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ENERGY TAXATION AND PRICE DISTORTIONS IN FOSSIL FUEL MARKETS: SOME IMPLICATIONS FOR CLIMATE CHANGE POLICY

In response to the potential threat of global warming many countries are considering cost effective policies to reduce greenhouse gas emissions. In this context much attention has been paid to taxes levied on the carbon content of fuels (carbon taxes), since they are a potentially efficient economic instrument for reducing emissions of CO_2, the main greenhouse gas. This paper first reviews the existing structure of fossil fuel prices and taxes and the relationship between energy prices and carbon emissions. It then analyses the economic cost of superimposing carbon taxes on top of current energy taxes. Finally, using a simple energy demand system, tax reform proposals are simulated including restructuring present energy taxation by the average implicit carbon tax and a carbon cum energy tax similar to the EC proposal.

* * * * *

En réponse à la menace potentielle de réchauffement planétaire, de nombreux pays étudient des politiques de coût efficaces pour réduire les émissions de gaz à effet de serre. Dans ce contexte, les taxes perçues en fonction de la teneur en carbone des combustibles (taxes sur le carbone) ont été l'objet d'une attention particulière, ces taxes étant un instrument économique potentiellement efficace pour réduire les émissions de CO_2, principal gaz à effet de serre. Ce document examine tout d'abord la structure existante des prix et des taxes s'attachant aux combustibles fossiles et la relation entre les prix de l'énergie et les émissions de carbone. Il analyse ensuite le coût économique que représente la superposition de taxes sur le carbone aux taxes déjà existantes sur l'énergie. Enfin, en utilisant un simple système de demande d'énergie, les propositions de réforme fiscale font l'objet d'une simulation comportant une restructuration du système actuel de taxation de l'énergie passant par une taxe implicite moyenne sur le carbone et une taxe à la fois sur le carbone et l'énergie similaire à celle proposée par la CEE.

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Energy Taxation and Price Distortions in Fossil Fuel Markets: Some Implications for Climate Change Policy

Peter Hoeller and Jonathan Coppel [1]

Introduction and Summary

This study focuses on the interaction between existing taxes on energy and the use of carbon taxes (taxes levied on the carbon content of fuels) to reduce emissions of carbon dioxide (CO_2). The paper poses four principal questions:

a) How large is the variation in energy prices among OECD countries and what factors contribute to it?

b) What is the relationship between energy prices and emission intensities (carbon emissions per unit of GDP)?

c) What is the economic cost of superimposing carbon taxes on top of current energy taxes?

d) Could a restructuring of current energy taxes alone achieve significant cuts in carbon emissions?

An efficient greenhouse gas control policy inevitably requires some assessment of the costs and benefits of an abatement strategy. Little is known on how to form credible estimates of the benefits from abatement. Usually, therefore, the less ambitious criteria is to evaluate different policies in order to see which achieves a given amount of emission reduction at least cost. In this context much attention has been paid to carbon taxes, since they are an economic instrument that can be used directly to influence emissions of CO_2, the main greenhouse gas. The economic cost of imposing a carbon tax will depend not only on the size of the new tax but also on current policies, for instance, taxes and subsidies. The four questions posed in this paper address the importance of the latter.

Variations in energy prices. Estimates of energy end-use prices and emission intensities (carbon emissions per unit of GDP) are presented in Section II. Both show a large variation across countries, with the level and variation of end-use prices and emission intensities depending on whether current exchange rates or purchasing power parities (PPP) are used to convert domestic price levels into a common currency. Using PPPs the average relative energy price in countries with high output price levels, such as Japan, is as much as 30 per cent lower than prices converted with market exchange rates. On the other hand, the emission intensity also increases sharply if measured in PPPs.

Differences in end-use energy prices among countries and between fuels are mainly accounted for by energy taxes. The current implicit average taxes on the carbon content of energy vary from $28 per ton of carbon in the United States to over $200 in France, Italy and Sweden. There is, however, also some variation in before-tax prices. For instance, coal prices in Germany are three times higher than in the United States. In order to estimate the size of non-tax distortions, a residual wedge is calculated for each fuel as the difference between the before-tax price and a so-called "reference price", which ideally should reflect prices in competitive markets. The estimates presented here suggest that non-tax distortions are large for most energy products in Japan, for natural gas in Europe and for coal in European coal-producing countries (Section II).

Energy prices and carbon emissions. Emission intensities tend to vary inversely with end-use energy prices. In general, countries with relatively low energy prices have high emission intensities, while high-price countries have low ones. This relationship across countries between emission intensities and relative prices suggests that carbon taxes could be a powerful instrument to reduce emissions (Section III).

Economic cost of carbon taxes. Energy price and energy tax data are used to highlight two issues: i) the effect of existing taxes on estimates of the economic cost from imposing a carbon tax, and ii) the effect of tax reform proposals on emissions. Theory indicates that under certain assumptions the economic costs of imposing a carbon tax on top of existing energy taxes are not additive, but could increase costs disproportionately. This would not be the case if current energy taxes are the most efficient way to charge for road use and congestion. But if they were mainly revenue raising, the basic result would hold. A simple energy demand system is used to illustrate the point that current taxes -- if they were distorting -- could magnify significantly the economic cost of imposing carbon taxes. The costs of imposing a carbon tax could, therefore, be higher than suggested in previous studies, at least in countries where energy taxes are already high. In order to make a welfare assessment the cost needs to be balanced against the benefits from reducing all pollutants from fossil-fuel use and take account of the road user charge element of current energy taxes (Section IV).

Restructuring taxes. Many governments are currently proposing changes to their energy tax systems in order to bring them more into line with the perceived externalities of fuel use. Finland, the Netherlands, Norway and Sweden have already introduced carbon taxes, and European Community (EC) governments are discussing a proposal by the Commission for a combined carbon and energy tax. Simulations with a simple energy demand system are used to highlight the economic costs and the likely effects of such proposals on emissions, energy prices, tax revenues and carbon intensity, (Section V).

The treatment of existing fossil-fuel taxes is shown to be an important determinant of the simulation results. Replacing existing taxes by a carbon tax, for instance, might reduce CO_2 emissions by 12 per cent. One reason for the rather small contribution from tax reform is the existing structure of end-use prices. The current implied average carbon tax equivalent is $70 per ton of carbon, of which oil contributes about 90 per cent. Moving from existing energy taxes to a carbon tax or hybrid carbon/energy tax would therefore imply an important switch in the taxation of different fuels, which would result in a fall in end-user oil prices and increases in coal and gas prices. The tax-switch policy would then give an incentive to substitute from gas, a low carbon-content fuel, into oil, a higher carbon-content fuel, but would nevertheless penalise coal. On the other hand, the economic cost would be reduced because of a lower dispersion among fossil-fuel tax rates, since the economic cost varies with the square of the tax rate. Adding an $80 carbon tax after such a tax reform would, however, lead to the substitution effects normally expected. Finally, it is shown that the difference in terms of emission reductions, energy prices and economic cost, between a carbon and a hybrid carbon/energy tax is likely to be small.

