditions:

- The notion of market failure should refer to those activities for which the market mechanism has a competitive advantage over other mechanisms.
- Policy should aim at achieving a socially desirable level *and* structure of such activities. This is not an optimising equilibrium in the neo-classical sense but rather the result of socio-economic and political interaction leading to consensus on economic and non-economic objectives and priorities.
- There are no system failures.

These statements set the terms for a *redefined* notion of market failure – one that is independent of equilibrium analysis and which avoids some of the criticisms mentioned above. It also defines the *potential domain* of such an analysis, although its *applicability* and usefulness will depend on other factors emphasized by the evolutionary perspective (such as the possibility of defining and identifying a socially desirable level and structure of an activity in whose undertaking market forces have a competitive advantage). I will try to clarify the concept by illustrating the impossibility of ascribing exclusively to the market mechanism all the activity surrounding the establishment of the new collective organisations and new technological infrastructures which, in this model, are linked to successful NSI transition. If this is true, the redefined notion of market-failure analysis cannot be used as the foundation for AIC.

The starting point is the realisation that the relevant activities leading to the establishment and operation of a TC are of two kinds:

- identification of strategic priorities, creation/adaptation of the institutional framework within which the TC will operate; and definition of the configuration of the new technological infrastructures;
- investment in, and operation of, the TC.

In undertaking the first group of activities, the market mechanism has a comparative disadvantage over a policy mechanism involving experts, stakeholders, bureaucrats, etc. A number of reasons could be put forward, *e.g.* the need to take into account the requirements of the business sector as a whole in the present and in the future, and not only of those advanced firms which are pushing today for establishment of a TC; the need to find not only an adequate institutional framework for the TC, but one that remains coherent with the broader framework existing in the country; and an advantage in enabling and promoting interfirm co-ordination and co-operation. In contrast to its relative inappropriateness for undertaking these ‘‘institutional and infrastructural planning and design’’ activities, there may be strong reasons why the market mechanism could be the most appropriate mechanism for operating the centre once established, *i.e.* it enjoys a comparative advantage in the second group of activities. In such cases any deviations from desirable or appropriate direction in operations could easily be tackled with incentives. However, what is clear is that *in attempting to promote the establishment of the TC, market-failure analysis by itself could not be used as the basis (or at least the sole basis) for AIC.*

This contrasts with the neo-classical perspective on market failure, where technology is an ‘‘innovation’’ (what we call ‘‘restructuring’’ in this article), with no separate identity given to technological infrastructure and to supporting institutions/organisations. This explains why this perspective assumes that the market mechanism enjoys a competitive advantage over other mechanisms, so that market-failure analysis is applicable. There is no real problem of knowledge or actions by the policy mechanism beyond providing incentives (incentives are also assumed not to require such knowledge and capabilities). Alternatively, we might say that the neo-classical view assumes that there is: *i)* no activity beyond the technological activity being supported; and *ii)* a sharp separation between ‘‘the activity being supported’’ and the policy promoting that activity.[19] This perspective allows for government failure in providing the right incentives, but does not allow for failure of the policy mechanism in the sense we mentioned above, *i.e.* a mechanism which should be directly involved in the activity or in some of the activities being promoted.

The upshot is that the redefined notion of market failure might be applicable to horizontal restructuring policies (HRP) – provided there are no system failures. It is inapplicable to the promotion of TC and to the characterisation of AIC. In relation to horizontal programmes, market-failure analysis would enable the identification of obstacles to enterprise restructuring and the conditions for generating a cumulative process; and this would feed into programme *design* including the enterprise focus required in the initial programme. Moreover, the *implementation* of such programmes requires market-failure analysis in order to determine the ‘‘additionality’’ of specific projects or types of projects.[20]

Market failure and system failure

A *system failure* is failure to stimulate in a timely fashion the emergence of a new component of a NSI which is deemed to be of strategic value for the economy (see ‘‘Strategy’’ below). In the model, failure to establish a TC in time – with its organisational and technological aspects – is a system failure rather than a market failure. More generally, system failures reflect deficiencies in the set of complex activities which should be undertaken both by the policy mechanism of a country and by market forces in order to stimulate such a NSI component. There are three aspects to the relationship between system and market failure:

- Market-failure *analysis,* for practical purposes, cannot be undertaken in the presence of a system failure (this is in accord with the above definition).
- Market failure may still exist even with a system failure. Its scope, however, would be uncertain and could not be determined in a precise way.[21]
- Due to systemic links, the scope of market failure in enterprise restructuring – the *a priori* domain of market-failure analysis – depends on the system of innovation as a whole and on present and future policies affecting it. ‘‘Deficiencies’’ in such a system cannot be visualised as resulting (exclusively) from market failure.

All of this reduces the applicability of market-failure analysis as a basis for policies affecting NSI transition. The importance of this transcends the context of this article. For example, it may make no sense to provide horizontal subsidies to R&D if there are no venture-capital sources to provide complementary finance both to technical development and for production and new-product launch by enterprises. The social benefits of such subsidisation alone would be negative. On the other hand, they could be strongly positive if complementary policies are adopted to enable implementation of innovations (or inventions) by business enterprises. This situation could, therefore, be characterised either as one with no market failure at all, or as one involving both market failure and system failure (where the scope of market failure would depend on the ‘‘scope’’ of system failure). Alternatively the *existence of a market failure may depend on whether the system failures that exist after the changes in the environment have been adequately dealt with by appropriate policies.*

The inapplicability of market-failure analysis, or of market-failure analysis as the sole basis for technological policy, would then follow from:

- the complexity and uncertainty involved in identifying market failures and calculating their scope;
- the need to co-ordinate policies to respond simultaneously to market failure and system failure;
- the need to implement policies for Ra even where there is no strict market failure in Ra, only a system failure.

Other limitations of market-failure analysis

To summarise some of the reasons which further limit the applicability of the redefined version of market-failure analysis, my perspective is that, despite these limitations, its role is not marginal at the programme and project level; in some contexts it may make a significant contribution to policy, although a clear resolution of these issues should, in my opinion, await the consolidation of a new technology policy framework which creatively incorporates the new approaches (including substituting and complementing the notion of market failure by that of ‘‘evolutionary failure’’ – see Malerba, 1997). The main limitations of even the redefined notion of market failure are:

– ***Strategy:*** *market failure analysis is applicable (and even then only partially) once the basic configuration of the NSI trajectory – a result of a strategic decision – has been established. It cannot be applied in order to select one strategy/trajectory over another.*

– ***Cause or effect of policy:*** *market failure is no less the result of policy than the cause or justification of policies.*

I will consider these aspects one at a time.

Strategy: The development path, or NSI transition, taken by a particular country is defined on the basis of strategic priorities which reflect first and foremost consensus on national objectives and also a particular process for their translation or articulation [the *‘‘policy process’’* – Lall and Teubal, (1997)]; There is no one-to-one relationship between objectives and strategies; a number of alternative strategies may follow from a set of national objectives and, given fundamental uncertainty and the impossibility of thorough quantification of each, it is not easy to compare strategies.[22] *Strategy selection and formulation at the national level does not belong to the realm of market forces, since it is (and should be*) a ***political*** and a ***policy*** *process, with the latter consisting of bureaucratic, professional and stakeholder mechanisms* (Lall and Teubal, 1997). This does not mean that market forces are not active as stakeholders or through the political process. But they are not the sole participants, and their participation is not through the market mechanism. An implication is that market-failure analysis is not applicable to define a strategy or strategic priorities at the national level. When applicable, its role is to help identify and design those policies whose objective is the implementation of a strategy selected or chosen elsewhere.

In this article, the national level strategy is reflected in the ‘‘ideal NSI transition trajectory’’ of Sections III and IV with its particular focus on a small set of priorities for innovation and for the supporting infrastructure. Such a strategy is only one of several possible strategies which might conceivably have been selected – given initial conditions – by political and policy mechanisms.[23] The strategy excludes non-enterprise organisations from the business of ‘‘innovation’’, although they are involved in diffusion of new technology, while the ‘‘supporting structure’’ focuses exclusively on newly created infrastructural organisations, rather than on universities or on the restructuring of existing public or semi-public organisations such as government laboratories. From what has been said above, redefined market-failure analysis might be applicable to the identification of appropriate programmes and policies required for the implementation of *some or all* of these strategic priorities. In our model it is applicable – in the best of cases – only to the design of the various HRP programmes.

Market failure as an effect of policy.[24] The realisation that market failure could not only be the basis for policy but also a result of policy can only be understood within a dynamic framework such as that used in this article. Successful HRP for advanced firms, through the collective learning generated and associated externalities, could lead to a situation where restructuring of imitators and laggards would generate positive social benefits net of costs. Not only will the latter group of firms benefit, but the benefits are such that a specific process new to these enterprises – restructuring – may become socially desirable for the first time. However, market failure, in the form of a new stream of externalities flowing from the imitator pioneers undertaking restructuring in Phase 2, may block such a process. This in turn calls for a new HRP focused on imitators.[25] This example makes use of a non-equilibrium, non-optimum concept of market failure and is careful to identify those activities where market forces should be involved before applying the ‘‘redefined’’ version of market-failure analysis. We can see that such an analysis is hierarchically dependent on a pre-existing strategy.

The upshot is a sequence:

market failure (time t) → policy (t) → market failure (t + 1) → policy (t + 1).

which undermines the usefulness of market-failure analysis for policy (even in relation to activities where the market mechanism should be dominant), because of the impossibility of proceeding myopically or sequentially. The unit of analysis for evaluating the desirability of policies cannot be a particular function (or technology) at a particular time for a group of firms, *e.g.* restructuring of innovators at time t, but rather a whole sequence of events up to the (complete) sequence comprising a full NSI trajectory. The desirability of a certain policy at time t would depend on the policies adopted at t + 1 to solve the market failures generated then by successful implementation of the aforementioned policies at t. The social desirability of the first tranche of restructuring (advanced firms) will depend on what will be done in the future with the second tranche (imitators). Alternatively, the desirability of the first HRP will depend on the timing and appropriateness of the second HRP (similarly with system effects, see below). This may introduce significant uncertainty into the decision process since which future policies *should* be adopted and which future policies *could* be adopted will depend on other factors or elements beyond the impact of policies today: tomorrow's policy capabilities; further changes in the environment; a redefinition of national objectives, etc.

In conclusion, if market-failure analysis is considered as a method for identifying/designing policies sequentially along the NSI transition trajectory (this would be a good definition of the usefulness of this type of analysis), it may have very serious limitations – due to complexity, uncertainly and problems of co-ordination.[26] In some contexts the role of market-failure analysis may be minimal – a perspective which coincides with a pure evolutionary perspective. In other contexts, there may still be a role for market-failure analysis (in the redefined sense), but rarely independently of other approaches of a systemic, evolutionary and even ''political'' nature.

In any case, there is no substitute for an integrated and co-ordinated view of policy for NSI transition. The usefullness of market-failure analysis alone – even in its redefined version – may be seriously limited. A simplistic application of such an approach would create distortions in the NSI transition trajectory and could even lead to a truncated trajectory.[27]

V. SUMMARY, CONCLUSIONS AND FURTHER RESEARCH

The starting point of this article is a systemic analysis of NIS transition which focuses simultaneously on the direct requirements of enterprise restructuring (the ''innovation'' and ''diffusion'' phenomena of the article) and on the beefing-up of the technological and institutional infrastructure of the economy. Since both of these elements of the process are priorities for system transition in a wide range of contexts, there is a possibility that the relevance of the policy implications transcend the specific limits of the appreciative theory model analysed here.

The analysis of policy should be viewed as an attempt to go beyond what is usually done, namely: *i)* formulating a taxonomy of policies; and *ii)* a static analysis of the various contexts which could justify the implementation of this or that type of programme. More specifically, the potential relevance of the analysis is a result of the model's structure, developed in Sections II to IV, which enables a dynamic analysis of technological and industrial policy. The two types of priorities are reflected in two types of policies: *horizontal policies* promoting enterprise restructuring (*general* aspects such as the establishment of new research and development routines in firms); and *targeted policies,* such as anticipated institutional change (AIC), which aim at stimulating new technological infrastructures of strategic value for the economy and creation of the new collective organisations/institutions housing them (a condition for full enterprise restructuring). One possible conclusion suggested by this article is that successful NSI transition necessitates a pattern of policies through time that triggers a cumulative process of enterprise restructuring. A second conclusion is that this process requires careful attention to *initial* policies, which should focus on firms having both a strong restructuring potential (*advanced firms* or *innovators*) and strong dynamic effects and spillovers which favour or ease the restructuring of other firms (*imitators* and *laggards*). In this article, these dynamic effects and spillovers include relevant learning about restructuring and the generation of new institutional and infrastructural components in the system with economy-wide usefulness and applicability. Thus, a third implication is that policy making should take learning (to restructure) processes and system effects into account. A fourth implication is that these will normally depend on a combination of horizontal and targeted policies. A fifth is that the success of policies at time t will change the horizontal-targeted mix implemented at t + 1. Thus, the initial horizontal policies directed to restructuring advanced firms (HRPa), if successful, will generate a fund of knowledge and experience justifying a follow-up programme supporting the restructuring of imitator firms (HPRi). It is clear that in some cases policies not only respond to market failure, but also generate such failures (this is only one limitation in the applicability of market-failure analysis).[28]

A major objective of the analysis – only partially achieved here – is to link the policy framework of the article and the policy dynamics which evolved with the neo-classical (as reflected in Arrow’s seminal paper and in standard welfare analysis), structuralist (Justman and Teubal and, in particular, the various papers authored or co-authored by Lipsey), and evolutionary approaches to technology policy (Metcalfe, Malerba and Teubal). Section IV mainly deals with links between the first two approaches. It surveys the limitations of neo-classical market-failure analysis and proposes a redefined concept of market failure, based neither on equilibrium nor on optimisation, which – while recognising the importance of the market mechanism in growth and in system adaptation – takes into account the existence of non-market mechanisms of decision making, resource allocation and selection. These include a *policy mechanism* (involved, in interaction with stakeholders, in strategic priorities and in the design of new institutions and infrastructures) which should be embedded in a policy sub-system, not specified in the model; professional and institutional (*e.g.* within universities) mechanisms; the political mechanism, etc. Section IV also considers the domain and applicability of the so-called ‘‘redefined’’ market-failure analysis and, in particular, mutual links with another type of NSI transition failure, termed ‘‘system failure’’. A system failure is a failure of at least one non-market mechanism, such as the policy mechanism, or an institutional-professional mechanism, such as that operating within universities; it may involve failure or non-adaptive behaviour in both the market and the relevant non-market mechanism. While ‘‘redefined’’ market failure may be applicable to underpin horizontal policies (with considerable limitations, depending on the specific context), the analytical foundation of targeted policies directed to the further complexity of the supporting infrastructure or technology support system is the existence of system failure.

The more explicit aspects of the analysis follow: *i)* a structuralist perspective to innovation (although with systemic and evolutionary aspects) which recognises the distinction between innovation and the supporting structure, infrastructure or support systems; and *ii)* a structuralist perspective to economic growth and development which recognises that at nodes of structural change an economy may require the establishment of a ‘‘specific’’ or non-universal infrastructure (Justman and Teubal, 1991). Also, the two broad types of policies – horizontal and targeted – roughly correspond to the two broad types of policies, defined by objective, of both structuralist approaches (and to the broader taxonomy of Lipsey and collaborators). The analysis also considers learning phenomena, particularly collective learning resulting from policy-induced enterprise restructuring; diffusion of restructuring experience towards less advanced segments of enterprises (imitators and laggards); and system effects.

Links with evolutionary technology policy perspectives: Our emphasis on learning and on system connectivity is consistent with an evolutionary perspective both in general (Metcalfe, 1993, Metcalfe and Georghiou, 1997) and in connection with policies for particular industries (Malerba, 1997). Learning in our model also generates ‘‘variety’’ in organisation/technology and heterogeneity of firms in the domestic economy (some firms restructure instead of all firms being the same at time zero with respect to the restructuring variable). The model also implies operation of a certain mechanism of selection which is both market- and policy-driven. Thus, the changes in the environment at time zero (*e.g.* opening up the economy to imports, etc.) should be visualised as a *strengthening of the market selection environment* through enhanced competition originating from abroad. On the other hand, both horizontal and targeted policies should be viewed as *mechanisms fostering variety* which thereby help to restore a balance between variety and selection (the essence of successful evolution). However, from an evolutionary perspective, there seem to be three major issues and problems: first, there is no explicit selection process in the model (this should be a priority when attempting to formalise our appreciative theory ‘‘model’’); the links between learning and variety and selection are not clear (this is a general problem when applying the evolutionary metaphor of biology to economic systems); and the link between the industrial and technological policies analysed in this article and a broad evolutionary perspective on competition policy. I will briefly consider this latter point.

Metcalfe considers innovation policy – which more than anything else is directed to creating variety – as part of a broader view of competition policy whose objective is to ‘‘maintain open economic conditions’’. The other elements of competition policy are rules, *e.g.* antitrust laws, liberalisation, etc. (which can be thought of as the traditional or neo-classical view of competition policy); and promotion of technology support systems. If my interpretation is correct, then the three components of ‘‘evolutionary’’ competition policy would seem to be represented in the model. Thus the changes in rules, *e.g.* competition is now also allowed from firms located abroad, are part of the changed environment which creates for the first time the need for a new national system of innovation; the learning/variety condition is ensured by the various horizontal policies; and the need for new ‘‘technology support systems’’ is expressed in the model by the new collective organisation/technological infrastructures. The result is that, while the model does not make explicit the process of selection (and this is not due to its basic structure, but rather because it is an appreciative theory model rather than a formal model), it does seem to include all the components of evolutionary ‘‘competition’’ policy.

I would like to emphasize the role played by one element of the ‘‘selection environment’’ facing the business sector (or a particular industry), which goes beyond the antitrust laws, intellectual property rights and other rules which make up traditional competition policy. This element comprises the new components of the system which represent enhancements of the innovation or restructuring supporting structure; that is, the new institutional/technological infrastructures. Rather than making the selection environment stronger or weaker – which seems to be the main dimension considered in recent work on policy in an industry dynamics context (Malerba) – these change the ‘‘level playing field’’, *i.e.* open up new functional opportunities for survival and growth of local firms *vis-à-vis* foreign competitors. Their role is probably more important in a small country facing an increasingly harsh selection environment imposed from abroad (one typical NSI transition context), than in an industry dominated by a major economic power such as the United States or from a world-wide industry perspective. These infrastructural and institutional components may have to include much more than a ‘‘common infrastructure of standards and gateway technologies’’ (Malerba, 1997, p. 13), since policy makers in such an economy have a clear preference for growth of the domestic industry rather than growth of the industry in general (correspondingly, in such a small economy there is less room for ‘‘rules’’ than from a world-view perspective).

The future challenge is to consolidate a dynamic policy framework for NSI transition which integrates structuralist, evolutionary and system perspectives on policy. At some stage, it would be extremely fruitful to characterise the policy subsystem and the policy process as integral aspects of systems of innovation and as important determinants of a country’s capacity to identify and design the new policies required for such a transition.

NOTES

1. I am assuming that the changes in the environment are making the restructuring of a large share of business enterprises ‘‘socially desirable’’.
2. ‘‘System effects’’ in this article refer to the impact on enterprise restructuring of establishment and operation of the above-mentioned new collective organisations housing the new technological infrastructure.
3. See Teubal (1997*b*), Section 3.2 (Phase 3), for further details of the events and the context surrounding the metamorphosis of the TC.
4. A number of policy actions and activation of a well-developed policy sub-system are required for successful identification of a particular technology as being of strategic value to the economy. These would involve foresight studies, interactions with stakeholders, and assessment of the experience accumulated by those advanced firms who have initiated their restructuring prior to government action. These are not considered explicitly in this model which frequently focuses on ‘‘programmes’’ rather than on the broader set of policy actions and inner workings of the policy sub-system. Since I am considering ‘‘ideal’’ policies that could lead to a full NSI transition, the AIC category of this article presumes such actions and activities. For this reason, and because of the assumed relevance of the new technological input for the whole business sector, it would be a ‘‘blanket’’ rather than a ‘‘focused’’ policy in Lipsey’s scheme. See Lipsey and Carlaw (1997).
5. An objective of well-designed HRP whose implementation follows evolutionary principles is to generate a process of *collective* learning about the activity promoted (*e.g.* R&D or design) and to generate new organisational capital associated with such an activity (Teubal, 1996*b*). This requires transforming the aggregation of learning by individual enterprises into collective learning which is not an automatic nor trivial process. The impact would be endogenisation of the activity, *i.e.* its undertaking by business enterprises in the future without (or with much lower levels of) government support. This is consistent with our framework of analysis where the HRP for advanced firms is implemented in Phase 1 and implicitly suspended or greatly reduced in subsequent phases. Another objective of an evolutionary implementation of HRP is to promote diffusion of restructuring experience to firms who have not yet ‘‘adopted’’ the new function or the new organisational innovations. For this to take place collective/cumulative learning should be geared to benefit such a segment of enterprises – in our model, imitators and laggards – rather than firms who have adopted – advanced firms.

6. The process has been termed ''user need determination'' in Teubal (1979).
7. The reasons for this are specified in previous work. They include: *i)* the TC by itself is limited in its capacity to reach large groups of enterprises, and laggards may comprise a significant share of all enterprises in the economy; *ii)* the effort at customisation of the new input increases with customer (enterprise) heterogeneity, and significant heterogeneity either may exist or will emerge and become clear after diffusion of X to mild laggards; and, despite this last factor, *iii)* once demand is sufficiently large and a measure of routinisation of X has taken place, a market may be feasible and may even be relatively easy to stimulate.
8. This is a general problem for many business segments in relation to information technology generally speaking; and it may be made more acute by the absence of technical capabilities within enterprises to absorb the new inputs.
9. Visualising restructuring as a diffusion process implies a concept of what is diffused (organisational routines, technology) which goes beyond ''artefacts'' but which involves knowledge and skills as well. This conforms closely to Metcalfe's view of evolutionary diffusion processes (Metcalfe, 1988). In this model, effective diffusion of the ''restructuring artefacts'' to imitator and laggard firms requires generation and diffusion of knowledge concerning the prior restructuring experience of advanced firms.
10. I would like to thank P. Maskell for having suggested this point. Enterprise organisational lock-in of incumbent enterprises could play a role in de-linking past profits as a necessary and sufficient condition for being advanced or innovative in the new set of circumstances.
11. For a clear statement of the demand-creating effect of horizontal policies, see Teubal (1996*a,* 1996*b,* 1997*a*).
12. These last two implications imply that R&D subsidies, if applied according to a learning perspective, are not only supply-side policies. They should be regarded as demand-side policies as well.
13. Not all the sectors nor all the technologies need to be ''covered'' by the new set of targeted programmes. Unlike the situation in the early phase, some sectors and/or technologies might not receive support at this later phase (despite the fact that, for ''variety'' considerations, a residual and downsized horizontal programme could, ideally, still be retained to support new ideas and unexpected opportunities).
14. The supporting structure for innovation was suggested in Justman and Teubal (1986) as a main objective of technology policy. It is also a central category of the structuralist perspective to technology and innovation proposed by Lipsey and Carlaw (*op. cit.*) (according to these authors this is one of the main differences with the neo-classical approach). Metcalfe 1996 also analyses the central role played by ''technology support systems'' and policies supporting these systems such as the United Kingdom's Science Foresight exercise. This article focuses on the technological infrastructure component of Lipsey and Carlaw's ''supporting structure'' rather than on the innovation implementation aspect (the latter would include, *e.g.* the plant and equipment within business enterprises which implement inventions on a commercial scale).

15. It should be noted here that the ‘‘targeting’’ activity is directed not to a specific innovation nor even to a specific firm or its specific ‘‘dynamic capabilities’’ (Teece, 1995). Targeting relates here to ‘‘generic capabilities’’, *i.e.* those supporting the innovation requirements of large numbers of enterprises (strictly speaking, in this model, all firms in the business sector). It is still up to each individual enterprise to innovate and to develop its own non-easily-reproducible capabilities. The targeting function therefore is certainly feasible and even desirable in a number of contexts, *e.g.* economies of scope; when background foresight studies are undertaken; when stakeholders are involved; and when the policy sub-system is such that appropriate long-term objectives and priorities can be set. The importance of a targeted AIC directed to collective organisations is particularly strong if there is no pre-existing pattern of behaviour or culture in the economy involving interfirm collaboration in technological development.
16. Having given arguments justifying a measure of targeting in NSI transition, I would like to mention that justification of horizontal policies must be obvious at present to policy makers world-wide, despite the fact that economists of both the neo-classical and evolutionary persuasion have systematically ignored them (at least until recently). For a discussion of this point see Teubal (1996*a,* 1997*a*). The basic point is the potential for collective learning about socially desirable technological activities such as R&D, innovation, etc., whose impact straddles sectors, firms and technologies.
17. There is a difference, however. Horizontal policy programmes apply to specific types of socially desirable technological activity such as enterprise R&D or pre-competitive, collaborative R&D (‘‘generic’’ R&D). The programmes are very different, and in my opinion should not be mixed; moreover, a country’s focus may shift from regular R&D to generic R&D. (This is not considered in this article. It would mean that advanced firms would receive a different type of HRP in Phase 2 rather than giving way to an HRP for imitators.) Lipsey and Carlaw seem to imply that framework policies should relate to all types of R&D; and that a programme supporting ‘‘... particular types of R&D such as pre-commercial research’’ should be considered a focused programme (Lipsey and Carlaw, 1997, p. 10). I would probably not agree.
18. I already mentioned that Lipsey and Carlaw’s ‘‘facilitating structure’’ also involves physical and organisational capital within enterprises, and not only non-enterprise organisations like the TC in this model which (indirectly) support innovations within firms. Therefore horizontal policies in the model, while directed to supporting ‘‘innovation’’, also support part of Lipsey and Carlaw’s facilitating structure. This in itself is not a problem; it only makes it difficult, as Lipsey and Carlaw mention, to separate policies increasing the incentives to innovation from policies changing the supporting structure of implementation. A final point concerns PD and MD which, like AIC, are ‘‘targeted’’ policies. While they certainly support innovation capabilities and the supporting structure (which should now also include ‘‘new markets’’), they also directly support ‘‘innovation’’ – the absorption of new chips into new product designs. Again, it is difficult to categorise these policies as being either directed exclusively to innovation or to innovation capabilities.
19. In the case of the TC, there is *no* sharp distinction between the activity being supported – technological infrastructure, etc. – and policy since the policy mechanism is involved both in a series of strategic or planning meta-activities *and* in providing incentives.

20. In Lall and Teubal we contrast the role of market-failure analysis in two types of decisions: *i)* in strategy formulation (no role); and *ii)* in ‘‘project approval’’ (an important role). Projects are units of promotion within a particular programme such as HRPa (which programme is also a reflection of a broader strategy). These different roles reflect the nature of the activity and the amount of co-ordination and overall vision required for appropriate decisions to be taken.
21. This in fact is the meaning of the statement ‘‘market-failure analysis cannot be undertaken’’. A system failure in infrastructure may considerably reduce the scope of market failure in innovation because it reduces the social value of the latter. Under certain circumstances it may mean that there is no market failure at all in innovation/ restructuring.
22. Different strategies assign different roles for market forces and therefore, a different scope for the application of market-failure analyis. Needless to say, part of the uncertainty in evaluating the desirability of a particular strategy is uncertainty about the exact role that market forces should play.
23. These mechanisms would operate within a policy sub-system which has not been specified and which therefore should be considered as exogenous to the analysis.
24. To simplify the argument of this sub-section, I will assume that there are no system failures.
25. Other examples can be shown in our model. They also are the result of technical complementarities as emphasized by Lipsey and Carlaw, *e.g.* supporting innovation may generate externalities in the supporting structure, and *vice versa.*
26. In extreme circumstances any market failure, in order to be defined and identified as such, is also a potential co-ordination failure which could be avoided by complex intertemporal co-ordination procedures. The market failure would then not be identifiable, let alone be operational, without reference to the underlying policy sub-system and its mechanisms. Moreover, once we relate to this sub-system, we may not be able to refer to market failure alone but the analysis should refer also to the scope and structure of the activities and policy actions occurring within this sub-component. The basis for policy would then be, as with AIC, a hybrid – both market failure and ‘‘policy sub-system’’ failure would play a role.
27. For example, a simplistic or static application of even a redefined market-failure analysis may lead us not to undertake a HRP directed to advanced firms and thereby preclude from the beginning any triggering of a cumulative transition trajectory. This would be the case when for example the social net benefits of HRPa (a = advanced) can only be positive if account is taken of the restructuring of imitators (the value of Ra in this case will be due only to its function as a trigger of the whole restructuring process).
28. It is important to link the analysis of this paper with OECD (1997), which uses the notion (already used in Galli and Teubal, 1997) of ‘‘system failures’’ and which attempts to provide an empirical base to the links among the various components of a NSI. This is an important contribution to the literature, especially in its empirical base which was lacking in Lundvall (1992), Nelson (1993) and Edquist (1996). However, it focuses on characterising empirically existing systems of innovation – especially

measuring various types of links among existing system components – rather than on introducing an empirical basis for a study of NSI transition and the emergence and links of new system components (its data and analysis however are also relevant for such a study). The analysis here may conceivably contribute to extracting some of the potential policy implications of such an empirical analysis, *e.g.* the policy implications of weak links seem to me to indicate the appropriateness of horizontal policies rather than simply networking policies, *e.g.* to promote university-industry collaborations in R&D.

BIBLIOGRAPHY

ARROW, K. (1962), ‘‘Economic Welfare and the Allocation of Resources to Invention’’, in *The Rate and Direction of Inventive Activity: Economic and Social Factors,* NBER, Princeton.

DOSI, G. (1988), ‘‘The Nature of the Innovative Process’’, in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.), *Technical Change and Economic Theory,* Pinter Publishers, London.

EDQUIST, C. (ed.) (1997), *Systems of Innovation: Technologies, Institutions and Organizations,* Cassel.

FREEMAN, C. and C. PEREZ (1988), ‘‘Structural Crisis of Adjustment: Business Cycles and Investment Behaviour’’, in G. Dosi *et al.* (eds.), *Technical Change and Economic Theory,* Pinter Publishers, London.

GALLI, R. and M. TEUBAL (1997), ‘‘Paradigmatic Changes in National Systems of Innovation’’, Chapter 15, in C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations,* Pinter Publishers, London.

IMAI, K., I. NONAKA, and H. TAKEUCHI (1988), ‘‘Managing the New Product Development Process: How Japanese Companies Learn and Unlearn’’, published in K. Clark, R. Hayes, and C. Lorenz (eds.), *The Uneasy Alliance: Managing the Productivity-Technology Dilemma,* Harvard University Press.

JUSTMAN, M. and M. TEUBAL (1986), ‘‘Innovation Policy in an Open Economy: A Normative Framework to Strategic and Tactical Issues’’, *Research Policy,* 15, pp. 21-138.

JUSTMAN, M. and M. TEUBAL (1991), ‘‘A Structuralist Perspective on the Role of Technology in Economic Growth and Development’’, *World Development,* Vol. 19, No. 9, pp. 1167-1183.

JUSTMAN, M. and M. TEUBAL (1995), ‘‘Technological Infrastructure Policy: Generating Capabilities and Building Markets’’, *Research Policy,* April. Reprinted in Teubal, Foray, Justman and Zuscovitch (1996), *Technological Infrastructure Policy (TIP): An International Perspective,* Kluwer.

LALL, S. and M. TEUBAL (1997), ‘‘Market Stimulating Technology Policies in Developing Countries: A Framework with Examples from East Asia’’, forthcoming, *World Development.*

LIPSEY, R. and K. CARLAW (1995), ‘‘A Structuralist View of Innovation Policy’’, paper presented at the Conference on Implications of Knowledge-based Growth for Micro-Economic Policies, Ottawa (revised version).

LIPSEY, R. and K. CARLAW (1997), ‘‘Technology Policies in Neo-classical and Structuralist-Evolutionary Models’’, see this volume.

LUNDVALL, B.A (1985), ‘‘User-Producer Interaction’’, Aalborg University Press.

LUNDVALL, B.Å. (1992), *National Systems of Innovation,* Pinter Publishers, London.

MALERBA, F. (1997), ‘‘An Evolutionary Perspective on Technology Policy in Industrial Dynamics’’, CESPRI-Bocconi University, typescript.

METCALFE, S. (1988), ‘‘The Diffusion of Innovation: An Interpretative Survey’’, Chapter 25 in G. Dosi, R. Nelson, L. Soete and G. Silverberg (eds.), *Technical Change and Economic Theory,* Pinter Publishers, London.

METCALFE, S. (1993), ‘‘The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives’’, typescript, University of Manchester, Discussion Paper No. 95, August; reprinted in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technical Change,* Basil Blackwell, Oxford.

METCALFE, S. (1996), ‘‘Science Policy and Technology Policy in a Competitive Economy’’, PREST and School of Economic Studies, University of Manchester.

METCALFE, S. and L. GEORGHIOU (1997), ‘‘Equilibrium and Evolutionary Foundations of Technology Policy’’, see this volume.

NELSON, R. (1983), ‘‘Government Support of Technical Progress: Lessons From History’’, *Journal of Policy Analysis and Management,* Vol. 2, No. 4, pp. 499-514.

NELSON, R. (1987), ‘‘Roles of Government in a Mixed Economy’’, *Journal of Policy Analysis and Management,* Vol. 6, No. 4, pp. 514-541.

NELSON, R. (ed.) (1993), *National Systems of Innovation,* Oxford University Press.

NELSON, R. (1994), ‘‘The Co-evolution of Technology, Industrial Structure and Supporting Institutions’’, *Industrial and Corporate Change.*

NELSON, R. and S. WINTER (1982), *An Evolutionary Theory of Economic Change,* Belknap Press.

OECD (1997), *National Innovation Systems,* free brochure, Paris.

SMITH, K (1991), ‘‘Innovation Policy in an Evolutionary Context’’ in Saviotti and Metcalfe (eds.), *Evolutionary Theories of Economic and Technological Change,* Harwood Academic Publishers.

TEUBAL, M. (1979), ‘‘On User Needs and Need Determination: Aspects of the Theory of Technological Innovation’’, in M. Baker (ed.), *Industrial Innovation: Technology, Policy and Diffusion,* Macmillan, London, pp. 266-293.

TEUBAL, M. (1982), ‘‘The R&D Performance Through Time of Young, High-Technology Firms: Methodology and an Illustration’’, *Research Policy* 11, 333-346; Chapter 6 in M. Teubal (1987), *Innovation Performance, Learning and Government Policy,* Wisconsin University Press.

TEUBAL, M. (1983) ‘‘Neutrality in Science Policy: The Case of Sophisticated Industrial Technology in Israel’’, Minerva, Chapter XX in M. Teubal (1987), *Innovation Performance, Learning and Government Policy,* Wisconsin University Press.

TEUBAL, M. (1987), *Innovation Performance, Learning and Government Policy,* Wisconsin University Press.

TEUBAL, M. (1993), ‘‘The Innovation System of Israel: Description, Analysis and Outstanding Issues’’, in R. Nelson (ed.), *National Systems of Innovation,* Oxford University Press.

TEUBAL, M. (1996*a*), ‘‘R&D and Technology Policy at NICs as Learning Processes’’, *World Development.*

TEUBAL, M. (1996*b*), ‘‘Implications of Organizational Learning for Horizontal Technology Policies: An Exploratory Study’’, in L. Tsipouri and M. Storper (eds.) (1998), *Latecomers in the Global Economy,* Routledge.

TEUBAL, M. (1997*a*), ‘‘A Catalytic and Evolutionary Approach to Horizontal Technology Policies’’, *Research Policy,* 25, pp. 1161-1188.

TEUBAL, M. (1997*b*), ‘‘Restructuring and Embeddedness of Business Enterprise: A Systems of Innovation Perspective on Diffusion Policy’’, *Danish Research Unit on Industrial Dynamics (DRUID),* Report 97-6 (a revised version will appear in *Industrial and Corporate Change*).

TEUBAL, M., D. FORAY, M. JUSTMAN and E. ZUSCOVITCH (eds.) (1996), *Technological Infrastructure Policy (TIP): An International Perspective,* Kluwer.

ASSESSING THE INFRASTRUCTURAL NEEDS OF A TECHNOLOGY-BASED SERVICES SECTOR: A NEW APPROACH TO TECHNOLOGY POLICY PLANNING

TABLE OF CONTENTS

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SUMMARY

Just as technology has long been the driver of economic growth in the manufacturing sectors of industrialised nations, sustained growth in the rapidly growing service industries will rely on the continual adoption and implementation of new technology, especially information technology. Aware of this fact, an Information Technology Laboratory (ITL) was formed within the US Department of Commerce in 1996. This article describes the policy planning we conducted to assist the ITL in identifying and assessing the infrastructural needs of an IT-based service sector.

I. INTRODUCTION AND OVERVIEW

For more than two decades, the service sector has been the dominant sector in most industrial nations. In 1990, its output as a share of gross domestic product exceeded 50 per cent in all G7 countries, and was growing. The United States is no exception to this trend. The service sector’s output share increased from 57.2 per cent in 1960 to 63.2 per cent in 1990. In 1994 it was 75.3 per cent.

Just as technology has long been the driver of economic growth in industrial nations, sustained growth in service industries will rely on the continual adoption and implementation of new technology. Information technology (IT) is at the heart of technological changes in the service sector.[1] IT is the technology that has brought about the most pervasive and dramatic changes in the growth of the sector, and IT is the single category of technology that is present throughout all service industries. As the National Research Council (1994, pp. 1-2) reported: ‘‘As IT becomes less expensive, more portable, better integrated and interconnected, and embedded in [an even] wider variety of devices, new applications ... and whole new industries ... are likely to evolve and to have profound effects on industry structures, employment, and economic growth.’’

Academics and policy makers are beginning to realise that technology consists of attributes that are private in nature, attributes that are public in nature, and attributes that are mixed. It is the public and mixed attributes (*i.e.* public and quasi-public goods) that give technology an infrastructural character. As such, it is likely, if not inevitable, that the private sector will underinvest, from a societal point of view, in the public and mixed attributes of a technology. IT should be no exception to this generalisation.

If US public policy is to be designed and implemented to encourage greater innovative activity, it is imperative for planning purposes to understand the role of technology in the largest and fastest growing sector of the economy – the services sector. More specifically, it is critical for technology policy planners to understand the sources and uses of IT in the services sector and the supporting role of R&D in adopting and using IT. If policy is to be designed to encourage not only investment in IT but also more effective use of IT in services industries, thereby enhancing productivity growth and the overall competitiveness of the sector, policy planners must further understand the infrastructural elements of IT that leverage both the manufacturing sector's development as well as the services sector's implementation of IT and the extent to which there are underinvestments in these infrastructural elements.

In 1994, planning began for a new laboratory within the US Department of Commerce's National Institute of Standards and Technology (NIST), the Information Technology Laboratory (ITL).[2] Also, in that year, as part of the strategic planning, ITL began to realise that a significant part of its focus would be toward services industries, and that there was limited information about the sources and uses of IT in those industries. Accordingly, the Program Office within NIST initiated a comprehensive, long-term planning project to quantify the role of IT in the services sector, to determine if significant market failures exist in the process of developing and utilising IT, and to identify and assess the infrastructural needs of a technology-based services sector. The methodology we developed and implemented for NIST to accomplish this consists of a process to:

1. understand sources and uses of information technology in services industries;
2. investigate the assertion (and *a priori* belief) that services industries are underinvesting and underutilising IT;
3. ascertain (given the conclusions from #2) the type of market failure(s) that is (are) present to lead to such underinvestment and underutilisation;
4. prioritise (given the findings from #3) aspects of market failure that affect the use and implementation of IT in service sindustries;
5. suggest (given the prioritisation from #4) a direction for the infrastructural technology-based policy needs of the services sector.