The negative relationship between energy prices and emission intensities suggests that there is scope for a carbon tax as an effective instrument of environmental policy. The cost of superimposing carbon taxes on top of current energy taxes may be substantial given that the costs are not additive In some countries, however, there could be scope to reduce both carbon emissions and the economic cost of taxation by reforming the current tax and regulatory structure -- a "no-regrets" policy. Given the uncertainty surrounding the timing, form and magnitude of the greenhouse effect, any abatement strategy should start with these policies. However, large cuts in carbon emissions are likely to require sizeable increases in fossil-fuel taxation.

II. Energy Prices, Taxes and Other Distortions

Energy-related carbon emissions largely depend on the fossil fuel consumed, with emissions varying by as much as a factor of two for a given heat content. Since the risk of global warming is linked to carbon dioxide and other greenhouse gas emissions [2], rather than the consumption of energy *per se*, it is instructive to examine energy volume and price data expressed in terms of the amount of carbon emitted. The fuel coverage and method used to construct energy prices, taxes and consumption data expressed per ton of carbon emitted are discussed in Annex I.

International price level comparisons

There are several methods for making international price and volume comparisons, each of which have their weaknesses and strengths. If there are no differences in price levels for goods and services across countries, then domestic prices can be converted to a common currency simply by using the relevant market exchange rate. This approach offers the advantage of being computationally straightforward. However, evidence from international price comparison surveys suggests that, when prices in different countries are converted into a common currency at market exchange rates, average price levels are not the same. Countries with lower levels of per-capita income tend to have lower prices than high-income countries (Hill, 1986). If data were converted at market exchange rates, price levels would differ. Converting the relevant data with purchasing power parities adjusts for price level differences between countries and allows a true comparison of volumes [3].

Although most prices of primary fossil energy sources and energy products are determined in world markets, domestic end-use prices, whether expressed in U.S. dollars or PPPs, differ significantly across countries (Table 1). Using market exchange rates, for example, average energy prices per ton of carbon in Switzerland are almost three times as great as in the United States. Measured in PPPs, final energy prices also display a great deal of variation among countries, with the difference between the highest and the lowest being even greater. While the carbon price in countries such as Japan, Switzerland and the Nordic countries is considerably lower, the price in some of the poorer countries increases when expressed in PPPs [4].

Emission intensities also vary considerably among countries and tend to be inversely related with end-use prices. Consequently, the share of fossil-fuel carbon expenditure to gross domestic product does not differ greatly between countries, except for Ireland and Portugal. The GDP weighted average fossil-fuel carbon expenditure share is 5.8 per cent of PPP GDP and the standard deviation is 1.3 per cent, or 0.9 per cent when the two outliers are excluded (Table 1).

Part of the variation in emission intensities among countries is due to the differing importance of carbon-free energy -- nuclear, hydro and renewables. France, Norway and Switzerland, which source 40 per cent or more of their energy requirements from carbon-free fuels, have emission intensities close to half the GDP-weighted OECD average of 220 kilos of carbon per million dollars of output. Japan and Italy, however, have relatively small shares of carbon-free fuels and yet also feature among the countries with a low carbon intensity. A large carbon-free proportion of energy supply, however, does not ensure a low carbon intensity. Canada produces 75 per cent of its electricity requirements from hydro and nuclear and yet has one of the highest carbon intensities.

Variations in energy prices across countries

Results from an OECD project comparing different global models show that the economic cost of a carbon-tax policy and its effectiveness in terms of abatement reduction depends importantly on the existing level of energy prices (Dean and Hoeller, 1992). Countries with high energy prices will require larger carbon taxes than low energy-price nations to achieve a certain degree of abatement. It is relevant, therefore, to analyse what factors explain the large difference in energy prices per ton of carbon across countries. Four key determinants are:

a) taxes and subsidies;

b) the composition of fuel demand and the proportion of each fuel consumed by the industry, household and power generation sectors;

c) other market distortions, such as price-support measures, certain government policies and non-competitive industry structure; and

d) local distribution costs and quality differences.

Estimates of average implicit carbon taxes are shown in Chart 1 and Table 2 for 20 OECD countries expressed in U.S. dollars. Among the major OECD countries, the implicit carbon tax is low in North America, intermediate in Germany and Japan and high in France and Italy. It is also generally high in small European economies. The tax is much higher for oil than for gas in all countries and coal is usually untaxed (Chart 2 and Table 2). In many European countries, the oil product tax is above $250 per ton of carbon (equivalent to about $30 on a barrel of oil), which is much higher than the taxes suggested by recent energy tax reform proposals, for instance by the EC or the Swedish Government. The taxes on some specific oil products, such as gasoline and diesel, are higher still.

While before-tax prices per ton of carbon show less dispersion across countries than end-use prices, the variation is still large (Charts 1 and 2). In Japan and some European countries, before-tax prices are close to double the U.S. price, or even more. Part of the remaining difference is explained by the sectoral composition of fuel consumption. Energy prices for industrial and power generation users are lower than for households, reflecting lower distribution and marketing costs. Household natural gas prices, for instance, are in nearly all OECD countries more than double industrial and power generation prices. Countries which have a large proportion of gas consumed by households, such as the 70 per cent share in the United Kingdom, have a considerably higher average pre-tax gas price than, for example, Canada where household gas accounts for 45 per cent of total consumption.

Remaining differences in before-tax prices mainly reflect aggregation across different fuel types, trade restrictions and other market imperfections. In the absence of very detailed data, the effect of these factors on end-use prices is difficult to quantify. Using the available partial information, an attempt is made to calculate the aggregate contribution of various non-tax distortions on energy prices. First, reference prices are calculated for each country, which ideally should approximate before-tax prices prevailing in a deregulated competitive environment (for details on how this is measured see Annex I). The difference between the before-tax price and this reference price represents the residual wedge. The residual wedge is a measure of the non-tax distortions in fossil-fuel markets. However, given the degree of approximation necessary for those calculations, the size of the wedge also reflects measurement error and includes differences in refining and distribution costs. For natural gas, distribution costs are likely to vary significantly across countries.