The development and implementation of our methodology is what we call a new approach to technology policy planning. For, if policy is thoroughly planned on the basis of factual information, its effectiveness is greatly leveraged when implemented.

The remainder of the article is outlined as follows. The formation and goals of the ITL are described in Section II. In Section III, we describe sources and uses of technology in the services sector with a particular emphasis on IT. In Section IV, we present evidence from various sources that confirms that the services sector underinvests and underutilises IT. In Section V, we prioritise for planning purposes those aspects of market failure that, from a societal perspective, adversely impact the use and implementation of IT, and we emphasize the importance of such a prioritisation if public policy is to be effectively planned and designed.

II. PLANNING FOR AN INFORMATION TECHNOLOGY LABORATORY

Formation and goals of the Information Technology Laboratory

In 1994, the Director of NIST charged the Director of the Computer Systems Laboratory and the Director of the Computing and Applied Mathematics Laboratory to initiate planning to combine the two laboratories into a single laboratory. An ITL Planning Group was constituted to formulate the steps necessary to create the ITL. In mid-1995, NIST approved the establishment of the ITL to respond to the growing need, arising out of the national effort to develop an information infrastructure to support US industry in a global market-place, for measurement and testing technology to support the development of computing and communications systems that are usable, scaleable, interoperable, (reliable), and secure.[3] More specifically, the mission of the ITL was defined (ITL, 1996*a,* p. 2): ‘‘to stimulate US economic growth and industrial competitiveness through technical leadership and collaborative research in critical infrastructure technology ... to promote better development and use of information technology.’’

In support of the ITL and its mission, the Program Office within NIST initiated a comprehensive long-term planning project to quantify the role of IT in the services sector, determine if significant market failures exist in the process of developing and utilising IT, and identify and assess the infrastructural needs of a technology-based services sector.

Government’s role in technology

The first formal domestic technology policy statement, *US Technology Policy,* was released by the Office of the President in 1990.[4] As with any initial policy effort, this was an important general document. However, precedence aside, it failed to articulate a foundation for government’s role in technology. Rather, it implicitly assumed that government had a role, and it then set forth a rather general goal (p. 2): ‘‘The goal of US technology policy is to make the best use of technology in achieving the national goals of improved quality of life for all Americans, continued economic growth and national security.’’

President Clinton took a major step forward in his 1994 *Economic Report of the President* by articulating first principles about why government should be involved in the technological process (p. 191): ‘‘The goal of technology policy is not to substitute the government’s judgement for that of private industry in deciding which potential ‘winners’ to back. Rather, the point is to correct [for] market failure...’’

Policy makers today recognise the conceptual importance of formulating technology in a manner that is aimed at addressing market failures.[5] However, there has not been, to our knowledge, many (if in fact any) legislated technology policies that were planned by first identifying the nature of the market failure, and then formulating a policy to specifically overcome the barriers in technology that led to the market failure.

Perhaps it is the case that a good policy maker knows a market failure when he/she sees one.[6] Maybe so, but maybe not. Even if market failures are so well known that they do not have to be quantified, how to prioritise policy prescriptions in the absence of such quantification is at best problematic. As such, the planning initiative by NIST – to determine whether significant market failures exist in the technology development and utilisation process, and to identify and assess the infrastructural needs of a technology-based services sector – is not only ambitious, compared to historical policy-planning and policy-setting practices, but also economically sound. This approach to policy planning may go a long way to overcoming government failure.[7]

The methodologies set forth in the following sections of this article regarding how we went about identifying market failures are intended to illustrate one effort to operationalise a systematic approach to policy planning as related to IT in services industries.

III. SOURCES AND USES OF TECHNOLOGY IN THE SERVICES SECTOR

This section describes sources and uses of technology in the services sector with a particular emphasis on IT.[8] Based on our analysis of several sources of information, we conclude that:

- more than 50 per cent of services sector R&D is directed to IT;

- services sector firms do some of their IT R&D directly with internal R&D, and they obtain the rest indirectly through R&D embodied in purchased IT equipment – the internal R&D is about 15 per cent of the total IT technology expenditure for the internal R&D and the purchased IT equipment taken together;
- IT is primarily used by services sector firms to improve customer service and to improve the timeliness with which new services are delivered to the market.

R&D within services sector industries

Surprisingly, very little information is available about sources and uses of technology in the US services sector, although we attempt below to make some inferences. One might speculate that the reason for this void of information about services-sector technology is due, in part, to the predominance of the US manufacturing sector in R&D, although the services sector's share of performed R&D has been slowly increasing from approximately 2 per cent in the early 1960s to approximately 26 per cent in the early to mid-1990s.[9]

The literature clearly points to IT as the critical technology driving services-sector growth. According to IT specialists, information technology is still evolving as a distinct category of technology due to the ongoing convergence of two distinctively different industries: communications and computing. Advances in digital technologies have eroded the demarcation between the historically analog communications world and the digital computing world. And despite the fact that communication technologies were firmly entrenched in incompatible analog systems, the digital basis upon which the computing world has built is expanding to encompass the formerly analog technologies of telephone, broadcast, cable television, wireless communication and satellite transmissions (ITL, 1996*b*).

The data in Table 1 suggest that a disproportionate amount of the R&D activity in services industries appears related to information technology (given the convergency noted above). Communication services (SIC 48) take 17.5 per cent of the total non-manufacturing (mostly services) R&D and 15.5 per cent of the R&D scientists and engineers in the non-manufacturing sector. As seen in Table 2, communication services account for only 3.4 per cent of private services' value added and 1.8 per cent of private services' full-time equivalent employees. Also from Tables 1 and 2, computer-related services (SICs 737, 871) take 32.2 per cent of total non-manufacturing R&D and 38.2 per cent of the R&D scientists and engineers. Computer-related services account for about 4.1 per cent of private service's value added and 2.8 per cent of private service's full-time equivalent employees.[10]

Table 1. **Total R&D activity in selected industries**

Industry and SIC code	1993 total R&D performed (million US$)	1993 R&D scientists and engineers (thousands)
Total	118 334	764.3
Manufacturing (SICs 13, 20-39)	87 013	573.5
Communication services (SIC 48)	5 491	29.5
Electric, gas and sanitary services (SIC 49)	339	1.6
Computer programming, data processing, other computer-related engineering, architectural and surveying services (SIC 737, 871)	10 092	72.9
Hospitals and medical and dental laboratories (SICs 806-807)	132	0.9
Research, development and testing services (SIC 873)	2 084	13.6
Other non-manufacturing industries	13 183	72.3

Source: National Science Foundation (1996).

Table 2. **Size of industry by value added and by full-time equivalent employees**

	1994 value added (Billion US$)	1993 full-time equivalent employees (thousands)
Nation	5 495.5	105 593
Non-services	1 360.1	24 438
Agriculture, forestry and fisheries	101.9	1 642
Mining	40.2	597
Construction	238.3	4 523
Manufacturing	979.7	17 676
Services	4 135.4	81 155
Private		
Transportation	177.5	3 999
Communications	113.4	1 157
Electric, gas and sanitary services	116.5	929
Wholesale trade	310.2	5 800
Retail trade	475.6	16 728
Finance, insurance and real estate	894.2	6 508
Other private services	1 254.6	28 121
Government		
Government services	793.4	18 513

Source: US Department of Commerce (1988, 1994, 1995*b*).

Thus, a lower-bound estimate is that 49.7 (17.5 + 32.2) per cent of services-sector R&D is directed to IT. This lower-bound characterisation comes from the presumption that portions of R&D performed by non-communication and non-computer industry firms in services are devoted to IT as well (and our case studies justify that presumption), and the presumption that the IT-related R&D in those services firms would exceed the modest shortfall in IT-related R&D below the total R&D for computer services and communication firms.

Technology flows into services industries

The data needed to formulate a benchmark estimate of imported technology (*i.e.* technology flows into) *vs.* indigenous technology (*i.e.* R&D-based) in services industries are in Table 3. The implicit assumption underlying the analysis that follows is that IT purchased by firms in non-manufacturing industries is a lower-bound estimate of the total technology that is imported into those industries. Certainly, firms in services industries purchase other capital equipment that has non-information technology embodied in it.[11]

Table 3. **Comparison of value added, IT investments and company funded performed R&D in 1991**

Billion US$

Industry	Value added	IT investments	R&D
Non-services	1 178.7	26.7	
Agriculture, forestry and fisheries	90.9	0.0	
Mining	36.7	0.9	
Construction	210.1	0.5	
Manufacturing	841.0	25.3	67.6
Services	3 391.2		
Private	2 691.8	126.8	
Transportation	140.8	3.8	
Communications	95.3	21.1	
Electric, gas and sanitary services	99.0	8.0	
Wholesale trade	266.0	17.0	
Retail trade	403.3	17.9	
Finance, insurance and real estate	685.0	38.7	
Other private services	1 002.4	20.3	
Government	699.4	n.a.	
Private non-manufacturing	3 029.5	128.2	22.9

Source: National Research Council (1994); National Science Foundation (1996).

The data in Table 3, albeit conservative in terms of its characterisation of imported technology into the services sector, show that 82.6 per cent of 1991 investments in IT hardware were by private services-sector industries. Included in these estimates of IT are expenditures for office, computing, and accounting equipment; communication equipment; instruments; and photocopy and related equipment. Not included are software, electronic information services, data processing and network services, computer professional services, custom programming, system integration, consulting or training services.

The non-manufacturing sector's R&D, which is mostly services industry R&D, accounts for US$22.9 billion in company-performed R&D, or 25.3 per cent of all company-performed R&D in 1991. This estimate proxies indigenous investment in technology, compared to imported technology. Adding to this R&D amount the US$126.8 billion that services industries invest in information technology yields a total services-sector investment in technology of at least US$149.7 billion for 1991.[12]

Therefore, based on the conservative estimate of US$149.7 billion for investments in technology by services-sector firms, 84.7 per cent of that is imported in the form of purchased IT hardware and 15.3 per cent is generated through R&D. Or, approximately 85 per cent of the technology used in services-sector companies is imported and 15 per cent is descriptively called ‘‘home grown’’.[13]

One could argue, however, that the R&D investment estimate of US$22.9 billion in Table 3 understates the R&D activity in non-manufacturing industries in that year. The estimate does not do so from a National Science Foundation definitional sense, or it would have been reported to the National Science Foundation on its RD-1 reporting survey forms. Nevertheless, in the case of IT, there are other costs that need to be considered, particularly the costs for related programming and software. If these additional costs are treated as R&D – and we are not advocating that they should be – then the foregoing 85 per cent estimate of imported technology would decrease. But were that to be done, some adjustment would have to be made for the portion of imported technology that is non-IT related. Our prior belief is that an R&D adjustment would be minor and certainly offset by any non-IT technology embodied in other purchased capital.

Information technology requires significant adoption costs. Including the services sector's expenditures for implementation of IT in its own technology bill reverses the stylised ratio of 85:15 for imported technology to home-grown technology in the services sector. When internal technology implementation costs are considered, the imported portion of the technology bill is approximately 16 per cent, while the internally-developed technology portion is about 84 per cent.

The International Data Corporation (IDC) (1996) provides a breakdown of various costs of using information technology for basic types of IT sites. In particular, for large distributed sites, IDC reports that there is the cost of the operations

Table 4. ***Information Week* survey questions and responses**

Survey question	Mean response
Question: Please rate the importance of each of the following reasons as to why your organisation invests in information technology. ***(Please rate each on a scale of 1 to 10, where 10 = extremely important and 1 = not at all important.)***	
Improve customer service	9.25 (n = 99)
Improve flexibility (*e.g.* customisation)	8.36 (n = 99)
Improve managerial information systems	8.06 (n = 99)
Improve timeliness (*e.g.* faster time to market)	8.84 (n = 99)
Improve product quality	8.57 (n = 98)
Learn about new technologies	5.37 (n = 98)
Maintain state-of-the-art IS shop[1]	5.28 (n = 98)
Provide IT infrastructure	7.48 (n = 97)
Reduce costs	8.52 (n = 99)
Support reengineering or business process redesign	8.00 (n = 97)
Question: Please rate the importance of each of the following factors in guiding your organisation's selection of new information technologies/systems. ***(Please rate each on a scale of 1 to 10, where 10 = extremely important and 1 = not at all important.)***	
Adherence to open (non-proprietary) standards	8.30 (n = 99)
Availability of service and support	8.99 (n = 98)
Compatibility with existing systems	7.91 (n = 99)
Functionality	9.16 (n = 99)
Low initial cost	6.48 (n = 99)
Low training costs	6.34 (n = 99)
System reliability	9.42 (n = 98)

1. IS = information systems.

Source: *Information Week.*

staff (38 per cent), the central site location (17 per cent), software (25 per cent), hardware (17 per cent) and support (5 per cent). Based on these estimates, if a representative services-sector firm allocates US$100 to new technology, US$85 for the imported technology hardware and US$15 for the internal R&D, and if the US$85 represents 17 per cent of its total cost to make the information technology operable, then the total cost for using the IT is US$500. Accordingly, for this hypothetical services-sector firm, its total internal technology costs are US$515, thus making the purchase price of the IT hardware about 16.5 per cent of its total cost of operation.

Use of information technology in services industries

To gain insight into how information technology is used by services-sector firms, specific survey questions were posed to the top IT executives of the 500 largest domestic users of IT as part of the 1996 *InformationWeek* survey.[14]

Our survey questions relevant to this ITL planning project are reproduced in Table 4, along with the mean response. Although 103 surveys were completed by IT executives in the services sector, not all respondents completed all questions. The number of responses is also reported in Table 4 in parentheses, by response.

Several insights about the use of information technology in services industries can be gleaned from the survey responses summarised in Table 4. One, based on responses to the first question, investments in IT seem to be primarily intended to improve customer service and to improve the timeliness with which new services reach the market. Two, based on responses to the second question, the dominant factors associated with the selection of new IT are the reliability of the IT system and its functionality.[15]

IV. EVIDENCE OF MARKET FAILURE RELATED TO INVESTMENTS IN IT

This section is divided into four sub-sections. First, the concept of risk is discussed in the context of creating barriers to technology, and it is barriers to technology that lead to an underinvestment in or underutilisation of technology. In the second sub-section, we present evidence from the academic literature and from the professional trade literature that market failures do exist with regard to investments in IT. Then, we present complementary statistical information that services-sector firms are underinvesting in IT. However, all of this evidence of underinvestment in IT fails to ascertain the aspect or type of market failure present in services industries and therefore is, or so we contend, of limited value for technology policy planning. But, the detailed case studies (on retail banking, health care, and home entertainment) in the final sub-section do provide some needed insight.

Barriers to technology and market failure as related to IT

Risk and closely related difficulties appropriating returns create barriers to technology, and as a result, there will be an underinvestment in or underutilisation of a technology. Much of the market failure literature focuses on investments into the creation or production of technology (*e.g.* R&D). Equally relevant, and perhaps even more important for technology policy planning as related to services industries, are investments for the use and application of others' technology. Our discussion below relates to R&D investments used to create new technology, but we explore in this discussion the extent to which our arguments are generalisable to the purchase and utilisation of IT. The following characterisation of barriers as evolving from technical and market risk of various sorts is from Tassey (1995).

Risk measures the possibilities that actual outcomes will deviate from the expected outcome, and the shortfall of the private expected outcomes from the expected returns to society reflects appropriability problems. The technical and market results from technology may be very poor, or perhaps considerably better than the expected outcome. Thus, a firm is justifiably concerned about the risk that its R&D investment will fail, technically or for any other reason. Or, if technically successful, the R&D investment output may not pass the market test for profitability. Further, the firm's private expected return typically falls short of the social expected return.

The expected outcome is the measure of central tendency for a random variable's outcome. Risk is sometimes quantified as the variance of the probability distribution for a random variable's outcome – here, the technical outcome of R&D or the market outcome of the R&D output are the random variables – although other aspects of the probability distribution may affect risk as well. Thus, the contribution to a firm's overall exposure to risk associated with a particular investment will be different depending on the collection of projects in the portfolio. In that sense, a large firm, with a diversified portfolio of R&D projects, might find a particular project less risky than a small firm with a limited portfolio. Similarly, society faces less risk than the individual firm, large or small, because society has, in essence, a diversified portfolio of R&D projects and that diversification reduces risk that, because of bankruptcy costs or managers' firm-specific human capital, the decision makers in individual firms will consider. As risk is reduced to society, overall outcomes become more certain. Further, for each particular technological problem, society cares only that at least one firm solves the technical problems and that at least one is successful in introducing the innovation into the market. The individual firm pursuing the technical solution with R&D and then trying to market the result will of course face a greater risk of technical or market failure.

Facing high risk – both technical and market risk not faced by society – or simply because society has a longer time horizon than the decision makers of individual firms, a private firm discounts future returns at a higher rate than does society. Therefore, the private firm values future returns less and, from society's perspective, will invest too little in R&D. Put another way, the higher the risk, the higher the hurdle rate or required rate of return for a project. Thus, when social risk is less than private risk, the private firm will use a hurdle rate that, from society's perspective, is too high. Socially useful projects will accordingly be rejected. Further, when the firm's expected return falls short of society's expected return, the firm has less future returns to value than society does, and again, underinvestment will result.

Tassey (1995) observes several technological and market factors that will cause private firms to appropriate less return and to face greater risk that does society.

One factor comes into play when technical risk (outcomes may not be technically sufficient to meet needs) is high – the risk of the activity being undertaken is greater than the firm can accept, although if successful there would be very large benefits to society as a whole. Society would like the investment to be made, but from the perspective of the firm the present value of expected returns is less than the investment cost and hence less than the amount yielding its acceptable return on investment. In other words, the private discount rate is greater than the social discount rate.

Two, high risk can relate to high commercial or market risk (although technically sufficient, the market may not accept the innovation, see below) when the requisite R&D is highly capital intensive, meaning that it requires too much capital for any one firm to feel comfortable with the outlay. As such, the minimum cost of conducting research is viewed as excessive relative to the firm's overall R&D budget which considers the costs of outside finance and the risks of bankruptcy and, when this is the case, the firm will not make the investment, although society would be better off if it did, because the project does not appear to be profitable from the firm's private perspective.

Three, many R&D projects are characterised by a long time to market. That is, when the time expected to complete the R&D and the time to commercialisation of the R&D are long, then it will be a long time to the realisation of a cash flow from the R&D investment. Because a private firm will have a higher discount rate than does society, it will value future returns less than society does. Because the private discount rate exceeds the social discount rate, there is an underinvestment, and the underinvestment increases as the time to market increases because the difference in the rates is compounded and has a bigger effect on returns further into the future.

Four, it is not uncommon for the scope of potential markets to be broader than the scope of the individual firm's market strategies so that the firm will not perceive or project economic benefits from all potential market applications of the technology. As such, the firm will consider in its investment decision only those returns that it can appropriate within the boundaries of its market strategy. While the firm may recognise that there are spillover benefits to other markets, and while it could possibly appropriate them, such benefits are ignored or discounted heavily relatively to the discount weight that would apply to society. A similar situation arises when the requirements for conducting R&D demand multidisciplinary research teams; unique research facilities not generally available within individual companies; or ''fusing'' technologies from heretofore separate, non-interacting parties. The possibility for opportunistic behaviour in such ''thin'' markets may make it impossible, at reasonable cost, for a single firm to share capital assets even if there were not R&D information-sharing difficulties to compound the problem.

Five, the evolving nature of markets requires investments in combinations of technologies that, if they existed, would reside in different industries that are not integrated. Because such conditions often transcend the R&D strategy of firms, they are unlikely to be pursued owning not only to a lack of recognition of possible benefit areas or to the perceived inability to appropriate whatever results, but also to the fact that the costs of co-ordinating multiple players in a timely and efficient manner is cumbersome.

Tassey (1995) identifies other situations where the private firm will not anticipate an adequate return on its investments and hence where market failure and underinvestment can occur.

A sixth situation exists when the nature of the technology is such that it is difficult to assign intellectual property rights. Knowledge and ideas developed by a firm that invests in technology may spillover to other firms during the R&D phase or after the new technology is introduced. If the information creates value for the firms that benefit from the spillovers then, other things being equal, the innovating firm may underinvest in the new technology. Similarly, when competition in the development of new technology is very intense, each firm, knowing that the probability of being the successful innovator is low, may not anticipate sufficient returns to cover costs. Further, even if the firm innovates, intense competition in application can result because of competing substitute goods, whether patented or not. Especially when the cost of imitation is low, an individual firm will anticipate such competition and may therefore not anticipate returns sufficient to cover the R&D investment cost. To elaborate, competition in the post-innovation market can be a problem. Knowledge about technology has some of the characteristics of public goods – the knowledge remains for others to use even after it has been used by an innovator. Because the average cost of producing the technology (or information more generally) is typically greater than the marginal cost of disseminating it, many firms are likely to compete in a post-innovation market, perhaps with substitutable patented versions of the technology. In fact, they are likely to compete the price for the technology down to a level that will not allow appropriation of the initial investment required to create the technology. Also, appropriability will be difficult, and underinvestments may result, when the buyers of technology can bargain for lower prices or if imitators successfully compete with the innovator.

A seventh situation exists when industry structure raises the cost of market entry for applications of the technology. The broader market environment in which a new technology will be sold can significantly reduce incentives to invest in its development and commercialisation. Many technology-based products in today's complex market-place are part of larger systems of products (*e.g.* an automated factory and a communications network). Under such industry structures, if a firm is contemplating investing in the development of a new product but perceives a risk that the product – even if successful technically – will not ''fit'' or ''interface'' with other products in the system, the additional cost of attaining compatibility or interoperability may reduce the expected rate of return to the point that the project is not undertaken. Similarly, multiple sub-markets may evolve, each with its own interface requirements, thereby preventing economies of scale or network externalities from being realised.

An eighth situation exists when the complexity of a technology renders agreement with respect to product performance between buyer and seller costly. As Teece (1980) explains, the paradox of information (discussed below) and opportunistic behaviour by firms attempting to share the information and facilities needed for the exchange and development of technology can make the needed transactions between independent firms in the market prohibitively costly if the risks of opportunistic behaviour are to be reduced to a reasonable level with obligational contracts. The successful transfer of technology from one firm to another often requires careful teamwork with purposeful interactions between the seller and the buyer of the technology. In such circumstances, both the seller and the buyer of the technology are exposed to hazards of opportunism. Sellers, for example, may fear that buyers will capture the know-how too cheaply or use it in unexpected ways. Buyers may worry that the sellers will fail to provide the necessary support to make the technology work in the new environment, or they may worry that, after learning about the buyer's operations in sufficient detail to transfer the technology successfully, the seller would back away from the transfer and instead enter the buyer's industry as a technologically-sophisticated competitor.[16]

Literature-based evidence of market failure related to investments in IT

Given the productivity-enhancing potential of IT, the so-called ''information technology paradox'' has gained attention. As the name implies, despite the large investments in IT, measured productivity in services industries has not grown accordingly. Yet, experts from academia and management conclude that such productivity studies have focused too narrowly on imperfect productivity measures, and that overall performance in services has been good. Further, much of the most recent evidence shows strong services-sector performance even in the narrow productivity sense. There is a prevalent view that market processes are serving us well here. Although services-industry technology is evolving rapidly and unpredictably, breakthroughs and the productivity gains are occurring; the missteps are small compared to the size of the forward leaps.

However, despite the optimism about the productivity-enhancing effects of the new information technologies in services, the consensus to date is that there is great uncertainty created by the rapid changes in technology and that the potential for productivity gains can be realised only if new technologies are carefully tailored to allow services providers to effectively meet the needs of the customers. That potential for productivity gains should not be surprising. Difficulties in acquiring, developing, and implementing technology would be expected to be especially pronounced in most services industries for several reasons, many having their origin in market failures that are likely to be important for information technology. Success of new technologies in services requires close co-operation of the users and the originators of the technology (whether a manufacturer or a services firm that integrates the new technologies and packages them to meet the needs of specific clients in the services industries), both to plan the path that the acquisition of technology will take and then to make the acquired technology work well for the services firms. Further, for the services firms acquiring technology and the services integrators providing the new technologies, there is the need for testing new technologies, evaluating the technological performance and compatibility of the new technologies with other interacting technologies, and training of all involved individuals.

All of these difficulties and needs are affected by the extent to which standards for performance and compatibility of technologies are developed. In a market system where a government has not succeeded in providing an appropriate infrastructure to support science and technology, the barriers to technology are likely to cause two types of underinvestments.[17] One type will affect own R&D and the other type will affect the purchase and use of others' technology. In services industries, where the dominant technology is imported from others, this second type of market failure may be most prevalent and may lead to an underinvestment in and underutilisation of information technology. We provide an indirect statistical demonstration of such underinvestment in the next section of the paper, and then subsequently we use case studies to provide direct evidence of underinvestment.

Thus, without appropriate infrastructure, markets will not provide sufficient investment in technology. Society would like greater investments because, from its perspective, the value of such investment would exceed its cost. But, due to technology barriers, such a level will not be achieved because, from the private perspective of firms, the cost of such investment exceeds its benefit.

There is general evidence in the literature that there are barriers to the development and implementation of IT in services industries. As Brynjolfsson (1993, p. 67) explains, the paradox is that while "delivered computing power in the US economy has increased by more than two orders of magnitude since 1970 ... productivity, especially in the services sector, seems to have stagnated''. As related to the barriers in technology discussed above, one suspects that the observed paradox reflects real failures in the market to provide adequate investments in information technology.

The professional trade literature is a rich source of information related to technology in the services sector. Described below are selected examples from this literature related generally to the risk (as discussed above) associated with IT.

Haber (1995) reports one example of high technical and market risk acting as a barrier to technology. Purchasers of asynchronous transfer mode (ATM) services face technical difficulties because of evolving standards and limited functionality and services.[18] Although most telephone companies offer ATM, the services are still expensive, not universally available, and are functionally limited. Access to ATM means little without the availability of ATM-related services to support voice, video, and data; and carriers are just beginning to introduce additional features. On the demand side, ATM service users confront the complexity caused by evolving standards and limited functionality. While ATM technology will gain form and substance over time, according to industry analysts, it is quite clear that many problems need to be overcome to make the technology fully useable, reliable and interoperable. These are technical risks, and with many interoperable developments evolving, the market acceptance of a particular technical success is not assured, and so there are market risks as well.

Regarding appropriability difficulties and related market risk, the inability to assign intellectual property rights can bring about market failure. Phillips (1995) discusses the potential for publishing on the Internet, and the major problems that are to be dealt with regarding copyrights and the proprietary nature of information. Information placed on computer systems can be vandalised, destroyed, copied and misused to a far greater extent than hard-copy documents due to the ease of manipulation of electronic documents. Both internal and external security is widely regarded as a serious problem by IT providers and users (CMP Media, Inc., 1996).[19]

Just as the literature provides selected examples of risk and appropriability difficulties that may cause underinvestment in IT by services-sector firms, it also illustrates the existence of IT implementation barriers in shaping the evolution of new IT across the services sector. For example, regarding usability, Kirchner (1995) suggests that communications from personal computers are too complicated. While electronic mail or linking to the World Wide Web have become less difficult, most users still cannot take these services for granted. Also, Means (1995) emphasizes that networks require that information technology be interoperable. He observes that the interactive broadband operations support systems (OSS) to manage billings for the proliferation of products offered by cable and telephone companies will have to interoperate with other network components such as network management systems, various types of set-top boxes and other database servers. Wilken (1995) reports that the provision of Switched Multimegabit Data Service (SMDS) to the printing industry by the regional Bell operating companies, among other things, provides scalability that printing firms need to support the applications of the future since SMDS can be integrated with existing frame relay and Integrated Service Digital Network (ISDN) technologies plus with the emerging technologies such as asynchronous transfer mode (ATM). And related, Levitt (1995) reports that ISDN is worth the extra cost relative to older telephone service because, among other things, it is more reliable. And finally, Flint (1995) comments on security issues regarding electronic ticketing in the airline industry. Chief among the hurdles to secure electronic ticketing are passenger resistance, airport egress/security issues and fraud protection.

Statistical-based evidence of market failure related to investments in IT

The Brynjolfsson-Hitt data set, arguably the most complete and widely cited data set related to investments in information technology, is a quasi-balanced panel across services industries, by year (1987-94).[20] Brynjolfsson and Hitt have collected, from surveys, interviews and other sources, detailed information on investments in IT at the firm level, and have matched those data with other production and financial data (using Compustat as their primary source).

Here, we utilise the Brynjolfsson-Hitt data set to search, more systematically, for evidence of an underinvestment in IT in services industries. To do this, we rely on estimates from a linear regression model of the form:

$$\ln(VA) = \ln(A) + \exists_0 \ln(L) + \exists_1 \ln(ITK) + \exists_2 \ln(ITK) + \varepsilon \qquad (1)$$

where VA represents value added, L represents labour measured as number of full-time employees, ITK represents the stock of information technology capital, NITK represents the stock of non-information technology capital, and ε is a random error term introduced for estimation purposes. Definitionally, the stock of capital associated with each firm in the sample, K, equals the sum of information plus non-information technology capital, K = ITK + NITK.

The regression results from our estimation of equation (1) are reported in Table 5. Not only is the estimated coefficient on ln(ITK) positive and significant, but the results suggest that a US$1 investment in IT capital contributes substantially more to value added than a US$1 investment in non-IT capital, *ceteris paribus.*[21] The calculated marginal product of IT capital, based on the regression results in Table 5, is 1.96 compared to 0.11 for non-IT capital. A US$1 investment in IT capital yields US$1.96 each period, or if there were no depreciation that yield would continue in perpetuity, and hence in that sense the literature would often refer to this finding as evidence that the average estimated rate of return to IT capital in services-sector firms is 196 per cent. The corresponding estimated rate of return for non-IT capital is 11 per cent.

Table 5. **Least-squares regression results from equation (1)**

n = 2,247

Variable	Estimated coefficient (t-statistic)
ln(L)	0.69 (65.33)
ln(ITK)	0.03 (4.82)
ln(NITK)	0.21 (21.67)
Industry dummies	Yes
Time dummies	Yes
R^2	0.93

Source: Author.

In the absence of information on the long-run return to investment in IT and on depreciation of IT, we cannot assert that a 196 per cent rate of return is a competitive rate of return or not. If the gross rate of return of 196 per cent is greater than the competitive return, then the results in Table 5 complement the literature findings; services-sector firms appear to be underinvesting in IT. Compared to the rate of return earned by manufacturing firms on their self-financed R&D capital, however, 196 per cent is high by a factor of about four. Certainly, 196 per cent is higher than the hurdle rate used in most private sector firms for R&D investment decisions by a factor of about ten. However, IT capital probably has been depreciating more rapidly than other forms of capital, and the discrepancy in rates of return may not be as great as it seems at first look.

Case-based evidence of market failure related to investments in IT

While the above material from the literature and from our first-order econometric illustrations clearly suggests the existence of market failure, these so-called standard investigatory tools are limited in their ability to identify the market failure specifics needed for effective ITL policy planning. To begin to identify aspects of market failure, case studies are needed. This sub-section summarises the findings from four case studies. These case studies relate to research joint ventures in services industries, the retail banking industry, the home entertainment industry, and the health-care industry.

Unless specifically referenced, many of the stylised facts presented in the three industry-specific case studies came from a series of telephone interviews conducted with leading banking,[22] health-care,[23] and entertainment institutions' chief technology officers or chief information officers.[24] While some information about the strategic role of IT in each of these three industries can be gleaned from the literature, it was our belief that the level of insight needed to identify and prioritise aspects of market failure for effective policy planning can only come through expert dialogue.

Research joint ventures in service industries

Our analysis of the data in the Brynjolfsson-Hitt sample reveals that the mean annual investment level in IT by firms that are active in research joint ventures (RJVs) is 2.86 per cent of value added, compared to a mean investment in IT by non-RJV-active firms of 1.98 per cent of value added. Based on this statistical finding, and on the observation by Meltzer (1993, p. 12) about services industries that: ''collaborative R&D development of appropriate IT products, services and environments for exploiting knowledge [is] the key to generating sustained economic growth'', we conjectured that selected services-sector firms have perhaps found, through RJV participation, a partial inter-firm solution to the barriers in technology that bring about underinvestments in or underutilisations of IT. Stated alternatively, if there are a number of barriers to technology associated with market failure in IT-related investments, then perhaps a sub-set of these barriers is being overcome through RJV collaboration.

Of the 561 joint ventures registered with the US Department of Justice through the end of calendar year 1995, there were 132 joint ventures classified in service industries (in SICs numbered above 39), and 429 in other sectors. To identify those ventures among the 132 services-sector joint ventures that are in fact engaged in research focused on IT, an electronic mail survey was administered to a contact person in each joint venture. Of the 57 responding joint ventures, 51 are from the communications industry. Given the preponderance of communication industry RJVs in the population of 132,[25] and given our *a priori* understanding that IT is critical to that industry, this dominance in response percentage was not unexpected.

Regarding the general nature of the RJV's research, 56 of 57 respondents noted on their survey that the primary focus of their joint venture research is related to information technology. This result is also not surprising since much of the identified published literature related to the topics of ''technological change'' and ''services'' concerns IT as the relevant services-sector technology. And, the remaining survey respondent noted that IT was of secondary importance to the joint venture's research.

As to the primary reason for each of these IT-related joint ventures being formed, open-ended responses could easily be categorised into six groups as shown in Table 6. Clearly, the responses indicate that services-sector RJVs, primarily in the communications industry, are formed as a strategic means to gain complementary research or technical skills. Each respondent was also asked to select one pre-stated response to explain why the specific research of the joint venture had not been undertaken individually, but rather was undertaken collaboratively. The purpose of this focused question was to probe into market-failure reasons to explain the systematic underinvestment in IT by services industry firms suggested by our statistical analysis. The five response categories correspond directly to elements of risk that lead to an underinvestment in technology, in general, and perhaps in IT, in particular. As seen in Table 7, the dominant response category chosen was that ‘‘no one participant had the requisite in-house technical capabilities to undertake the research on their own’’. There was not a secondarily dominant response category selected. Obviously, then, the dominant response from Table 7 conveys the same information as the dominant response in Table 6.

Eighteen respondents agreed to participate in a follow-up telephone interview. During these interviews it was learned that the technical capability that was sought through the joint venture related overwhelmingly to human capital, as opposed to technical capital, expertise. The complexity of the IT research necessitated a breadth of human capital that no single participant had. It was also learned that the majority of the R&D performed within the participants’ companies was directed to IT. In other words, it seems, based on these few observations, that firms involved in IT research collaboratively are also those so involved independently. This preliminary finding could be interpreted to suggest that RJV research activity is a complement to, rather than a substitute for, in-house R&D. Respondents did not offer an opinion as to the R&D focus of the other participants.

Table 6. **Survey responses describing the primary reason for forming the joint venture**

Response	Frequency
To gain complementary research or technical skills	45
To reduce cycle time	6
To move into new market segments	3
To reduce research costs	1
To continue a strategic form of conducting in-house R&D	1
No response	1
	57

Table 7. **Survey responses describing the primary explanation for why the research in the joint venture was undertaken collaboratively**

Response statement	Frequency
The technical risk of the research activity was greater than any one participant would accept.	3
The capital intensity required to undertake the research was too large in dollar terms to make the project profitable for any one participant.	3
The research, if successful, would have a long time to market and thus the project was viewed as unprofitable by any one participant.	2
No one participant believed that they could appropriate a sufficient amount of the research results to make the project profitable.	2
No one participant had the requisite in-house technical capabilities to undertake the research on their own.	47
	57

The follow-up telephone interview was mainly devoted to probing about specifics of the IT-related research being conducted. Each of the 18 communications-industry respondents was asked to rank five attributes in terms of expected outputs from the RJV's research. The five attributes were usability, interoperability, scalability, reliability and security. In other words, as was explained to each respondent, if the expected research outcomes of the RJV's research are primarily related to interoperability issues (as a hypothetical example), then interoperability is ranked as ''1''; if no aspect of the RJVs research is related to scalability (as a hypothetical example), then scalability is ranked as ''5''. Each respondent was requested not to report ties.

Table 8 shows the distribution of responses related to this ranking. Albeit 18 responses is a small and certainly unrepresentative sample of services-sector-wide collaborative research aimed toward information technology, the pattern of responses is nonetheless interesting. Interoperability and reliability ranked as the more dominant IT attributes among the five. Because of the nature of communication technology and its inter-relationship with computer hardware and software, our prior feeling was that interoperability would rank toward to the top of the list.

To summarise, and perhaps to generalise albeit from a small sample of observations and albeit from subjective information reported by RJV participants, services-sector firms (or at least communications-industry firms) seem to be engaged in joint venture activities that relate specifically to information technology, and the joint venture arrangement exists because individual firms lack sufficient technical capabilities (human capital in particular) to undertake the research individually. As well, the research in these joint ventures is oriented toward interoperability and reliability issues related to IT more so than to issues related to

Table 8. **Interview responses to the relative importance of IT attributes resulting from the RJV research**

IT attributes	Mean ranking
Usability	4.9
Interoperability	1.4
Scalability	3.2
Reliability	1.7
Security	3.8

usability, scalability or security. If the aspects of risk discussed above represent barriers to technology that result in services-sector firms underinvesting in or underutilising IT, then the interview findings suggest that services-sector firms are to some extent overcoming these barriers through inter-firm collaborations. In particular, services-sector firms are on their own utilising RJV mechanisms to acquire the relevant human capital needed to conduct their IT-related research. That finding corresponds most closely to our eighth factor creating barriers to technology. RJVs are a way to reduce the costs and risks of sharing know-how among independent firms.

An analysis of the retail banking industry

The regulatory environment of the banking industry began to unravel in the late 1970s. Competition increased, thus causing consolidation, a restructuring of the business mix, a concomitant shift to consumer credit, and a dramatic increase in technology investments to economise on banking practices.

Banking analysts argue that non-interest expenses are a critical competitive factor in banking industry dynamics.[26] Systems expenses are the category of non-interest expenses growing most rapidly, with automatic teller machines – which increased from 13 800 in 1979 to 109 080 in 1994 – being the most obvious of these system technology expenses.[27] But more general system examples include the ability of a bank to, on demand, report a corporate customer's global cash position or to shift funds between multiple accounts. Obviously, banks are creating value with these system investments.

Today, the banking industry is in the stage of technology absorption that directly affects the retail delivery interface between the bank and its customers. According to one estimate, approximately 33 per cent of banking's IT investments are directed toward the retail delivery of services.[28] This percentage is larger than the percentage going to any other single IT category of expenses, including data centres, department systems or telecommunications.

While investments in system technology have been substantial, industry observers note that banks have just begun to tap the potential of current and projected technologies to facilitate the shift toward an increasingly customer-driven industry. For example, only about 300 banks, out of a potential of some 8 000, now have Internet sites. And, while the number of on-line banks is expected to grow rapidly in the next few years, customer confidence generally, and security concerns in particular, limit all but a relatively small number of banks from offering electronic service. According to the Bank Administration Institute (1995), 58 per cent of bank customers interact remotely through telephone and mail, 32 per cent interact physically through a branch or ATM, and only 10 per cent interact electronically. This is beginning to change as banks appear to be orienting much of their IT technology initiatives towards interacting with customers in a way that preserves customer confidence, while at the same time expanding the relative position of the retail banking segment within the larger financial services industry.