The resulting reference prices and residual wedges are shown in Charts 1 and 2. The deviations in reference prices across countries reflects differences in patterns of fuel use and, in a few instances, the fact that a country-specific product price is below the reference price. Countries with a high share of coal, for instance, tend to have a lower reference price, while countries with a high gas share tend to have a higher reference price. While negligible in the United States, Australia and the Netherlands, the calculated wedges suggest that non-tax distortions may be large in some OECD countries. Indeed, in New Zealand and several European countries, the residual wedge is large compared with the tax wedge. For Japan, it is even larger.

A decomposition of the residual wedges by fuel for the major seven economies is provided in Chart 2. Apart from Japan and Canada, the residual component is small for oil products, where price differences are mainly explained by taxation. Residual wedges for gas are large in Japan and the European countries. For coal, large residual wedges in Japan, Germany and the United Kingdom [5] account for all end-use price differences, while residual wedges are zero or close to zero in the other major economies.

It would be instructive to be able to quantify the contributions of different government policies and other factors to the size of the residual wedge. This is only possible with detailed knowledge and data on government policies and market structures. Part of such information is available for the coal industry. Steenblik and Wigley (1990) have computed producer subsidy equivalents (PSE) for Japan and several European countries. PSEs measure the assistance to producers as gauged by the value of policy-induced transfers from consumers and taxpayers to producers. Their estimates of subsidies and price support for coal producers per ton of carbon, as updated in IEA (1991*b*), are shown in Table 2. Despite large subsidies, price support measures have kept coal prices far above world market prices in most of these countries. A large part of the residual wedge for coal in Chart 2, therefore, reflects the cost of policies to sustain production from inefficient coal mines [6].

For the other sectors, contributing factors are more difficult to identify and even more difficult to quantify. In oil product markets, a large wedge in Austria and Finland (not shown) may reflect monopoly rents of nationalised refiners [7], while in Japan import restrictions are sizeable [8]. In most European countries, gas distribution is in the hands of public monopolies. Monopoly rents from current marketing arrangements in most European countries could equally be viewed as tax revenue from implicit, and less transparent, taxes on natural gas [9]. Recently, the EC Commissioner for Competition Policy has asked member states to justify their gas import and export monopolies, arguing that deregulation of the U.S. gas market was a success and prices in Europe could be much lower if markets were liberalised (*Financial Times*, 11 October 1991, page 2). In the United Kingdom, where the gas distribution system was privatised in 1986, the Office of Fair Trading has stated that privatisation of British Gas has only marginally increased competition for industrial gas and has argued that further liberalisation steps are necessary to induce more competition (*Financial Times*, 11 October 1991, page 16). The International Energy Agency argues in a recent report (IEA, 1991) that liberalisation of gas markets in Europe may not necessarily lead to the same results as in the United States because the industry structure differs considerably. In addition, open access or common carriage by itself may not increase competition as long as monopolies and exclusive rights are still present [10].

III. Energy Prices and Emission Intensities

Cost effectiveness of carbon abatement policies is achieved when the marginal cost of abatement is equalised across regions. The factors which contribute to differing marginal abatement costs include the fuel composition of energy demand, the intra-fuel price elasticities of substitution, the aggregate energy price elasticity of substitution and the current level of energy prices. Clearly, an examination of price distortions in energy markets is relevant in any evaluation of the effectiveness and economic cost of abatement policies. A fuller treatment of these issues requires a more rigorous specification of the relationship between energy prices and emission intensities.

The links between prices, aggregate output and energy demand can be represented simply via an energy demand equation derived from a constant-elasticity-of-substitution (C.E.S.) aggregate production function, where total energy demand (EN) depends on the price of energy (p_{EN}) relative to the output price (p_Q), output (Q), an elasticity of substitution (e) and a scale parameter (k):

$$EN = k \cdot [p_{EN}/p_Q]^{-e} \cdot Q \qquad [1]$$

As carbon emissions are fixed in proportion to the type of fuel used, energy-related carbon emissions will depend on the same factors as those shaping the demand for energy. The impact of relative price changes on energy demand depends critically on the elasticity of substitution among production inputs. In addition, substitution possibilities among fuels also matter for CO_2 emissions because emission factors differ among fossil fuels. In order to capture these two channels of substitution effects, an aggregate price of fossil fuels per ton of carbon (p_C) is calculated, which depends on the amount of fuels used (F_i), emission factors (a_i) and the price of fuels (p_{ENi}):

$$p_C = \sum_i F_i \cdot p_{ENi} \; / \; \Sigma \, a_i \cdot F_i \qquad [2]$$

where the "i" subscripts represent the seven fuels covered in this study -- gasoline, diesel, light fuel oil, heavy fuel oil, natural gas, steam coal and coking coal. Price and volume numbers are further disaggregated into end-use by households, industry and electricity generation (see Annex I for details).

Using relationships [1] and [2], one can infer the emissions of carbon (C) directly as a function of relative prices and output:

$$C = 1 \cdot [p_C/p_Q]^{-e} \cdot Q \qquad [3]$$

Apart from prices, emission intensities are likely to be influenced by endowment, as with hydroelectric energy, and energy policy, as with nuclear energy. Other factors may also play a role: population density, urbanisation, climate and the stringency of energy efficiency or environmental regulations. While it is impossible to construct economy-wide summary measures for the stringency of regulations, proxies for the other variables exist.

An emission function like [3] has been estimated for 1988 across 20 OECD countries, with relative prices and output being based on PPPs [11]. Correctly signed coefficients capturing factors other than relative prices and activity which were significant could only be found for the combined ratio of hydro and nuclear energy in total primary energy (HN). In the following regression energy prices relative to the United States are related to the output price levels relative to the United States and output is measured in PPPs:

$$\ln C = -3.3 - 0.75 \ln p_C/p_Q + 0.95 \ln Q - 1.53\, HN \qquad S.E.E. = 0.19 \qquad [4]$$
$$(-2.9)(-4.9) \qquad (28.1) \qquad (-4.9) \qquad R^2\ adj = 0.98$$

Equation [4] suggests that relative energy prices have had a considerable influence on emission levels and that carbon taxes could be a useful policy lever to influence future emissions. The relationship presented in equation [4] is, of course, a partial equilibrium relationship. Scenarios of future emission abatement would need to be assessed in a full general equilibrium framework such as OECD's GREEN model (Burniaux *et al.*, 1991).