Retail banking is highly fragmented. This is readily seen in the thousands of independent banks that still remain after years of consolidation in the industry. In our interviews with information technology managers throughout the banking industry, fragmentation and an industry culture not experienced with co-operative strategies were common themes. This fragmentary nature complicates the industry's competitive response to the serious competitive challenge posed by the entry of non-bank financial firms, such as credit card companies, and non-financial firms, such as software providers, into a market historically served by banks.

This competitive challenge – referred to as ‘‘disintermediation’’ by those in the banking industry – is taken to be quite serious by those in the industry. While some counsel that the industry must ‘‘act or die’’, others acknowledge the market share loss to non-banks, but point to the tremendous off-setting growth in these markets as a positive sign for banks.[29] This challenge comes at a time when the banking industry is entering a new phase of its implementation of IT.

Enabled by new information and communications technology, banks are attempting to reorient their focus towards customers. This will require the implementation of new capabilities, such as assuring security of electronic banking over the Internet, as well as the reorientation and rethinking of existing systems and capabilities, such as developing more sophisticated mathematical models for predicting risk. As Steiner and Teixeria (1990, p. 192) observe: ‘‘The realm of current technology offers an abundance of problems and issues that have yet to be solved. Current technology is so complex, and already offers so many choices, that banks have their hands full with it.’’

Surprisingly, none of the banking experts that we interviewed described what could be called a ‘‘technology roadmap’’ for the industry. While we can report on individual technology visions, the industry has not articulated a higher-order consensus on where it is headed technologically.

Based on pre-interview discussions with experts within the ITL at NIST, we developed a list of general technologies expected to be relevant to services industries. This list, which is also referred to in the home entertainment and health-care case studies, was divided into five general areas: computer security, user interfaces and information access, networking, software, and computational sciences. When discussing this list with IT experts in the banking industry, seven specific technology areas emerged as critical for them to achieve their IT-related goals: *i)* monitoring and control for large networks; *ii)* set-top boxes for interactive TV; *iii)* design for speech recognition hardware and software; *iv)* electronic commerce applications; *v)* distributed databases; *vi)* cryptographic standards; and *vii)* firewalls and Internet-based tools. When discussing potential barriers that exist with regard to implementing these technologies, two themes emerged. One, there is much uncertainly in the banking industry about the state-of-the-art in IT, and two, there remain many network and system integration problems to be understood and overcome. Both of these concerns pervade the banking industry and are consistent with the logic of market failure that brings about an underinvestment in and underutilisation of the technology.

If forced to select elements of risk as a primary cause for the observed market failure in banking, we would select high market risk (being fully aware that our previously listed risk elements that lead to market failure are interrelated). It is our impression technology managers have difficulty in seeing beyond an 18-month planning horizon. A picture emerges of a technology investment planning environment that is fraught with uncertainties and risks that make long-term technology issues very difficult to identify, much less to plan for and allocate sufficient resources to. At the root of these perceptions of high market risk is what we call information inadequacy, meaning lack of information about the capabilities of existing elements of IT, the acceptance of associated banking services by consumers, and the uncertainty associated with IT system choices in the future. Thus, although managers may know that particular innovations will be technically sufficient in themselves, they do not know whether the innovations will be the ones that the market accepts within a secure, reliable, interoperable network. There also appears to be concern with the usability of the technology – a concern implicit in the interest in set-top boxes for interactive TV. Implicit as well, scalability of investments is a factor, since more scaleable technology could mitigate some of the planning concerns.

To summarise, banks rely on IT as a competitive response to a restructuring industry to meet the needs of consumers. Banks are, however, underinvesting and underutilising the technology because of its high technical risk and high transactions costs as evidenced by concerns related to the interoperability of IT elements needed to deliver electronic banking services to consumers.

An analysis of the health-care industry

The health-care industry, much like the banking industry, is undergoing a dramatic restructuring. In health care, this has been brought on primarily by the pressures to contain costs through technological advancements that will not impact the quality of service. Such changes are being made possible through the adoption of new information technology. According to the Office of Technology Assessment (1995, p. 111): ‘‘Information technologies are transforming the way health is delivered. Innovations such as computer-based patient records, hospital information systems, computer-based decision support tools, community health information networks, telemedicine, and new ways of distributing health information to consumers are beginning to affect the cost, quality and accessibility of health care.’’

However, the health-care field has been, compared to the successful stand-alone medical applications of IT, slow to use IT in its non-financial operations more generally. This is, in our opinion, not an accident but rather a reflection of barriers in technology that occur when technical and market risks are present. The discreet, relatively narrow medical science applications that can be developed as stand-alone proprietary equipment to be used by a hospital physician are far less likely to founder on technological barriers than the integrated systems of technologies to be used in an administratively intricate network.

The health-care industry is even more fragmented than banking, and the current trend is toward vertical and horizontal integration of the various parts of the industry. Acquisitions and mergers, joint ventures and contracts can be used, according to the Office of Technology Assessment (1995, p. 6), to forge an ‘‘integrated delivery system ... that brings together hospitals, primary care providers, nursing homes, home health-care providers, pharmacies, and other services into a single system’’.

The heart of the challenge for the health-care industry is the need to develop the substance of the health-care product and the organisational modes of its delivery simultaneously with, and in the context of, the development of new IT. There is a deep-rooted problem with the predictions that IT will quickly contain the costs of health care.

Interviews with the chief technology or information officers in major health-care organisations reveal that the organisations are coping with the rapid evolution of the new technology through internal research, development, test and evaluation groups (RDT&E). At least 80 per cent of the time of these 15 to 25 person groups is devoted to strategic planning, research on emerging IT, pilot and implementation projects related to IT, research on emerging vendors of IT, and evaluation and testing. These concerns are primarily applications concerns, unlike the technology development concerns addressed by R&D in manufacturing. It was our impression that these groups were acting like a proprietary technology roadmap committee for their applications of IT, while the industry-wide effort to address major technological concerns is focused on developing standards – for example, common language for medical terms.

When discussing the ITL technology list with health-care experts, seven specific technology areas emerged as critical for achieving existing IT-related goals: *i)* firewalls and Internet-based tools; *ii)* WWW and IPv6 security; *iii)* Internet security policy development and guidance; *iv)* techniques for manipulating unstructured textual information; *v)* visualisation methods for access, manipulation and exchange of complex visual information; *vi)* network scaling; and *vii)* systems management. When discussing potential barriers that exist with regard to implementing, or in some cases developing, these technologies, two themes emerged. One, the technologies must be usable; and two, the technologies must be reliable.

While much of the desired technology is available on the market, it is, for one reason or another, not viewed as usable or reliable by IT experts in health care. We can speculate as to the reasons for this opinion. The data acquisition, communication and storage problems to be addressed with IT are immense. As one chief information technology officer noted: ‘‘Our financial services have been automated for decades, so that part of our IT is quite mature. But our client systems are still very much paper-based. I say we have a ‘‘sneakernet’’ for moving paper. We move 4 000 patient [paper] charts a day in one hospital, and that is growing by 26 linear feet a week. Archival policy is forever, so there is a big problem here.’’ The key to the successful implementation of potentially cost-containing IT in health-care organisations is the ability to interoperate across large numbers of organisations, both with a parent organisation and across independent organisations such as providers and insurers.

On average, our respondents in the health-care industry estimated that if barriers to technology were removed, investment in IT would more than double. In terms of aspects of risk, we are of the opinion that health-care organisations are underinvesting and underutilising IT because manufacturers of IT have underinvested in the development of appropriate technology owing to the fact that the scope of the potential health-care market, although broad, is as yet unarticulated. Investors do not yet perceive a clear path to economic benefits. One piece of evidence toward this conclusion is that health-care organisations are collaborating with IT manufacturers to develop health-care-related products. This perception by manufacturers may change over time as the health-care industry consolidates and better articulates its IT needs. Thus, to summarise, it is not surprising that usability ranks at the top of the list of priorities relevant to IT.

An analysis of the home entertainment industry

The home entertainment industry is, like many services industries, being transformed by information technology. In fact, the development and implementation of IT is affecting the competitive nature of the many industries that are integral to the production and delivery of home entertainment. The essential dynamic is one of technological and industrial convergence. Content providers have merged with cable companies; traditional broadcast companies have merged with major content providers, and are increasingly looking for involvement in cable transmission and the Internet; cable broadcasting and telephone companies are angling to serve each other's traditional markets for cable programming as well as telephone service.

The market turmoil that this convergence generates, and the implications for generating uncertainty that may lead to underinvestments in IT, are succinctly summarised in what has been called the ‘‘Negroponte Switch’’: what currently goes by air – chiefly broadcast video – will soon switch to wires (*e.g.* optical fibre) and what currently goes by wire – chiefly voice telephony – will massively move into the air.[30] Industries that have been the mainstay of home entertainment for decades are giving ground to industries rooted in alternative digital technologies, and industries that have long been thought of as distinct are merging together to provide multiple information and entertainment services.

The single most important competitive issue for the home entertainment industry is the strategic posturing for technological and industrial convergence. It appears that firms are positioning themselves horizontally (in all delivery modalities like broadcast, satellite, cable and the Internet) as well as vertically (from content to delivery) through mergers and alliances to take advantage of the bandwidth that is increasingly available. Certainly from the perspective of those that deliver content to the home, competition for advertising dollars is among the most important competitive issues. But underlying this is a deeper technological issue, the substitution of a cornucopia of bandwidth for regulated bandwidth scarcity, brought about primarily by the shift to optical fibre and fibre optic technologies that effectively increase signal carrying capacity.

It is widely believed, although there is no evidence that the industry is thinking in terms of a technology roadmap, that the development of new information and entertainment services will take place along two broad fronts associated with two families of user interface equipment, the television and the associated technologies (*e.g.* set-top boxes and multimedia CD players), and information access via a general purpose personal computer. However, it is also widely believed that in the foreseeable future, computers and entertainment devices will continue to develop as related but separate digital system families, rather than converging into a single family. While the merging of the two into so-called ‘‘information appliances’’ or ‘‘teleputers’’ is believed likely, most in the industry consider it to be a decade away. For one thing, it is conventional wisdom in the consumer electronics industry that entertainment-oriented products will not sell if they seem too much like a computer.

When discussing the list of ITL technologies with experts in the home entertainment industry, three specific technology areas emerged as critical for achieving existing IT-related goals: *i)* video servers; *ii)* set-top boxes for interactive TV; and *iii)* firewalls and Internet-based tools. When discussing potential barriers that exist with regard to implementing these technologies, concerns emerged about interoperability and usability issues. These concerns are expected because home entertainment is very much at the convergence between communications and computers and, as such, for systems to be accepted by consumers in the home they have to work together and be user-friendly.

As with banking and health care, entertainment companies are underinvesting and underutilising IT owing to risk. On average, our respondents in the home entertainment industry estimated that investment in IT would more than triple if barriers to technology were removed. As with health care, it seems to be the case that until the home entertainment industry evolves and better articulates its technological needs, manufacturers of IT will face a market-related risk causing them to underinvest in relevant R&D. But much like banking, the critical performance attribute in the minds of entertainment firms is interoperability, as might be expected because of the direct consumer-service provider interface.

V. TOWARDS A NEW APPROACH FOR POLICY PLANNING

Prior to formulating any policy specific to investments in technology by services industries or to R&D conducted by services industries, it would seem reasonable to rely on the Information Technology Laboratory attempting to fulfill its mission of providing technical leadership in critical infrastructural technologies. And, it is well known that such infrastructural technologies have attributes that are public in nature.

Before embarking on a research mission based on the presumption that services industries need infrastructural support across the board, it would be prudent, in our opinion, for the ITL to consider the findings from this policy planning project. Namely, we conclude from our study of the US technology-based services sector that there is much evidence to support the claim that services industries are underinvesting and underutilising IT owing to a failure of the market. Based on detailed case studies we conclude that there is evidence that technical and market risks are bringing about this market failure.

More specifically, as summarised in Table 9, we have identified not only the elements of risk that are bringing about market failure but also specific technology attributes that industry believes will be needed to overcome these elements of risk. Accordingly, given that there is quantifiable evidence of market failure and hence a justifiable role for government, the ITL, given its infrastructure support mission, should undertake generic research and be involved in the promulgation of standards related to: the usability and security of identified technologies in the retail banking industry; the usability and reliability of identified technologies in the health-care industry; and the interoperability and usability of identified technologies in the home entertainment industry.

Table 9. **Roadmap for information technology policy planning**

Industry	Aspects of market failure	Performance attribute
Retail banking	High market risk related to IT is perceived on the part of the banks using IT, hence banks underinvest in IT.	Usability and security as related to: *i)* monitoring and control for large networks; *ii)* set-top boxes for interactive TV; *iii)* design for speech recognition hardware and software; *iv)* electronic commerce applications; *v)* distributed databases; *vi)* cryptographic standards; and *vii)* firewalls and Internet-based tools.
Health care	Scope of the market for health-care-related IT products and services is viewed by manufacturers as so broad that the profitable investments have not yet been perceived and articulated.	Usability and reliability as related to: *i)* firewalls and Internet-based tools; *ii)* WWW and IPv6 security; *iii)* Internet security policy development and guidance; *iv)* techniques for manipulating unstructured textual information; *v)* visualisation methods for access, manipulation and exchange of complex visual information; *vi)* network scaling; and *vii)* systems management.
Home entertainment	Technical and market risk related to the combination of technologies required in the evolving entertainment industry leads manufacturers to underinvest in relevant R&D.	Interoperability and usability as related to: *i)* video servers; *ii)* set-top boxes for interactive TV; and *iii)* firewalls and Internet-based tools.

Source: Author.

In conclusion, if US public policy is to be designed and implemented to encourage greater innovative activity, it is imperative for technology planning purposes to understand the role of technology in the largest and fastest growing sector of the economy – the services sector. More specifically, it is critical for policy planners to understand the sources and uses of IT in the services sector and the support role of R&D in adopting and using IT. If policy is to be designed to encourage not only investment in IT but also more effective use of IT in services industries, thereby enhancing productivity growth and the overall competitiveness of the sector, policy planners must understand the infrastructural elements of IT that leverage both the manufacturing sector's development as well as the services sector's implementation of IT, and the extent to which there are underinvestments in these infrastructural elements. The project described in this paper is, in our opinion, a first step towards what we call a new approach to policy planning.

We are of the opinion that much more research – of a case study nature – is needed in services industries before definitive answers can be provided about the technological needs of that critically important sector. But the methodology that we developed and implemented in this project has convinced us that it is indeed possible to obtain specific information not only about the extent to which the market fails to allocate a socially desirable level of resources to technology in general (and to IT in particular), but also about why the market has failed.

Certainly this limited exercise has not prioritised all aspects of market failure, but it has, perhaps for the first time, advanced the state-of-policy-art in thinking about how to plan effectively for policies directed toward a technology-based economy.

NOTES

1. We offer as a workable definition if IT the following: ‘‘Information technology is the body of methods and tools by which communications and computing technologies are applied to acquire and transform data, and to present and disseminate information to increase the effectiveness of the modern enterprise’’ (ITL, 1996*b,* p. 1).
2. For an overview of NIST, see Link (1996).
3. Reliability was not originally part of the 1995 strategic plan, but was later added. See also National Research Council (1996).
4. See Office of the President (1990).
5. The conceptual importance of identifying market failure for policy is today emphasized, albeit without any operational guidance, in Office of Management and Budget (1996).
6. Certainly a good economist knows a market failure when he/she diagrams one! But, according to Coase (1988, p. 19), ‘‘Blackboard economics is undoubtedly an exercise requiring great intellectual ability, and it may have a role to play in developing the skills of an economist, but it misdirects our attention when thinking about economic policy’’.
7. Toward this end, one rationale for the Vienna workshop is to address the ‘‘need for governments to redesign the institutions and instruments of technology and innovation [planning and] policy to increase their leverage’’ (OECD, 1997, p. 14).
8. For additional details about this analysis, see Scott (forthcoming).
9. See Wolfe (1995) and National Science Foundation (1996).
10. The US Department of Commerce (1995*a*) shows that SIC 737 and SIC 871 represent 10.9 per cent of the receipts for the ‘‘other private services’’ listed in Table 2, while ‘‘other private services’’ make up 37.5 per cent of the private services for the private sector as a whole. The employment figures from the Census show that SIC 737 and SIC 871 represent 6.2 per cent of the employment in ‘‘other private services’’, which itself takes 44.9 per cent of the employment in private services.
11. See Scherer (1984).
12. As a first level approximation, we are comfortable adding R&D expenditures to capital expenditure to arrive at new technology expenditures. Both expenditures are investment flows into knowledge-enhancing activities, and we want to quantify what the services sector spends for new technology and the portion of those expenditures for externally-developed technology. As we note later, the cost of operationalising purchased IT is often greater than the cost of the IT hardware.

13. If data were available to account for purchased technology other than IT, then the 85 per cent estimate of imported technology by services industries would increase. Thus, the 85 per cent estimate is without question a conservative lower-bound estimate.
14. *InformationWeek* expressed interest in conducting a broad-based survey of IT users. They contacted Brynjolfsson and Hitt (1996*a*) to design an appropriate survey instrument. As part of the ITL planning project, we appended two questions to the survey. These questions are reproduced in Table 4.
15. Functionality refers to the capabilities of hardware or software to perform various tasks.
16. Teece (1980) emphasizes that when the barriers to technology development and acquisition become too severe to be handled by arm's-length transactions in the market, or by detailed contracts specifying the obligations of the buyer and the seller of the technology, then an intra-firm solution to the sharing of technological and managerial know-how will be used. Namely, the selling and the buying organisations will merge. Or, the seller or the buyer will expand internally and acquire a new line of business to allow the interactive sharing across activities to take place within a single firm wherein the hazards of opportunistic behaviour and the transactions costs of dealing in market or with contracts are avoided.
17. Overviews of the barriers to technology from the perspectives of the managerial literature, the industrial organisation literature, and the public policy and technology literature are found in Teece (1980), Baldwin and Scott (1987) and Tassey (1995).
18. ATM is a data transmission technology designed to transmit digitised data over copper cable and optical fibre cable at very high rates (600 megabits per second or higher). This is accomplished by combining elements of the two main approaches to handling telecommunications traffic: circuit-switching and packet-switching.
19. There is also evidence in the literature that there are elements of market failure regarding the implementation of IT. Most notable is a set of important and ambitious case studies undertaken by Columbia Business School (1994).
20. See Brynjolfsson and Hitt (1996*b,* 1996*c*) for a more complete description of the data set.
21. Calculated marginal products equal the corresponding estimated coefficient multiplied by the ratio of the mean value of value added divided by the mean value of the variable.
22. The chief technology officers at the following banks and banking organisations were interviewed: ANSI, Bank Administration Institute, Bank of Boston, Bankers Roundtable, Chase Manhattan, Citibank, CommerceNet, Huntington Bank, X9.
23. Technology managers at Columbia/HCA, Humana, UniHealth America, Lahey-Hitchcock Clinic and Dartmouth Hitchcock Medical Center and Wisconsin Health Information Network were interviewed.
24. Representatives in the following entertainment organisations were interviewed: ABC, AT&T Wireless, CBS, CNN, NBC, Time Warner Cable, Walt Disney.

25. Of the 132 RJVs classified to the services sector, 100 were from the communications industry. Also, recall from Table 1 that the communications industry is second only to computer-related services in its level of R&D spending.
26. See Steiner and Teixeira (1990).
27. See Berger, Kashyap and Scalise (1995).
28. See Bank Administration Institute (1995).
29. See Berger, Kashyap and Scalise (1995) and Whaling (1996).
30. See Gilder (1994). Nicholas Negroponte is the Director of the MIT Media Laboratory.

BIBLIOGRAPHY

BALDWIN, William L. and John T. SCOTT (1987), *Market Structure and Technological Change,* Harwood Academic Publishers, London.

BANK ADMINISTRATION INSTITUTE/BOSTON CONSULTING GROUP (1995), *The Information Superhighway and Retail Banking.*

BERGER, Allen, Anil KASHYAP and Joseph SCALISE (1995), ''The Transformation of the US Banking Industry: What a Long, Strange Trip It's Been'', *Brookings Papers on Economic Activity,* pp. 55-218.

BRYNJOLFSSON, Erik (1993), ''The Productivity Paradox on Information Technology'', *Communications of the ACM,* pp. 67-77.

BRYNJOLFSSON, Erik and Lorin HITT (1996*a*), ''The Consumer Counts'', *InformationWeek,* pp. 48-54.

BRYNJOLFSSON, Erik and Lorin HITT (1996*b*), ''Information Technology, Organizational Architecture and Productivity: Firm Level Evidence'', mimeographed.

BRYNJOLFSSON, Erik and Lorin HITT (1996*c*), ''Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending'', *Management Science,* pp. 123-136.

CMP MEDIA, INC. (1996), ''Internet Vulnerability, Malicious Internal Attacks and Lack of Confidence Are Key Findings'', in *InformationWeek*/Ernst and Young Security Survey, *PR Newswire.*

COASE, Ronald H. (1988), *The Firm, the Market, and the Law,* University of Chicago Press, Chicago.

COLUMBIA BUSINESS SCHOOL (1994), *Studies in Technology and Productivity in the Service Sector,* Columbia Business School Press, New York.

ECONOMIC REPORT OF THE PRESIDENT (1994), US Government Printing Office, Washington, DC, February.

FLINT, Perry (1995), ''The Electronic Skyway'', *Air Transport World,* January, pp. 38-43.

GILDER, George (1994), *Life After Television: The Coming Transformation of Media and American Life,* W.W. Norton, New York.

HABER, Lynn (1995), ''ATM Aspirations'', *Computerworld,* 25 September, p. 152.

INFORMATION TECHNOLOGY LABORATORY (ITL) (1996*a*), ''ITL Strategic Plan: Executive Summary'', mimeographed, 15 May.

INFORMATION TECHNOLOGY LABORATORY (ITL) (1996*b*), ‘‘ITL Strategic Plan: Why ITL Exists’’, mimeographed, 15 May.

INTERNATIONAL DATA CORPORATION (1996), ‘‘Meeting the Challenge of Client-Server Computing: Maximizing Return-on-Investment of Network Computing’’, *IDC Insight.*

KIRCHNER, Jake (1995), ‘‘PC Communications Are Still a Major Pain’’, *CommunicationsWeek,* 25 April, p. 36.

LEVITT, Jason (1995), ‘‘ISDN Takes a Shot at POTS’’, *InformationWeek,* 15 May, p. 102.

LINK, Albert N. (1996), *Evaluating Public Sector Research and Development,* Praeger Publishers, Westport, CT.

MEANS, Ed. (1995), ‘‘Tomorrow’s OSS is Here Today’’, *Telephony,* 20 March, pp. 104-110.

MELTZER, Richard J. (1993), ‘‘Closing the Technology Gap: Mandate for the ‘90s’’’, *Research and Technology Management,* September-October, pp. 8-12.

NATIONAL RESEARCH COUNCIL (1994), *Information Technology in the Service Society: A Twenty-first Century Lever,* National Academy Press, Washington, DC.

NATIONAL RESEARCH COUNCIL (1996), *The Unpredictable Uncertainty: Information Infrastructure Through 2000,* National Academy Press, Washington, DC.

NATIONAL SCIENCE FOUNDATION (1996), *Research and Development in Industry: 1993,* Government Printing Office, Washington, DC.

OFFICE OF THE PRESIDENT (1990), *US Technology Policy,* Executive Office of the President, Washington, DC, 26 September.

OFFICE OF MANAGEMENT AND BUDGET (1996.), ‘‘Economic Analysis of Federal Regulations Under Executive Order 12866’’, mimeographed.

OFFICE OF TECHNOLOGY ASSESSMENT (OTA) (1995), *Bringing Health Care Online: The Role of Information Technologies,* Government Printing Office, Washington, DC.

OECD (1997), ‘‘Technology, Productivity and Job Creation: Towards Best Policy Practice’’, Interim Report of the Directorate for Science, Technology, and Industry, Paris.

PHILLIPS, John T., Jr. (1995), ‘‘Internet Publishing – A Tangled Web?’’, *Records Management Quarterly,* July, pp. 38-42.

SCHERER, F.M. (1984), *Innovation and Growth: Schumpeterian Perspectives,* The MIT Press, Cambridge, MA.

SCOTT, John T. (forthcoming), ‘‘The Service Sector’s Acquisition and Development of Information Technology’’, *Journal of Technology Transfer.*

STEINER, Thomas and Diego TEIXEIRA (1990), *Technology in Banking,* Dow Jones-Irwin, New York.

TASSEY, Gregory (1995), ‘‘Technology and Economic Growth: Implications for Federal Policy’’, NIST Planning Report 95-3.

TEECE, David J. (1980), ‘‘Economies of Scope and the Scope of the Enterprise’’, *Journal of Economic Behavior and Organization,* pp. 223-247.

US DEPARTMENT OF COMMERCE (1988), *Survey of Current Business,* Government Printing Office, Washington, DC, July.

US DEPARTMENT OF COMMERCE (1994), *Survey of Current Business,* Government Printing Office, Washington, DC, July.

US DEPARTMENT OF COMMERCE (1995*a*), *1992 Census of Service Industries,* Government Printing Office, Washington, DC, February.

US DEPARTMENT OF COMMERCE (1995*b*), *Survey of Current Business,* Government Printing Office, Washington, DC, July.

WHALING, Christopher (1996), ‘‘Innovation in the US Retail and Wholesale Banking Sectors’’, Institute for Policy Studies, mimeographed.

WILKEN, Earl (1995), ‘‘SMDS Service Gets Nod’’, *Graphic Arts Monthly,* July, p. 103.

WOLFE, Raymond (1995), ‘‘1993 Spending Falls for US Industrial R&D, Non-manufacturing Share Increases’’, *Data Brief,* US National Science Foundation, 4 August.

COMPETENCE BLOCS AND INDUSTRIAL POLICY IN THE KNOWLEDGE-BASED ECONOMY

TABLE OF CONTENTS

This article was written by Gunnar Eliasson of the Swedish Royal Insitute of Technology, Industrial Economics and Management in Stockholm. It summarises several published and ongoing papers on the experimentally organised economy and growth through competitive selection (Eliasson, 1996*a,* 1996*c*), on competence blocs (Eliasson and Eliasson, 1996, together with his daughter), on the importance of competent venture capitalists (Eliasson, 1996*d*), on technological spillovers (Eliasson, 1996*b*), on getting the institutions right (Eliasson, 1997*a*), on the dynamics of kicking the economic system into motion (Eliasson, 1996*e*) and on micro-to-macro quantification through a generalised Salter-type analysis (Eliasson, 1991).

SUMMARY

The policy maker is confronted with the economy he or she is supposed to govern. This confrontation has both a theoretical and a real dimension. *Ex ante* policy advice and the results of policy decisions are always conditioned by the intellectual model within which the advice is formulated and the decisions conceived. In reality the situation is, of course, rather different, and it is an advantage if the model used for policy analysis has some correspondence with reality. To that end, this article contrasts two conceptions of the economic system – the general equilibrium, or Walras-Arrow-Debreu (WAD), model and the model of the Experimentally Organised Economy (EOE), and compares the intellectual and real outcomes of the two models. The WAD model has been widely used to discuss, formulate and quantify the results of industrial policy. The EOE is a new, dynamic conception, based on a Smith-Schumpeter-Wicksell (SSW) theme, with properties that are radically different from those of the WAD model.

The two models give completely contrary advice. Whereas the WAD model imposes a highly centralist policy regime, the extreme version of the EOE model suggests that government ought to stay away from ambitious policy programmes altogether, as it otherwise runs the risk of generating unpredictable, significant and often undesirable side-effects, notably in the long run.

By introducing a *competence bloc* into the EOE, a middle policy way can be theoretically formulated in which government has a well-structured role to play, notably as an infrastructure, a collective institution and (to some extent) a provider of social insurance, so long as it stays away from those tasks that are better performed by the many agents co-operating and competing in decentralised markets. Moreover, where self-regulation through competition does not function, no other actors in the market with the exception of government can prevent unlimited monopoly formation by private actors.

The article is mainly theoretical, but concludes with a discussion of the policy implications of two empirical case studies: the aircraft and the biotech industry competence blocs.

I. FORMULATING THE POLICY PROBLEM

Policy advice and the results of policy decisions are effectively and unheedingly conditioned by the prior intellectual model within which the advice is formulated and the policy decisions conceived. In reality, the situation is, of course, rather different, and it is an advantage if the model used for policy analysis has some correspondence with the real world. To that end, this article contrasts two conceptions of economic systems – the general equilibrium, Walras-Arrow-Debreu (WAD), model and the alternative model of the Experimentally Organised Economy (EOE), and compares the intellectual and real outcomes of the two models. The WAD model is, as we know, static and far removed from real economic processes, but it has been widely used to discuss, formulate and quantify the results of industrial policy. The EOE is a fairly new conception (Eliasson 1987, 1991, 1992*a*), based on a Smith-Schumpeter-Wicksell theme and embodying incommunicable tacit knowledge capital as a dominant factor input in production. It thus features properties that are radically different from those of the WAD model.

Enormous productivity potential

The productivity potential in the *knowledge-based information economy* (Eliasson, 1990*a,* 1990*b*) is generally recognised to be enormous, provided that certain access conditions can be satisfied. It is also recognised that, if it is to be of any help to the economy in navigating through the enormous space of opportunities that characterises the experimentally organised economy, the government (central) policy maker has to be unusually competent if he is to improve on the situation, rather than mess up. As is the case for any management task, this competence includes the ability to focus on making critical choices.[1]

However, technical and economic competence is not sufficient. The economy, including its actors (individuals, firms, market intermediaries and government), has to be viewed as a *technical* (competence), *economic* and *social* system co-ordinated by the systems technology embodied in its institutions. As is the case for all systems, this system requires systems support, and some of that support is not naturally forthcoming in markets. This is particularly the case when it comes to making the system changes required to realise the socially and politically acceptable productivity potential, but also, of course, the task of preventing private actors from colluding and destroying the dynamic competition mechanisms that move economic growth. We are essentially talking about institutions in terms of Coase’s (1937) original meaning of facilitating market transactions, or Williamson’s (1985, p. 1) meaning of economising on transaction costs. This political role is dual, because failing to achieve a positive economic system change usually prolongs and worsens the social adjustment problem. In discussing such system changes through political modification of institutions, where such changes are largely endogenous, it is, of course, an advantage if the model used to support intellectual coherence allows these institutions to exist, be explicit and be discussed as both privately created (in the market) and politically instituted. The *competence bloc approach* (Eliasson and Eliasson, 1996) is one such model device.

We outline the critical elements and links in the system in which the policy maker has to act, beginning with the *competence bloc* concerned with selection, continuing with the institutions that make it possible for the agents in the competence bloc to capture the rents from good selections, and then linking these activities with the statistical accounts of the knowledge-based information economy to economic growth. We then go on to identify the role of the policy maker in the EOE and illustrate this with two case studies: the aircraft and health-care industry competence blocs. Finally, we compare this policy analysis with the Swedish policy model, and conclude with some comments on social insurance and the problem of distribution.

Since this article attempts to identify the actual policy options open to government, I have not imposed the unrealistic assumptions of the neo-classical or neo-walrasian (Clower, 1996) model. The WAD model is used for pedagogical contrast, and I base my discourse on the EOE and the understanding that state space or the investment opportunity set is sufficiently large and varied in its content to preclude any policy maker from coming even close to a full information situation and the possibility of optimal choices (Eliasson, 1984*a,* 1991, 1992*a;* and Pelikan, 1986, 1989). This means that policy action will involve considerable uncertainty and the risk of fundamental – and sometimes devastating – mistakes. This requires some consideration of what it entails to be an informed policy maker in the WAD and in the EOE worlds.[2]

Competent selection defines market competence

A critical part of the economic system is concerned with the tasks of identifying, selecting and realising investment opportunities such that positive economic development occurs. We call that part of the system concerned with selection and choices (picking winners, removing losers), the *competence bloc.*

To function properly the competence bloc needs support. Thus, there must exist *institutions which make it possible for actors to capture the rents from their commercial activities* (Eliasson, 1997*a*), infrastructure organisations which supply the necessary qualities embodied in actors, notably education, and institutions which render the social adjustment associated with economic development acceptable (‘‘social insurance’’, etc.).

Some of the (competence bloc) system support is in demand and will be supplied in the market at a price, for instance in the form of chargeable infrastructure services or insurance. Much of it will not, however, and it is an intrinsic element of any society that some collective action for the benefit of the group (‘‘society’’) is needed to generate positive system support. There is also the question of whether artificially enhanced collective action (‘‘policy’’) can speed up the economic development process. In a neo-classical sense (Coase, 1937; Williamson, 1985), institutions would do that by lowering transaction costs. Examples of such system support include the legal system, education, labour market rules and social insurance. But there is much more to it.

Business mistakes and organisational learning

While system support is a natural area for government policy, the competitive selection processes within the competence bloc are not. While some rules enhance and improve the selection process in terms of contributing to economic growth, others (‘‘regulation’’) may not. And the costs of bad selection are incurred in ways which are fundamentally different from those conceived in neo-classical theory, a fact first pointed out by Dahlman (1979). These costs occur through mistaken business decisions in the form of losses or sub-normal performance. And to deal with such costs requires a model that gives an explicit economic role to business success and failure. Schumpeter’s (1942, p. 84) argument that conventional economic theory sees capitalism as the administrator of ‘‘existing structures, whereas the relevant problem is how it creates and destroys them’’ is as relevant today as it was in 1942.

Wicksell (1898), through his influence on the Lund economists, first through Åkerman and then Dahmén gave a role to *ex ante, ex post* differences in outcomes and business mistakes, that appeared (Palander, 1941), after Wicksell had moved to Stockholm, in the so-called Stockholm School economics, but vanished altogether in the streamlined post-World War II WAD economics that hit Sweden with a ten-year lag in the 1960s.

The way collective institutions (private or public) in the EOE make intermediate choices in pluralistic selection processes (‘‘business experiments’’) is central for economic system performance. And here the WAD and the EOE models tell completely different stories. In the WAD model business mistakes cannot occur and the underlying assumptions are tailored to make agents fully informed both *ex ante* and *ex post.*[3] In the EOE model business mistakes do not cause much harm but instead constitute a necessary form of organisational learning (Eliasson, 1992*a*). In the EOE each actor is grossly ignorant of the whole (see below) and has to try (perform an experiment) before a final selection can be made and unsatisfactory experimental designs abandoned: the economic system learns through selection. In fact, Eliasson and Lindberg (1981) show (in an EOE type simulation model) that the big business investment mistakes during the oil crises of the 1970s were a costly, albeit reasonably so, learning experience for the economy as a whole. The really big macroeconomic costs, however, occurred in the form of lost output and growth, and were caused by policy when the Swedish Government tried to avoid temporary unemployment through industrial subsidies. It can be demonstrated that it is more efficient to support a high rate of business experimentation and a certain incidence of business failure as a learning cost, than to attempt (in vain) to eliminate business failure as waste, as is the theoretical advice of the standard Walras-Arrow-Debreu (WAD) model. The limits to the experimental process are the systems stability properties (Eliasson, 1984*a,* 1991) and the political willingness of people to accept unpredictable change. This theoretical result, however, only holds in the dynamics of what we call the experimentally organised economy, one which produces two policy conclusions entirely alien to the WAD economy. *First,* the EOE needs institutions that make people accept the incidence of widespread business failure. *Second,* the important part of system support is to keep it pluralistic (‘‘competition policy’’), to prevent monolithic, single-minded choices (‘‘central planning’’) from dominating selection and to support an optimal rate of organisational learning through business mistakes and selection.

Table 1 ranks the theoretical policy priorities and possibilities going from the EOE to the WAD economy.

Table 1. **Policy priorities**

1. General infrastructure provision (EOE and market co-ordination)
2. Targeted infrastructure provision (competence bloc formation)
3. Targeted sectors and centralist policy overview
4. Picking winners (WAD)

The argument of this article is that policy makers are too ignorant to perform all the tasks listed in Table 1, but instead have to focus. In so doing, however, they make mistakes. Being the big player, government ought to be careful and not dominate. By moving down the table, not only does it engage in activities for which it has no competitive advantage over actors in the market or in the competence bloc, but its activities also detract attention from the important infrastructure provisions.

Example: Providing (non-market) support for the transfer of people from stagnating to growing production areas; necessary to make a positive economic development socially and politically acceptable.

It is obvious by now that in order to identify an efficient role for central government in the EOE economy we have to take the analysis down to the micro market level.

Before we discuss the policy implications of this intellectual refocusing, we, therefore, first have to establish the links between market institutions and market performance in terms of generating economic growth through the development of the competence to make intelligent competitive choices.

II. THE KNOWLEDGE-BASED INFORMATION ECONOMY: THE POTENTIAL

The knowledge-based information economy is a term coined (Eliasson, 1990*a,* 1990*b,* p. 14*ff*) to capture the fact that resource use in an advanced industrial economy is dominated by various forms of information and communication activities, and that much of the knowledge capital put to use in production is of the tacit incommunicable kind. This is sufficient to make the state space or business opportunity space in which economic agents operate extremely heterogeneous, unpredictable and totally non-transparent. Information processes in an uncertain economic environment become a dominant, resource-using economic activity. Awareness of this fact should radically change our views on things economic, compared to the notions propagated by textbook mainstream economic theory. Here we indicate how and why – as a consequence – experimental search and selection become a dominant economic activity and why mistakes in such search and selection determine business and macroeconomic outcomes.

Choice and selection dominate

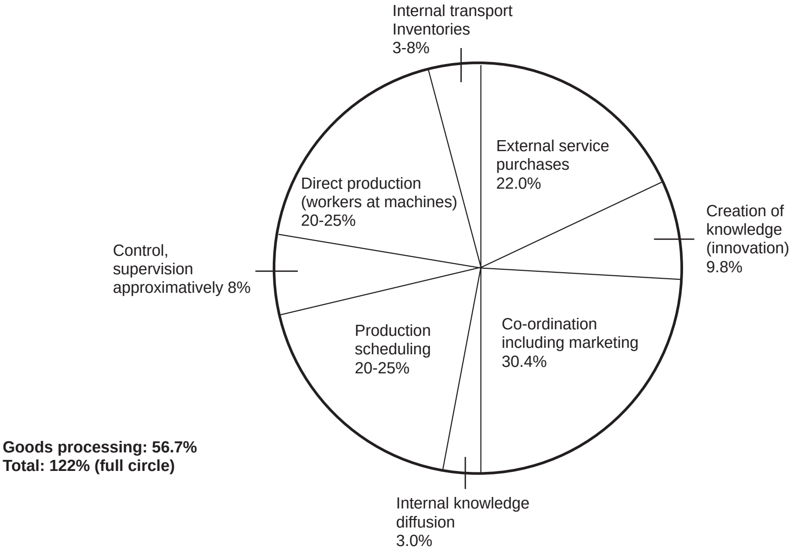
The work specialisation theory of Adam Smith naturally extends to the theory of the knowledge-based information economy. Reorganising for further specialisation is an act of *innovative organisational choice and selection.* The greater the specialisation (decentralisation), the higher the demands on *co-ordination* in space and time which occurs in hierarchies (*management*) and over markets (*competition*). Each such organisational choice involves a change in the composition of hierarchies and markets and, hence, in the structure of firms as more or less monolithically controlled hierarchies. Once a new solution has been found, all actors in the market will observe and *learn.* Table 2 lists the four information and communication activities that occur on top of actual physical production. Most reasonable statistical definitions of business identification, choice, co-ordination and learning activities show that they together dominate as resource users over physical production (Eliasson, 1990*a,* 1990*b,* p. 68*ff*), completely in private service production, but also in most modern manufacturing firms (see Figure 1). This is in contrast to the WAD model (where information use is at best a marginal, calculable activity).[4] For the EOE the dominance of knowledge-based information processing means *that productivity advance at the macro level is predominantly a matter of productivity advance in information processing and communication, which* in turn – as we have defined it – *occurs in a large measure through, or is accompanied by, organisational change at all levels of production.* The reorganising process is evolutionary and should be modelled endogenously. This indicates the social problem associated with productivity advance: to enjoy the benefits of economic growth, society has to be politically and socially prepared to accept the accompanying change. Hence, education, social insurance and labour market policy are key elements of industrial policy (Eliasson, 1992*b*). Consequently, when structure (organisation) is changing as part of the ongoing economic processes, theories such as the WAD model, based on stable exogenous structures, will lose their explanatory power and instead provide misleading advice.

Table 2. **The statistical accounts of the knowledge-based information economy**

1.	**Identifying business opportunities** (exploring state space)	*The creation of new knowledge* – Innovation – Entrepreneurship – Technical development
2.	**Choice and selection**	*Filtering* – Entry – Exit – Mobility – Careers
3.	**Co-ordination**	*Disciplining* – Competition (in markets) – Management (in hierarchies)
4.	**Learning**	*Knowledge transfer* – Education – Imitation – Diffusion

Source: Eliasson (1990*b*).

Figure 1. **The distribution of labour costs over different internal firm activities**
Swedish manufacturing firms with more than 200 employees



Source: Eliasson, 1990*a*.

In the EOE economy, information and communication activities are guided by a dominant and highly diversified knowledge capital embodied in human beings and teams of human beings in hierarchies and markets. The economic potential of this economy is only limited by the ability of this mass of heterogeneous competence to comprehend. It is, thus, enormous.

While the most valuable economic inputs originate in the identification and selection accounts described in Table 2, most directly measurable resource use occurs through the co-ordination and learning (knowledge transfer) accounts. These are, however, the least important information and communication activities in the experimentally organised economy. When state space is enormous, experimental choice and selection dominate. This observation takes us into the tricky area of how to identify the resource use with its output results; a task that has frustrated neo-classical growth economists for a long time.

First, the experimentally organised economy in which we conduct our reasoning allows for two kinds of business mistakes that cannot occur in the mainstream economic model. Business errors of Type I mean allowing bad projects to go on for too long, while business errors of Type II mean terminating winners before they have been identified (see Eliasson and Eliasson, 1996).

Errors of Type I should be regarded as a standard cost for economic development in a growing economy. The prescription from neo-walrasian or WAD economics that they should be eliminated is simply wrong. Reducing the incidence of business errors of Type I too far will increase the incidence of errors of Type II – and errors of Type II are the really costly ones. They are only indirectly ‘‘observable’’ in the form of lost output and profits.[5]

Explicit business failure of Type I can, however, normally be captured statistically, although most of these costs are indirect and incurred in the form of sub-normal performance. This points to a tricky theoretical problem that we have with the EOE, but not with the static equilibrium requirement of ‘‘modern’’ or ‘‘new’’[6] growth theory, that goes under the name of the product exhaustion theorem.

In the WAD model the reference is well defined, and in equilibrium factor costs exhaust total value produced. In static equilibrium the rates of return of all firms equal the market interest rate. In the EOE model business errors and superior performance mean that more or less value is produced and total factor costs, including a market interest charge on all capital, do not exhaust total value added.[7] A difference in the form of sub-normal profits or losses, or excess profits, can be recorded and the Salter curve 2B (see Figure 2, p. 221) illustrates the distribution of such ‘‘rents’’ over Swedish manufacturing firms. In Schumpeterian terms, excess profits can be called temporary monopoly profits. In our terminology we talk about temporary competence rents.

III. THE ACTORS IN THE COMPETENCE BLOC

The competence bloc has a market and product definition[8] which includes all the competencies needed to create, develop and support the growth of a new industry. In that sense a competence bloc can be seen as an *extended form firm* that is co-ordinated both through hierarchies and over markets.[9]

The actors in the competence bloc carry on the very demanding, but seemingly not very resource-using, task of identifying the business opportunities and selecting the best (the two first items in Table 2); a typical top-level task in the firm.[10]

In advanced industries – call them high tech[11] – the competent customer interacts actively with the producer and contributes ‘‘market close’’ competence. The *innovator* is the technological bridge builder who integrates different technologies in different and unexpected ways to come up with new solutions. The *entrepreneur* identifies commercially interesting innovations, while the competent *venture capitalist* discovers (''understands'') the commercially viable ideas of the entrepreneur such that he is willing to participate with reasonably priced[12] equity finance. The actors in the *secondary markets* also have to be reasonably competent to provide exit opportunities for the early venture capitalists, also at reasonable conditions.

The attraction of a competence bloc builds on synergies among all its actors that can be very large (Carlsson, Eliasson and Taymaz, 1997) as well as spillovers. In the latter sense a competence bloc functions as a technical university and research lab (Eliasson, 1996*b*) by diffusing new technologies and labour experienced in integrating economic and technical considerations to other industries. Such synergies and spillovers are the source of the increasing returns to search that we associate with a competence bloc.

Business establishments in the competence bloc are attracted by the potential synergies offered, but also contribute to an increasingly varied and advanced environment. Critical mass is therefore associated with each competence bloc (Eliasson, 1997*c*).

Together (Eliasson, 1997*d*) the competence of venture capitalists and the actors of secondary markets determine how much they are prepared to pay upstream. They are therefore critical incentive providers for the entrepreneurs and innovators. Their conditions of existence are, however, tough.

European countries such as Germany and Sweden have been fairly good at moving industrial ventures through to industrial scale production, marketing and distribution as long as they have not strayed too far from the established industrial knowledge base; engineering industry, or the 200-year or so old technology upon which the industrial revolution was once based. The creative knowledge base needed for truly novel industrial creation seems, however, to be rather lacking in Europe. Most new firms that have grown large can be found very close to existing traditional technologies.

As a consequence, European policy makers have rushed in to innovate: European industry, armed with the WAD model and WAD advisers, has attempted to take over business decisions and pick winners (Eliasson and Ysander, 1983). This was theoretically OK in the WAD world, but liable to fail completely in the EOE world.

We will next link experimental business activities to incentives and institutions and then through selection and competition to economic growth. After that we will formulate a middle way for the policy maker in the EOE in terms of competence bloc formation and support, one case being the establishment of industrial or science parks.

IV. HOW DOES GROWTH OCCUR?

We will now go on to link the productivity potential and the problem of the experimentally organised economy to the performance of the macro economy. We will first address the problem of incentives to invest and then link investment in a broad sense to economic growth, fuelled by competitive selection in markets.

Institutions make it possible to capture the rents from successful selections – property rights and the incentive problem

The competence block identifies the actors needed to move new and old industries forward. This is an existence problem. To bring *dynamics* into the picture, *incentives* have to be right and competence has to be in place to challenge and make life economically insecure for incumbent resource holders. Incentives are a problem of property rights. There should be a guarantee – and the existence of markets depends on it (Commons, 1893, 1934; North and Thomas 1970, 1973) – that the rents from superior performance can be captured by those who create them. The sole exception to this general principle is that institutions should be organised in such a way as to facilitate the competing away of these rents by superior performers. Getting these institutions right – certainly a policy task – is not easy; witness the attempts by the former centrally planned economies of Eastern Europe, and the welfare economies of the West, to get back to a market mode (Eliasson, 1997*a*). What is particularly important in advanced economies is the capacity of the economy to handle the complex financial transactions associated with the investment allocation process and the transfer of abstract property rights embodying the right to manage, access and trade in future profits arising from investment commitments made today (Eliasson, 1993).

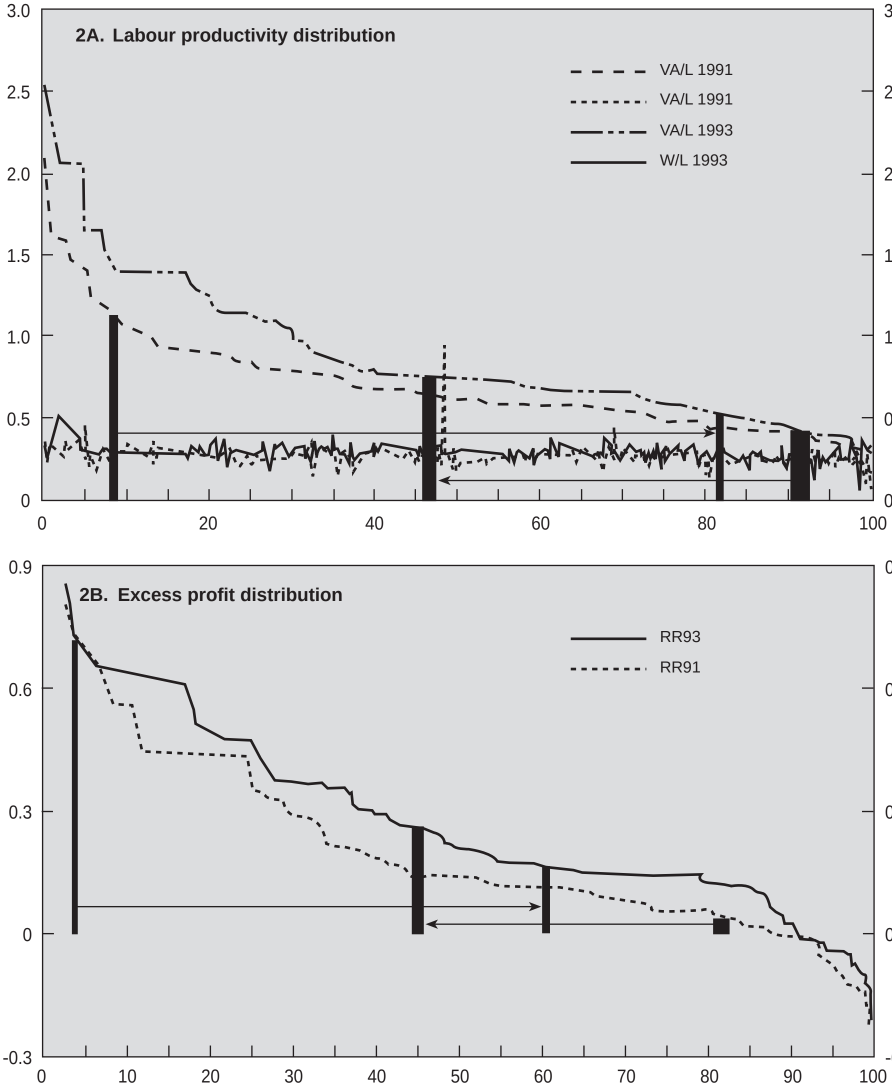
It would take too long to go into further detail here. Suffice it to refer to the formulation of the problem and the fairly detailed specification of the institutions required to handle it presented in Eliasson (1997*a*), and to note that so long as the property rights problem has not been adequately dealt with both politically and legally, there will always be a corresponding industrial problem of growth.

The four investment growth mechanisms

Consider a performance ranking of all existing firms in terms of a Salter (1960) diagram (Figure 2). If we disregard for the moment (and without loss in generality) the possibility of mergers and acquisitions,[13] we can easily see that change in this curve occurs through the reorganising and rationalising of existing

Figure 2. **Productivity distribution across Swedish manufacturing firms**

Salter curves



Source: Excess profits are measured as the difference between the nominal returns to total assets and the nominal market interest rate.

firms, the entering of new firms,[14] and the exiting of low performers at the right-hand corner.[15] As a consequence the Salter curve is pushed outwards and growth occurs. It is as simple as that. The four investment mechanisms in Table 3 explain *how* growth occurs,[16] but not *how* firms realise that change internally and *what* keeps the process going. WAD-based micro theory is not capable of such an explanation. You need to introduce the enormous state space of the knowledge-based information economy, and the business mentality and choice processes of the EOE. Then you can proceed to model policy decisions.

Table 3. **The four investment growth mechanisms**

1. Entry
2. Reorganisation
3. Rationalisation
4. Exit

Source: Eliasson, 1996, p. 45.

V. GROWTH THROUGH COMPETITIVE SELECTION

The remaining analytical task is to identify the forces that kick the economic system, or the competence bloc, into motion and keep it growing. Then we can go on to identify the policy parameters.

The *first* condition that has to be met is the existence of a potential for large positive rents from search and competent selection and combination. One could restate this condition as the existence of positive increasing returns to competent search. The competence bloc has been defined so as to create, once a critical mass has been reached, such increasing returns to scale. Appropriate institutions make it possible for the innovator to capture the rents he or she has created.

The *second* condition is the existence of the incentives and competition that activate those search activities. This is essentially a free *access* (to the opportunity set) condition. Free access includes unrestricted competition that forces incumbent actors to improve. This second condition can also be said to take care of the *third* condition, namely a sufficiently low risk aversion on the part of individual actors to initiate search. Free access to search for opportunities subjects incumbents to increased competition, thus increasing the risks associated with doing little or nothing for incumbent actors, and hence, forcing them to improve or exit. Risk aversion remains a problem only when the second condition is not met.

While Condition 1 is a competence and innovation problem relating to the competence bloc, Conditions 2 and 3 restate the traditional ‘‘antitrust’’ argument within the dynamic framework of an EOE and relate directly to the four investment growth mechanisms in Table 2. When conditions 2 and 3 are met, competitive selection sets the system into motion, and the potential outcome depends on the nature of the (first) competence and innovation situation.[17]

Access and incentives guarantee new competitive entry in Table 3, forcing incumbents to reorganise, rationalise or exit, making room for others. Growth occurs, but this process obviously has a negative social side, since factors of production will have to be reallocated across markets. The labour market is particularly troublesome in this respect, and individuals make their voices heard through the political system, or else organise themselves to slow down or stop the competitive selection process through unions. One consequence of this condensed presentation of the growth machinery of an economic system is that there are three areas upon which policy makers must concentrate their attention, one of which is technical/competence, another economic/allocation, and the third acceptance/social:

- infrastructure provisions in the form of competence bloc *support* and/or institutions – the *technology/competence* problem;
- dynamic competition policy guaranteeing free *access* to the opportunities embodied in the competence bloc – the *economic allocation* problem;
- the *acceptance* or *social* problem.

It should be realised, however, that government is only one among many actors that can contribute positively to Conditions 1 and 2, and it faces private competition on both counts. Very often ‘‘typical’’ public responsibilities may be better taken care of by private sector agents. *One element of policy competence is understanding when to stay away from activities better managed privately.*

Most of the competence bloc structure of a viable economy, in fact, exists through private initiative. And if the institutions that guarantee property rights are not in place, there will be strong private incentives to substitute private initiatives for the government initiatives that are lacking and/or to support private market-induced corrections to government action, that work against the market (Eliasson, 1993, 1997*a*). The last few decades have seen many government regulations rendered ineffective or redundant through market activities.

VI. THE ROLE OF THE POLICY MAKER

This article presents two contrasting approaches to industrial policy: *i)* the traditional approach based on the central overview argument, theoretically possible in the neo-walrasian WAD world; and *ii)* the cautious one, policy ambitions being frustrated by the centrally non-transparent dynamics of the experimentally organised economy (EOE). Choosing either of the two extreme positions, we come up with extreme policy advice; either the far-reaching centralist interventionism based on static general equilibrium analyses that dominated economic discussion and policy in the 1960s and 1970s (*e.g.* Malinvaud, 1967), or the ‘‘do very very little doctrine’’ since you are likely (in the EOE) to misunderstand what you are doing and do more harm than good (Eliasson, 1990*a*). The extreme version of the EOE restricts the role of government to infrastructure provision, notably the creation and maintenance of the institutions necessary for the functioning of dynamic markets. Even that task borders on the impossible, as witnessed by the difficulties in getting the institutions right in the former centrally planned economies and the economically deteriorating welfare economies (Eliasson, 1997*a*).

The competence bloc theory in the EOE allows for a middle way; namely, to identify those institutions required to ensure a competent allocation of human capital. The distinction that has to be made at the outset is that we are not talking about centralist picking of winners, so popular among bureaucrats in the 1960s and 1970s, but about improving the selection of competence through decentralised markets. Hence, the rather elaborate presentation of the EOE and the competence bloc in the previous sections of this article.

In contrast to the WAD model, the EOE has a theoretical place for collective action of the kind exercised in hierarchies and firms. Dynamic competition among collective agents causes inefficiencies in the WAD model through ‘‘wastage’’. In the EOE, business failure appears as a learning cost for society as a whole, and we can thus talk about more or less efficient learning. The temporary knowledge monopoly that we call a firm, therefore, has an explicit competition role in the EOE, as has the extended form firm that we have called a competence bloc (Eliasson, 1997*c,* 1997*d*). In modern evolutionary game theory the existence of incentives to form such co-operative solutions has been demonstrated (see, for instance, Wärneryd, 1990, 1994). Large hierarchies such as General Electric or the old IBM internalise most of the functions of a competence bloc. What are the efficient organisational consequences of breaking up such giant hierarchies into a fragmented market of small firms, or forcing them to decentralise through competence bloc formation? Or, when industrial fragmentation is the rule, inducing firms to form larger and more resourceful hierarchies through mergers? Is the merger of Boeing and McDonnel Douglas good or bad? In what sense? And for whom?

Once you allow for tacit competence exchange and support between differentiated actors in the market that both compete and co-operate (share competence), the formation of a competence bloc has begun. Somehow critical competencies are missing, and market agents may or may not be capable of identifying them and inducing new firm establishment. Governments – who do not think in terms of the EOE and competence bloc formation – have deliberately introduced institutions that destroy the mechanisms that efficiently create, allocate and use competence. The worst case was the central plan of the former Soviet Union, but extreme welfare states with far-reaching centralist ambitions are not much better. To do less badly is a case for enlightened policy. But the other extreme of breaking up efficient knowledge monopolies may not be the best solution either.

New firms can remain small and yet capture increasing returns through competence bloc formation. The whole issue is empirical, rather than principal, and the situation changes with technological development. Integrated production in the aircraft and automotive industry (Eliasson, 1996*b*) is a competence bloc arrangement to capture increasing returns through market decentralisation on a fairly small scale. The new IT and health-care industries are based on innovative technologies which thrive in small firms and capture rents from economies of scale through competence bloc arrangements.

The previous analysis provides for three principal policy openings:

- *Technical competence/infrastructure.* Support of competence bloc formation: there may be a rationale for the creation of industrial or science parks to complement what is missing, but it is not obvious how this should be done correctly if the policy maker is not wearing his EOE glasses.
- *Economic institutions, allocation.* Creating the necessary institutions for a market economy is an all-important task, but it should not be overdone. The market is perfectly capable of developing its most important institutions, without government support (Wärneryd, 1994).
- *Social/acceptance of change*:
  - efficient *social insurance* is necessary to remove distorting institutions of welfare economies and replace them with appropriate insurance institutions in order to reduce resistance to change;
  - *competition policy* to prevent concentration and inefficient lock-ins through monopoly formation.

Government-sponsored industrial and science parks have been a popular idea among policy makers keen to show off their activity. Typical of most such ambitions has been the dominant focus on supporting new technology development, for instance through government-sponsored laboratories and universities that derive naturally from neo-walrasian general equilibrium and neo-classical macro theory, and such attention-catching articles as Arrow (1962). This focus is proven wrong in the EOE and a competence bloc setting: industrial policy that neglects the economic and commercial selection side of technological development will always fail. That most successful of science parks, Silicon Valley, is not a government creation, and the diffusion of innovative technology in Silicon Valley that has spawned the most impressive new industry creation ever seen, did not originate in Arrow-type laboratories, but rather in private profit-making firms. The new US IT and communications industry that currently dominates world markets was created (Eliasson, 1996*a*) by people leaving their employers to start new firms (Item 2 in Table 4). And this would not have been possible without a viable venture capital industry and well-functioning secondary markets for IPOs (Eliasson, 1996*d*). On the other hand, the presence of nearby elite universities (both private and public) provided the growing competence bloc with well-educated young people keen not only on creating new products and industry but also on making a profit. It is interesting to note that this entrepreneurial profit-making spirit may be even more pronounced in the new biotech industry (Eliasson and Eliasson, 1996; Eliasson, 1996*d*), which in its current state entirely derives from academia, again notably in and around Silicon Valley in California.

Table 4. **The diffusion of technology from advanced firms takes place through four channels**

1. Mobility of competent people (*labour market*)
2. Entrepreneurial new establishment (*innovative entry*)
3. Learning among subcontractors (*integrated production*)
4. Outright *imitation* by other firms

Source: Eliasson (1995).

It may happen that the solution to the social insurance problem may be the most pressing problem: the mature welfare economies of the West must reduce the resistance of their popultions to the radical industrial and social change required in order to stay ahead economically. This problem is easily confused with a need for technology support, and requires the use of a competence bloc approach to identify it. Hence, it is probably more important to create functioning labour markets that induce and force people to move to new jobs than to help firms become technologically more competitive.

The social acceptance and institutional policy problems overlap at critical junctions. While the creation of the necessary institutions which are currently missing is a pressing problem in the former centrally planned economies, the removal of deadwood or hindering institutions is an equally important, though less acute, problem in the mature welfare economies (Eliasson, 1997*a*). Some of these institutions have been put in place to reduce social impacts by slowing the process of change, and should be replaced by more efficient social insurance arrangements. Other such institutional impediments have been created with the aim of achieving income and wealth redistribution. Here the policy maker faces a more tricky choice. Should he be concerned with the distribution or level of income and wealth per capita? Rational policy makers may eventually learn, as more evidence from the global, ongoing change process accumulates, that the choice is perhaps not so difficult after all: a rich, healthy and growing economy with a minimum of political interference may very well be the best long-term guarantee of a sustained and desirable distribution of income and wealth.

Finally, there is the portentous problem of technologically locking-in an entire industry into an old technology. Ballot and Taymaz (1996) show theoretically that this can easily occur in an EOE type economy, and Glete (1996) argues that this is exactly what may have happened to Swedish manufacturing over a 100-year or so period of extreme success. With the industrial competence base embodied in human beings locked into an industrial technology of the past, and a labour force locked into that industry by mobility-reducing welfare programmes, the priority task for policy is how to get out of the situation. And getting out will require extremely well-functioning social insurance and labour markets.

We have a clear case for competence bloc formation and social insurance reform. It would be interesting to apply the competence bloc policy analysis concept to two types of industries: an ‘‘exiting’’, currently important industry that will have to be restructured from within in order to survive as a growth contributing force in an advanced economy; and a new, high-technology, ‘‘entering’’ industry, in which a currently advanced industrial economy has to excel in order to remain an advanced industrial nation.

VII. COMPETENCE BLOC POLICY ANALYSIS OF THE AIRCRAFT AND HEALTH-CARE INDUSTRIES

The competence bloc can be viewed as a filter device through which production can be effectively decentralised across markets. The competence bloc provides the institutions and organisations required to create, develop and support the growth of an industry. It has a product market definition in the sense that it captures all the competencies needed to carry out that task. Very large firms tend to internalise most of the institutions and agents of the competence bloc. To make the industry radically innovative, however, the hierarchy has to be decentralised through the market as a competence bloc; technology makes it possible to do that and still capture the returns to scale. The concept has been applied, first to the Swedish aircraft industry (Eliasson, 1995); the IT and communications industry (Eliasson, 1996*a*); the biotech industry (Eliasson and Eliasson, 1996) – where the concept was first elaborated in detail; the pharmaceutical industry (Eliasson and Eliasson, 1997); and the health-care industry (Eliasson, 1997*c*). Studies are currently under way on the Swedish construction and property management industry, on the forest industry and – to illustrate the general applicability of the concept – on art production in *quattro centro* Florence. This article will briefly discuss the aircraft and health-care industry competence blocs. The aircraft industry is interesting because it represents frontier commercialised technology in the engineering industry, the backbone of European mature industries. The health-care industry is also an old industry, but it incorporates in its modern form several of the most sophisticated new types of industries, upon which the politicians of many mature industrialised countries are pinning their hopes for future economic growth.

The aircraft industry

The aircraft industry (Eliasson, 1995, 1996*b*) employs today the technologies and tools of the engineering industry of the future. It therefore generally operates as a technical teaching and research university for the rest of the engineering industry by diffusing people with competence and know-how to other industries. This insight has taken on very different practical manifestations, and some bizarre ones prone to failure, such as the ambition in the 1980s of the large automotive firms to acquire an aircraft producer to boost automobile technology, and the ambition of hopeful industrial and non-industrial nations to build aircraft industries to engineer growth. These ambitions have mostly failed because visionary top-level firm managers did not know how knowledge is diffused and policy makers did not understand that industrial competence is a very sophisticated complex of integrated economic and technical competencies.[18] Generally speaking, you cannot create industrial competence by subsidising technology development in the aircraft industry: it is industrial and commercial competence that contributes to economic growth, not technology in isolation.

An aircraft is *i)* a very *large* and complex product with *ii)* a very *long life,* that *iii)* is produced under very *complex* circumstances. Today an aeroplane cannot be designed, developed and manufactured (*i.e.* produced) within a single firm. Both development work and manufacturing are integrated and co-ordinated over hierarchies and markets. Such integrated production requires a sophisticated systems co-ordination competence that exists only in a very small number of advanced industrial countries.

Aircraft production uses and integrates *i)* the most advanced forms of mechanical engineering technology; *ii)* sophisticated information and communication technologies; and *iii)* new materials. This integration has also been typical of frontier engineering industry over the last couple of decades. This total knowledge is experience-based and can only be developed in production, which is a matter of slow, incremental learning.

Once in place, however, it can be quickly diffused and destroyed through negligence and mismanagement. The particular problem with this type of industry is that knowledge is embodied in human beings or teams of human beings. The investments in knowledge made by a firm can, therefore, easily disappear through the movement of competent staff and/or through imitation. These investments are difficult to lock in or charge for. For it to be willing to invest in such accummulation of relatively freely available infrastructure knowledge, a firm has to either earn very high returns to its capital, or be subsidised. However, subsidisation is an inefficient way to stimulate the accumulation of such knowledge, since technology then tends to dominate industrial and commercial competence accummulation.

This leaves the policy maker with two choices: *i)* the impossible task of using public money to induce the creation of new industrial technologies; and *ii)* the difficult task of making it profitable to use and further develop existing, commercially viable knowledge. However, this task is not politically delicate, since with externalities of this kind traditional trade theory conclusions do not hold up. The aircraft company should charge for its spillovers, if it can, and no one will object. It cannot, but governments could instead pay for such collective services, and there would be no reason to object on international trade policy grounds, the only discussion being about how much they should pay. The problem is to devise an appropriate pricing method to keep the source of downstream knowledge alive and flowing. There is no difference in principle between subsidising a technical university and paying for collective services. The problem is not to destroy the technology source in the process. The ways in which technical universities are paid for their collective services to industry are, of course, the reason why university research is rarely very productive from an industry point of view (see Eliasson, 1996*f* and further below on health care). Let us see how this looks in terms of our competence bloc structure.

The aircraft industry, more than any other industry, thrives on competent customers (Table 5) for technical development (notably in military aircraft) and on commercial aviation technology in developing civilian aircraft. Innovative technology (Item 2 in Table 5) through combinations of many technologies weighs in heavily. Many military product technologies are, however, too advanced and too specific for the civilian aircraft industry, except in cases where a military producer such as Saab expands into civilian aircraft production. Innovative technical competence diffuses in four principal ways: through the diffusion and application of

Table 5. **The actors in the competence bloc**

1. Competent and active customers
2. Innovators that integrate technologies in new ways
3. Entrepreneurs that identify profitable innovations
4. Competent venture capitalists that identify and finance entrepreneurs
5. Secondary markets that facilitate ownership change
6. Industrialists who take successful innovations to industrial-scale production

Source: Eliasson and Eliasson (1996), ''The Biotechnological Competence Bloc'', *Revue d'économie industrielle*, 78-4th quarter.

new manufacturing processes; through subcontracting arrangements; through the movement of people with competence; and – to some extent – through new establishment and outright imitation (see Table 4 above).

The unintended function of the aircraft industry as a technical university that diffuses experienced people to other firms is well documented in the spillover literature (Eliasson, 1995, 1997*d*). Many subcontractors have developed into new firms on the basis of what they had been able to learn from participation in aircraft production. In Sweden it appears that large subcontractor firms have been more successful than smaller firms; notably Volvo Aero, which has developed into an advanced, autonomous aircraft engine systems developer and manufacturer, and which has in turn spun off several smaller firms as subsidiaries. Ericsson, a supplier of electronic systems to the Swedish military, sports several successful developments. The most stunning, but largely accidental, spin-off is Ericsson Mobile Telephony, which would hardly have been possible without a keen, civilian customer (Swedish Telia) and technology contributions from the military side. In fact, a computer industry had been developed within Saab as from the late 1950s. In the 1970s it was incorporated, and in 1981 acquired by Ericsson as part of its failed venture into business information systems. And that was the end of Swedish computer industry.

It is interesting to ask why successful spin-offs in Sweden are largely restricted to large firms. One possible answer is that Sweden lacks a viable entrepreneurial and venture capital industry (Table 5). New ventures, thus, have to rely on big business and government venture financing, making them very conservative and/or not very innovative (Eliasson, 1996*d*). The policy implications are clear: to create new innovative technology, the country needs a broad technology base in technical universities, research laboratories and industry. Nobody can foresee and plan ahead of time how technologies will combine and integrate into new ones. Thus, an advanced economy will probably sport many innovations. Among these technical innovations an entrepreneur identifies those that are commercially viable and adds the economic dimension in the form of market understanding, etc. Not much entrepreneurship will be seen, however, unless there are venture capitalists around to recognise the entrepreneurial idea and provide reasonably priced financing (Eliasson, 1996*d*). Certainly, the venture capitalist has to be not only very competent but also possess a creative mind. The venture capital community at large, furthermore, has to cover a very broad range of competencies to be capable of understanding and supporting a broad range of new industry formation. If over several decades government deprives venture capital of such embodied competence (Eliasson, 1996*d,* 1997*c*), the outcome will be a conservative, and in this respect incompetent, financial community of bankers, large firms with resources and government-financed institutions. There will be little new industry formation.

The health-care industry

In contrast to the aircraft industry, and for that matter to the IT industry, health-care technology derives directly from academia. The health-care industry has only recently – at least in Europe – begun to be regarded as an industry. We tended to view health care as a publicly run and socially inclined institution, separated from commercial thinking, with fragmented support from the pharmaceutical industry. This view of health care is, however, changing rapidly (Eliasson, 1997*c*). Health care is a significant consumption and investment activity in the economy, previously tucked away in public sector accounts. On the one hand, it is a privately demanded luxury consumer product. On the other, the health of the population is critical to the economic efficiency of the national economy. With the elderly, non-working share of the population (that takes most of health-care resources) growing rapidly, the rich economies are facing a delicate cost, insurance and distribution problem, part of which will have to be solved through new technology developments in the health-care industry.

Moreover, technology is changing the nature of the health product, making it possible to *prevent* ill health for longer than in the past and producing a ‘‘light bulb’’ sudden death life-cycle effect. This has been achieved through technical and economic interaction among the various parts of the health-care industry; namely:

- hospital care;
- medical instruments;
- pharmaceuticals;
- biotech.

These four industries/technologies, which previously lived separate lives, are currently being integrated to produce sophisticated inputs to the health-care sector, which is in turn a very sophisticated customer. The overall tendency is a movement away from costly hospital care towards prevention and towards keeping patients out of hospital and at home (Eliasson, 1997*c*). The medical instrument industry has successfully combined medical technology with engineering and information technology to produce new devices of early disease detection, surgery (*e.g.* Swedish Elekta), kidney dialysis (*e.g.* Swedish Gambro), etc. The pharmaceutical industry draws increasingly on biotechnology, an industry that was non-existent in its modern form just 20 years ago (Eliasson and Eliasson, 1996, 1997), and these factors all combine and integrate within care.

Health care is a luxury product, a service that is technologically developed in the rich countries that can afford it. The fact that health care is typically administered and produced in the public sector makes government a major player in the development of this industry, a policy task that introduces, as an alternative, both privatisation and the design of health insurance to deliver health-care services that are fairly distributed and at reasonable cost.

Since all four industries are intense in their use of information and communication technology and of the new biochemistry – micro biology technology, the health-care sector will be instrumental in the development of the new biotech industry and will rely heavily on the local presence of a sophisticated IT industry. Again, the policy implications are clear: if the production of care services in the health-care industry is not advanced and innovative and if the entrepreneurial venture capital and other financial support services do not function properly, total industry development will be slow in what is currently the most sophisticated industrial competence bloc in the industrial countries. And, to take the Swedish health-care sector as an example (see Eliasson, 1997*c*), what is lacking today is not innovative activity but rather entrepreneurship and venture capital-financed new industry formation. It is also symptomatic that the development of this industry in Sweden has been rapid in those fields in which big firms participate, *i.e.* medical instruments, but has lagged behind in both Sweden and in Europe (compared to the United States), in areas where small-scale private entrepreneurial and venture capital finance dominate. The government certainly has a policy role to play in ensuring that all the necessary actors of the competence bloc are present and active.

VIII. SUMMING UP ON POLICY

It is certain that, in the past, industrial policy was oriented towards economic growth and little more. The Swedish policy model is a famous example, and I will conclude with a few comments on that model, since it most certainly does *not* function in the perspective of this analysis. The problem of distribution has also to be settled; and this should be done in the context of addressing the role of education, the labour market and (social) insurance in industrial policy making (Eliasson, 1992*b*). This is a key issue: imagine what will happen to distribution if industry in a very rich country facing global competition fails to regenerate itself.

The Swedish policy model

The Swedish policy model (Table 6) is famous for its capacity (once) to co-ordinate the interests of industry, labour and government and to minimise labour unrest (Eliasson and Ysander, 1983). However, its responsibility in the generation of industrial concentration and large firm dominance, and perhaps, as a long-term side-effect of the policy design, in the technological and competence lock-in of Swedish industry into a now obsolete technology, has not been fully discussed (for one such discussion, see Glete, 1996).

Table 6. **The Swedish policy model**

1. Non-interference in the production system
2. Free entry and exit (trade and technology)
3. Active labour market policy
4. Redistribution through taxes and public sector growth

Source: Eliasson (1988).

The key idea was to leave investment and production decisions where they belong, *i.e.* in the firm (Item 1), and to prevent labour from interfering with new technology introduction (Item 2), but to subject firms to the discipline of the open market (Item 2). To cover the ensuing labour market risks, an active labour market policy (Item 3) was devised to move people out of exiting industries into growing firms and to ensure through general wage settlements that the average wage level remained low enough to generate large profits for investing and growing firms.

To make the scheme politically palatable, a fourth item, ‘‘redistribution’’, was added. This scheme worked as long as advanced Swedish firms were globally very competitive, as long as a pool of low-paid people on the farms and in the countryside of the north existed to keep work compensation at reasonable levels, a dual labour market similar to the Japanese labour market of more recent years, and as long as government ambitions to use taxes and the political sector to redistribute income were minimal. By the mid-1960s Sweden still had a tax take and a public sector share of GNP below the European average. From the mid-1960s on, this began to change.

To keep wage bargaining disciplined, profits generated from economies of scale had to be sufficient, and such that the origin could not be claimed by individual parties. This required consensus among the partners with a model of distribution which was synonymous with a small number of negotiating partners, *i.e.* large companies and centralised unions. This situation became increasingly reflected in the legislation, which notably favoured large business and labour unions at the expense of small businesses, individuals and labour market outsiders.

This policy scheme supported a concentration of industry among large firms in mature (engineering) industries that was not seen elsewhere in Europe. The other side of the coin was the absence of new, innovative firm establishment, the consequences of which became apparent when traditional industries began to suffer from competition in the 1970s and responded by rationalising at home (see Table 3) and/or moving production abroad. Until the beginning of the 1990s the unemployment consequences could be kept at bay through public sector growth and the retraining of labour, keeping people out of the unemployment figures. Then, public sector deficits forced a change, unemployment suddenly started to rise and the Swedish economy became one among many European economies facing similar problems, although it was an exceptionally bad case (see Andersson, Carlsson, Eliasson *et al.,* 1993). Perhaps the worst side-effect is an impaired system of industrial regeneration. This example illustrates how policies that look good in the short and medium term can turn very sour in the long run.[19]

Distribution

Provided that people are prepared politically to bear major changes and their distributional consequences, economic growth can always be generated in the way described above, as long as industrial competence and innovation are sufficient to keep a large share of industrial production internationally competitive.

By the mid-1960s not only Sweden, but the industrial world at large, began to believe, looking back along an unbroken growth trend, that the rich countries could afford the luxury of a slower rate of change and a more equal income distribution. Taxes and subsidies were the instruments suggested by the WAD model. With public sector distress, vanishing growth, lost competitiveness and high unemployment in a large part of the industrial world, the policy of shifting consumption to current generations from future generations does not appear to have been based on very good advice.

An additional problem, realised along the way, is that ambitious redistributional policies were frustrated by the market, and were soon seen (by the political bureaucracy) to be achievable only through even further interference in the market mechanisms (Item 1 in Table 6).

In a fairly short space of time several European economies – and, again, Sweden was an extreme case – found themselves involved through legislation, regulation, taxation and subsidies in an incomprehensible morass of economic activities, previously delegated to the market, and responsible for the welfare of individuals to an extent far beyond the capacity of any public actor to honour. Instead of an appropriate labour market insurance, legislation committed firms and public bodies to pay without giving them the means to enforce change. Publicly run production was unable to shut down inefficient activities. With the exit machinery (Item 4 in Table 3) largely immobilised, a slowed entry process and labour generously locked into existing firms, the whole organisational change process that accompanies growth ground to a standstill. As outlined in some detail for Sweden already in 1985,[20] this could only mean a growing disparity of income and wealth. Competent firms and individuals would continue to earn large incomes. Taxes would not be sufficient to pay for the welfare services of government and public deficits would drive up interest rates to the benefit of savers and the wealthy. The conflict between distribution and growth may, in fact, be largely misconceived.