Based on equation [4], the partial relationship between emission intensities and prices per ton of carbon is depicted in Chart 3. In order to plot the relationship between carbon intensity and prices, the coefficient on output has been restricted to one and an adjustment made for the average contribution from the hydro and nuclear energy share (HN). It shows that countries with a relatively low price per ton of carbon (e.g. the United States, Canada or Australia) have a high emission intensity, while the reverse is true for countries with a high price (Italy or Portugal). The share of carbon-free energies is also important. Countries with a high share of hydroelectric or nuclear power, such as France, Norway, Sweden and Switzerland are clearly to the left of the curve.

IV. The Cost of Reducing Emissions with Existing Taxes

As is well known, the deadweight cost due to a tax or tariff increases with the square of the tax or tariff rate, if the demand schedule for a good is linear and supply perfectly elastic. Hence, small taxes often have negligible economic cost, while the cost for large taxes increases disproportionately. Furthermore, the combined impact of two taxes on the same product is not just the sum of the individual deadweight losses, but could be much larger (Newbery, 1990). To put the following exercise into context it should be borne in mind that:

a) Carbon taxes are levied in order to internalise the eventual cost of climate change. In order to assess the welfare implications of policies to reduce GHG emissions, the cost of reducing emissions needs to be balanced against the benefits from avoiding climate change. In the following, the focus is only on the cost side of reducing energy-related carbon emissions. Emissions of other energy-related greenhouse gases are not considered.

b) In addition, the analysis only focuses on cost calculations on the energy side, which is only part of the total cost. Total cost may also be affected by terms-of-trade changes, repercussions of energy price changes on saving and labour supply decisions, and the way the government uses the tax receipts (Burniaux *et al.*, 1991; Goulder, 1991).

c) There are externalities that arise from fossil-fuel use other than climate change, such as damage from high levels of sulphur emissions, in particular from coal burning, and indirectly through road congestion. Current taxation of fossil fuels could reflect such externalities. However, this is not apparently the case, as coal and heavy fuel oil, the "dirtiest" fuels -- not only with respect to climate change -- are currently untaxed or taxed lightly in most countries, or even subsidised. In any case, the cost of policies needs to be balanced against the total beneficial effects from fuel taxation, be it benefits from reductions in CO_2 or other emissions, in order to assess welfare.

The arguments about the economic cost of taxation can be illustrated in a simple way, as shown in Chart 4 (see also Newbery, 1992). Assume that two countries of about the same size impose an equal amount of carbon constraint and that the derived demand curve for carbon is the same for both countries. In country A fuels are not taxed and the price P_A is associated with emissions C_A. In the other country fuels are taxed at T_{FB} and the after-tax price P_B+T_{FB} is related to emissions C_B. To a first approximation, the carbon constraint (C^*A and C^*B) will imply a carbon tax T_{CA} for one country and T_{CB} for the other. In order to achieve the emission constraint, T_{CB} is larger than T_{CA}, because for a given elasticity of energy demand the absolute price increase must be larger in order to increase energy prices by the same relative amount. The importance of differences in starting conditions has, for instance, been highlighted with OECD's GREEN model (Burniaux *et al.*, 1992), where carbon taxes vary considerably among regions, depending importantly on the large regional differences in fuel prices.

The average cost of emission reductions is measured by the shaded area ABC in the case of country A. For the other country with an existing tax the average cost is measured by the area DEGH and not the smaller area DEF. The deadweight loss of the current tax is ADH. The existing tax amplifies the cost of imposing the carbon tax. In the case of a linear demand schedule, a carbon tax of the same size as the existing tax would quadruple the cost, as the economic cost rises at the square of the tax rate. With a unitary demand elasticity, cost would increase at less than the square of the tax rate but still more than proportionately. In the case of subsidies to energy production or use, the argument would be the opposite. Up to the world market price a carbon tax would not impose a cost to the subsidising country, but rectify an existing distortion (Shah and Larsen, 1991). So far simulations with global models have not taken account of existing distortions in calculating average cost. In many of these models costs are large in developing countries, even though energy prices are far below world market prices (Dean and Hoeller, 1992).

The question still arises as to whether current taxes on energy are mainly revenue raising or should be regarded as user charges for road use, construction, congestion or other externalities. If they were user charges, set at just the right level, cost would be just the upper triangle DEF. At issue is what proportion of existing fuel taxes can be regarded as a tax on road use and congestion as opposed to raising revenues or protecting domestic production. In the United States, for instance, excise, transport fuel and vehicle taxes are paid into a road fund, in order to finance road expenditure. In most European countries, such taxes are much higher, yet even higher taxes may be justified if account is taken of the capital cost of the road network, congestion costs and the cost of other externalities (Newbery 1988, 1990*a*). On the other hand, the current way of collecting user charges by fuel taxes may be very inefficient in minimising the cost of road maintenance and construction and in its way of charging for congestion (Winston, 1991).

The following numerical exercise asks whether current energy taxes, even though low compared to carbon taxes, are large enough to influence cost calculations significantly. Simulations are performed with a small, highly-simplified energy demand system based on the translog cost function originally developed by Christensen, Jorgenson and Lau (1973). From the translog cost function, fuel-cost share equations can be derived. Fuel shares (S_i) depend on own-prices and the prices of other fuels (P_j):

$$S_i = a_i + \sum_j b_{ij} \ln P_j \qquad [5]$$

The i and j subscripts stand for the three primary fuels (oil, gas and coal). In order to have a well-behaved demand system, symmetry and adding-up conditions are imposed [12]: $\Sigma a_i = 1$, $b_{ij} = b_{ji}$ and $\Sigma b_{ij} = 0$.

The price, quantity and tax data are the same as presented in Section II, but are now expressed in tons of oil equivalent. The model does not allow substitution between fossil fuels and non-fossil fuels. During the next 15 to 20 years, it is unlikely that a massive non-fossil fuel expansion could take place in response to price changes. The framework is partial equilibrium and comparative static, and as such, is unable to shed light on aggregate effects and on the path of adjustment.

Parameters for the share equations have been based on priors and a limited survey of the literature. Country-specific elasticities depend on actual fuel shares. The higher the fuel shares are, the lower the cross-price elasticities are and vice versa. Evaluated at the average OECD fuel shares, own-price elasticities are -0.4, -1.3 and -0.9 for oil, coal and gas respectively, while cross-price elasticities are all positive. An elasticity of 0.75 is assumed between aggregate energy and other inputs.

Simulation results for successive $40 step increases in a carbon tax are summarised in Table 3. The carbon tax is applied to after-tax prices. For the 20 countries in the sample emissions fall considerably for the first $40, while the decline is modest when the tax increases from $120 to $160. Economic cost, on the other hand, would be negligible at the start but increase rapidly at higher tax rates [13]. Emission reductions and cost measures are rather sensitive to the substitution elasticities chosen, especially for high carbon taxes.