NOTES

1. There is a companion paper (1997*b*) that characterises the role of the business manager in the EOE. Contrary to conventional wisdom, the policy maker has a far more difficult task than the business manager. He cannot predict because he both significantly affects the environment by his moves and has to reckon with significant strategic responses from all actors in the market. The consequences of misconceived action on the part of government are far more serious than for the business manager. Finally, whatever else he may be good at, his political platform makes it impossible to rapidly abandon a policy mistake (Eliasson, 1990*a*).
2. It is not a particularly edifying experience to read academic policy texts from the 1960s and 1970s and far into the 1980s and to see how the hidden priors of the WAD model not only limit insights but confer a dominant, always beneficial role to government. I know myself; see Eliasson, 1984*b.*
3. Modern I/O theory allows ‘‘bounded rationality’’ to be introduced in the restricted sense of asymmetrically distributed, but tradeable information. This does not principally change the above argument.
4. Most WAD writing up until recently, in fact, tacitly assumes zero information costs in the tradition of the walrasian auctioneer, who did not charge for his services.
5. They can, in fact, only rarely be ascertained, *i.e.* when a business winner can be documented as having been almost terminated, such as Astra’s Losec prescription drug, currently the world’s best selling drug (Eliasson and Eliasson, 1997), and Ericsson Mobile Telephony (Eliasson, 1995). In fact, the Tetra Pac corporation was on the verge of being shut down in 1965 (see Rydenfelt, 1995). The implication of these close failures that are documented as business successes is that there must be many, many more projects that really failed, implying again that the costs of errors of Type II may be considerable, and that both business and policy practice are probably biased in favour of excessively minimising errors of Type I. Unfortunately, that practice is intellectually supported by WAD thinkers.
6. It is not really either modern or new. Marshall (1919) said it already, when he introduced the concept of *industrial districts.* For a discussion of Marshall’s industrial districts impinging on this argument, see Laestadius (1997).
7. For the mathematics involved, see Eliasson (1976, p. 191*ff*; or 1996*a,* p. 76*ff* and 114).

8. As distinct from input- or technology-defined industrial cluster formations such as Dahmén's (1950) physically defined *development blocks* and Carlsson's (1995) *technological systems,* representing a generic technology, such as robots, that can be used in many industries.
9. See integrated production in Eliasson (1996*b*) and the KaroBio organisation in Eliasson and Eliasson (1997), which allows a cluster of specialised firms to capture increasing returns through their participation in a larger competence bloc of co-operating actors.
10. Eliasson (1990*a*). Often such identification and selection are performed better in a decentralised competence bloc organisation, especially when we are concerned with the new type of advanced industries (Eliasson, 1997*c*).
11. But do not make high R&D intensity in production synonymous with high tech. See Laestadius (1996).
12. The argument in Eliasson (1997*d*) is that ‘‘incompetent’’ venture capitalists, like ‘‘bankers’’, do not understand entrepreneurial ideas and only provide unreasonably priced financing. If there are only ‘‘bankers’’ in the market, as is the case in Europe, the entrepreneurs will be left out in the cold and be predated upon when they are close to giving up.
13. Which only complicates, but doesn't change, the principal argument (see Eliasson, 1996*a*).
14. Entering firms are not better on average than incumbent firms, but the spread in performance is much wider and only the best performers survive (Granstrand, 1986; Granstrand and Sjölander, 1990).
15. In badly functioning markets, notably financial markets, the selection process may not function well, and superior performers may accidentally exit.
16. This growth mechanism is explicit in the Swedish micro-to-macro model. See Eliasson (1977, 1985, 1991, 1996*c*).
17. This is exactly what keeps endogenous growth in motion in the Swedish micro-to-macro model (Eliasson 1977, 1991, 1996*c*). The difficult problem is to make sure that the innovation process, about which we have very limited knowledge, is realistically represented.
18. See Eliasson (1996*b*), where this integration is illustrated in so-called ‘‘integrated production’’.
19. Consequences that can be recreated on the same mode in simulation models of the EOE type. See Eliasson (1996*c*), Eliasson and Taymaz, 1993).
20. See Chapter VII (‘‘New Institutions, A Changing Market Organisation and Modified Social Values – Horizon 2000’’) in *Att rätt värdera 90-talet;* The IUI Long-term Survey, Stockholm, 1985.

BIBLIOGRAPHY

ANDERSSON, Thomas, Bo CARLSSON, Gunnar ELIASSON *et al.* (1993), *Den långa vägen* (The Long Road), IUI, Stockholm.

Att rätt värdera 90-talet (Choosing the Right ’90s), *IUIs långtidsbedömning 1985,* IUI, Stockholm.

ARROW, Kenneth J. (1962), ‘‘Economic Welfare and the Allocation of Resources for Invention’’, in R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors,* NBER, Princeton University Press, Princeton.

BALLOT, Gérard and Erol TAYMAZ (1996), ‘‘Human Capital, Technological Lock-in and Evolutionary Dynamics’’, paper presented at the 6th International Conference of the Joseph A. Schumpeter Society, Stockholm, 2-5 June. Forthcoming in G. Eliasson and C. Green (eds.) (1998).

CARLSSON, Bo (ed.) (1995), *Technological Systems and Economic Performance: The Case of Factory Automation,* Kluwer Academic Publishers, Boston/Dordrecht/London.

CARLSSON, Bo (ed.) (1997), *Technological Systems and Industrial Dynamics,* Kluwer Academic Publishers, Boston/Dordrecht/London.

CARLSSON, Bo, Gunnar ELIASSON and Erol TAYMAZ (1997), ‘‘The Macroeconomic Effects of Technological Systems: Micro-macro Simulation’’, in B. Carlsson (ed.).

CLOWER, Robert W. (1996), ‘‘A Theory of Economic Growth’’, paper presented at the 6th International Conference of the Joseph A. Schumpeter Society, Stockholm, 2-5 June. Forthcoming in G. Eliasson and C. Green (eds.) (1998).

COASE, R.H. (1937), ‘‘The Nature of the Firm’’, *Economica,* IV (13-16), November, pp. 386-405.

COMMONS, John R. (1893), *Distribution of Wealth,* New York.

COMMONS, John R. (1934), *Legal Foundations of Capitalism,* New York.

DAHLMAN, C.J. (1979), ‘‘The Problem of Externality’’, *Journal of Law and Economics,* pp. 141-162.

DAHMÉN, Erik (1950), *Svensk industriell företagarverksamhet* (Entrepreneurial Activity in Swedish Industry, 1919-39), IUI, Stockholm. Also published in 1970 by the American Economic Association Translation Series under the title ‘‘Entrepreneurial Activity and the Development of Swedish Industry, 1919-1939’’.

DAY, Richard H. and Gunnar ELIASSON (eds.) (1986), *The Dynamics of Market Economies,* IUI, Stockholm and North-Holland, Amsterdam.

ELIASSON, Gunnar (1976), *Business Economic Planning – Theory, Practice and Comparison,* John Wiley and Sons, London, etc.

ELIASSON, Gunnar (1977), ‘‘Competition and Market Processes in a Simulation Model of the Swedish Economy’’, *American Economic Review,* 67 (1), pp. 277-281.

ELIASSON, Gunnar (1984*a*), ‘‘Micro Heterogeneity of Firms and Stability of Growth’’, *Journal of Behavior and Economic Organization,* 5 (3-4), September-December, pp. 249-298.

ELIASSON, Gunnar (1984*b*), ‘‘The Micro-Foundations of Industrial Policies’’, in A. Jacquemin (ed.) (1984), *European Industry, Public Policy and Corporate Strategy,* Oxford University Press. Also IUI Booklet No. 173, Stockholm.

ELIASSON, Gunnar (1985), *The Firm and Financial Markets in the Swedish Micro-to-Macro Model: Theory, Model and Verification,* IUI, Stockholm.

ELIASSON, Gunnar (1987), *Technological Competition and Trade in the Experimentally Organized Economy,* Research Report No. 32, IUI, Stockholm.

ELIASSON, Gunnar (1988), ‘‘Schumpeterian Innovation, Market Structure and the Stability of Industrial Development’’, in H. Hanusch (ed.), *Evolutionary Economics: Applications of Schumpeter’s Ideas,* Cambridge University Press, Cambridge.

ELIASSON, Gunnar (1990*a*), ‘‘The Firm as a Competent Team’’, *Journal of Economic Behavior and Organization,* 13 (3), pp. 275-298.

ELIASSON, Gunnar (1990*b*), ‘‘The Knowledge-based Information Economy’’, Chapter 1 in G. Eliasson and S. Fölster *et al.* (1990), *The Knowledge-based Information Economy,* IUI, Stockholm.

ELIASSON, Gunnar (1991), ‘‘Modeling the Experimentally Organized Economy’’, *Journal of Economic Behavior and Organization,* 16 (1-2), pp. 153-182.

ELIASSON, Gunnar (1992*a*), ‘‘Business Competence, Organizational Learning and Economic Growth: Establishing the Smith-Schumpeter-Wicksell (SSW) Connection’’, in F.M. Scherer and M. Perlman (eds.) (1992), *Entrepreneurship, Technological Innovation, and Economic Growth. Studies in the Schumpeterian Tradition,* The University of Michigan Press, Ann Arbor.

ELIASSON, Gunnar (1992*b*), *Arbetet* (Work), IUI, Stockholm.

ELIASSON, Gunnar (1993), ‘‘A Note: On Privatization, Contract Technology and Economic Growth’’, in R.H. Day, G. Eliasson and C. Wihlborg (eds.), *The Markets for Innovation, Ownership and Control,* IUI, Stockholm and North-Holland, Amsterdam.

ELIASSON, Gunnar (1995), *Teknologigenerator eller nationellt prestigeprojekt? Exemplet svensk flygindustri,* City University Press, Stockholm.

ELIASSON, Gunnar (1996*a*), *Firm Objectives, Controls and Organization – The Use of Information and the Transfer of Knowledge Within the Firm,* Kluwer Academic Publishers, Dordrecht/Boston/London.

ELIASSON, Gunnar (1996*b*), ‘‘Spillovers, Integrated Production and the Theory of the Firm’’, *Journal of Evolutionary Economics,* 6, pp. 125-140.

ELIASSON, Gunnar (1996*c*), *Endogenous Economic Growth through Selection,* in A. Harding (ed.), *Micro-simulation and Public Policy,* North Holland, Amsterdam.

ELIASSON, Gunnar (1996*d*), ‘‘The Venture Capitalist as a Competent Outsider’’, mimeo INDEK, KTH, Stockholm.

ELIASSON, Gunnar (1996*e*), ‘‘On the Micro Foundations of Economic Growth – Human Capital, Firm Organization and Competitive Selection’’, paper presented to The International Conference on Self-organisation and Evolutionary Economies. New Developments (CNAM), Paris, 30 September-4 October.

ELIASSON, Gunnar (1996*f*), *The Use of Highly Educated People in Production,* KTH, TRITA-IEO R, 1996:10.

ELIASSON, Gunnar (1997*a*), ‘‘From Plan to Market’’, forthcoming in the *Journal of Economic Behavior and Organization.*

ELIASSON, Gunnar (1997*b*), *The Nature of Economic Change and Management in the Knowledge-based Information Economy,* paper prepared for the 14th Nordic Conference on Business Studies in Bodø, 14-17 August.

ELIASSON, Gunnar (1997*c*), *Hälso- och sjukvårdsindustrin – ett kompetensblock med stor affärspotential,* KTH, INDEK, T/RITA 97:03.

ELIASSON, Gunnar (1997*d*), ‘‘General Purpose Technologies, Industrial Competence and Economic Growth’’, in B. Carlsson (ed.) (1997).

ELIASSON, Gunnar and Åsa ELIASSON (1996), ‘‘The Biotechnological Competence Bloc’’, *Revue d’Économie Industrielle,* 78, 4e trimestre.

ELIASSON, Gunnar and Åsa ELIASSON (1997), *The Biotechnological and Pharmaceutical Competence Bloc,* in B. Carlsson (ed.) (1997).

ELIASSON, Gunnar and Christopher GREEN (eds.) (1998), *The Micro Foundations of Economic Growth,* University of Michigan Press, Ann Arbor.

ELIASSON, Gunnar, and Thomas LINDBERG (1981), ‘‘Allocation and Growth Effects of Corporate Income Taxes’’, in G. Eliasson and J. Södersten (eds.), *Business Taxation, Finance and Firm Behavior,* Conference Reports 1981:1, IUI, Stockholm.

ELIASSON, Gunnar and Bengt-Christer YSANDER (1983), ‘‘Sweden: Problems of Maintaining Efficiency Under Political Pressure’’, in B. Hindley (ed.), *State Investment Companies in Western Europe,* Trade Policy Research Centre, London.

ELIASSON, Gunnar and Erol TAYMAZ (1993), ‘‘The Limits of Policy Making: An Analysis of the Consequences of Boundedly Rational Government using the Swedish Micro-to-Macro Model (MOSES)’’, Working Paper No. 333, IUI, Stockholm.

GLETE, Jan (1996), ‘‘Entrepreneurs and Social Elites: Some Reflections on the Case of Sweden’’, paper presented at the 6th International Joseph A. Schumpeter Conference, Stockholm, 2-5 June. Forthcoming in G. Eliasson and C. Green (eds.) (1998).

GRANSTRAND, Ove (1986), ‘‘On Measuring and Modeling Innovative New Entry in Swedish Industry’’, in R.H. Day and G. Eliasson (eds.) (1986).

GRANSTRAND, Ove and Sören SJÖLANDER (1990), ''The Acquisition of Technology and Small Firms by Large Firms'', *Journal of Economic Behavior and Organization,* 13 (3), pp. 367-386.

LAESTADIUS, Staffan (1996), ''Technology Level, Knowledge Formation and Industrial Competence within Paper Manufacturing'', paper presented at the 6th International Joseph A. Schumpeter Conference, Stockholm, 2-5 June. To be published in G. Eliasson and C. Green (eds.) (1998).

LAESTADIUS, Staffan (1997), ''Marshall on New Growth Theory'', Mimeo, INDEK, KTH, Stockholm.

MARSHALL, Alfred (1919), *Industry and Trade,* London.

MALINVAUD, E. (1967), ''Decentralized Procedures in Planning'', in E. Malinvaud and M.O.L. Bacharach (eds.) (1967), *Activity Analysis in the Theory of Growth and Planning,* Macmillan, London.

NORTH, D.C. and R.P. Thomas (1970), ''An Economic Theory of the Growth of the Western World'', *The Economic History Review,* 2nd series, 22 (I), pp. 1-17.

NORTH, D.C. and R.P. Thomas (1973), *The Rise of the Western World: A New Economic History,* Cambridge University Press, Cambridge, MA.

PALANDER, Tord (1941), ''Om 'Stockholmsskolans' begrepp och metoder. Metodologiska reflexioner kring Myrdals 'Monetary Equilibrium''', *Ekonomisk Tidskrift,* Årg. XLIII, No. 1, March, pp. 88-143.

PELIKAN, Pavel (1986), ''Why Private Enterprise? Towards a Dynamic Analysis of Economic Institutions and Policies'', in *IUI Yearbook 1986-1987,* Stockholm.

PELIKAN, Pavel (1989), ''Evolution, Economic Competence, and the Market for Corporate Control'', *Journal of Economic Behavior and Organization,* 12 (3), December, pp. 279-303.

RYDENFELT, Sven (1995), *Sagan om Tetrapak,* Fisher and Co., Trelleborg.

SALTER, W.E.G. (1960), *Productivity and Technical Change,* Cambridge University Press, Cambridge, MA.

SCHUMPETER, Joseph A. (1942), *Capitalism, Socialism and Democracy,* Harper and Row, New York.

WICKSELL, Knut (1898), *Geldzins und Güterpreise* (English translation, *Interest and Prices,* published by Macmillan, London, 1965).

WILLIAMSON, Oliver E. (1985), *The Economic Institutions of Capitalism,* The Free Press, New York, London.

WÄRNERYD, Karl (1990), *A Coordination Theory of Transaction Costs and the Firm,* Department of Economics, Stockholm School of Economics, Stockholm.

WÄRNERYD, Karl (1994), ''Transaction Costs, Institutions and Evolution'', *Journal of Economic Behavior and Organization,* 25, pp. 219-239.

CHANGES IN THE R&D STRATEGIES OF TRANSNATIONAL FIRMS: CHALLENGES FOR NATIONAL TECHNOLOGY AND INNOVATION POLICY

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I. INTRODUCTION

Since the early 1980s, the extent of internationalisation of R&D has greatly increased, both in basic research and industrial R&D. During earlier periods of global expansion (thee 1960s and 1970s), multinational corporations first built up their sales, distribution and assembly operations in foreign countries. In later phases (late 1970s/early 1980s), efforts were directed towards supporting foreign subsidiaries with corresponding capacities in application engineering and applied R&D. Although initially the tasks of development departments abroad were limited to adapting product and process technologies from the home country to local production and market requirements, there was a clearly recognisable trend since the late 1980s towards strengthening R&D in foreign countries and extending the global competence portfolio. Increasingly, research became established at a high level in foreign locations.

The globalisation of research and development is a major topic within the business community as well as for academic researchers and decision makers in governments. Large multinational firms play a key role in the generation and diffusion of new technological knowledge (Cantwell, 1994; Nonaka and Takeuchi, 1995; Patel and Pavitt, 1992; Roberts 1995*a* and 1995*b*). In recent years, the R&D and international location strategies of transnational corporations have changed substantially. This article will describe these trends on the basis of empirical research in 21 internationally active corporations, and assess the consequences for national technology policy.[1]

The promotion of industrial R&D and innovation by the state is always based on premises of enterprise behaviour. Our study has revealed a number of new trends and behavioural patterns of firms which require changes in the approaches which have been used by public science and technology policy until now. However, the presentation is one-sided, in the sense that it takes into account only the viewpoint of international corporations, as do the consequences described for technology and innovation policy. A analysis of support for innovations taking place in small and medium-sized enterprises (SMEs), or of the links between SMEs and large firms, is not included. In addition, a fictional ‘‘national’’ policy is initially assumed, with no distinction being made between the supra-national level (*e.g.* the European Union), the national level (*e.g.* the federal government) and the regional level (*e.g.* the so-called *Bundesländer* in Germany).

In Section II the methodology and the selected corporations are described. Section III provides a summary of the main changes in industrial R&D strategies that are significantly influencing technology and innovation policy. Section IV analyses the conclusions for technology and innovation policy and discusses new policy issues. In Section V a framework for national innovation policy in response to dominant types of innovations is elaborated. The final section summarises the central premises of this article.

II. METHODOLOGY AND SELECTED CORPORATIONS

Our study aims to understand the new trends in R&D and the decision-making processes of internationally active corporations. For this purpose we gave our investigation an empirical orientation from the start, and focused on gathering information and insights from ‘‘trend-setting’’ corporations and decision makers. We conducted a total of 120 semi-structured expert interviews at three levels (board member, head of research, project leader) in 21 internationally active corporations. The results of the survey were presented, at three workshops, to representatives from enterprises and to policy makers, and were intensively discussed. The precise stipulations and comments elaborated at these workshops were incorporated into the final report of our study (*cf.* Gerybadze, Meyer-Krahmer and Reger, 1997).

The empirical sample consisted of 21 transnational corporations, most of which are engaged in electronics and information technology, in the chemical and pharmaceutical industry, as well as in machinery and advanced engineering (*e.g.* turbines and aeroengines). Table 1 gives an overview of the corporations studied. Eleven enterprises were from Western Europe, eight from Japan and two from the United States. For the reasons given above, we concentrated our investigations on corporations from Western Europe (Germany, Switzerland, the Netherlands) and Japan. The 21 selected enterprises are among the leading R&D-performing industrial firms world-wide. Many are technology leaders in their specific business, and are very far advanced in terms of degree of R&D globalisation.

Four of the ten enterprises with the highest R&D expenditures in the world were included in the survey (Siemens, IBM, Hitachi and Matsushita). Approximately one-third of the 50 most important corporations with the highest R&D expenditure were included in our survey. Sixteen of the 21 enterprises spend more, some considerably more, than US$1 billion on R&D annually. The enterprises included in the study have an above-average intensity of R&D (R&D expenditure as a proportion of turnover) of 8.3 per cent. Most of them are characterised by a high R&D intensity at the corporate level, or at least one of their business units is very R&D intensive.[2]

Table 1. **R&D intensities and the degree of internationalisation of R&D within our sample**

Rank	Company	R&D intensity 1993 in percentage	Share of foreign R&D 1993 in percentage	Degree of internationalisation of R&D	Industry
1	Siemens	9.2	28	**	Electrical engineering
2	IBM	7.1	55	***	Computers
3	Hitachi	6.7	2	*	Electrical engineering
4	Matsushita Elec.	5.7	12	**	Consumer electronics
5	ABB	8.0	90	***	Electrical engineering
6	NEC	7.8	3	*	Telecommunications
7	Philips	6.2	55	***	Electrical engineering
8	Hoechst	6.2	42	***	Chemical/Pharmaceuticals
9	Sony	5.8	6	**	Consumer electronics
10	Ciba-Geigy	10.6	54	***	Chemical/Pharmaceuticals
11	Bosch	6.7	9	**	Electrical engineering
12	Roche	15.4	60	***	Chemical/Pharmaceuticals
13	Mitsubishi Elec.	5.2	4	*	Electrical engineering
14	BASF	4.5	20	**	Chemical/Pharmaceuticals
15	UTC	5.4	5	*	Engineering/Aeroengines
16	Sandoz	10.4	50	***	Chemical/Pharmaceuticals
17	Sharp	7.0	6	*	Consumer electronics
18	Kao	4.6	13	**	Chemical/Cosmetics
19	Eisaj	13.2	50	**	Chemical/Pharmaceuticals
20	Sulzer	3.4	27	**	Advanced engineering
21	MTU	Ca. 25	–	*	Engineering/Aeroengines

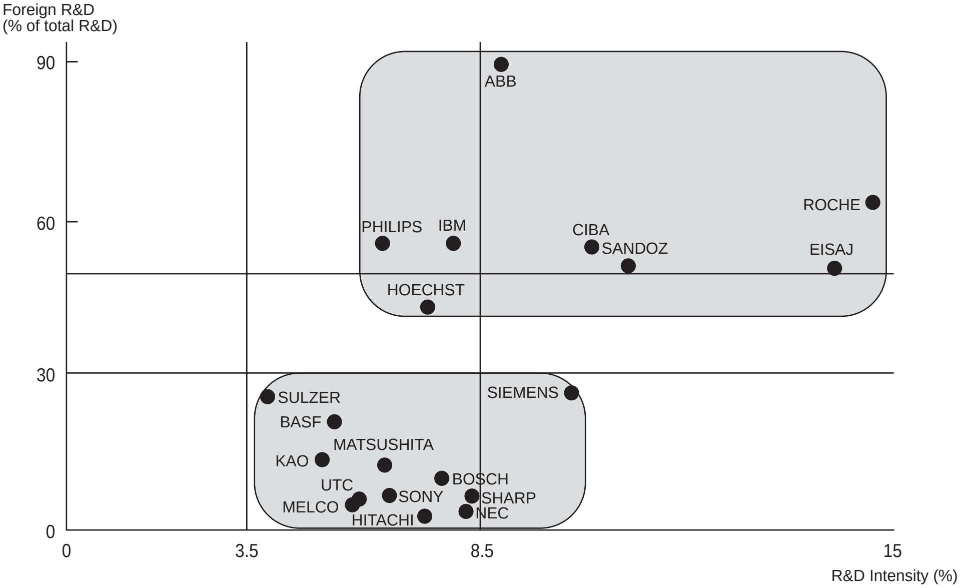
*** Globalisation of R&D very advanced.
** Above-average globalisation of R&D.
* Relatively low internationalisation of R&D.

Source: Database on International R&D Investment Statistics (INTERIS) and ISI Database on International Research and Innovation Activities (ISI-DORIA).

In addition to presenting R&D intensity and share of foreign R&D, Table 1 provides a qualitative evaluation of how far the R&D globalisation process has advanced in the corporations in our sample. This qualitative assessment of the extent of internationalisation cannot be compared with the parameter of the share of R&D performed abroad. The former also considers the extent of world-wide distribution of R&D and innovation activities, the globalisation of management and corporate culture, and the type of transnational co-ordination and interaction. If the average values for R&D intensity and the share of foreign R&D are compared at the level of the corporation, two clusters can be distinguished (Figure 1):

- A group of high-tech corporations with a strong global orientation, which invest relatively large amounts in R&D and have a strong R&D presence abroad (close to 50 per cent, or even above). These include ABB, Ciba-Geigy, Eisaj, IBM, Hoechst, Philips, Roche and Sandoz.

Figure 1. **R&D intensity and proportion of R&D conducted abroad in the enterprises analysed**



Source: Database on International R&D Investment Statistics (INTERIS) and ISI Database on International Research and Innovation Activities (ISI-DORIA).

– Apart from these corporations, there is a group of enterprises mainly active in the area of medium to high technology, in some cases with divisions classified as high-tech, but with an overall R&D intensity of between 4 and 10 per cent, which are not so far advanced in transferring research functions abroad. A few of these enterprises have a share of foreign R&D of 20 to 30 per cent (*e.g.* BASF, Siemens and Sulzer); however, the majority of enterprises in this group are less advanced regarding their share of R&D abroad.

III. MAIN DEVELOPMENTS RELEVANT TO TECHNOLOGY POLICY

From production machinery to the global learning enterprise

While the situation up to the end of the 1970s was largely characterised by the dominance of a world centre for research and innovation (the United States in many important fields of technology, and Western Europe in individual fields, such as chemistry), it is now true to say that, for the important fields, two to three centres are crystallising out within the Triad countries. These are in fierce competition with one another, and from time to time very rapid changes in ranking take place. Because of this development, enterprises which are leading performers of R&D have to demonstrate a presence in several locations at the same time, establish sufficiently competent and extensive structures there, and react as quickly as possible to dynamic changes in relative location advantages.

For this reason, R&D centres and product development capacities were established within the same corporation at several different Triad locations as part of entrepreneurial integration strategies. At the same time, attempts are being made, through R&D co-operation exercises and strategic alliances – the numbers of which have risen substantially since the mid-1980s – to form networks as fast and as flexibly as possible between institutionally and regionally scattered centres of competence. In the course of the 1980s these strategies resulted in growing co-ordination problems, which in the meantime have led to new consolidation efforts, both in international corporations and among decision makers in national science and technology policy. Thus, in several well-known international corporations an initial, euphoric phase of R&D decentralisation was followed in the mid-1990s by a stronger tendency towards the formation of single ‘‘global’’ centres.

This development is linked with the fiscal consolidation of R&D, observed in almost all OECD countries. Both public institutions and private firms are increasingly coming up against the limits of ‘‘financeability’’ of R&D. In the highly developed industrialised countries, a share of 3 per cent of R&D expenditure in GDP represents a kind of ‘‘sound barrier’’. In some of the leading industrialised countries this value has been further reduced in the last few years: in Germany, the share of R&D expenditure in gross domestic product fell from 2.88 per cent (1987) to 2.48 per cent in 1993, and in the United States from 2.84 per cent (1987) to 2.72 per cent (1993). Corporations performing leading R&D are also reporting extreme problems in financing, on a private economic basis, certain parameters forced upon them by international competitors (*e.g.* expenditure on R&D amounting to well over 10 per cent of turnover).

In both public institutions and enterprises, this fiscal consolidation leads initially to short-sighted approaches: a stronger application-orientation and a corresponding reduction in long-term oriented research are observed. In many corporations this has led to a weakening of central research and to increasing ‘‘divisionalisation’’ of R&D. In universities and public research institutes, too, altered fiscal and policy priorities have not infrequently led to short-term pressure and the atrophying of long-term research competence.

A lack of equilibrium between strategic research and application-oriented development can have grave consequences, however, because in innovation-intensive fields that promise future growth the relationship strategic research-development-innovation is fundamentally altered. Research centres and international enterprises are increasingly gaining their competitive advantages from a close, undistorted link between basic and applied knowledge. Integrated product development processes, simultaneous engineering and increasingly close links between R&D, production and marketing are progressively emerging as the principles that shape innovation management.

With regard to R&D activities, it is a fact that changes in structure are triggering decisive changes in linking the elements of the value chain, both within corporations (*e.g.* in the co-ordination of transdisciplinary topics) and between enterprises (adoption of very different forms of co-operation in R&D). More and more, a re-thinking of the traditional view of the international enterprise is taking place: interest is no longer focused on a production machine for optimisation, seeking out its locations according to theoretical factor costs, but on the globally learning enterprise, gaining knowledge of options at the leading centres of intelligence and transferring them as rapidly as possible into marketable products.

On the one hand, this confirms that *globalisation* follows *different paradigms in different entrepreneurial functions:* the internationalisation of markets is determined by the search for markets with high income elasticities and low price elasticities in conditions of free world trade (‘‘logic of exchange’’), the transnationalisation of production locations is driven by the regime of production possibilities (work force, costs, other comparative advantages, closeness to market) (‘‘logic of production’’); and, lastly, globalisation is characterised by the pursuit of system competence through global ‘‘R&D sourcing’’ and the need for global firms to innovate on a permanent basis (‘‘logic of innovation’’) (see Gordon, 1994). On the other hand, our results show that the ‘‘three worlds’’ postulated in this theoretical approach repeatedly impinge on one another, so that the different paradigms merge again to some extent.

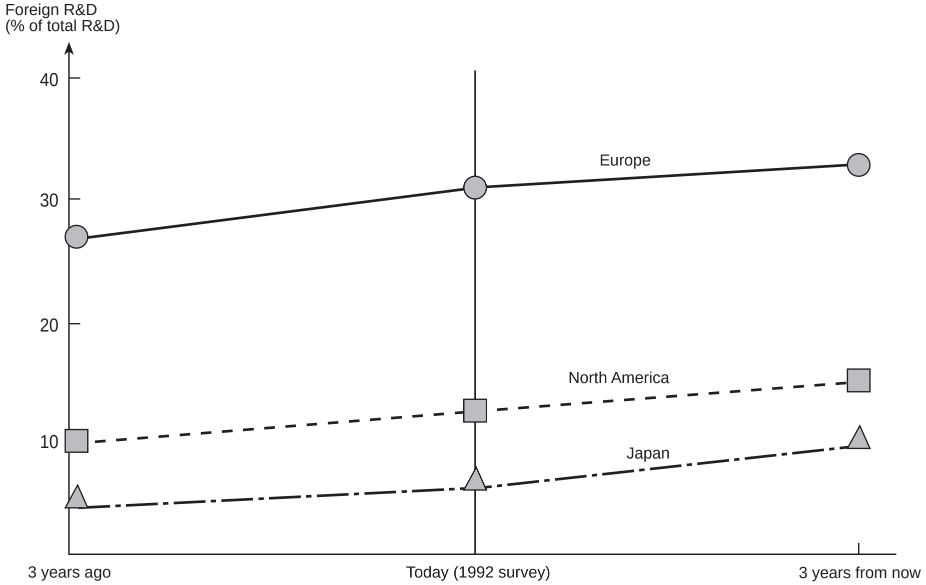
The sustained trend towards internalisation and the motives involved

In most R&D-intensive international corporations, the degree of internationalisation of research, product development and innovation has increased continuously throughout the 1980s and 1990s. The tendency towards the internationalisation of R&D can be seen in corporations with their headquarters in Germany: in 1970, Hoechst’s expenditure on R&D conducted abroad constituted only 5 per cent of its total R&D expenditure, while, in 1995, it reached nearly 50 per cent; the trend to internationalisation was most intensive in the 1980s and at the beginning of the 1990s. In 1993, Siemens’ share of R&D personnel employed abroad amounted to 28 per cent; in the period 1989-93, the number of Siemens’ R&D employees abroad went up by 60 per cent, while its R&D employees in Germany increased by only 6 per cent. Among the corporations in our survey, further efforts towards globalisation and tendencies to shift R&D to locations abroad are an explicit part of entrepreneurial policy and R&D strategy for the second half of the 1990s.

A recently published survey pursued at MIT, in collaboration with PA analysed 244 globally active enterprises which together account for 80 per cent of total industrial R&D expenditure in Japan, the United States and Western Europe. These firms were asked how the foreign part of their R&D had developed over the past three years, and how it would foreseeably develop over the next three years. As shown in Figure 2, European enterprises have the highest proportion of R&D abroad (about 30 per cent – but with the emphasis on R&D units in other European countries), followed by US and Japanese firms. Firms from all three of the Triad regions have increased their share of foreign R&D in the last few years and will be further increasing this ratio in the future. This result confirms the firm-specific statements in our empirical survey: in the period 1980-95, all the enterprises analysed, without exception, substantially increased the share of their R&D abroad. In the majority of the enterprises, R&D strategy consists in further building up and strengthening R&D units abroad.

The globalisation of research and innovation is comparatively advanced in branches and product segments with a high generation of knowledge and a strong country-specific differentiation of products and research systems. Until now, the pace in the globalisation process has been set by certain segments of the chemical/pharmaceutical industry (particularly agricultural chemicals,

Figure 2. **Proportion of foreign research and development in selected enterprises in Western Europe, the United States and Japan**



Source: Results of the MIT/PA study, summarised in Roberts (1995*a*, p. 55).

pharmaceutics, biotechnology) and the information technology industry (semiconductors, EDP, telecommunications, consumer electronics). There is still some ‘‘catching up’’ with the trend towards internationalisation of R&D to be done in branches where production and assembly still constitute a substantial part of value added, such as the automobile industry and the construction of industrial plants and machinery, but as the 1990s progress these sectors, too, are being swept along by the current of globalisation. Enterprises that are very far advanced in globalisation in specific branches are already showing counter-tendencies towards ‘‘de-globalisation’’, as growing complexity makes efficient steering increasingly difficult.

The motives for establishing R&D units abroad and the main factors in selecting locations have been examined in various empirical surveys.[3] These emerge mainly as market characteristics (size/attractiveness of foreign market, combined with the need to adapt product variants to country-specific situations) and specific location determinants (desire to access a local talent pool). Most of these studies, however, are driven by factor cost and factor availability considerations related to the R&D function. Our interviews, as well as more recently published investigations, emphasize the knowledge- and innovation-generating capacities of particular locations, and dynamic interaction effects between R&D, lead-marketing and advanced manufacturing. When deciding to establish or expand R&D units abroad, enterprises are motivated by the wish to gain access to highly sophisticated resources which cannot be found anywhere else, and to learn about specific customer requirements, market and production constellations on the spot. In our survey, the following motives for the ongoing globalisation of R&D and innovation activities were given particularly often:

- access to leading research results and talents;
- on-the-spot presence, learning in lead markets and adaptation to sophisticated customer needs;
- initiation and strengthening of R&D at locations where the effects of greatest usefulness can be expected and the highest cash flow is generated;
- monitoring and taking advantage of regulatory frame conditions and standardization;
- support of production and sales on-the-spot by local R&D capacities.

Thus the primary motive and aim of the internationalisation of R&D is not – as was the case in the past – the simultaneous maintaining of several globally ‘‘dislocated’’ R&D units, but rather the globalisation of learning processes along the whole of the value-added chain (research, development, production, marketing/sales, service relations, embedding in supply and logistic networks). The decisive parameter for the intensity of transnational learning and innovation processes is the proportion of value added within the corporation constituted by the generation of knowledge.

Many leading enterprises – and especially German corporations – are planning to expand their R&D capacities world-wide in the medium term, but generally not in their countries of origin. In view of a *latent growth potential of world-wide research capacities,* for which the locations have not yet been decided, national technology policy will have to orient itself more strongly towards the strategies of enterprises from other countries. This would offer chances for Germany to attract foreign enterprises to locate R&D in Germany, and to build up centres of competence.

Establishing world-wide centres of competence in R&D

Whereas during 1980s the internationalisation of R&D was associated with decentralisation and the ‘‘dislocation’’ of activities, the 1990s are characterised by a continuing trend towards internationalisation, accompanied by concentration, focusing and strategic emphasis. International enterprises that are leading performers of R&D are pursuing the strategy of a presence with R&D and product development at precisely those locations where there are the best conditions world-wide for innovation and the generation of knowledge in their product segment or field of technology. They are no longer satisfied with locations which ‘‘just about keep up’’ with the global technology race – they deliberately seek out the unique centres of excellence.

Although the majority of large international enterprises performing R&D are still following the strategy of keeping the competence base for their core technologies in their country of origin, processes of re-thinking are in progress. The dynamics of change in this context are dependent on global technology strategy on the one hand and, on the other, on the size and the resource base of the country of origin. The largest Swiss chemical firms internationalised their R&D earlier, and to a much greater extent than, for instance, the German ones. Thus, within a branch or product segment, a broad distinction can be made between two patterns: in corporations with a strong research and market base in their country of origin, units abroad mostly continue to have only scanning and exploration functions as well as application development tasks (this is true particularly of enterprises originating in Japan, in the United States, and in Germany, with the exception of chemicals/pharmaceutics). Compared with these, corporations with a less developed research and market base in their country of origin have come to occupy a ‘‘vanguard’’ role in globalisation. In corporations with their headquarters in Sweden, the Netherlands or Switzerland, and also in some individual enterprises from the large industrialised countries, R&D activities are increasingly being shifted to centres of excellence abroad, and the idea of concentrating ‘‘core technologies’’ in centres of competence abroad is also being firmly considered.

Even in large international corporations, this world-wide focusing of strategy and formation of centres is associated with considerable adaptation measures in organisation and management. The absorptive capabilities of an organisation, which enable it to draw sustained benefit from centres of excellence abroad, depend on whether the enterprise itself has concentrated enough competence on the spot, and whether it provides support from headquarters in the form of resources and decision-making competence. Despite their growing importance in terms of R&D expenditure, R&D units abroad in many enterprises still do not receive sufficiently strong strategic support and are sometimes inadequately co-ordinated. In the 1980s the linking of internationalisation with decentralisation led to duplication of tasks, to R&D units lacking the ‘‘critical mass’’ of resources and capacities, and to disputes about competency. From these experiences, transnationally oriented enterprises are now moving to consistent, cross-corporate technology management (*e.g.* ABB, Philips, Hoffmann-LaRoche, Hoechst). This generally also implies that the core activities of their R&D are concentrated as far as possible in one place and assigned as clearly as possible to responsible groups and locations.

This development leads to the fixing of a single centre as a ‘‘leading house’’ for one specific product group or technology within a corporation, to the extent possible. In view of this, the competition between innovation systems will increase. For allocation decisions in R&D, this change of direction implies that excellence of a national research system, although a necessary prerequisite for these decisions, is not in itself a sufficient condition. The conditions that have to be satisfied include particularly the presence of lead markets in the case of radical innovations (Table 2). With incremental innovations, it is mainly a case of building up local R&D capacities for the support of production and sales.

Table 2. **Orientation of R&D according to degree of innovation**

R&D	Incremental innovation	Radical innovation
Global	Development of equal parts	Centres of excellence and lead markets
Local	Adaptation to local/national conditions	Dissemination of start-ups

Formation of high performance units and ‘‘clusters’’

The relationship between production and R&D locations has become much looser. Competitiveness of production locations obviously tends to be based on the ‘‘cluster formation’’ of regional production structures and supply networks, nearness to large markets and minimisation of factor costs, rather than the presence of lead researchers, whose knowledge, wherever produced, can now be used world-wide. On the other hand, the concentration of industrial research in a very few ‘‘centres of excellence’’ in the world gives a small number of science centres the opportunity to offer themselves as attractive locations. The implications for technology and innovation policy are:

- Combining the attractions of market location with those of production location and R&D location, and exploiting the advantages of these links, works very effectively in enhancing attractiveness for the allocation decisions of internationally oriented enterprises.

– However, making use of the attractiveness of these three types of ‘‘Standort’’ in combination, and realising sustained synergies, can probably only succeed under very special conditions. The decisive factor is the type of driving force behind the synergy relations. The generation of cash flow is one powerful driving force. Production, as a cash flow generator, thus brings R&D in its wake, as for instance in the pharmaceutical industry and the automobile industry. Due to their cash flow, large and interesting markets still have good chances of becoming production locations as well as important R&D locations.