Existing energy taxes in OECD countries are approximately equivalent to an average $70 carbon tax. If they are included in the assessment of economic cost -- assuming that they are all distorting -- then the cost changes significantly (last column of Table 4). For instance, the economic cost would double for a 39 per cent emission reduction, even though the average tax underlying the cost assessment has only increased from $160 to $230 (see bottom line of Table 3). To the extent that existing energy taxes are not distorting but correct for externalities, this numerical example may overstate the additional cost. However, assessments to date of the cost of reducing emissions, which have ignored existing taxes and other distortions, may have been biased downwards, at least in countries with energy taxes which are already high.

Goulder (1991) produced the first model-based results for the United States showing the effects of prior tax distortions on cost assessment in the wake of the introduction of a carbon tax. The main focus of his paper was on the use of carbon tax revenue to reduce personal income, corporate and payroll taxes. Concerning energy taxation, he considers carbon taxes in the face of changing capital and labour taxes in energy-producing industries. He concludes that such changes would have a considerable effect on cost calculations, but he does not consider the effects of existing indirect taxes on energy.

While taxation of fossil-fuel use is high in many OECD countries, subsidies to energy users are large in many developing countries. Shah and Larsen (1991) estimate world energy subsidies in 1990 to be in excess of $139 billion. Elimination of such subsidies is estimated to reduce carbon emissions by 17 per cent in subsidising countries and 8 per cent globally. Removal of subsidies would improve allocative efficiency and generate a welfare gain in subsidising countries. Shah and Larsen also provide partial and comparative static analyses of the effects of using tax receipts to reduce taxes on labour and capital in the United States, Japan, India, Indonesia and Pakistan. They conclude that the replacement of corporate taxes by a carbon tax would pay on efficiency considerations alone in countries such as Indonesia or India, with low or no energy taxes.

V. Restructuring Energy Taxes

Most studies which analyse the imposition of carbon taxes assume that existing energy taxes do not change. One advantage of the methods used to compute the data base underlying this paper is its scope to analyse the impact of reforming existing taxes, adding new energy taxes or a combination of the two. In all countries where a carbon tax has been introduced, existing energy taxes have indeed been reformed at the same time. It is clearly important, therefore, to understand the differing impacts from adjusting current energy taxes compared with imposing new taxes. To quantify the differences entailed, the following four simulation scenarios are performed:

a) existing taxes on oil, gas and coal are replaced by the current average implicit carbon tax in each country (as shown in Table 2);

b) the same tax switch as in case a) but with an additional $80 carbon tax (equivalent to about $10 per barrel of oil);

c) an $80 carbon tax but with existing taxes unchanged;

d) a combined carbon/energy tax of $40 per ton of carbon and $33 per ton of energy with existing taxes unchanged; this roughly corresponds to the amount by which taxes would be increased in the EC's proposed tax changes.

None of these simulations mimic current tax reform proposals one-to-one. In Sweden, for example, current energy taxes on oil products were halved. The remaining tax is a carbon tax, which is also levied on gas and coal. The energy tax on oil products is motivated by externalities from oil product use even in the absence of climate change. However, power generation is tax-exempt and there are thresholds for total tax payments by industry. Tax reform in Sweden was also more comprehensive. For example, a charge on the sulphur content of fuels was also imposed at the same time (see Hoeller and Wallin, 1991). The proposal by the EC to introduce an energy-cum-carbon tax (roughly equivalent to $80 per ton of carbon), is -- if adopted -- also likely to exclude energy-intensive industries.

Simulation results

Simulations are again performed with the energy demand system outlined in Section IV. The first scenario examines the potential to achieve emission reductions at the same *ex-ante* tax level by changing the existing tax structure. Currently, most OECD countries tax oil products relatively more than gas and leave coal largely untaxed (Table 2). Country-specific results will, therefore, differ widely and *a priori* an increase in emissions cannot be excluded. Whether, for example, emissions from fuels with a low carbon content increase or decrease would depend on the initial price and tax levels on gas and other fuels. The second scenario is compared with the first simulation rather than with the base case. Analysed in this manner, changes in the composition of energy consumed due to a realignment of existing taxes are abstracted from. The tendency will be for a substitution away from coal and oil towards gas, the magnitude of the shift depending on the initial price levels of fossil fuels and the elasticities of substitution.

Simulation results for the OECD in aggregate are summarised in Table 4. Replacing current taxes on fuels by country-specific average carbon taxes increases the OECD-wide average energy price by 8 per cent. The restructuring of end-use prices favours oil products, which is currently the fuel most heavily taxed in all countries. The average price of oil falls by about 17 per cent, whereas gas and coal prices increase by 17 and 77 per cent respectively (Table 5). As a result, the composition of fossil fuels in energy demand moves to being less coal and gas intensive and CO_2 emissions are 12 per cent lower. The average carbon intensity (the ratio of carbon emissions to energy use) falls from 0.83 to 0.79 and fuel substitution contributes 4 percentage points to the area-wide decrease in emissions. The tax revenue raised is lower, despite higher prices, than under the current tax regime. Replacing existing taxes with a pure carbon tax more than halves the economic cost to 0.1 per cent of GDP. The reduction in economic cost mainly occurs because of a "levelling of the playing field" among fuel-specific tax rates. The finding is in line with a large number of studies which have shown the beneficial effects resulting from a reduced dispersion of statutory tax rates or tax exemptions.

The second simulation examines the effects of replacing existing taxes by the implicit carbon tax equivalent (as in the first simulation) and adding a further $80 per ton of carbon tax. To isolate the impact of the additional carbon tax, the results are compared with case a). Average energy prices increase 24 per cent. The composition of the price changes is markedly different from case a). The gas price increases by 18 per cent, slightly less than the average oil price increase. The price of coal, the high carbon and low-cost fuel, increases by 50 per cent. The improvement in the relative competitiveness of gas encourages a switch from both coal and oil into gas.

The carbon intensity declines further to 0.78 and the economic cost is 0.5 per cent of GDP.

The third scenario -- an increase in current end-use prices by an $80 tax per ton of carbon -- is applied to all 20 countries. This is approximately equivalent in aggregate to a doubling of average existing energy taxes. The major source of emission reductions is an average 41 per cent increase in end-use prices. Although the carbon tax imposes a larger wedge on oil and coal *vis-à-vis* gas, the current energy tax base is predominantly on oil. As a consequence, the price level of oil is greater than gas or coal for a unit of heat. The percentage price increases from the imposition of an $80 carbon tax are therefore lowest for oil. Fuel substitution contributes 3.9 percentage points to the 29 per cent aggregate reduction in emissions. The reductions are largest in those countries with low prices before the tax imposition and with a high share of coal.