From time to time, contrary developments can also be observed: in areas where the dynamics of technological change are weak and/or where there are no substantial synergies between product- and production-related knowledge, R&D locations and production locations may well become dissociated. On the other hand, for certain types of strategies – particularly in highly dynamic fields – the close linkage of both locations is important. Under certain conditions, all three functions (market, production, R&D) may even coincide in one location. In the latter case, both from the viewpoint of the investing enterprise and of the location being invested in, only those projects and development strategies in which functioning high performance units are established along the whole length of the value chain can have a sustained and really positive impact. Under these conditions, R&D laboratories are set up primarily where the best conditions are to be found world-wide, both for research and also for the transfer of its results. These R&D units are part of a functioning cycle in the host country, and at the same time are embedded in a highly effective network of transnational learning.

The variety of co-ordination mechanisms

Following an initial phase of over-enthusiastic decentralisation of R&D in the 1980s, growing problems of co-ordination led to disillusion and the increasing formation of centres in a global context. At present, many multinational enterprises are experimenting with various mechanisms for steering and integration, with the aim of creating synergies world-wide and avoiding the duplication of tasks. It is certain that, in order to co-ordinate global R&D activities, an intelligent set of mechanisms is needed which must be combined as effectively as possible. Whereas the Japanese enterprises investigated place the emphasis on personal contacts, informal communication and socialisation, combined with a centrally dominated decision-making process, the Western European enterprises in the survey mainly rely on contract research for the divisions and daughter companies as a co-ordination mechanism (see Reger, 1996 and 1997 for detailed analyses). Especially in the German enterprises investigated, the importance of informal instruments and the formation of a corporate culture is often underestimated.

Particular importance attaches to the use of ‘‘hybrid’’ co-ordination mechanisms (such as multifunctional, interdisciplinary projects, strategic projects, technology platforms, core programmes and core projects). The novel aspects of these co-ordination mechanisms are that they cut across – or overlay – organisational and hierarchical structures, and that they are often used for the simultaneous co-ordination of several different aspects – for instance, co-ordination of R&D strategy with business strategies, integration of the business functions of R&D, production and marketing, as well as ensuring synergies between various areas of technology. In most of the enterprises investigated, R&D units abroad are not involved in strategic projects; so far, this is only the case in a few, truly transnational enterprises.

Manifold requirements for co-ordination also exist in public research systems. In this context, it can be observed in several countries that the development of new, flexible types of co-ordination mechanisms is not nearly so advanced in the public research systems as it is in the enterprises investigated. Several approaches, some of them newly developed, others already tried and tested, can also be transferred in adapted form to meet new networking needs in the public research system. This particularly applies to hybrid and informal co-ordination instruments, which can be used to form networks between various different levels and types of actors.

Management of corporate research and new businesses

In the transition from the first generation of R&D management (dominance of central research) to the second generation (divisionalisation, subordination of research to divisional interests), most large international enterprises substantially weakened their basic research in the course of the 1980s. At the beginning of the 1990s, the third generation of R&D management tried to achieve a kind of synthesis (simultaneity and equilibrium of group development and basic research, formation of portfolios). Empirical investigations in the 21 enterprises in the survey show, however, that third-generation management of R&D is causing problems in all the enterprises to a greater or lesser extent, and that to date various models have been experimented, all of which have to be regarded as ‘‘second best’’.

Japanese corporations are particularly consistent in their way of opening up promising future areas that require many years of preliminary research. A new research laboratory with a clear mission is set up, well-equipped in terms of staff and financial resources. As soon as a topic shows promise of becoming marketable, the laboratory is affiliated – as, for instance, in Matsushita Electric – to an existing division; the new technology is used for the expansion of existing fields of business. Alternatively, the laboratory forms the nucleus of a new division, if the enterprise has not previously been active in the relevant market. Several good examples of establishing R&D laboratories abroad, and the subsequent founding of ‘‘spin-offs’’, can be found in Canon, Mitsubishi Electric, Sharp and Matsushita Electric.

In any case, it can be stated that the enterprises surveyed are attempting to establish a balance between central research and development in divisions or business groups – no ‘‘best practice’’ has so far been found. In the Japanese enterprises investigated, excellent use is made of basic research abroad as an instrument for opening up promising fields of business in the long term. This example not only demonstrates the importance of global ‘‘technology sourcing’’ but also shows that judicious linking and embedding into the research systems of other countries is a necessary practice. Thus, enterprises and research institutions, in their efforts to achieve a stronger international presence in this way, will necessarily enter the orbit of national technology policy.

As a general result of this situation, the premise of national science and technology policy, encountered in many countries; that the main benefit from the public allocation of resources in this policy area flows into the national economy is progressively dissappearing. Not only the know-how produced in the national innovation system, but also other public investments, for instance in training and education, are increasingly being swept into the stream of the international exchange of knowledge. This development enlarges the focus of policy: it is not simply the appropriation of nationally generated knowledge that is involved, but the strengthening of a generally beneficial, interactive transnational exchange of knowledge. It is possibly as important to absorb knowledge generated world-wide as to support the production of knowledge in one’s own country.

IV. CONSEQUENCES FOR NATIONAL TECHNOLOGY AND INNOVATION POLICY

It is a general phenomenon that in many highly developed industrialised countries the globalisation of markets and the internationalisation of R&D have had relatively little effect on their national technology policies. However, over the past few years smaller countries have been more open in their attitudes than larger ones; the latter, due to their inertia and to their greater techno-scientific power, still have necessary adaptation processes ahead of them. In Germany, too, a national orientation predominates: in 1992, the share contributed by other countries to the financing of the total German research budget amounted to 2.4 per cent. In particular, R&D expenditure by other countries includes funds from the European Union and other international organisations, as well as the R&D funds of enterprises abroad, paid to domestic actors for carrying out R&D projects. The large amounts spent on R&D by the daughters of foreign corporations in Germany are not included in these figures. The share of R&D expenditure flowing out of the domestic sector into other countries in 1992 amounted to 3.8 per cent (DM 3.05 billion in absolute terms). This figure includes payments to other countries made by firms in Germany, as well as the contributions pledged by the Federal Republic to international scientific organisations in the area of research and to joint public R&D institutions. This form of expenditure by the federal government amounted to DM 1.66 billion in 1992, with 1.19 billion of this going to the European Space Agency (ESA) in Paris.

Nevertheless, global thinking has, of course, also found its way into German technology policy, for instance with respect to international standardization, the opening up of European supply markets, European technology policy – including large-scale European projects – and support of German enterprises in order to make them ‘‘fit’’ international partners in strategic alliances. In addition, the Federal Ministry of Education, Science, Research and Technology (BMBF) continues to implement new initiatives, such as the recent Asian-Pacific concept. Quantitatively speaking, however, these initiatives are modest; important new initiatives are not yet forthcoming.

On the other hand, R&D in German industry can be said to be already comparatively highly ‘‘internationalised’’. In the reports on the technological competitiveness of Germany (NIW, DIW, ISI, ZEW, 1995) that have been regularly submitted over the past few years, it is ascertained that, to date, foreign daughter companies in Germany have spent at least DM 7.8 billion on R&D approximately 15 per cent of R&D personnel in industry in Germany are employed by foreign daughter companies, and the share of foreign enterprises in total expenditure on R&D in Germany’s domestic economy was just under 16 per cent in 1993.

As a location for research, Germany has so far held a strong position in international comparison, especially with regard to US and Japanese enterprises. For example, Germany ranks second as a European location, after the United Kingdom, with regard to the number of research-performing enterprises with Japanese capital investment. The percentage of producing Japanese daughter enterprises performing their own R&D is actually highest in Germany. US daughter firms have the greatest R&D potential in Germany, followed by firms with Swiss majority ownership. About one-quarter of all R&D expenditure of US daughter enterprises abroad is in Germany; thus from the viewpoint of the United States, Germany has headed the list of locations abroad for a long time now.

Presence in, and learning from, the research and innovation systems of other countries

Recent results in innovation research show that in view of the increasing international mobility of enterprises and technology, and the growing similarity of important conditions in the offer of facilities (infrastructure, human capital), great importance attaches to efficient national innovation systems. Consequently, in contrast to the classic supply of facilities, it is the characteristics of task distribution and networking between the actors – in other words, organisational structural characteristics – that determine the comparative superiority or inferiority of a national innovation system. One of its most important characteristics from the viewpoint of globalisation is linkage to the research and innovation systems of countries that occupy a lead position in research and technology. The R&D allocation decisions of multinational enterprises show that as well as the criterion of proximity to, and presence in, important markets, enterprises also strive for a close link with leading research world-wide.

Although from the viewpoint of administrative law (*Ordnungspolitik*), it is a matter of contention whether the tasks of national technology policy include supporting internationally active firms in attaining these goals, it should not be controversial to suggest that at least national research establishments should be motivated and supported in their efforts to achieve a stronger presence and better integration in world-wide research networking and transfer. This implies that the ‘‘absorptive capability’’ of national innovation systems is becoming more important, *i.e.* the ability and speed with which they can absorb knowledge produced world-wide and pass it on to enterprises. The ability to open up fields and markets for the application of new knowledge and new technologies by rapid learning is decisive; this strategy is deliberately pursued, for instance, by small, technology-intensive countries such as the Netherlands, Switzerland and Sweden.

As an example, the efforts of the Fraunhofer Society (FhG) to become active ‘‘on-the-spot’’ in other countries can be cited. For instance, the FhG is attempting to link up with the ‘‘scientific community’’ in the United States in the area of graphic data processing – a field in which the United States is the recognised world leader in research – where it is trying to achieve the position of a seriously regarded partner. By contrast, in the area of production technology, particularly lasers, the FhG is instead pursuing the aim of presence in a market which is of increasing global importance for FhG services. The FhG has also intensified its activities in South-East Asia, where it is treading new ground by taking on the role of an international ‘‘broker’’ between technology supply and demand.

‘‘Learning’’ from other research and innovation systems relates to the behaviour of enterprises, particularly the reduction of ‘‘home-grown’’ deficits such as inadequate linkage of R&D to the market, too much concentration on technology and insufficient optimisation of technology use, organisation and qualification – *i.e.* conscious efforts to strengthen transfer competence. Telefax, cutting down the incidence or emissions of nitrogen in power stations, inventions by a German electronics firm and a German plant construction enterprise respectively, were successfully further developed by the Japanese into robust, user-friendly, reasonably priced products, and provide much-quoted demonstration material for the management of successful innovations. Learning also includes a forward-looking attitude with regard to the acceptance of technology. For example, in the case of foods produced by genetic engineering there is an urgent need for enterprises to enter into an intensive dialogue with consumer associations. This is happening in the Netherlands and Denmark, but not in Germany. The commonly made assertion of a dominant and widespread attitude of technology rejection in this country obscures the fact that science, state and industry have often omitted to explain the impacts of their actions or discuss them with society at a sufficiently early stage. In other innovation systems, acceptance of technology is better prepared by involving the various parties early on in the process. The list of such examples of success can be extended indefinitely. Early anticipation and active influencing of market acceptance enhance the chances of success for innovations.

Learning relates to structural changes. Thus, it emerged from a comparative analysis by the Fraunhofer Institute ISI of transfer systems in the United States and Germany that, despite considerable differences in the two national innovation systems, they have many similarities, and that technology transfer instruments are therefore transposable from one system to the other (Schmoch, 1996). From a German viewpoint, for instance, more active marketing of patents at universities, improving the framework conditions for venture capital, and intensifying co-operation between national large-scale laboratories and industry along the lines of the American CRADA model, are of interest. On the other hand, however, regarding stronger mobilisation of industrial sponsorship capital for universities, the limits of the German ‘‘sponsorship culture’’ would probably be reached very quickly. From an American perspective, the models of German ‘‘An-Institute’’ (extramural-type institutes close to universities with various forms of organisation and status), the Fraunhofer institutes and industrial joint research can act as models for the improvement of the United States’ own system. In both systems, public institutions fulfil a central function. Following the trend towards globalisation, they will have to open up more than has been the case so far to the participation of foreign research institutions in national programmes.

It is decisive for the German innovation system that it should enable efficient transfer and rapid learning to take place through intelligent interlinkage, in order to pursue the strategies of the rapid second innovator, become seriously considered as an international ‘‘player’’ and intelligently transfer structures, processes and framework conditions that foster innovations. This recognition brings with it a number of specific implications for technology policy, of which some examples are cited here. Some of these have already been elements of S&T policy for many years now, whereas others set new policy accents:

- Supporting the international activities of national public R&D institutions and enterprises by:
  - establishing international training/education and research programmes;
  - fostering the international mobility of students and scientists (*e.g.* in Germany, personnel exchanges have been found to be in the ‘‘under 5 per cent’’ zone), as well as encouraging researchers and students from abroad to come to Germany;
  - supporting the presence of domestic research institutions in other countries (joint ventures with other research establishments, research teams or institutes on a temporary basis);
  - supporting enterprises in their efforts towards a stronger global presence in R&D (including the acceptance of this strategy);
  - building up technological competence and positioning as an international ‘‘player’’ to be taken seriously in areas which have not so far been among the country’s classical strengths.
- Supporting the location of foreign R&D establishments.
- Two-way incentives such as:
  - promoting transnational projects (*e.g.* further developments of the EUREKA type);
  - supporting the ‘‘brokerage function’’ of public research institutions, to support the international exchange of technology supply and demand;
  - creating framework conditions and structures conducive to innovation at the national and regional levels;
  - monitoring innovation-friendly structures in other countries and making use of this experience for national policy.

Enhancing international attractiveness: lead markets and learning for the mastery of complex innovations

Analysis of the innovation activity of transnational enterprises shows that they are increasingly thinking in terms of integrated process chains, and are not primarily transferring their value added to locations which provide the best conditions for research only. The demand side obviously plays a more important role in R&D allocation decisions than do supply factors. From a macroeconomic viewpoint, the central question is rather: ‘‘Where will income be generated, where will the benefits be felt and where will new resources be created?’’ than: ‘‘Where will costs be created and where will existing resources be consumed?’’ In their transnational investment activities, enterprises are acting according to the following decision patterns: Where are the attractive, future-oriented markets in which users can be learned from, and which generate a sufficiently high return-on-investment for costly product development? Where can these markets be best served by highly developed production, logistic and supply structures? Where would it therefore be worthwhile to build up value added in *one* place? In what countries do attractive markets, highly developed production structures and excellent research conditions coincide, so that innovative core activities can be concentrated there?

In view of the strategic decision processes in transnational enterprises, the determinants and motives we have identified raise the following questions for national technology policy:

- In which end-user markets is the country regarded as a trend-setter, both in Europe and internationally?
- In which regions are production structures and supply networks so highly developed that high value added can be secured for the innovation system as a location in the long term?
- Which areas of the regional research and technology system are at a leading level world-wide and can also induce effects of strengthening national/regional lead markets and production structures?
- Where is influence being exerted (through participation in research and standardization alliances or in complex learning processes taking place in a national and/or regional context) on ‘‘dominant technological designs’’ for innovations, which will subsequently bring lead advantages in the global innovation competition?
- What is the relative strategic importance of the country as a market, and as a production location, from the viewpoint of enterprises world-wide?

By creating effective links with these fields of competence and building up ‘‘forward-backward linkages’’, it may prove possible to create high performance units with low transferability which are unique by world standards. Only by combining excellence in research with highly developed European lead markets, or by combining research with highly developed production structures, can the national innovation system position itself as a location for core competences that are not readily internationally transferable.

An important new item of knowledge to emerge from this survey is the significance of so-called lead markets. Small countries, too, can be very innovative and can function as lead markets. Examples of this include Switzerland (for medical implants and clinical instruments) and the Scandinavian countries for setting standards in mobile telephones. What are the characteristics of lead markets? They match one or more of the following criteria:

- a demand situation characterised by high income elasticity and low price elasticity or a high per capita income;
- demand with high quality requirements, great readiness to adopt innovations, curiosity concerning innovations and a high acceptance of technology;

- good frame conditions for rapid learning processes by suppliers;
- authorisation standards that are ‘‘trailblazing’’ for permit authorisation in other countries (*e.g.* pharmaceuticals in the United States);
- a functioning system of exploratory marketing (‘‘lead user’’ principles);
- specific, problem-driven pressure to innovate;
- open, innovation-oriented regulation.

The attractiveness of the national innovation system from this perspective is determined not so much by comparative, static competition factors such as costs and wages, as by its ‘‘dynamic efficiency’’.[4] This is largely dependent on the extent of social and organisational intelligence in the finding and acceptance of new structures and markets. Will complex system innovations (such as road pricing, product/service packages, closed-cycle economic concepts, new applications for information technology) be elaborated *e.g.* in Germany which will be used world-wide? Offensive learning through numerous field trials and pilot schemes to find technical, economic, legislative and social solutions is important. Learning processes of this kind often take years. The innovation system that first succeeds in mastering these complex solutions gives participating enterprises competitive advantages, and appears more attractive to foreign investors.

Opening up the science system, and technology policy, to other countries

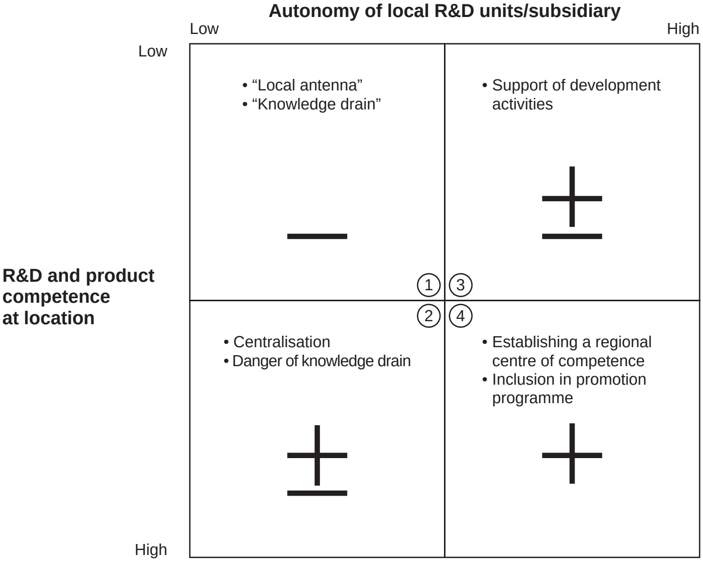
The discussion on regional locations is often suggestive of the notion of defending a national fortress (the stronghold of the nation as a location for industry, or other national domains such as science and culture) while extending, in a one-way process, the possibilities of its industrial subjects to conduct their business in other countries. However, globalisation is forcing the course of events in another direction: it implies a mutual opening-up and ‘‘penetrability’’ of legal and economic frontiers, of science and research systems, mobility of people, cultures, organisation and management systems. A proactive national technology policy will therefore also open up to other countries’ enterprises and research establishments.

A considerable number of foreign enterprises are actively performing research and development in Germany – some of them in their own R&D laboratories. The idea of the national science system being opened up to foreign enterprises, or foreign research establishments being set up – the Republic of Korea, for instance, is in the process of setting up a research institute for environmental technology in Saarbrücken – is frequently associated with the fear that antennae are simply being installed to ‘‘siphon off’’ nationally accumulated knowledge. These enterprises and establishments are considered with reserve, since there are fears of a one-sided drain of science and technology to headquarters abroad. It is feared that the ‘‘knowledge and technology drain’’ may take place without there being any positive impacts for the national innovation system, and that in the long term it will serve only to enhance the innovativeness and competitiveness of foreign rivals. However, it is not so much the geographical situation of the parent enterprise that is decisive for the impacts, as what type of R&D activities, what production capacities and services locate in the host country (*e.g.* autonomous research versus local antenna, highly-skilled manufacturing as opposed to the ‘‘extended workbench’’).

There is still a lack of clarity regarding the impacts of foreign R&D units on the national or regional location. However, the decisive factor is probably not the ownership situation so much as the willingness of foreign enterprises to establish the whole value chain, including research and development. A few US studies have shown that the R&D performed within a national economy is increasingly exploited world-wide, so that the idea that national technology policy primarily causes positive effects in its own country is no longer applicable. A stronger inclusion of foreign enterprises into national technology policy is thus inevitable in the end, and the issue at stake is to shape this process as usefully as possible for the home country. Japan, for instance, supports the presence of industrial R&D in its own country. ‘‘Useful’’ in this context implies *the generating of as many spill-over effects as possible within the country.* The involvement of Sony, for example, in regional DAB (Digital Audio Broadcasting) pilot projects in Germany is leading to a build-up of high-grade R&D capacities, and also possibly production capacities.

With the help of a matrix, the R&D activities at the location can be subjected to a first evaluation (Figure 3). If both the autonomy and the competence of the local R&D are low, it can be described as a ‘‘local antenna’’. Local antennae monitor the newest technological and market trends and transfer information to the corporation’s country of origin; such transfer is *one-way* (Case 1). If autonomy is low but competence is high, the R&D management is characterised by centralisation of the decision-making process (Case 2). Although R&D activities are carried out autonomously, the appreciable domestic spill-over effects will probably be only moderate, due to the centralised decision making. If autonomy from headquarters is high but competence is low, knowledge tends to be exploited on-the-spot (Case 3). This type of R&D is usually associated with production-supportive technology centres and the exploiting of local market chances. If the competence and freedom of decision of the local R&D unit are both high, the unit is a centre of R&D competence which also contributes to integrated transnational R&D activities. In this case (Case 4), it may definitely prove useful to include it more strongly in national technology policy. With regard to Cases 2 and 3, the advantages and disadvantages more or less balance out; in Case 3, at least, gains in competence can lead to positive development into a real, leading R&D centre within the corporation, which is also beneficial for the location.

Figure 3. **Matrix for evaluation of local R&D units**



Source: Author.

Some countries, such as the United Kingdom, Canada and Singapore, pursue a deliberate policy of attracting foreign R&D. Depending on the technological specialisation of national industry, different patterns of ‘‘location policy’’ can be observed: the United States, as a world leader in many research areas, behaves as a ‘‘bastion’’ in order to avoid too great a science and technology drain. Japan, by contrast, is (still) pursuing the course of a ‘‘claim’’, still trying to isolate itself by ‘‘soft’’ access barriers. Other countries, such as Singapore, pursue a strategic location policy, aiming to attract foreign R&D by focusing on specific fields and building up centres of competence.

In the context of regular reporting to the Federal Ministry of Economics on the structure of industry, two reports were submitted recently. The study by the HWWA-Institut für Wirtschaftsforschung (1995) comes to the conclusion that the globalisation of German industry (primarily with regard to production) implies a growing importance for industrial policy. With the internationalisation of production increasing, improving the quality of locations would mainly mean improving the qualification and flexibility of the work force, promoting investment and accelerating public decision making. According to this report, the financial support of domestic enterprises (*i.e.* enterprises with their headquarters in Germany), including the public promotion of technology, are increasingly missing the mark, since it is not certain whether these measures will generate income in the national or regional locations.

With regard to this question of whether or not traditional technology policy is ‘‘on target’’, our investigation reaches similar conclusions (*e.g.* on the subsiding of R&D). However, it is precisely this circumstance which leads us to plead the case for a reformulated concept of technology promotion; namely, both to support national research institutions and enterprises on their path towards globalisation and, at the same time, to gain foreign research institutions and enterprises for the national innovation system and, in both cases, to attain synergy effects and spillover effects beneficial to the location. The fact that, on its own, technology policy will fall into an ‘‘inadequacy trap’’ under these altered circumstances needs to be emphasized again and again. Technology and innovation policy is a strategic, interdisciplinary task, and the effectiveness and success of this policy will depend in large measure upon whether it proves possible to establish internal networking in this field between policy areas which have previously been fragmented.

Integrating different policies into innovation policy and building up lateral policy structures

All in all, it can be stated that globalisation is forcing national (and European) technology policy to re-focus technology promotion, orienting it towards the initiation of complex innovations that reach far into economic, legislative, social and societal domains. Here, too, it is the pace of learning and the mastery of new solutions that count. Not only leading-edge research, but the opening-up of new (lead) markets by anticipatory, future-oriented pilot projects is decisive for the international attractiveness of the national innovation system (‘‘keeping ahead in the learning race’’). The target group for technology policy has altered: research-driven enterprises are engaging in a change of strategy and are giving more consideration to the conditions of lead markets and production networks. Technology policy will scarcely be able to avoid following this change.

For this reason, successful R&D locations have particularly good chances of inducing economically positive impacts, *e.g.* on employment, if they coincide with production and market locations. Technology policy *on its own* cannot constitute a policy strategy promising success, this is an inherent dilemma. Thus the results of our study underline the necessity – much called for, but not as yet fulfilled – for better networking between different areas of policy. Insofar as they influence science and technology, these include – to name but a few examples:

- fiscal framework conditions for the formation of venture capital;
- the phasing-out of subsidies that preserve the *status quo;*
- regulation and approval procedures that relate to specific results and not to specific techniques;
- departmental policies such as transport, health, planning, environment, and economic policy;
- an active competition policy; and
- increased flexibility of civil service law in order to enhance the flexibility of institutionally supported research establishments.

To match the ever-increasing international demand for complex innovative and high performance units/networks, the lateral structures essential for their formation must once more be called for in policy.

In the Western European, US and Japanese enterprises investigated, different forms of organisation are used to co-ordinate various business functions, different areas of technology and corporate strategies or sub-strategies. These methods and experiences could possibly be exploited by actors in technology policy when generating and shaping public strategic ‘‘lead projects’’. One example is the use of strategic projects to build up, at a regional, national or supranational level, networks of non-transferable tasks, involving task-sharing by firms and institutions from each of the three steps of the value chain (R&D, production; lead market or final use). Strategic lead projects organised at a public level can help to attain the necessary ‘‘critical mass’’ and build up promising new networks of competences. For example, large German enterprises and foreign enterprises located in Germany both play an important role in these high performance units, which aim to build up domestic value added on at least one level, and if possible on several levels.

Difficulties in applying these co-ordination mechanisms lie in the details: technology policy should definitely draw on the experiences of large corporations in the use of these instruments. The following examples, drawn from the wide-ranging set of co-ordination instruments, illustrate possible applications for policy:

- interdepartmental ‘‘core projects’’ offer a means of focusing promotion funds on specific trans-disciplinary topics that cut across the technology-specific departments and promotion programmes of a Ministry of science and technology (*e.g.* the German BMBF is organised in technology-specific departments);
- qualitatively improved networking between education policy/technology policy, industry and science can be achieved through systematic ‘‘job rotation’’ of personnel in these three areas (or sub-systems), offering career incentives;

- strategic lead projects and technology/innovation platforms can serve for the selective, temporary integration of various ministries, enterprises and public R&D institutions in topics that are strategically important for society and the national innovation system.

Our study also sheds light on ways in which various corporations are trying to tackle problems of externality and long-term research by using new models of financing, and how sub-systems are co-ordinated with regard to certain aims. These aspects may also provide starting-points for shaping the principles of financing in public research and science promotion, and for the co-ordination of policy fields involving different policy actors. In addition, these modern R&D management approaches point the way to new forms of institutional flexibility, which are urgently needed in the public research system.

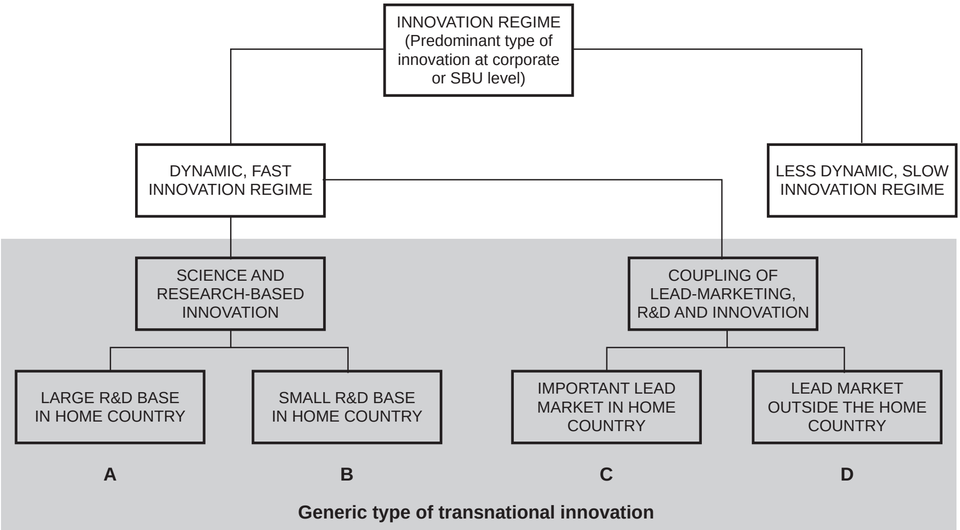
V. A FRAMEWORK FOR DESIGNING INNOVATION POLICY

Our empirical investigations have shown that R&D and innovation activities are – to a large extent – globally dispersed. Several companies in our sample indicated that they will perform more R&D abroad in the future, and that they are willing to be present in the most dynamic, innovation-enhancing foreign markets. Increasing global dispersion of activities, however, does not necessarily lead to greater decentralisation of ownership and control. Corporations want to benefit from multiple centres of learning on a global scale, but they tend to concentrate ownership and control of their most critical resources in only one country, or in a very small number of a few dominant innovation centres. The following framework may serve as a basis for analysing predominant patterns of globalisation, and to assess the related policy instruments of each pattern.[5]

According to our illustration in Figure 4, we have distinguished between two generic *innovation regimes,* characterised by the predominant types of innovation and their dynamics at the corporate level, or, if further differentiation is needed, at the strategic business unit (SBU) level.[6] These two innovation regimes represent polarised cases and may be further sub-divided into different sub-classes. We have found it useful to distinguish between:

- *dynamic, fast innovation regimes,* characterised by high R&D intensities, fast innovation cycles and a relatively strong importance of breakthrough innovation;
- these may be distinguished from *less dynamic, slow innovation regimes* (such as manufacturing or shipbuilding) which can be characterised by low R&D intensities, comparatively slow innovation cycles, and by the predominance of incremental innovation.

Figure 4. **Four generic types of transnational R&D and innovation**



Source: Gerybadze and Reger (1997, p. 23).

Our empirical study has been concentrated on corporations and strategic business units characterised by dynamic, fast innovation regimes (as illustrated by the shaded area in Figure 4). However, some of the large, multiproduct firms in our sample (*e.g.* ABB, Hitachi, Siemens, Sulzer, UTC) are active in different industries, and in diverse markets characterised by different innovation regimes. In those cases, we have mainly concentrated our analysis on the more dynamic, innovation-intensive business units.

Dynamic, fast innovation regimes have often been described synonymously with ‘‘science-based’’ and ‘‘technology-push’’ types of innovation. Our study shows that this connotation is no longer valid. While some dynamic business segments can still be considered as ‘‘science-based’’ (*e.g.* biotechnology), an increasingly large share of innovations is generated through demand articulation (Kodama, 1995), *i.e.* through an effective coupling of lead marketing, R&D and innovation. We have found it useful to clearly distinguish between these two clusters of dynamic innovation processes as outlined in Figure 4, because both require completely different innovation and location strategies of the corporation and different policy measures.

On the left hand side of Figure 4, we find *science- and research-based innovation,* for which corporations are dependent on excellence in R&D (*e.g.* genetic engineering or artificial intelligence). The most critical assets are leading researchers and world-class research laboratories. For these types of innovation, it is important from the corporate point of view whether the company is based in a large country with a highly advanced research capability in the particular field(s), or whether there is only a small, less-developed R&D base in the home country. According to these characteristics, we may distinguish between the following two generic types of transnational, science- and research-based innovation:

- *Type A:* The corporation is dependent on excellence in R&D and is located in a large, highly advanced home country with strong R&D capabilities in the particular field.
- *Type B:* The corporation is dependent on excellence in R&D, but is located in a small country and/or in a country with a less-developed R&D capability in the particular field.

While science- and research-based innovation still play a strong role for several corporations in our sample, many respondents emphasize other market-related factors which drive the innovation process. Innovations in the fields of consumer electronics, factory automation, instrumentation, advanced engineering, energy or medicine are at least as dependent on the interplay of lead markets, regulation and customer-supplier relationships, as they require a sophisticated R&D base. The most critical assets for the innovation process are the downstream-related complementary factors; crucial for success is the *effective coupling of lead marketing with R&D and innovation.* Demand patterns are driving investment behaviour which in turn influences the selection of new technologies. Corporations active in these fields are dependent on excellence in lead marketing and on presence in the most dynamic locations.

While learning from lead markets can occur at any location in the world, for the long-term success of a corporation it appears crucial that its top management can transform market stimuli into a sustainable business. Headquarters have to be involved, top managers have to understand the new businesses and their risk, and they have to mobilise the appropriate resources. The type and coherence of innovation management will thus crucially depend on the cultural and functional distance between the corporate headquarters and the lead market(s). In our empirical investigation, we found it useful to distinguish between the following two types of transnational innovation:

- *Type C:* The corporation can benefit from proximity to a world-class lead market, and can establish an effective coupling of lead marketing, R&D and innovation. Most of these high-end activities can be performed close to the corporate headquarters, at least within the same nation state.

– *Type D:* The firm is strongly dependent on access to a foreign lead market. Due to the small size of its home country and/or the level of market evolution, the firm is forced to perform critical functions abroad. Demand articulation and corporate resource allocation will be geographically, and often functionally, separated.

The observed changes and the dominant types of transnational innovation will also affect national technology and innovation policy, which has overemphasized supply-side R&D capabilities in the past. Since R&D capabilities and science-based innovation tend to be only one, often less important driver of global innovation, more emphasis has to be placed on downstream-related processes, effective lead markets, and on the enhancement of systems of demand articulation (Kodama, 1995). National innovation policy has to prevent simple ‘‘me-too strategies’’, but emphasize sustainable leadership positions, based on R&D capabilities, dynamic firms, effective clusters of business activity, as well as on dynamic lead markets.

This pattern of dominant innovation types deals on the level of the corporation with the expression of ‘‘home country’’ and as such on a national level. The thought behind this is that the degree of internationalisation depends on the size of the R&D base in one country (this explains *e.g.* why Swiss pharmaceutical corporations internationalised their R&D earlier and to a higher degree than German pharmaceutical companies). In fact, the absolute size of a country is not the factor which counts, but rather the extent and the quality of the R&D infrastructure and the R&D capabilities of the various institutions.

In this respect, Figure 5 may serve as a useful characterisation of the core issues of a national innovation policy in response to the four different types of innovation. In *Type A innovation,* there is a rich R&D base in the home country which should be built up to world-wide leading-edge research capabilities. This basis should be nourished by supporting talented R&D groups and networks. This excellent R&D base of the national innovation system will be an attractive location for R&D centres of foreign companies. Contrary to this desirable case is the *Type D innovation* which is strongly dependent on the coupling of lead marketing and innovation. In this case, firms are very contingent upon foreign lead markets and will be forced to perform critical functions abroad. Learning from this foreign lead market and facilitating reverse technology and know-how transfer should be supported by national policy. The growing up of a niche market in a selected field may be supported if necessary or possible. In the case of *D-type innovation* it will hardly be possible in the long run to keep home-country firms or attract foreign firms through traditional science and technology policy.

Figure 5. **Dominant types of radical innovation and core issues for national innovation policy**

	A	B
"Rich" R&D base and capabilities/ critical assets or market in home country	• Building up world-wide leading-edge research capabilities. • Nourishing this basis by supporting talented R&D groups/networks. • Attractive location for foreign R&D centres.	• Nourishing lead market. • Supporting demand-oriented lead projects, task forces, pilot networks. • Attractive centre of "customer learning" for foreign firms. • Attractive location for functions of foreign firms.
	C	**D**
"Poor" R&D base and capabilities/ critical assets or market in foreign locations	• Focus on the support of specialised R&D capabilities (*if possible*). • Acquisition of external knowledge from foreign R&D systems/institutions. • Relocation of R&D abroad.	• Promoting niche markets (*if possible*). • Support learning of firms from foreign lead market. • Facilitate reverse technology and know-how transfer. • Relocation of critical functions abroad.
	Science- and research-based innovation	**Coupling of lead marketing and innovation**

Source Author.

VI. NEED FOR A CHANGE IN NATIONAL TECHNOLOGY AND INNOVATION POLICY

Qualitative factors and dynamic upstream and downstream interactions are increasingly driving R&D location decisions. Thus the motives and aims underlying the internationalisation of R&D and innovation do not relate primarily to exploiting the cost advantages of globally distributed R&D units, but emphasize more the value-added effects of transnational learning processes along the whole value-added chain (research, development, production, integration into supply chains and logistic networks, marketing/sales and services relationships). The motives for establishing R&D units abroad are very much driven by learning from technological excellence *and* lead markets *and* dynamic interactions between R&D, marketing and advanced manufacturing. The attractiveness of a national innovation system will be increasingly determined by ‘‘dynamic efficiency’’, the ability to support learning processes in complex system innovations, and the interaction of specific institutions (firms, R&D institutes, universities, policy administration).

R&D-intensive companies are undertaking far-reaching transformations of their R&D activities. For many of these companies, the process of internationalisation in research, product development and innovation has been accompanied by an increasingly selective focus on a very few R&D locations and the concentration of innovation activities at so-called first-class centres. A parallel trend to establish a single centre of competence per product group or technology field is also taking place. The dynamics of change depend upon an enterprise’s global technology strategy, on the one hand, and upon the size and resource base of the enterprise’s home country, on the other hand. As a consequence, strengthening the public research system is a necessary but not sufficient, condition; highly-developed locations can be characterised by a lead market for various product areas and innovative production systems.

National technology policy as a *single* measure will no longer be a successful policy strategy. Innovation policy is a ‘‘cross-functional’’ task and various policy areas have to be combined to an *integrated* innovation policy. The efficiency and effectiveness of administrative processes in policy making and the establishment of lateral structures and co-ordination mechanisms between the different policy areas are becoming decisive factors for the ‘‘absorptive capacity’’ of the national system of innovation.

As well as modern methods of networking and co-ordination, business approaches to international R&D management also clearly show how strongly innovation processes are influenced by non-technical determinants. The necessity for a change of perspective in technology and innovation policy is apparent in other contexts, too – a move away from technical aspects and towards ‘‘soft’’ innovation factors such as organisation, qualification, management mentality, communication and styles of behaviour. This is true not only for the area of R&D management, but also applies, for instance, to new production concepts, energy saving, the use of environmental technologies, and to communication technology (Meyer-Krahmer, 1996). The promotion of technology can be complemented by support in the ‘‘management of change’’. The growing importance of these innovation factors will bring with it an analogous change in the approach of innovation policy. At present, however, actors in technology policy in many countries are seen to be only hesitantly embracing this process of change. In our estimation, many of the policy blockades that have been described will be swept away by the strong dynamics of globalisation.

NOTES

1. This article is based on an empirical research study on the R&D and innovation strategies of transnational corporations which was carried out jointly between the Fraunhofer Institute ISI in Karlsruhe, the University of St. Gallen and the University of Hohenheim (see Gerybadze, Meyer-Krahmer and Reger, 1997).
2. Examples for a very high R&D intensity at the corporate level are Roche (15%), Eisaj (13%) and Ciba-Geigy (11%). Several other firms spend less than 10 per cent of turnover for R&D at the *corporate* level, but display very high R&D intensities at the *business* level. As an example, SulzerMedica invests more than 10 per cent of its turnover for R&D, while the average ratio for the Sulzer corporation is only 3.4 per cent.
3. On this aspect, see particularly the overview in Cheng and Bolon (1993) and also Lall (1980), Mansfield, Teece and Romeo (1979), Ronstadt (1977), Teece (1976) and Kogut and Zander (1993).
4. Economic theory differentiates between static efficiency – relating to one point in time; and dynamic efficiency – relating to a long-term development. It is quite possible for static and dynamic efficiency to conflict with one another.
5. For a more detailed and elaborated analysis of the dominant patterns of transnational innovation and the policy effects, see Gerybadze and Reger (1997).
6. If most businesses of a corporation are characterised by similar innovation regimes, corporate-level generalisations are useful. If different businesses display different regimes, a detailed analysis at SBU level is required.