The fourth simulation examines the effects of maintaining existing taxes and adding a combined carbon/energy tax, which is equivalent in total to the tax increase in the third scenario. The carbon tax is set at $40 per ton of carbon and the energy tax at $33 per ton of oil equivalent. The average energy price also increases by 41 per cent. However, the gas price is higher and the coal price lower than under a carbon tax (Table 5), because the tax does not take into account to the same extent the different carbon content of the fuels. For this reason the substitution effect is smaller although the difference in the reduction in emissions (in both cases close to 28 per cent) is negligible. The economic cost for cases c) and d) are insignificantly different from each other at 0.67 per cent of GDP, but are higher than in case b) where existing energy prices have already been put onto a carbon basis before the introduction of the new carbon tax.

These simulation results suggest that both emissions and the economic cost of taxation could be reduced by a realignment of existing taxes to better reflect the externalities associated with fossil-fuel consumption. Welfare gains will, however, also depend on the extent to which energy taxes reflect other externalities associated with fossil-fuel consumption. In the first simulation -- switching existing energy taxes to a carbon basis -- aggregate energy prices change only marginally and both emissions and the economic cost of taxation fall. The aggregate price movement masks considerable compositional changes. Because the existing energy tax base falls almost solely on oil products, leaving coal and gas largely untaxed, the reform package actually decreases average oil prices. The change in relative prices motivates substitution from coal and gas (the lowest carbon-emitting fossil fuel) into oil. The substitution effect from scenario a) is, therefore, partly weakened by this switch from gas into oil. The substitution effects that are usually expected from a carbon tax only show up in scenario b) where a carbon tax is added only after environmental tax reform.

Table 1. **Carbon prices and intensities in 1988**

	Price per ton of carbon $US	Price per ton of carbon PPP (1)	Emission intensity $US (2)	Emission intensity PPP (2)	Per cent share of fossil-fuel spending in GDP $US	Per cent share of fossil-fuel spending in GDP PPP
United States	192	192	294	294	5.7	5.7
Japan	466	343	94	147	4.3	5.0
Germany	335	308	163	198	5.5	6.1
France	491	376	105	118	5.2	4.4
Italy	460	478	126	129	5.8	6.2
United Kingdom	357	400	193	199	6.9	8.0
Canada	278	234	254	270	7.0	6.3
Australia	193	244	283	294	5.4	7.2
Austria	467	359	130	151	6.1	5.4
Belgium	322	314	191	205	6.2	6.4
Denmark	341	330	154	215	5.2	7.1
Finland	357	268	169	248	6.0	6.7
Ireland	378	453	241	261	9.0	11.8
Netherlands	326	327	184	207	6.0	6.8
New Zealand	437	336	167	175	7.3	5.9
Norway	503	266	94	137	4.7	3.7
Portugal	365	794	233	140	8.5	11.1
Spain	309	441	157	138	4.8	6.1
Sweden	502	289	112	157	5.7	4.5
Switzerland	560	302	68	100	3.8	3.0
GDP weighted average	335	294	194	219	5.4	5.8
standard deviation	99	124	63	58	1.3	1.3

1. Relative energy prices related to relative output prices, defined as the U.S. price multiplied by the ratio of energy PPPs to GDP PPPs.

2. Kilos of carbon emitted per million dollars of output.

Table 2. **Implicit carbon taxes in 1988**

$ per ton of carbon

	United States	Japan	Germany	France	Italy	United Kingdom	Canada
Implicit carbon tax							
Oil and oil products	65	130	212	351	317	297	108
Gas	0	2	23	38	80	0	0
Coal	0	0	0	0	0	0	0
Total	28	75	95	229	223	107	52
Implicit subsidy and price support for the coal industry							
Subsidy	..	2	28	..	..	10	..
Price support	..	15	49	..	..	36	..

	Australia	Austria	Belgium (1)	Denmark	Finland	Ireland	Netherlands
Implicit carbon tax							
Oil and oil products	178	267	162	297	200	277	221
Gas	0	39	35	110	0	4	27
Coal	0	0	0	0	0	0	0
Total	61	150	86	147	107	139	89

	New Zealand	Norway	Portugal	Spain (2)	Sweden	Switzerland
Implicit carbon tax						
Oil and oil products	235	258	205	176	268	224
Gas	0	0	13	19	13	2
Coal	0	0	0	0	6	18
Total	117	182	147	112	214	198

1. Subsidies to coal producers amounted to $24 per ton of carbon.

2. Subsidies to coal producers amounted to $25 per ton of carbon and price support to $5 per ton of carbon.

Source: Estimates based on IEA (1990) and IEA (1991a).

Table 3. **Economic costs associated with increasing carbon taxes**

Average values for 20 countries

Carbon tax ($ per ton)	Carbon plus current energy taxes ($ per ton)	Emission reduction		Economic cost (% GDP) with:	
		per cent	bil. tons	Carbon tax	Carbon and current energy tax
0	70	0	0	0	0.37
40	110	-19	-0.49	0.07	0.49
80	150	-29	-0.75	0.21	0.67
120	190	-35	-0.90	0.38	0.89
160	230	-39	-1.01	0.57	1.13

Table 4. **Summary of simulation results**

	Per cent change in			$ tax per ton of		Carbon intensity	Substitution effect (1)	Economic cost (2)
	Emissions	Energy prices	Tax revenue	Carbon	T.O.E.			
Base case	0.0	0.0	0.0	70.5	58.2	0.827	0.0	0.37
Carbon tax	-11.7	8.1	-10.3	71.6	56.5	0.790	4.2	0.13
Carbon tax equivalent plus $80 carbon tax add-on (3)	-16.2	23.6	65.7	141.4	109.8	0.777	1.4	0.48
$80 carbon tax add-on	-28.5	41.0	74.6	172.0	134.9	0.784	3.9	0.67
Half energy/half carbon tax	-28.1	41.3	76.9	173.2	136.8	0.790	3.4	0.67

1. Percentage point contribution to the change in emissions.
2. Expressed as a percentage of GDP.
3. Per cent changes are computed using the carbon tax scenario as the base.