BIBLIOGRAPHY

CANTWELL, J. (1994), ‘‘Transnational Corporations and Innovatory Activities’’, in *The United Nations’ Library on Transnational Corporations,* Vol. VIII, London.

CHENG, J.L.C. and D.S. BOLON (1993), ‘‘The Management of Multinational R&D: A Neglected Topic in International Business Research’’, *Journal of International Business Studies,* First Quarter, pp. 1-18.

GERYBADZE, A., F. MEYER-KRAHMER and G. REGER (1997), *Globales Management von Forschung und Innovation (Globalisation of R&D and Innovation,* forthcoming in English), Stuttgart.

GERYBADZE, A. and G. REGER (1997), ‘‘Globalisation of R&D, Recent Changes in the Management of Innovation in Transnational Corporations’’, Discussion Paper on International Management and Innovation, February, Stuttgart.

GORDON, R. (1994), ‘‘Mastering Globalisation’’, Seminar on ‘‘The Future of Industry in Europe’’, Brussels, December.

HWWA-INSTITUT FÜR WIRTSCHAFTSFORSCHUNG (1995), ‘‘Grenzüberschreitende Produktion und Strukturwandel – Globalisierung der deutschen Wirtschaft’’, Forschungsauftrag des Bundesministerium für Wirtschaft, Hamburg.

KODAMA, F. (1995), *Emerging Patterns of Innovation,* Boston, MA.

KOGUT, B. and U. ZANDER (1993), ‘‘Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation’’, *Journal of International Business Studies,* Vol. 24, Fourth Quarter, pp. 625-645.

LALL, R. (1980), ‘‘Monopolistic Advantages and Foreign Involvement by US Manufacturing Industry’’, *Oxford Economic Papers* 32, pp. 102-122.

MANSFIELD, E., D. TEECE and A. ROMEO (1979), ‘‘Overseas Research and Development by U.S.-based Firms’’, *Economica* 46, pp. 187-196.

MEYER-KRAHMER, F. (1996), ‘‘Technologiepolitik’’, in D. Kahsnitz, G. Ropohl and A. Schmid (eds.), *Handbuch zur Arbeitslehre,* Munich.

NIW, DIW, ISI, ZEW (1995), ‘‘Zur technologischen Leistungsfähigkeit Deutschlands’’. Erweiterte Berichterstattung 1995. Zusammenfassender Endbericht an das Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF); vorgelegt durch das Niedersächsische Institut für Wirtschaftsforschung (NIW), Deutsche Institut für Wirtschaftsforschung (DIW), Fraunhofer-Institut für Systemtechnik und Innovationsforschung (ISI), Zentrum für Europäische Wirtschaftsforschung (ZEW), Hannover, Berlin, Karlsruhe, Mannheim.

NONAKA, I. and H. TAKEUCHI (1995), *The Knowledge Creating Company, How Japanese Companies Create the Dynamics of Innovation,* New York, Oxford.

PATEL, P. and K. PAVITT (1992), ‘‘Large Firms in the Production of the World’s Technology, An Important Case of Non-Globalization’’, in O. Granstrand, L. Håkanson and S. Sjölander (eds.), *Technology Management and International Business, Internationalisation of R&D and Technology,* Chichester, New York, Brisbane *et al.,* pp. 53-73.

REGER, G. (1996), ‘‘Internationalisation and Coordination of R&D in European and Japanese Companies’’, paper presented at the 12th International Conference of the Industrial Marketing and Purchasing Group (IMP) on ‘‘Interaction, Relationships and Networks’’, 5-7 September, Karlsruhe.

REGER, G. (1997), *Koordination und strategisches Management internationaler Innovationsprozesse,* Heidelberg.

ROBERTS, E.B. (1995*a*), ‘‘Benchmarking the Strategic Management of Technology (I)’’, in *Research Technology Management,* January-February, pp. 44-56.

ROBERTS, E.B. (1995*b*), ‘‘Benchmarking the Strategic Management of Technology (II): R&D Performance’’, Working Paper No. 119-95, Sloan School of Management, Cambridge, MA.

RONSTADT, R. (1977), *Research and Development Abroad by US Multinationals,* New York.

SCHMOCH, U. (ed.) (1996), *Technology Transfer in Germany. Interim Report for the German-American Academic Council Foundation,* Karlsruhe.

TEECE, D.J. (1976), *The Multinational Corporation Cost of International Technology Transfer,* Cambridge, MA.

NEW APPROACHES IN TECHNOLOGY POLICY – THE FINNISH EXAMPLE

TABLE OF CONTENTS

This article was written by Erkki Ormala, of the Science and Technology Policy Council of Finland (e-mail: erkki.ormala@ktm.vn.fi).

I. THE EVOLVING SCOPE OF R&D POLICY

Traditionally, R&D policies were oriented towards the creation of new scientific results – strengthening the national and global knowledge base. In the 1980s, the increased understanding of the importance of knowledge for economic and social development oriented the focus of R&D policies more towards the problems of dissemination and utilisation of knowledge. New concepts, such as the systems model of innovation, national innovation systems, the distribution power of the innovation system, the information society, etc., together with a better understanding of knowledge, *i.e.* the distinction between tacit and codified knowledge, further expanded the scope of R&D policies in the 1990s. Corporate governance, networking and the absorptive capacity of firms have become important issues in R&D policy. A new concept of innovation policy has been developed to complement traditional R&D policy.

The gradual shift in the orientation of R&D policies towards innovation has drawn attention to the other conditions of innovation. Innovation activities are dependent not only on the effective production, circulation and absorption of new knowledge, but also on stable macroeconomic conditions, learning, financing, regulations, market conditions, etc., which are all issues beyond the scope of R&D and innovation policies. These conditions have been widely discussed during the last few years at both the OECD and European Union levels. The conditions for innovation are strongly affected by other policies such as industrial policy, education policy, regional policy, financial policy, etc. R&D and innovation policies have to learn to interact with these other policies in order to create favourable conditions for innovation in the whole economy. The aim is to develop different policies which work together in a co-ordinated way.

II. THE DEVELOPMENT OF INNOVATION POLICY IN FINLAND

The development of science, technology and innovation policies in Finland followed the same path. The national innovation system approach was selected as a basis for national policy planning at the beginning of the 1990s. This approach has been followed consistently ever since.

Policy development entered a new phase in Autumn 1996 when the Finnish Government decided to increase government research financing with a view to raising the national research input to 2.9 per cent of GDP by 1999. The decision reposes on the privatisation of the state-owned companies. The level of government research funding will increase by Mk 1.5 billion (US$300 million) over the next two and a half years. This represents a 25 per cent increase on current government research funding. This increase, together with the projected increase in private sector R&D expenditure, will raise the national research input to the target level by 1999.

The government invited the Science and Technology Policy Council to draw up plans for the allocation of these new resources. The special aim of the increased research funding defined by the government was to develop the national system of innovation to the benefit of the economy, business and employment.

The Prime Minister characterised the decision as ‘‘the most important industrial policy decision this government has made’’. I will try to explain briefly the motivations behind this decision and how the money will be used. Current plans for allocating the funds reflect our best understanding of the future challenges of science, technology and innovation policy in a small, open economy preparing for monetary union.

III. THE RATIONALE UNDERLYING THE DECISION

It is not possible in this context to give a full account of the various arguments and discussions which preceded the decision. Rather, the following observations are impressions, characterising the debate and highlighting its nature.

Industrial structure. Finland has been able to create a strong renewal process in its industrial structure. Industrial structure is becoming more specialised towards knowledge-intensive, high-growth sectors and products. This process, which started at the beginning of the 1980s, has accelerated during the last few years. There is enough empirical evidence available to describe the characteristics and prerequisites of this development.

A more diversified industrial structure is vital for Finland’s economic stability within the single currency. The structure of the Finnish economy has traditionally differed from that of the large European economies; this implies that the decisions of the European Central Bank do not necessarily reflect the needs of the Finnish economy. Knowledge-intensive growth is seen as the most important process for diversification. On the other hand, the decision to increase public R&D funding contained a clear message that the money needed was to be raised from the sales of state-owned companies and would not affect Finland's endeavour to meet the convergence criteria.

Job creation. The high unemployment rate (some 16 per cent of the labour force, *i.e.* about 400 000 people) makes job creation a crucial policy issue in Finland. Knowledge-intensive firms were able to continue increasing employment throughout the recession of the beginning of the 1990s. This process has accelerated since 1994. For example, the electrical and electronics industries have created 15 000 new, well-paid jobs over the last two years. The Science and Technology Policy Council has estimated that the direct net effect of the knowledge-intensive growth on employment will be 30 000-50 000 new jobs over the next three years. This estimate does not include the additional jobs that will be created through subcontracting and related business services. Some empirical evidence suggests that these indirect effects could create 0.5 to 1.5 jobs for each job generated directly.

Income. From the point of view of the national economy, knowledge-intensive jobs are of vital importance. The bulk of knowledge-intensive output is exported and the relevant jobs are well paid. Thus, this growth adds significantly to revenues from abroad and taxes for the economy, and creates considerable demand for domestic services.

Other arguments were presented during the debate. For example, knowledge-intensive growth is seen to contribute to *balanced regional development* and to the prerequisites for *environmentally sustainable development.*

Innovation is the driving force of knowledge-intensive growth. Innovative firms have the ability to adjust to changes in the global market-place, increase productivity and create new jobs. These firms are, however, in many ways dependent on a favourable environment that facilitates the emergence and growth of innovation and new business.

The national system of innovation is the main policy instrument involved in the enhancement of innovation. The examples presented above reflect the context in which innovation policy is discussed in Finland. Effective innovation policy is considered highly relevant for economic stability and other major policy concerns. Innovation policy is a part of an overall government strategy to respond to the economic and social challenges of the future.

Innovation is dependent on many different factors: R&D, education, innovation financing, networking, innovation management and new work organisations all contribute to innovation. The decision to invest new resources in R&D, however, is based on an understanding of the generic role played by R&D in innovation. R&D is not simply a way to produce new knowledge: it is an essential characteristic of a learning organisation. It integrates the different types of knowledge required for innovation to take place. It opens up channels to external sources of knowledge and facilitates participation in joint ventures. Ultimately, R&D should strengthen firms' absorptive capacity and ability to apply new knowledge. Therefore, the government's decision to increase R&D spending is expected to strengthen the innovative performance of the economy on an economy-wide basis.

IV. ALLOCATION OF THE NEW FUNDS

The decision to use the increased resources to the benefit of the economy, business and job creation provided a clear focus for resource allocation. The first criteria of selection was to allocate financing to end-users on the basis of competition. Consequently, the basic funding of universities or research institutions was not increased. Instead, the new funds were used to increase non-committed ‘‘competitive’’ funding. A second principle was to use the bulk of the money for technology and targeted basic research and education. Some funds were also allocated to sectoral ministries for so-called ‘‘cluster programmes’’.

The increase earmarked for technology (some Mk 900 million of the total Mk 1.5 billion) was allocated to the Technology Development Centre (TEKES) to strengthen the core activities of the organisation: technology programmes and product development funding, with a special aim to expand the number of firms participating in the programmes and development projects. In addition, the scope of operations was expanded to cover targeted basic research, programmes to be conducted in the regional competence centres, R&D projects in the services sector, cluster programmes within the sectoral ministries and new schemes (*e.g.* the capital loan scheme) to bridge the gap between traditional R&D funding and venture capital financing.

The new resources for basic research were allocated through the Academy of Finland (the scientific councils) to launch research programmes in strategic fields, to strengthen the centres of excellence in the universities, to create a system for post-doctoral education and to expand international scientific co-operation. The additional university resources were allocated to strengthening the best graduate schools and to establishing new ones in selected fields of science and technology, to improving scientific instrumentation, to intensifying co-operation between universities and industry and to increasing education in those scientific and technological fields relevant to knowledge-intensive growth. All new investment in basic research and education (about Mk 550 million) is intended to increase the relevance of the science base and education for innovation.

The remaining additional funds were allocated to the sectoral ministries for use in the cluster programmes and to the Ministry of Labour for the development of high-performance work places, which can provide ‘‘benchmarks’’ for an economy-wide organisational renewal. The cluster programmes comprise telecommunication, foodstuff, transport, environment, forest and welfare clusters. The aim of these programmes is to encourage new forms of co-operation between scientific and technological organisations, industry and government organisations. This co-operation is intended to strengthen the links between innovation policy and other relevant policy sectors, providing new opportunities, for example, for developing regulatory frameworks so that they become more conducive to innovation and generating demand for new innovations within the public sector.

The overall objective of the new resource allocation is to make the whole research and higher education system more demand-driven, increase its flexibility and strengthen the links between knowledge producers and users. New activities are also expected to bring about systemic changes in the institutional structure of the innovation system.

The efficiency and effects of the new investments will be evaluated. Specific arrangements have been designed to respond to this need, including, for example, an independent high-level expert group disposing of sufficient resources and calling upon expertise from both Finland and abroad. A ‘‘real-time evaluation process’’ will be implemented. It is also anticipated that new developments in evaluation methodology will be necessary in order to provide a sufficiently comprehensive view of the industrial and employment effects of the whole exercise.

V. SOME CONCLUDING REMARKS

These considerations lead to three challenges relevant for governments’ efforts to implement consistent innovation policy.

Science, technology and innovation policy has become a key element of governments’ strategies to achieve economic stability. Traditional measures, such as fiscal policies or subsidy-based industrial policies, are disappearing from governments’ arsenals. By developing national systems of innovation, countries can provide an environment favourable to knowledge-intensive growth, increasingly seen as the key option for the future in the OECD area. Innovation policy will tend to remain in the national domain within the global economy.

Governments are not necessarily organised in the best possible way to manage innovation policy. Ministries usually have clear sectoral responsibilities. Innovation policy is a horizontal policy, requiring a co-ordinated contribution from a number of different sectors. To borrow the words of Alan Nymark at the Oslo Conference on ‘‘Creativity, Innovation and Job Creation’’ in January 1996: ‘‘Governments have a key integrating role to play, not only in managing knowledge in their ministries and agencies but also in improving the acquisition and application of knowledge on an economy-wide basis’’.

Finally, innovation policy requires specific skills which traditionally are not always readily available in government organisations. Competence in business, public administration, economic policy and innovation is essential. Everett Ehrlich posed the following question at the Stockholm Conference on ‘‘Industrial Competitiveness in the Knowledge-based Economy’’, earlier this year: ‘‘Do the rules for government hiring lead to the right balance between developing expertise and institutional memory in the government, on the one hand, and avoiding entranced bureaucracies, on the other?’’ One way to proceed could be to encourage the mobility of personnel between the public sector and business. It is not enough to have one highly competent group working in some part of the administration. Competence must be found in all the relevant sectors in order to create a ‘‘critical mass’’ to push new approaches through the administration to the political debate.

TECHNOLOGY AND INNOVATION POLICY FOR THE KNOWLEDGE-BASED ECONOMY: THE CHANGING VIEW IN CANADA

TABLE OF CONTENTS

This article was written by Andrei Sulzenko, Assistant Deputy Minister, Industry and Science Policy, Industry Canada, Ottawa.

ABSTRACT

The global economy is undergoing a major structural adjustment – the shift to knowledge-based growth, characterised by falling costs and rising efficiency in the transmission, retrieval and analysis of information. The most distinguishing feature of this knowledge-based economy (KBE) is that it uses knowledge pervasively as both an input and an output throughout the economy. The ability to create wealth will be increasingly dependent on the effective management of knowledge, that is, the organisational capability to create, acquire, accumulate, disseminate and exploit information and knowledge. This adjustment has an impact on all segments of Canadian society, as well as all sectors of the economy.

A consequence of the emerging knowledge-based economy is that in virtually every OECD country, S&T policies are in a state of transition. A recent major review of Canada's federal S&T policy re-evaluated where and how to invest resources. An important conclusion from the S&T review was that, to the extent possible, public sector policy needs to stay ahead of the new dynamics and requirements of the knowledge-based economy, rather than continually play catch-up in response to new developments. This approach has three themes: effective new institutions, relationships and networks must be established to enhance the ability of Canadians to gain and share knowledge and information; the links between job creation, economic growth, advancement of knowledge and quality of life must be well understood and strengthened; and the federal government must develop effective partnerships with business, academic institutions, other governments and voluntary organisations.

Reflecting these themes, this article describes a number of important shifts in federal S&T policy that have taken place during the past two years in particular. These have had the effect of changing behaviour and relationships in both the private and public sectors, in ways that strengthen the national system capacity for innovation.

I. POLICY IMPLICATIONS OF THE KNOWLEDGE-BASED ECONOMY

To a large extent, the knowledge revolution is not revolutionary. Economic progress, since the invention of the first tools, has always depended on new ideas and innovation: better tools lead to better results; better organisation of work improves performance. And the combination of these two factors can increase the wealth of the community. The knowledge revolution has not changed these basic relationships. What has changed is our understanding of the process of economic growth and the role of knowledge in it, and the resources and technologies available to those whose job it is to apply knowledge to economic issues. These factors have intensified the relationship between knowledge and economic performance and this is having a profound impact on our economy and society. Knowledge is now recognised as being at least as important as physical capital, financial capital and natural resources as a source of economic growth. This is a recent development that challenges many of our current institutions and policies that were developed in times when the role of knowledge was less well understood.

There are two major underlying and interrelated forces that are helping to shape this emerging economy. First, there is the well-known force of globalisation. Increasingly, economic activity is undertaken without reference to international borders. This extends the size of markets and the horizons of companies, allowing greater specialisation and focus. Second is the falling cost and rising efficiency in the transmission, retrieval and analysis of information. Together, these forces are creating a global economy in which knowledge is used pervasively as both an input and an output. So, for example, information technology is a growing part of investment in all segments of the economy – from agriculture, to restaurants and aerospace firms. Knowledge inputs are becoming more important for productivity and growth. At the same time, knowledge is becoming more important as an output, with management consulting, software development and education joining the fastest growing sectors of the economy.

Characteristics of the knowledge-based economy (KBE)

In the KBE, the ability to generate and use knowledge – to innovate – is not only the determinant of wealth, it is also the basis of comparative advantage. Knowledge is fundamental to improving the efficiency of production and distribution processes, improving the quality and quantity of products, and increasing the selection of products and services.

The sectors that succeed will be those which develop new ideas, employ new processes, manufacture new products and deliver new services. Investments in knowledge (research and development, intellectual capital, software and technical expertise) contribute directly to the development of the manufacturing and service sectors through their demand for leading-edge goods and services and they also maintain demand and jobs in the primary sectors of the economy such as agriculture and natural resources.

In the past decade, the high-technology share of OECD manufacturing production and exports has more than doubled, and the OECD estimates that more than half of total GDP in rich countries is now knowledge-based. Employment in the KBE is characterised by an increasing demand for educated and highly skilled workers. In Canada, between 1971 and 1991, employment in high-knowledge and high-technology industries increased on average by 1.2 and 0.8 per cent per year, respectively, *versus* marginal decreases in other sectors. While the transition to a KBE holds the prospect of improved economic performance, it also brings with it formidable adjustment challenges with implications for firms, individuals, educational institutions and governments. The redefinition of the world of work and the transformation of the work place is an important source of insecurity and apprehension for Canadians. Since the mid-1970s, increases in non-standard employment (part-time, short-tenure and self-employment) accounted for 45 per cent of overall job growth. While most persons working in non-standard jobs choose this option, an increasing proportion has no other choice. Non-standard employment is often unstable and insecure, offers poor training opportunities, and wages and benefits tend to be low. This trend, coupled with persistently high unemployment rates and widespread business downsizing, have all raised concerns about the disappearance of good jobs that offer security and high wages.

Determinants of success in the knowledge-based economy

Evidence demonstrates that the individuals and firms that adjust and innovate are those that survive and thrive. More specifically, the firms that succeed in the new economy are globally-oriented, highly productive, and invest heavily in knowledge and skills. This investment includes innovating in three principal ways:

- adopting and applying new technologies;
- becoming more innovative in their organisational and human resource management; and
- exploiting the synergies between these two factors.

While innovation – finding better ways to do things – has always been the predominant factor in sustained productivity and long-term economic growth, in the new economy the effective management of knowledge will be the decisive determinant of success.

The failure to innovate has been a major reason for Canada’s relatively slow productivity growth over the past two decades. In the new economy, adaptation means innovating on all fronts – adopting not only the ‘‘hard’’ technologies such as information and communication technologies, but also the more flexible organisational structures, new management strategies and innovative human resource developments that are needed to make the hard technologies work. Failure to adopt these complementary innovations has meant failure to realise the productivity potential of the new technologies.

While Canada has not been the only developed country challenged by the new adaptation to change, its productivity growth record has been particularly poor. Some of the factors that have contributed to this weak performance include the slower and weaker adjustment to the energy-price and exchange rate shocks, slower capital accumulation, poor fiscal performance, slower R&D spending, slower adoption of leading hard and soft technologies, and relatively weak competition in domestic markets.

The KBE is generating a strong demand for knowledge workers; that is, those involved in acquiring and applying knowledge, who know how to learn and who continue learning by upgrading existing skills and acquiring new skills. These workers have transportable and transformable skills and are committed to and capable of lifetime learning and lifetime creativity. They are central to corporate competitiveness and the resilience of the economy. Census data show that the skills of the employed work force – not only educational attainment and years of experience, but also measures such as cognitive complexity and task diversity – have risen steadily over the period 1971-91.

However, many Canadians lack the skills required to take advantage of, and compete in, large parts of the KBE. The International Adult Literacy Survey shows that 42 per cent of Canadian adults are ill-equipped to work in an increasingly knowledge-intensive environment where fundamental skills such as basic literacy and numeracy are essential. The KBE requires skills that are broad and highly transferable, such as problem solving and the ability to learn. Three sets of employability skills are considered critical by major employers:

- academic skills, which provide the basic foundation to get, keep and progress on a job;
- personal management skills, which demonstrate attitudes and behaviour; and
- teamwork skills, which are needed to work with others.

The new economy is placing increasing demands on firms and universities to disseminate knowledge within their own organisation, among their work force, and with other firms and institutions. Firms need to build and strengthen alliances with information producers such as educational institutions, to expedite the transfer of knowledge into commercial application and to secure a steady supply of highly qualified personnel. Thus, the development of networks and strategic alliances, including research consortia of firms, joint R&D ventures, and university-industry partnerships which define and execute research in a collaborative manner, is crucial. Studies indicate that there are real benefits to university-industry collaboration. For instance, it has been estimated that the return on R&D is 35 per cent for firms with university links, compared to 13 per cent for firms without such links.

The challenge for firms is to transform themselves into learning organisations to improve the accumulation and retention of knowledge workers and to encourage the broader and continuous diffusion of knowledge. For workers, the challenge is to continuously upgrade and broaden their skills, through formal education, as well as through learning in the work place and in less formal surroundings. Firms also need to establish a high-performance work place to manage these knowledge workers more effectively. There is growing evidence that organisations which embrace the philosophy of the high-performance work place, by innovating in total quality management, organisation of work and human relations management, improve their performance in the form of productivity growth, market shares, profits and customer satisfaction.

Building a world-class knowledge-based economy

The transition to the KBE and the associated risk of excluding the less skilled and less educated demonstrate the importance of investing in education and training to improve the skills and competencies of the labour force. Successful adaptation to the KBE will depend on both the quality of the education system and the institutional framework that gives workers the opportunity to obtain the reschooling and retraining they need to make employment transitions throughout their lives. The first challenge is how to develop the skills of the widest possible number of individuals and how to provide the necessary opportunities and incentives for lifelong learning. The second is how to enhance industry’s commitment to human resource development to promote productivity gains, growth and jobs. Addressing these challenges is a shared responsibility on the part of governments, firms, institutions and individuals – each has a vital role to play.

Post-secondary education (PSE) institutions are critical to the creation, dissemination and transfer of knowledge through their research mission and the training of highly qualified and skilled personnel. In the KBE, these institutions can play a much broader role than they do today, including becoming the hub of economic, community and social development. Strengthening and broadening partnerships with these institutions and business, will also help to improve Canada’s ability to turn knowledge promptly into more and better jobs.

Past experience tells us that infrastructure is critical to the productivity performance of the economy. Over the years, Canada has invested heavily in infrastructure to support economic growth. In the 1950s and 1960s Canada focused efforts on building the transportation and education infrastructure, and in the 1980s, telecommunications took priority. Past investments in infrastructure have kept pace with the needs of society and the economy. The emergence of the KBE and the importance of the effective management of knowledge, demand that we look at infrastructure as more than just bricks and mortar. While a growing economy needs the support of dynamic new transportation and information infrastructures, we must increasingly view institutions and networks, human capital and science and technology, as the infrastructure that supports economic activity in the new knowledge-based global environment. Accordingly, the knowledge infrastructure can be seen as comprising those components necessary for the effective creation and transmission of knowledge, including transportation systems, communications systems, technological networks such as the information highway, research facilities and university laboratories, and investments in human capital such as education, training and apprenticeship.

II. THE SHIFT IN CANADA'S SCIENCE AND TECHNOLOGY POLICY

As a result of the transition to a knowledge-based economy, significant changes have taken place in the way Canada's federal government views and acts upon science and technology. 1994 marked the beginning of the current shift in science and technology (S&T) policy. The government launched a major policy review which resulted, in March 1996, in a Science and Technology Strategy (*Science and Technology for the New Century*).[1] This Strategy brought about some fundamental changes:

- The linear approach to innovation has been abandoned. It was recognised that innovation is non-linear and has to be holistic. National innovation performance is a function, not only of the innovation in individual organisations, but also of the relationships and networks between institutions. This represents a shift in paradigm to a national innovation system approach, with a particular emphasis on those parts of the innovation system that must be strengthened, *e.g.* the links between the advancement of knowledge, its commercialisation, sustainable economic growth and the quality of life.
- The federal government has shifted its role from ''prime mover'' to being a catalyst, facilitator and strategic investor. Initiatives must promote partnerships and lever funding, so that complementary and co-ordinated actions are taken by government, business, academia and other organisations. This produces better outcomes. For its part, the government is targeting its investments to fill gaps.
- Changes in the S&T governance system were an important feature of Canada's Science and Technology Strategy. For the first time, principles and directions were established which were used by each Minister with responsibilities for science and technology expenditures as the starting

point for preparing an action plan. Accomplishments in implementing the Strategy and the related action plans will be monitored through an annual report to Parliament. As well, Ministers now have a collective responsibility for oversight and, from time to time, will consider cross-government policy issues and science and technology priorities. Added to this is a new external Advisory Council on Science and Technology, which reports to the Prime Minister and will provide advice directly to Cabinet on policy matters.

Numerous policy and programme shifts have taken place over the past two years in particular, which flowed from the Science and Technology Strategy. The rest of this article provides examples which are intended to illustrate some of the more prominent new programmes and show how they are improving the innovation capacity of the nation.

Translating the science base into economic growth

Maintaining an adequate science base and translating it into jobs and growth poses some major challenges. The rapid obsolescence of university research infrastructure may lead to Canadian research falling behind research teams elsewhere which are better endowed. As well, in addition to the typical barriers to effective university/industry relationships research, the geographic dispersion of the major research universities in Canada meant that it was difficult to develop sufficient critical mass in certain research areas. In the past, issues such as these were dealt with by incremental policy responses. This has now given way to major new initiatives which are strengthening the science base and building its linkages to the private sector.

The networks of centres of excellence

The *Networks of Centres of Excellence (NCE)* programme,[2] announced in 1990, joins world-class researchers in common research programmes. From the start, it provided enhanced support for research excellence and accelerated results by encouraging the best researchers in Canada to work together, no matter what their institution. Networks were chosen on the advice of an independent international panel, using criteria that stressed world-class research. A second competition in 1994 reviewed both existing networks and new candidates. It gave more explicit weight to industry partnerships. In recognition of the programme's success, the federal government's February 1997 Budget made its funding permanent, instead of being subject to periodic renewal.

Currently, there are 14 networks in a variety of fields such as tele-learning, concrete technology, wood pulp, robotics and protein engineering. Together, they link 48 universities, 37 hospitals, 76 government agencies, 63 research institutes and 405 firms. Current employment in all networks is about 3 000, including 1 400 students. They are effective in training researchers. Ninety-eight per cent of people employed by networks find jobs in Canada, 58 per cent in industry.

Networks involve researchers from several universities, but have a common administration, budget and work plan. Firms and government departments may participate actively in the research, and contribute funds. For instance, ISIS, the *Network for Intelligent Sensing for Innovative Structures,*[3] is designing and field testing public infrastructure, such as bridges and parking garages, which incorporate ultra-high-strength fibres coupled with remotely monitored sensors – a direct response to growing infrastructure costs. This network has 28 participants (11 universities, 3 firms, 10 government departments and 4 institutes) and 19 non-participating industrial affiliates. Its director and administration centre reside at the University of Manitoba, while its Board of Directors is chaired by the CEO of a major engineering consulting firm. Delegation of all effective control to the networks promotes first-class achievement.

In less than eight years, the networks have generated 36 spin-off companies. They have developed an unusually high number of patents – 81 applications, 46 licences and a further 59 under negotiation. Most importantly, the NCE programme has changed the dynamics of leading-edge research in Canada. The networks have demonstrated that good research and good business can go hand in hand. A network link is a hallmark of excellence in the university research community and the programme is now followed closely in research journals.

An independent evaluation study of the NCE programme has been recently completed. It shows that the programme has succeeded in reaching its objectives: to support excellent research, to train and retain high quality personnel, to manage complex interdisciplinary and multi-sectoral programmes, and to accelerate knowledge exchange and technology transfer. Moreover, this acceleration of knowledge exchange and technology transfer is expected to lead to substantial social, environmental, health and economic benefits to Canadians, and the value of these benefits are expected to surpass programme costs.

Canada Foundation for Innovation

Notwithstanding the success of the Networks of Centres of Excellence programme, some universities can no longer support world-class research in some disciplines because of poor or outdated facilities. This highlights a gap in university support. The private sector has increased its support for university and hospital-based research. The federal government continues to provide over C$ 750 million annually for university research. However, both public and private support cover mainly the costs of research itself.

The federal government's response, the *Canada Foundation for Innovation,*[4] was announced in the 1997 Budget. The Foundation will be an independent non-profit corporation with a board of directors drawn from the research community and the private sector. Grants by the Foundation for eligible research infrastructure are expected to average 40 per cent of total eligible project costs. The rest will come from a wide range of contributors – universities, the private sector, the voluntary sector, individual Canadians and, to the extent they wish to participate, provincial governments. This provides an opportunity for industry to support the infrastructure that will be critical for the research base it will need in the future, as well as the highly trained personnel.

The C$ 800 million in federal funding to the Foundation is expected to trigger about C$ 2 billion in support for research infrastructure over five years. Projects will be chosen through a merit-based competition. The funds provided to the Foundation, while significant, cannot be expected to relieve all research-related infrastructure pressures in universities and hospitals. They will therefore be targeted toward key needs in the KBE, supporting areas of health, environment, science and engineering. Grants will cover capital costs involved in modernising the infrastructure needed to do research in these areas, such as acquiring state-of-the-art equipment, establishing computer networks and creating significant research databases. They will also cover the upgrading of laboratories and installations or, where justifiable, new construction, where this is needed to house the infrastructure.

Government provision of strategic information

Within Industry Canada, there has been a shift from simply promoting technology generation and diffusion, towards the management of knowledge. This recognises that government has a key role to play in creating the conditions that facilitate the acquisition of knowledge by the business community in particular. This shift to providing knowledge services is best exemplified by the STRATEGIS website.

STRATEGIS

Industry Canada's *STRATEGIS*[5] is Canada's largest business website. It contains information about industry developments, industry directories, notice of events, and business and industry databases. It provides direct access to technology information and opportunities. Examples are distCovery, which provides a database of more than 35 000 licensable technologies from Canada and around the world; the Canadian Technology Gateway, which lists S&T activities and capabilities in Canada; and Trans-Forum, a technology transfer tool for universities and colleges. STRATEGIS also provides links to the home pages of other agencies, federal, provincial and private, involved in technological innovation support.

Increasingly, attention is being paid to user-oriented packaging of information. For example, environmental industry ‘‘virtual offices’’ provide one-window access to environmental experts. The Ontario ‘‘office’’, for instance, provides direct access to 32 professionals from private and public sector agencies. Additional services, including management diagnostics, sample contracts for novice exporters or collaborative researchers, are growing. Discussion forums are proving useful. For example, the small-business site hosts an active discussion forum for small-business counsellors across the country.

STRATEGIS also contains policy research, discussion papers (with links that facilitate discussion), programme descriptions, extensive statistics in formats that invite additional manipulation and analysis, and news releases. It is therefore an excellent policy research tool, and is being used increasingly in the course of our work, as demonstrated by the endnotes to this article.

STRATEGIS is organised to allow business to tap into this knowledge easily. Users appear to appreciate the client-oriented way in which information is presented, the powerful search engines, and the one-stop concept. Clearly defined ‘‘ownership’’ responsibilities within Industry Canada keep the information up-to-date and authoritative. In most cases, information is backed up by e-mail addresses and phone numbers that invite follow-up. Business users can make critical decisions about opportunities for growth, explore new markets, find partners, form alliances, find and develop new technologies or processes, and assess the risks of new ventures.

The physical volume of information is impressive:

- 750 000 pages of searchable text;
- 3 billion bytes of economic data in formats that support easy manipulation;
- hundreds of links to other sites;
- hundreds of personal contacts.

During its first year of operation, use of STRATEGIS has exceeded our initial expectations:

- 9 million documents have been retrieved since March 1996;
- 220 000 IP addresses (the website of the client) have visited STRATEGIS;
- the small-business site estimates that they served 15 000 clients last year;
- 15 per cent of the usage was from outside Canada.

In the future, we will continue to enhance the content, interface and interactivity of the existing data, we will pursue external partnerships to enhance content, and we will work with individuals and associations so that they can tailor STRATEGIS information to their particular needs. These ‘‘satellite’’ sites will still display the STRATEGIS logo and link to the full service.

Changing industry's technology investment perspectives

Governments recognise that it is the private sector that creates jobs. However, many companies are not anticipating changes in the business environment that are creating entirely new success factors. These changes call for foresight, analysis and specific investments and behavioural changes if whole sectors are not to find themselves disadvantaged in the future. Governments have mounted significant foresight exercises in the past, but often with insufficient impact on firm behaviour. An alternative approach is for industry itself, through collaboration between firms on a sector basis, to identify where and when technology investments will be needed. Until recently, the tools to accomplish this were lacking.

Technology road maps

Technology Road Maps[6] are a mechanism to determine the future market needs in a particular sector and work back from there to determine the new technologies that will be required to meet those needs. They are a collaborative effort between government and industry to reduce risk, identify needed technologies, seize future market opportunities, respond to competitive threats, and strengthen the technological infrastructure. Road maps are government facilitated and industry led. They include all parts of sector supply chains and their time frame is usually three to ten years, depending on the sector. Currently, seven technology road maps are being developed as pilot projects with the support of Industry Canada. Parts of two reports, Aerospace, and Forest Operations in Canada, have been published.

Benefits to industry may include: a more precise focus on the technologies that should be introduced; identification of industry weaknesses and customers' needs; increased productivity; formation of expert networks; enhancement of knowledge; reduced length of product cycle; and influence on government policy development. For government, notable benefits include: supporting the jobs and growth agenda; gaining information on industry requirements and potentially critical technologies; nurturing industrial partnerships; and aligning policies and programmes to address industry needs. This process builds a consensus view of medium-term developments across industries and their supply chain; addresses issues like community training that seldom engage individual firms; and better informs all participants. Road maps set the stage for individual and collective action.

Abandoning the subsidy mentality

The 1995 federal budget de-emphasized subsidies to industry and led to much thinking about their role and utility. The point is not that subsidies are wrong, but that traditional subsidies may not work well in the knowledge economy. Subsidies can be legitimate when they respond to market failure or an unlevelled playing field. The change in government policy led to shifts in programme design in a number of areas.

Technology Partnerships Canada (TPC)

TPC,[7] announced in the March 1996 Budget, is a new funding approach to help Canadian firms compete in enabling technologies where market failure exists (*e.g.* biotechnology), or where there is an unlevelled playing field (aerospace). The programme invests in R&D and technology development. Examples of TPC investments to date include regional aircraft, aero-engines, closed cycle pulp and paper production technology, and fuel-cell plant development. The programme supports companies of all sizes.

TPC has some unique features. It has a Technology Advisory Board of industry leaders, chaired by the Minister of Industry, to assess trends in the market-place and ensure that the programme continues to target opportunities which generate jobs and economic growth. Stringent repayment criteria apply. On successful projects, the federal government's investment is repayable and, moreover, it will share in any upside returns. In the long term, Technology Partnerships Canada's goal is to be more than 50 per cent self-financing from these repayments.

WED Technology Loan/Investment Fund[8]

The Western Economic Diversification Agency (WED) has replaced its subsidy programmes by arrangements with three chartered banks. These banks have earmarked C$ 165 million of their funds for technology-intensive loans in agricultural biotechnology, health industries, information and telecommunications technology, knowledge-based industries and environmental technologies. To help small and medium-size businesses access these specialised loan programmes, WED provides them with assistance in developing and refining business plans, completing technology reviews and preparing other documentation required by the lending institutions. WED may also guarantee the banks against some of their risk, but firms know that their contract is with the banks and they understand they are getting a loan, not a subsidy.

This strategy increases technology financing by better exploiting existing competencies. Firms innovate, banks make loans, and government officials concentrate on giving advice to companies and developing a regional/sectoral synergies. At the same time, banks are learning how to work with technology-based firms – the real basis of knowledge lending. As time goes on, we expect that the financial sector and local technology firms will become used to working together, independently of government.

A new framework for federal-provincial co-operation

Another important aspect of S&T governance is federal-provincial co-operation. This takes many forms, including co-operation arrangements on the management of SchoolNet and the Community Access Program (see below). Until recent years, governments have also taken regional approaches based on economic regional development agreements which were co-funded by the provinces and the federal government. This practice has now started to give way to joint planning for the application of S&T to regional economic development.

Last year, the four western provinces, the Northwest Territories and the Government of Canada signed a *Memorandum of Understanding (MOU)*[9] which provides a planning framework for science and technology policy development throughout Western Canada. This MOU identifies three priority areas: strategic infrastructure, commercialisation of research and technology, and creating awareness of science and technology. The MOU promotes long-term thinking and co-ordinated initiatives involving all partners. For instance, when the MOU was announced, Ministers also announced a technology cluster strategy for Western Canada.

Financing growth-oriented firms

Among the recent policy shifts has been the development of new approaches for financing growth-oriented firms, which lever the knowledge and expertise of government. The following are examples of such approaches.