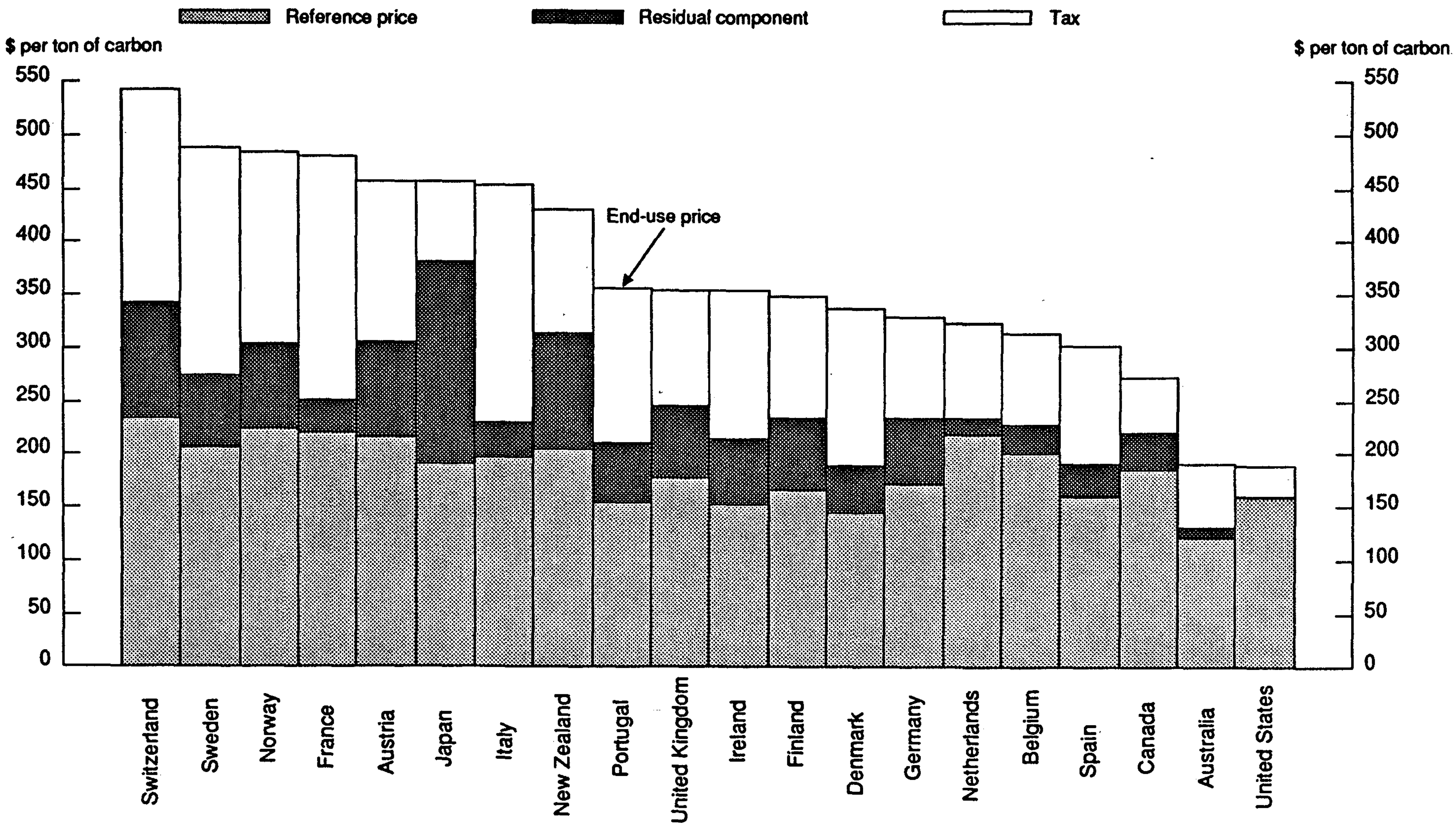
Table 5. **Energy price and emission changes**

per cent

	Change in prices				Change in emissions			
	Oil	Gas	Coal	Total	Oil	Gas	Coal	Total
Carbon tax								
North America	-12	12	51	10	21	-15	-51	-12
Other OECD (1)	-19	24	97	6	35	-31	-75	-11
OECD	-17	17	77	8	28	-21	-61	-12
Carbon tax equivalent plus $80 carbon tax add-on (2)								
North America	24	23	77	31	-12	-14	-52	-20
Other OECD (1)	16	13	34	16	-9	-8	-30	-11
OECD	19	18	50	24	-10	-12	-46	-16
$80 carbon tax add-on								
North America	25	31	140	50	-9	-20	-67	-32
Other OECD (1)	15	20	91	32	-6	-15	-56	-24
OECD	19	26	112	41	-8	-18	-63	-29
Half energy/half carbon tax								
North America	26	37	123	50	-10	-23	-64	-32
Other OECD (1)	15	23	80	32	-6	-18	-53	-23
OECD	19	31	99	41	-8	-22	-59	-28