A renewed Business Development Bank of Canada (BDC)

The *BDC*[10] has existed for decades. Its original role was to demonstrate new lines of banking in the hope that the chartered banks would subsequently move into the business. In recent years, the BDC has focused on technology start-ups and, in 1995, Parliament passed a new BDC act to permit an even greater technology focus. The new act allows the BDC to work with traditional institutions; it increased their lending ceiling and allowed them to issue hybrid capital instruments in the private market. Subsequently, the BDC has launched several new, or renewed, products focused on technology-based start-up companies, and has shifted its attention to the earlier phase of the innovation process.

Their Venture Loans allow companies to access funds on venture capital terms without diluting ownership. The traditional equity position, demanded by venture capitalists, is replaced by a combination of interest payments and royalties on sales. BDC still provides the management counselling that venture capital firms offer.

Another new quasi-equity product, Patient Capital, responds to the financial needs of new businesses with a high growth potential but insufficient profits to retire debt in the normal course of business. In these cases, financing can be made available to support working capital needs, market development projects, and even to finance intangible assets such as ISO registration and research and development. As the name implies, the dollars made available are patient, since loan repayment is postponed for up to three years.

In addition to financing, entrepreneurs can obtain access to a wide range of management services though BDC. These services include business counselling and training services, business mentoring and strategic planning. For example, two of the Bank's newest management services products are the ''New Exporters Training and Counselling Program'', and an ISO Accreditation Service.

Lastly, the BDC is partnering its pool of competent technology financiers with many other agencies. For instance, BDC officials help prepare companies to approach the WED/chartered bank loan funds discussed above. In a short period of time, the BDC has become a vital element of innovation policy.

The Medical Discoveries Fund and the Canadian S&T Growth Fund

Canada's contribution to the OECD's recent report on venture capital financing[11] describes a unique tax incentive – Labour Sponsored Venture Capital Funds. For the purposes of this article, the essential thing to recognise is that Canada now enjoys a surplus of venture capital funds, and consequently, a demand for people who can identify venture capital start-up opportunities.

The *Medical Research Council,*[12] the federal granting council for medical research in universities and hospitals, has pioneered a unique relationship with the private-sector *Canadian Medical Discoveries Fund.*[13] The Fund has been granted access to the MRC's peer review process and may review research proposal abstracts (as long as the researchers consent). Promising business opportunities can be pursued by the Fund with the researchers concerned and, to help this process, the Fund has a strictly limited period of exclusivity in which to negotiate appropriate arrangements. The Canadian Medical Discoveries Fund has over C$ 260 million seeking investment opportunities. Of this, about C$ 90 million is now invested in some 30 companies. About half these companies are start-ups, and the rest are very early-stage companies that gain research support in return for sharing patent rights. Start-up companies have a range of core activities, such as human blood substitute products and novel contact lenses.

This idea has been adopted by the Natural Sciences and Engineering Research Council (NSERC), which has established a similar relationship with another private sector fund, the *Canadian Science and Technology Growth Fund.*

NSERC grants assist all non-medical university research for science and engineering. This Fund will be looking for opportunities from NSERC-sponsored research and work at the National Research Council.

Modernising business frameworks

Business frameworks comprise the policies, laws, regulations and standards which attempt to balance the rights of consumers with the aspirations of business, and domestic objectives with international obligations. Globalisation and the revolutionary impact of information technologies are eliminating trade and distance barriers among countries. Consequently, the business environment created by government is increasingly significant. Supportive market-place frameworks encourage and attract the world's best knowledge-based economic activity.

In recent years, the Government of Canada has been systematically modernising its framework policies and laws in order to position business competitively in the international market-place. The government's objective is to benchmark its policies and laws against the best in the world. For example, in 1996 the federal Parliament passed a comprehensive new copyright law. Yet another current example is the Convergence Policy.

A Convergence Policy for Canadian Broadcasting and Telecommunications

The government's *Convergence Policy Statement*[14] of 6 August 1996, laid the foundation for, and ushered in, a new era of vigorous competition. The Convergence Policy Statement was intended to guide the Canadian Radio-television and Telecommunications Commission as it establishes rules and regulations which allow the traditional cable and telecommunications monopolies to compete head-on. It also provided greater clarity for broadcasting and telecommunications firms as they enter each other's traditional areas of activity. For consumers, the policy framework will help bring about more choices and the assurance that Canadian content remains prominent on their screens.

The Convergence Policy was developed through an exhaustive process of public and industry consultations. Reports in 1995, by both the *Canadian Radio-television and Telecommunications Commission*[15] and the *Information Highway Advisory Council*[16] examined in detail the complex issues involved. They provided insight and precision to the government's policy objectives. The Convergence Policy is key to implementing a competitive, consumer-driven, policy and regulatory environment. It is built around three primary policy goals:

- interconnection, unbundling, resale and sharing of network facilities;
- continued support for Canadian content; and
- competition in all facilities, products and services of the information highway.

These goals reinforce past policy objectives, such as ensuring a strong Canadian broadcasting presence, and bring to a close a series of initiatives aimed at introducing competition in virtually every area of the communications industry. Each of these elements is important for encouraging jobs and growth in the telecommunication and broadcasting sectors. The cable and telephone companies have said that they are poised to spend about C$ 15 billion over the next ten years to take advantage of new business opportunities. Consumers will benefit from the increased competition, new innovative services, and jobs and growth that are the certain results of this investment.

The Convergence Policy Statement contains provisions that will ensure competition on the basis of facilities, technology and service – not financial strength or history. Canadians will continue to own and control their broadcasting system. With due regard for differences in technologies, all broadcasting distribution undertakings will be subject to essentially the same rules governing contribution to Canadian programming. Finally, neither the cable nor the telephone companies will have a head start over the other in entering each other's core market.

Using innovation to support sustainable development

Sustainable development is a challenge which cuts across the mandates of all federal departments. Recently, all federal government departments have been required to table Sustainable Development Strategies in Parliament by December 1997, to report on progress annually, and to update the strategies at least every three years. This process will be reviewed by the Auditor General.

The collective efforts of individual departments to define and operationalise sustainable development through the lens of their respective mandates will contribute to a much deeper understanding and to more innovative approaches. It will provide a strong foundation for ongoing co-operation among departments and their clients.

The Minister of Industry has a responsibility for both strengthening the national economy and promoting sustainable development. Given this, much effort has gone into Industry Canada's Sustainable Development Plan. One of its four strategic objectives is to develop and use innovative technologies and tools that will contribute to sustainable development. This leads to an emphasis on sustainable development in industry consultation, support for appropriate practice like the ISO 14000 series for Environmental Management Systems, and assistance for the development of pollution control equipment and pollution-free processes. A special site on STRATEGIS will share information with a wide audience of users and providers. These initiatives are part of a nine-point action plan on sustainable development.

The success of this strategy will depend on change in several factors. Among them are the need for greater staff awareness, the need to build links with other departments and agencies and, most importantly, the need to support innovative new ways of doing business by our industry clients. The new strategy will help foster these needed changes.

The next generation of innovators

Knowledge workers are at the core of an innovation-based economy. They are adaptive learners, continually retraining. Knowledge work cannot be for the elite only: we cannot afford to create societies of information ‘‘haves’’ and ‘‘have-nots’’. Avoiding adjustment problems in such an economy means that young Canadians need to be exposed to knowledge acquisition skills through the school system. As well, the attention needs to be paid to the special needs of small communities, which tend to lack the communications resources of cities and are thus disadvantaged in terms of access to knowledge resources.

Canada’s SchoolNet

SchoolNet[17] is a set of Internet-based educational services and resources that provides learners and educators alike with an easy-to-use single platform from which to reach the Information Highway. SchoolNet contains a wide variety of tools and services, ranging from specialised information to chat rooms, and interconnectivity tools. It helps teachers exchange ideas on course content and teaching approaches. It stimulates learning by placing information and creativity directly into the hands of student users. It allows students across the country to work together on common projects. The variety of offerings and their vitality defies description. For instance, at last year’s G7 Summit in Halifax, local schools established a popular site covering the meeting and its impact on the community.

One of SchoolNet’s goals is to facilitate the access of all 16 500 schools and 3 400 public libraries to these information-highway-based services by 1998. To date, over 8 000 schools and 800 libraries are connected, allowing them access to the more than 1 000 educational resources and services, including informal training and research activities. SchoolNet currently receives more than 2.5 million ‘‘hits’’ a month.

SchoolNet is also being used as a way of generating employment. For example, the *Student Connection Program*[18] helps Canadian small and medium-sized businesses learn to use the online business services of the Information Highway with help from an estimated 2 000 third- and fourth-year university and final year college students. Over the three years of the Student Connection Program, some 50 000 small and medium-sized business managers will be provided with introductory level training sessions aimed at showing them how to use online information services in solving practical business issues. Businesses will gain needed information tools; students will receive valuable work experience – as well as a job to help finance their education; and the Canadian information technology industry will gain through exposure of their services. The cost to the businesses will be minimal (C$ 150).

SchoolNet has also been an entry point for business and non-profit groups into the school system. Partners include telephone companies, research and development agencies, software developers, provincial ministries of education, education and telecommunication associations. Through these partnerships, SchoolNet is promoting the development of Canadian-produced, multimedia educational resources and ensuring that the learning opportunities presented by the information highway are equally accessible to all Canadians.

Community Access Program

An interesting development arising from SchoolNet was that schools could, and did, become access points to the information highway for whole communities. This was formalised in the Community Access Program, which provided an opportunity for small and remote communities to obtain assistance in developing Internet access. The programme has already provided support to some 380 projects, in rural and remote communities. The original goal of connecting 1 500 communities by 1998 was increased to 5 000 communities by 2001 in the 1998 federal budget.

The Community Access Program aims to promote new business development, job creation and economic growth, including student employment, in rural communities. It also facilitates Internet training for local residents, businesses and organisations. Through a competitive process, communities may receive up to C$ 30 000 from the programme to establish their public access site. Proposals for the Community Access Program are received annually in late autumn during a national competition. Selection is based on peer review and conducted at arms' length from the federal government. Locally recruited committees review applications at the provincial and territorial levels, and rank proposals which met the programme criteria in order of merit. A National Community Access Selection Committee then reviews the integrity of the provincial selection process and recommends selected sites to Industry Canada.

Communities are already beginning to experience economic and social benefits as a result of the programme. In the far north, CAP terminals, commonly routed through satellites, are used by young and old for most of the day.

III. FUTURE POLICIES: THE ROLE OF THE OECD

We all understand the benefits we derive from the OECD's work. Together, we have undertaken and shared more policy research than any of us could have done alone. This work has been synthesised and disseminated in support of sound policy directions that will help us all. Moreover, the OECD's imprimatur facilitates policy decision making in OECD Member countries. Although Canada has made extensive policy shifts to anticipate and respond to the changed dynamics of the knowledge-based economy, there are critical policy issues which require further analysis and deliberation. Most are common to other OECD countries and would benefit from collaboration at the OECD. The list below is illustrative:

- The interim report on the OECD phase II work in best practices in technology and innovation policy highlights the importance of innovative firms to sustained employment growth. We need to find practical ways in which existing firms can improve their innovation performance. This involves developing a detailed understanding of the organisational capacities that are essential for innovation and using them as an assessment tool.
- We need to develop new internationally comparable indicators to allow governments to measure their economies' innovation capacity and performance. Statistics Canada has embarked on a multi-year, multi-million dollar programme to develop such measures. This will be a difficult task and we need to work with other countries to achieve timely, generally comparable results. Canada is pleased to see that the Secretariat of the Directorate for Science, Technology and Industry is implementing a work plan on new statistics and indicators.
- We need to improve methodologies to measure the effectiveness of industrial technology support policies. These measures will have to take explicit account of the impacts of these policies on the ability of companies to operate in a globalised economy.
- We need to assess the implications of the apparent global slowdown in the growth of industrial R&D. Does it reflect a diminished need for R&D inputs due to more effective collaboration among firms or is it a system/market failure? If the latter, what should be done?
- Universities are facing conflicting pressures and a more complex environment. There are demands for increased economic relevance – a strong contribution to competitiveness and economic growth. Shortages of highly qualified personnel have developed in various industries. There are demands for increased accountability and value for money. At the same time, universities in many countries are under severe budgetary pressures. There is an urgent need to determine how universities can maintain a balance between research and training, while ensuring that the science base, critical to innovation, is maintained and accessible.

NOTES

1. <http://canada.gc.ca/depts/science/english/summ-e.html>.
2. <http://nce.nserc.ca/>.
3. <http://nce.nserc.ca/blurbs/isiseng.htm>.
4. <http://www.fin.gc.ca/budget97/innove/innove.html>.
5. <http://strategis.ic.gc.ca/engdoc/main.html>.
6. <http://strategis.ic.gc.ca/sc–indps/trm/engdoc/homepage.html>.
7. <http://xinfo.ic.gc.ca/ic-data/industry/tpc/broche.html>.
8. <http://www.wd.gc.ca/eng/content/funds/index.html>.
9. <http://www.wd.gc.ca/eng/content/sitemap/index.html>.
10. <http://www.bdc.ca>.
11. OECD (1996), ‘‘Venture Capital and Innovation’’, OCDE/GD(96)168, Paris. For further information on venture capital, see also ‘‘Government Venture Capital for Technology-based Firms’’, OCDE/GD(97)201.
12. <http://wwwmrc.hwc.ca/title.html>.
13. <http://www.wwdc.com/cmdf/general.html>.
14. <http://strategis.ic.gc.ca/sc–indps/sectors/engdoc/dgtp–hpg.html>.
15. <http://www.crtc.gc.ca/eng/highway/hwy9505e.htm>.
16. <http://strategis.ic.gc.ca/cgi-bin/dec/wwwfetch?/sgml/ih01070e–pr702.sgml>.
17. <http://www.schoolnet.ca/>.
18. <http://strategis.ic.gc.ca/sc–hures/student/engdoc/fctsht.html>.

TOWARDS SYSTEMIC POLICY AT THE EUROPEAN LEVEL: FIVE KEY CHALLENGES FOR THE FUTURE

TABLE OF CONTENTS

This article was written by P. Caracostas, Advisor to the Directorate-General XII-AS for Science, Research and Development (Strategy and Co-ordination) of the European Commission in Brussels.

I. INTRODUCTION: IS THE ''LINEAR MODEL'' DEAD?

''The linear model of innovation is dead''. In recent years, policy experts and policy advisors have been travelling around the world to spread the message. New theories and approaches about innovation and its social and economic embeddedness are challenging the well-known arguments that justify public intervention in research, development and demonstration activities. Based on evolutionary theory, systems of innovation approaches and new knowledge about the social shaping of technology, these new ideas are progressively diffusing outside academic circles into the wider research and policy-making community.

What do these theories tell us? That if the economy and society need to adapt to and shape new economic and social dynamics at global or continental levels, they have to transform themselves into learning organisms. Public support to research and to the production of knowledge is an important component of a learning economy. The more complex and interactive relationships between the ''knowledge infrastructure'' and society at large have to be taken into consideration when designing policies aiming at enhancing innovation capabilities in a given society or region of the world. Moreover research policy itself is confronted with such a ''systemic'' reappraisal.

But do the new approaches tell us *how* to reshape public policies to better gear them to the needs of a globalised learning economy? The answer here could be ''yes and no''.

Yes, because they draw the attention of policy makers to new problems such as systemic failures. They show how science, technology and innovation are social processes influenced by the context in which they develop, as well as influencing this context. They emphasize diversity of trajectories and the risks of technological ''lock-in'' effects. More recently, they support the experimentation of participative methods of governance (*e.g.* foresight, constructive technology assessment, user involvement in policy design) and plead for the building of solid policy capabilities (the government as a major stakeholder), working in an open and creative policy framework.

No, because more experimentation is necessary to move away from the intellectual domination of the ''linear model''. Institutions and organisations have a long history and they have built solid cognitive models which resist change as long as the new approach has not totally proved its advantages for the major actors. One could use the term ''institutional lock-ins'' to describe these phenomena and the ''bounded rationality'' of policy makers is natural, given the increasing complexity of our societies.

However, things are changing for a number of reasons:

- budget restrictions in most industrialised countries imply dramatic reallocations of policy priorities; in addition, the globalisation of information and knowledge allows good practice elsewhere in the world to be compared;
- science, technology and innovation have lost their virginity for public opinion; recent crises linked to over-industrialisation and technology have provoked negative reactions from the public, and researchers, industry and governments need to develop a new rationale in order to convince society that innovation means growth, improved quality of life and more jobs;
- the debates on the various types of market economies have highlighted, since the fall of the Berlin Wall, the complexity of the factors leading here to growth and there to stagnation and unemployment (see Amable, Barré, Boyer, 1997, for a recent overview);
- the relative failure of recent large-scale technological ventures has demonstrated that ‘‘technology-push’’ strategies have reached their limits.

These changes are making public authorities and socio-economic actors more receptive to the new ‘‘systemic school of thought’’. For example, the non-optimality of the systems of innovation approaches, their interdisciplinary character and the emphasis they place on institutions, are challenges both for further advancement of theory and for policy experimentation. This latter is well under way, as has been shown in the evolution of European policy debates in the recent years.

II. THE EU AND INNOVATION-RELATED INSTITUTIONS: A BRIEF OVERVIEW

The European Union (EU) is a unique political construction in today’s world. Its 15 Member States have decided to share a significant part of their sovereignty in order to build a stronger Europe for the 21st century. They have devised an impressive set of common institutions and created a specific legal and decision-making framework to develop them further.

Research, innovation and learning form an important component of this European integration process which moves forward on the basis of a permanent interaction between the national and European levels of governance (‘‘subsidiarity’’).

The development of European integration from the European Steel and Coal Community to the European Union has led to the setting up of a number of original cross-border institutions that have contributed significantly to shaping the innovation process in the various European Member States.[1] These cross-border institutions have a history going back over more than 40 years. The results of this long process can be summarised, at the beginning of the 1990s, by describing the major areas of formal cross-border institutionalisation:

- The Single European market, the initial goal of the European Economic Community in the late 1950s, is becoming a reality through the ‘‘Single European Act of 1986’’ and the 1992 deadline (through mutual recognition and harmonization).
- The development of trade policy institutions and instruments is moving towards a more global institutional context (GATT, World Trade Organisation, etc.), therefore pushing for a redefinition of European integration policy tools in this domain.
- The strengthening and adaptation of competition policy as a key regulatory mechanism for the Single European Market (state aids control, merger regulation, attacking price and other cartel agreements, etc.).
- The consolidation of research and innovation policy institutions.
- The rapid growth, since 1988, of European redistributive (mainly regional development) mechanisms with the structural funds and the European Investment Bank as core organisations.
- The mobilisation of efforts for organising trans-European transport, telecommunications and energy networks.
- The Economic and Monetary Union programme which, from an EU institutional point of view, is the most powerful drive for ‘‘Europe-ification’’ of national policies since the Single European Market programme.

In contrast, three components that are critical to national systems of innovation appear to lag behind at EU level:

- specialised financial institutions for innovation;
- social regulation/conflict resolution mechanisms;
- education and training institutions (European programmes in this field have initiated an embryonic learning process, but education remains clearly a national matter).

We have, in other words, a market tending towards unification, regulated by well-defined competition and trade policy rules with emerging (research, innovation, regional development) structural policy institutions.

This emerging system of innovation produces, and is produced by, specific cross-border institutions that are both formal (treaties, community programmes and other European schemes) and informal (networks, common habits and norms).

One can assume that the core of a system of innovation at the European level is made up of those organisations and institutions regulating the production, distribution and use of knowledge and know-how in co-operation across Member States' boundaries; that is, organisations and institutions dedicated to research, innovation, education and training. Other structural policy institutions, although they often include a very significant innovation component, are not considered here because they are not primarily designed to contribute to the emergence of a cross-border innovation space but rather to strengthen national systems of innovation in less-favoured countries and in specific regions.

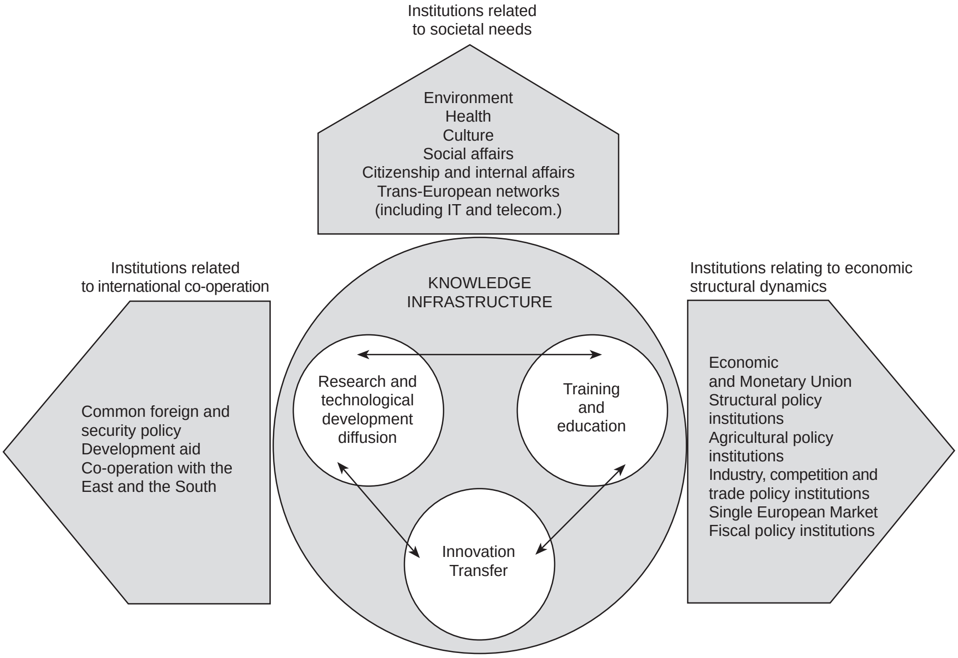
The Treaty of the European Union defines the rules governing research, innovation and education/training institutions. In the field of research, Title XV defines the objectives, the actions that can be carried out, the decision-making procedures and the implementation mechanisms. Innovation is only quoted in the title concerning industry where it is stated that the Community aims to favour a better exploitation of the industrial potential of innovation policies. Finally, a distinction is made in the Treaty between education for which no real policy is mentioned (only ‘‘Community action’’), and training, which is the subject of a true EC policy.

These institutions have relations between themselves and other EU institutions. Figure 1 presents in a simplified manner these basic links by clustering European institutions in three groups: the first mainly concerns the needs of society (and the citizen); the second covers institutional developments in the field of economic structural dynamics (a European economic space); the third links the Union with other regions of the world. These very general contextual elements serve to illustrate the fact that research and innovation institutions are developing in interaction with other major areas of cross-border institutionalisation.

Research institutions have the longer history. They promote transnational co-operation in the field of the production of knowledge and know-how and its diffusion across Europe. The Fourth Framework Programme (FP4) (1994-98) and related specific programmes are now key components, together with competition rules governing state aids and co-operation agreements between firms [see European Commission (1994) for a broader description of EU research policy].

Innovation policy institutions, if conceived in a narrow way as specific, formal rules influencing the innovation capacity of firms beyond R&D and technological demonstration, do not exist at the EU level. Support programmes for innovation and technology transfer, however, can be considered as quasi-institutions insofar as they have influenced the behaviour of specific actors in the innovation process, *i.e.* the wider category of intermediaries working in the field of technology transfer and application in SMEs. SPRINT (Strategic Programme for Innovation and Technology Transfer) is the embryo of such innovation policy institutions. From 1989 to 1994 it contributed to the development of innovation support

Figure 1. **European Union institutions concerning the knowledge infrastructure Links with other EU institutions**



services for SMEs, to the demonstration of intra-Community technology transfer and technology acquisition, and to the improvement of a common European knowledge of the innovation process. It has been followed by the Innovation Programme (1994-96) in the context of FP4.

Education and training institutions, although they were partly (for training only) foreseen by the EEC Treaty in the provisions related to the European Social Fund, were created by the Treaty of the European Union (1993). The new rules formalise previously *ad hoc* experimentation through Community programmes.

For example, the experience of COMETT (the European Union programme on co-operation between universities and industry regarding training in the field of technology) is very interesting from the point of view of nascent training institutions at European level.[2] This experience has led to the new LEONARDO programme.

To sum up what has been said above, we can say that the elements of a European system of innovation exist as a consequence of more than 40 years of intense institutional creativity at EU level. What is more recent is the progressive reflection of this reality at EU policy level, taking the form of cumulative ‘‘systemic’’ policy initiatives since 1995.

These initiatives, and five major challenges which they have to face, will be analysed hereafter.

III. FIVE KEY CHALLENGES FOR THE FUTURE

Challenge 1. From support to industrial competitiveness *to research and innovation for the citizen:* strengthening ‘‘socio-industrial complexes’’

The Single European Act, the first major review of the EEC Treaty in 1986, inserted a chapter on research and technological development (RTD). The objectives of a common RTD policy were mainly to support the competitiveness of European industry. The Maastricht Treaty broadens significantly the goals of the European Union by stating (Art. 130 F) that the Community, besides strengthening the scientific and technological basis of European industry, shall promote all the research activities deemed necessary by virtue of other chapters of the Treaty.

All the research needs stemming from other EU policies (in the field of the environment, health, safety, etc.) are addressing ‘‘societal activities’’ which are coherent with, and not in opposition to, the strengthening of the competitiveness of Community industry:

> *‘‘Indeed many of the new market openings and employment opportunities are related to the search for the solutions of the above societal problems; on the other hand, societal problems will not find solutions, on the contrary they will become more serious if the strengthening of industrial competitiveness does not ensure economic stability’’.*[3]

The combination of societal goals with scientific, technological and industrial dynamics can be translated into the notion of ‘‘*socio-industrial complexes*’’. This notion (a reminder of the ‘‘military-industrial complex’’ of the 1950s) attempts to express the new alliance between technology and society which most industrialised countries are seeking. In many EU Member States this transition has been initiated recently through various policy and planning initiatives (see the foresight exercises in the Netherlands, the United Kingdom, France, Germany, Italy, etc.).

In its proposals for the Fifth Framework Programme (FP5) published in April 1997, the European Commission stressed that research is not an end in itself. It must support common European objectives, and the message is now that European research activities have to be designed to meet economic and social needs. Similarly, the *Green Paper on Innovation* (1995*a*) viewed innovation as a social process in its objectives, effects and modalities, and the *White Paper on Education and Training* (1995*b*) indicated that related public policies in Europe need to support the move towards a ''learning society''.

Industrial competitiveness, job creation and quality of life are combined objectives for policies that shift emphasis *from the pursuit of scientific and technological performance to the contribution to the solution of common economic and social problems.*

The first challenge is thus that public policies concerned with the emergence of a ''searching, innovative and learning society'' must show a vision of the direction in which to go, *i.e.* of the *societal goals that the citizens have identified through the democratic process,* and articulate societal demand in their respective policy fields.

In the European context, the Treaties and EU policies determine the concrete goals to pursue together at European level. They are the result of a large democratic process regulated through a well-defined institutional framework.

Challenge 2. From a collection of national and sectoral interests *to a true European Union strategy*

The Commission's proposals for FP5 reflect such a long-term vision for Europe by pleading for the concentration of European Union research efforts on a limited number of common actions at European level.

Three actions (the ''thematic programmes'') address major societal challenges related to the reorientation of Europe's innovation systems:

- unlocking the resources of the living world and the ecosystem (responding to the requirements for a better quality of life, health, environment, agriculture and fisheries);
- creating a user-friendly Information Society (reaping the benefits of the advances in information and communication technologies and supporting a new kind of learning society for all citizens);
- promoting competitive and sustainable growth (strengthening the competitiveness of firms while moving towards sustainable development).

These challenges are interdependent insofar as sustainable growth will require the mastering of the living world and take into account the evolution of the ecosystem. It will require a new approach to the role of information and communications in our ways of living and working, and therefore particular efforts to implement the necessary infrastructures and promote advanced information and communication services responding to the needs of Europeans.

The three other actions proposed (the ‘‘horizontal programmes’’) concern the consolidation of a European RTD and innovation space by:

– ‘‘confirming the international role of European research’’;
– promoting ‘‘innovation and participation of SMEs’’;
– ‘‘improving human potential’’.

These programmes will both develop their own horizontal activities and ensure co-ordinated implementation of all the activities related to their objectives at the level of FP5 as a whole.

The second challenge for a ‘‘systemic’’ policy at European Union level is therefore to decide on a true European Union strategy, based on a set of common objectives and common actions.

A well-known bottleneck hindering such a leap forward is the decision-making process for research policy established by the Maastricht Treaty.

The Framework Programme must be decided by a co-decision procedure of the European Parliament and the Council of Ministers acting unanimously. A second decision-making procedure is required to adopt the specific programmes.

This unanimity clause implies lengthy discussions on what is the most important step of the EU decision-making process for RTD, *i.e.* the Framework Programme and the five-year strategy it crystallises. These discussions are moving inevitably to debates on details of the content of the specific programmes rather than on broad strategic priorities. Moreover, in the implementation process the European Commission is assisted by programme committees composed of representatives of Member States.

The heaviness of the decision-making process was recently highlighted by the Framework Programme Evaluation Panel, chaired by Mr. Davignon (Davignon Panel, 1997), which proposed to simplify the current two-stage adoption and implementation procedure (Framework Programme and Specific Programmes) by making the Framework Programme itself legally enforceable.

As stated by another well-known expert in this field: ‘‘*Time and efficiency would be gained if the Framework Programme and the implementation of Specific Programmes were combined in a ‘multi-annual programme’, to be adopted by co-decision of the European Parliament and Council by a qualified majority.*’’[4]

Moreover, clarification of the respective roles of strategy definition and decision, on the one hand, and implementation, on the other, would be made possible if the bulk of the authority for implementing programmes were delegated to the Commission alone, with the Programme Committees simply pronouncing on general matters and not on individual measures.

The Intergovernmental Conference, which should, in June 1997, finalise its work on the future functioning of the EU institutions in the perspective of the enlargement of the Union to new Member States, will consider among other things the extension of the qualified majority in the decision-making process in the field of RTD.

Challenge 3. From science and technology-driven *to socio-economic-driven programming*

The way in which a public authority organises its research and innovation activities is important. Four different ways of grouping these activities are usual:

- they can be grouped according to disciplinary science categories (*e.g.* life sciences, material sciences, social sciences, etc.);
- they can be structured along engineering- and technology-based groupings (*e.g.* biotechnology, information technology, microelectronics, etc.);
- a third way is to regroup into programmes all those activities that contribute to solving socio-economic problems (*e.g.* environmental or health issues);
- finally, programmes may be structured around bottlenecks or opportunities in the functioning of the innovation system (*e.g.* lack of mobility of researchers, need to improve co-operation between different actors within the system, etc.).

Very often public initiatives combine elements of the four classifications described above.

The EU is, with FP5, moving in the direction of combining the third and the fourth types as key building blocks of its research activities. Moreover the thematic programmes themselves will integrate measures aimed at improving the European innovation system's performance with those aimed at gearing research to socio-economic objectives. For example, activities that focus on a better exploitation of RTD results and the participation of SMEs will be embedded in these programmes.

The third challenge will soon be overcome as far as EU policy is concerned as the broad architecture of FP5 seems to be broadly endorsed by Member States and is in line with the European Parliament's thinking.

Challenge 4. From scientific and technological research *to problem-solving interdisciplinary research*

Several experts have shown recently (see Gibbons *et al.,* 1994) that a new model of knowledge production is emerging.

This model is characterised by heterogeneous groups of researchers, users and other actors working in temporary teams to address societal problems. The focus on problem solving implies that many different disciplines and types of research are integrated into these teams.

The EU's move towards a new modality of Community public support – the ‘‘key actions'' – is in line with such developments. The European Commission has proposed, for FP5, 16 of these actions, each linked to a major economic and social objective for Europe. The key actions:

- ‘‘will be defined according to problems to be resolved, and explicitly formulated economic and social objectives;
- will mobilise, as part of an overall systems approach, the resources of various relevant disciplines, technologies and know-how, and relevant expertise of various origins;
- will cover the whole range of activities needed to achieve their objectives, ranging from basic research to development and demonstration;
- will be firmly rooted in a European context; one of their major objectives being to focus public and private research carried out in Europe on their particular topic;
- will be prepared and implemented in close consultation with the scientific community, business, and more generally all those who are concerned with and use research, on the basis of forms of association which may vary''.[5]

This new approach, which also draws lessons from the experience of the ‘‘Research Task Forces'' of FP4, is in itself a challenge insofar as:

- a key action needs to clearly define the socio-economic objectives pursued;
- precise research objectives have then to be defined in a systemic way;
- the large and small projects selected and the various actors involved need to be interrelated in a coherent scheme (a cluster);
- the various disciplines and types of research will have to work together towards a common objective;
- the interfaces with national activities in the same field, as well as with other European schemes (such as Eureka), will have to be defined and made operational;
- coherence and synergy with other EU policy instruments and funding mechanisms (*e.g.* the structural funds, the EIB, etc.) need to be achieved to obtain a multiplier effect on research and innovation funding.

Challenge 5. From a wide range of EU actions *to an EU co-ordinated policy for research, innovation and learning*

The question of the ‘‘policy mix’’ for innovation is being discussed in various research and innovation policy debates. At EU level, various initiatives have recently been launched by the European Commission in a perspective which is ‘‘systemic’’ insofar as it aims at tackling specific bottlenecks for a well-functioning European research and innovation system.

In the field of education and training policies, the *White Paper on Education and Training: Towards the Learning Society* (1995) highlighted a few key systemic deficiencies (and suggestions for action):

- difficulty in evaluating informal competencies acquired in professional life (proposals to create European networks to identify key skills and competencies, to develop ‘‘personal competence cards’’);
- insufficient professional and geographic mobility (various proposals were made for reducing obstacles to mobility);
- difficulty in evaluating intangible investments in economic terms (proposals to review the accountancy rules);
- insufficient demand for ‘‘lifelong learning’’ activities (proposal to develop ‘‘training-saving plans’’ for individual workers).

The *Green Paper on Innovation* (1995), followed, after a very extensive debate, by a proposal for an Innovation Action Plan (1996), broadened the picture even further by stressing significant weaknesses in Europe’s research and innovation system:

- lack of specific innovation-friendly financial mechanisms;
- the complex patenting system;
- the lack of a legal status for a European company;
- the need for favourable and coherent fiscal environment for research and innovation, etc.

The Innovation Action Plan therefore proposed to concentrate the actions of the EU and its Member States on three major objectives:

- developing a true innovation culture;
- adapting the administrative, legal, financial and fiscal environment;
- reinforcing the links between research and innovation.

The Action Plan is a concrete policy tool co-ordinating the various EU policies that have an impact on innovation in Europe.

It is developing on the basis of tight inter-DG (Directorates General of the European Commission) co-ordination under the political responsibility of the Commissioner responsible for Research, Innovation, Education and Training Policies, Mrs. Cresson.

The Innovation Action Plan is at macro level what key actions represent at meso level. It therefore concerns a broader set of policy fields than just those embedded in running the Research Framework Programme.

The fifth challenge for a European ‘‘systemic’’ policy in the field of research and innovation is thus to continuously design, monitor, implement and evaluate the necessary ‘‘policy mix’’ for innovation for Europe. The practical difficulties of such an exercise are immense, but the problems require urgent solutions. One key, concrete challenge is to keep control over different fields of policy characterised by various problem-definition approaches, different stages of maturity, different procedures and different interactions by EU/Member States. However, regular reporting on the progress achieved in these interrelated fields will make it easier to monitor changes and highlight critical bottlenecks.

IV. CONCLUSIONS: A TWO-TRACK ‘‘SYSTEMIC’’ RESEARCH AND INNOVATION POLICY IS EMERGING AT EU LEVEL

The linear model of innovation is not dead, but it may be dying. At least, the evolution of EU policy debates show that the interactive, ‘‘systemic’’, society-driven approach is gaining ground.

Two policy tracks have recently emerged:

- research and innovation policy establishes a link between the needs of society and the economy, translated into EU policy objectives in various fields, and the initiatives and institutions supporting the creation, diffusion and implementation of new knowledge and new technology;
- the specific inefficiencies of an emerging, but insufficiently organised, European research and innovation system are tackled at the same time both within the research FP5 proposals (the ‘‘horizontal programmes’’ and the related activities in the ‘‘thematic programmes’’) and at a broader level (the Innovation Action Plan and the follow-up to the *Learning Society White Paper*).

The first concerns the *direction* that society wants to give to common research and innovation activities; the second focuses on *optimising the system* at the European level. Both are indispensable if Europe wants to enter the 21st century as an innovative society, concerned with sustainability, social cohesion and a better quality of life for its citizens.

NOTES

1. See Guzzetti (1995) and Caracostas and Soete (1997) for an analysis of European research and innovation institutions.
2. COMETT I ran from 1986 to 1989 with a budget of ECU 50 million, and COMETT II from 1990 to 1994 with a budget of some ECU 230 million. Both were centered on transnational university-industry co-operation in advanced technology education and training. The first strand of this programme supported consortia of higher education institutions, enterprises and other relevant organisations (enterprise training partnerships – UETPs) linked in a European network. The 200 UETPs created were essentially of two types: regional UETPs brought together universities, enterprises and other interested parties within a geographic area; sectoral UETPs did the same in a particular technology or industry.
3. P. Fasella (1997), ‘‘The Role of the European Commission in Supporting Research’’, *European Review,* Vol. 5, No. 2, p. 167.
4. P. Fasella (1997), ‘‘The Role of the European Commission in Supporting Research’’, *European Review,* Vol. 5, No. 2, p. 175.
5. European Commission, proposal for FP5, 1997.

BIBLIOGRAPHY

AMABLE, B., R. BARRÉ and R. BOYER (1997), ‘‘Les systèmes d’innovation à l’ère de la globalisation’’, *Economica.*

CARACOSTAS, P. and L. SOETE (1997), ‘‘The Building of Cross-Border Institutions in Europe: Towards a European System of Innovation?’’, in C. Edquist (ed.) (1997), *Systems of Innovation, Technologies, Institutions and Organizations,* Pinter.

‘‘DAVIGNON PANEL’’ (1997), ‘‘Five-Year Assessment of the European Community RTD Framework Programmes’’, an independent panel chaired by Viscount E. Davignon.

EUROPEAN COMMISSION (1994), *The European Report on Science and Technology Indicators 1994,* Report EUR 15897 EN, October.

EUROPEAN COMMISSION (1995*a*), *The Green Paper on Innovation,* Luxembourg.

EUROPEAN COMMISSION (1995*b*), *The White Paper on Education and Training, Towards the Learning Society,* Luxembourg.

EUROPEAN COMMISSION (1996), *The Action Plan for Innovation,* Luxembourg.

EUROPEAN COMMISSION (1997), ‘‘The Commission’s Proposal for the 5th Framework Programme (1998-2002)’’, EUR 17651.

FASELLA, P. (1997), ‘‘The Role of the European Commission in Supporting Research’’, *European Review,* Vol. 5, No. 2.

GIBBONS *et al.* (1994), *The New Production of Knowledge,* Sage.

GUZZETTI, L. (1995), *A Brief History of European Union Research Policy,* Office for Official Publications of the European Communities, Luxembourg.

OECD PUBLICATIONS, 2, rue André-Pascal, 75775 PARIS CEDEX 16
PRINTED IN FRANCE
(90 98 22 1 P) ISBN 92-64-15976-2 – No. 50223 1998
ISSN 1010-5247