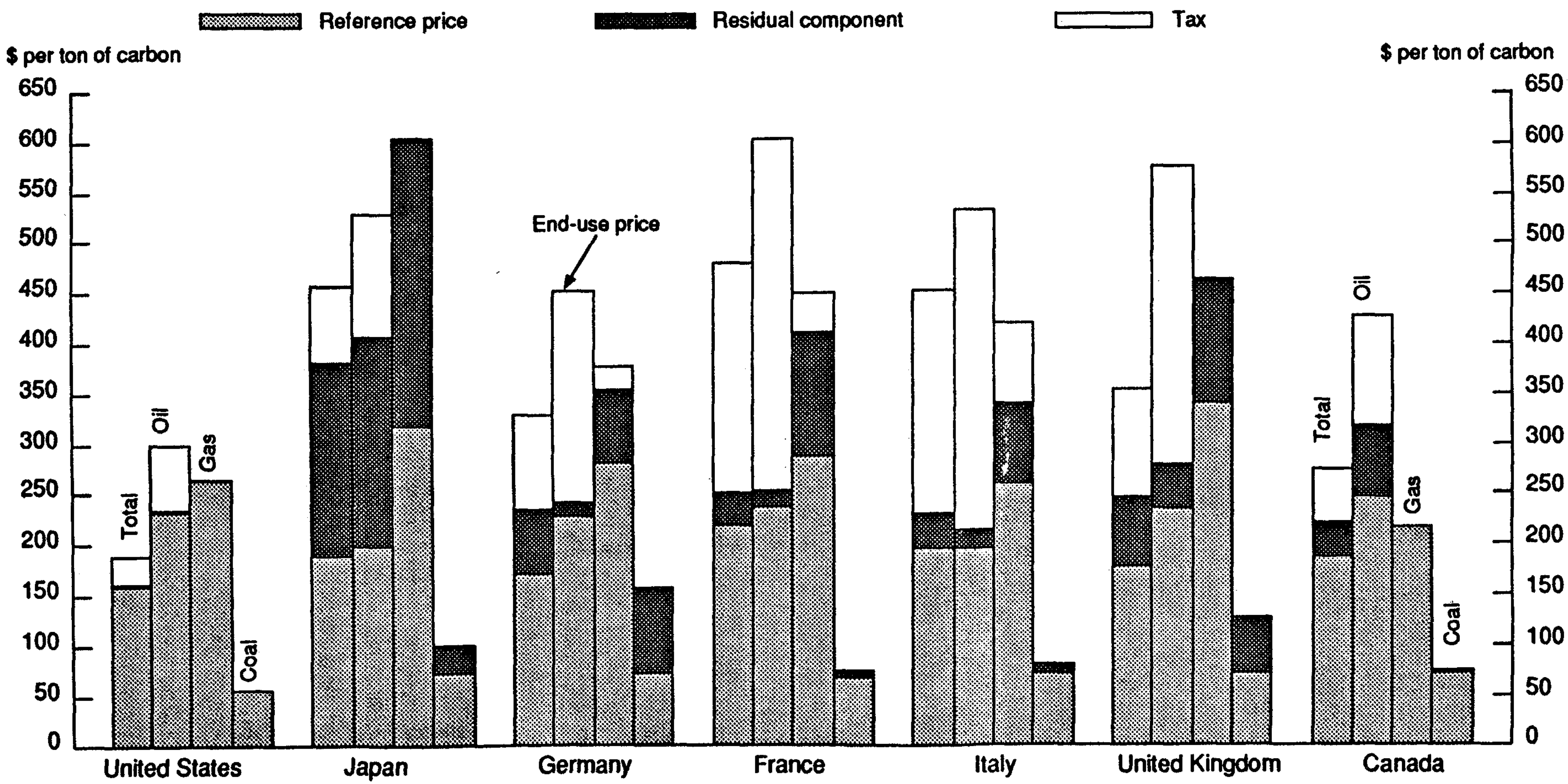
1. "Other OECD" excludes Greece, Iceland, Luxembourg and Turkey.
2. Per cent changes are computed using the carbon tax scenario as the base.

Chart 1. **The tax and total wedge between a reference and end-use price**
(Dollars 1988, US exchange rate)



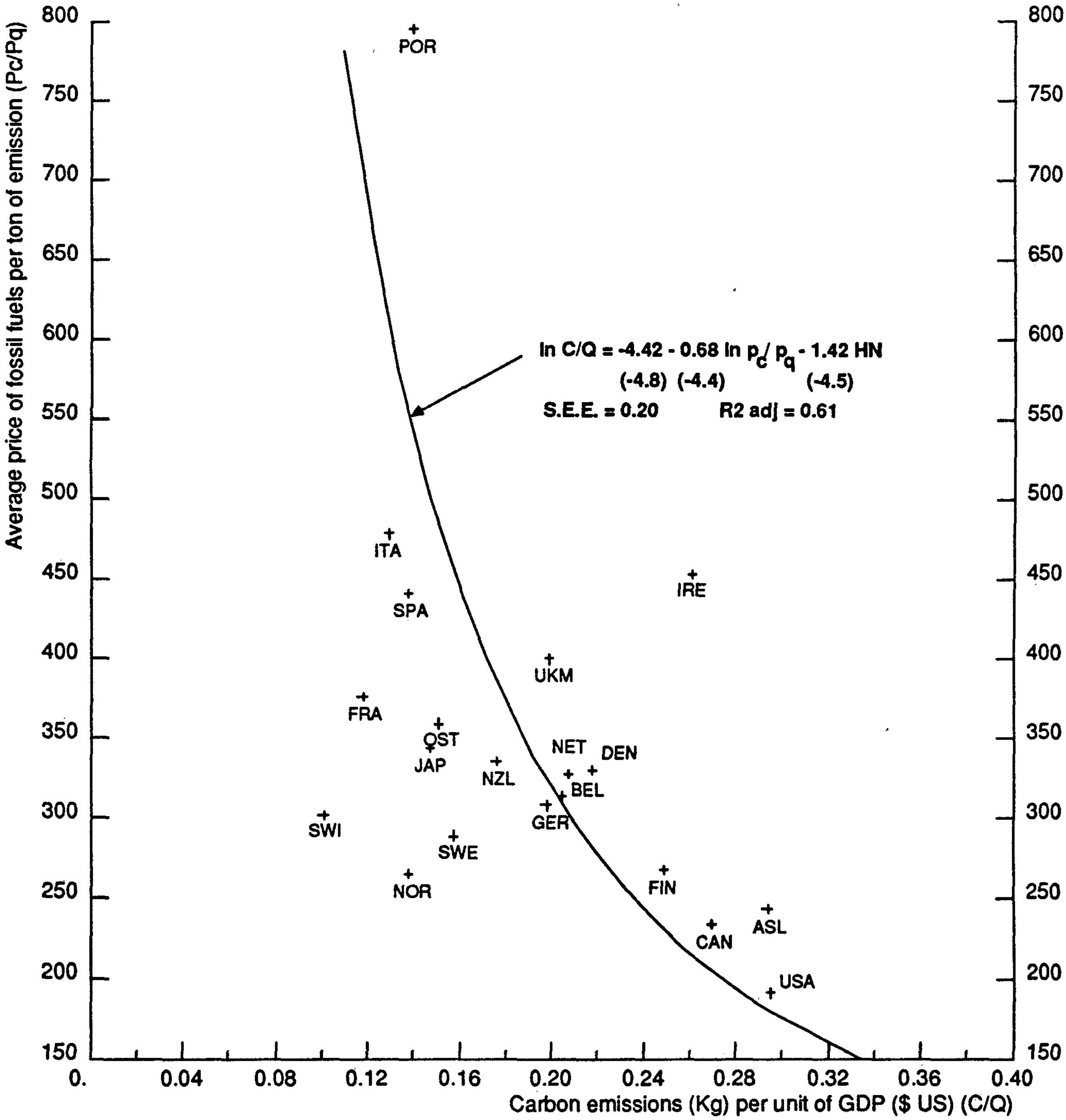
Source : Estimates based on IEA data.

Chart 2. **The tax and total wedge between a reference and end-use price, by fuel type**
(Dollars 1988, US exchange rate)



Source : Estimates based on IEA data.

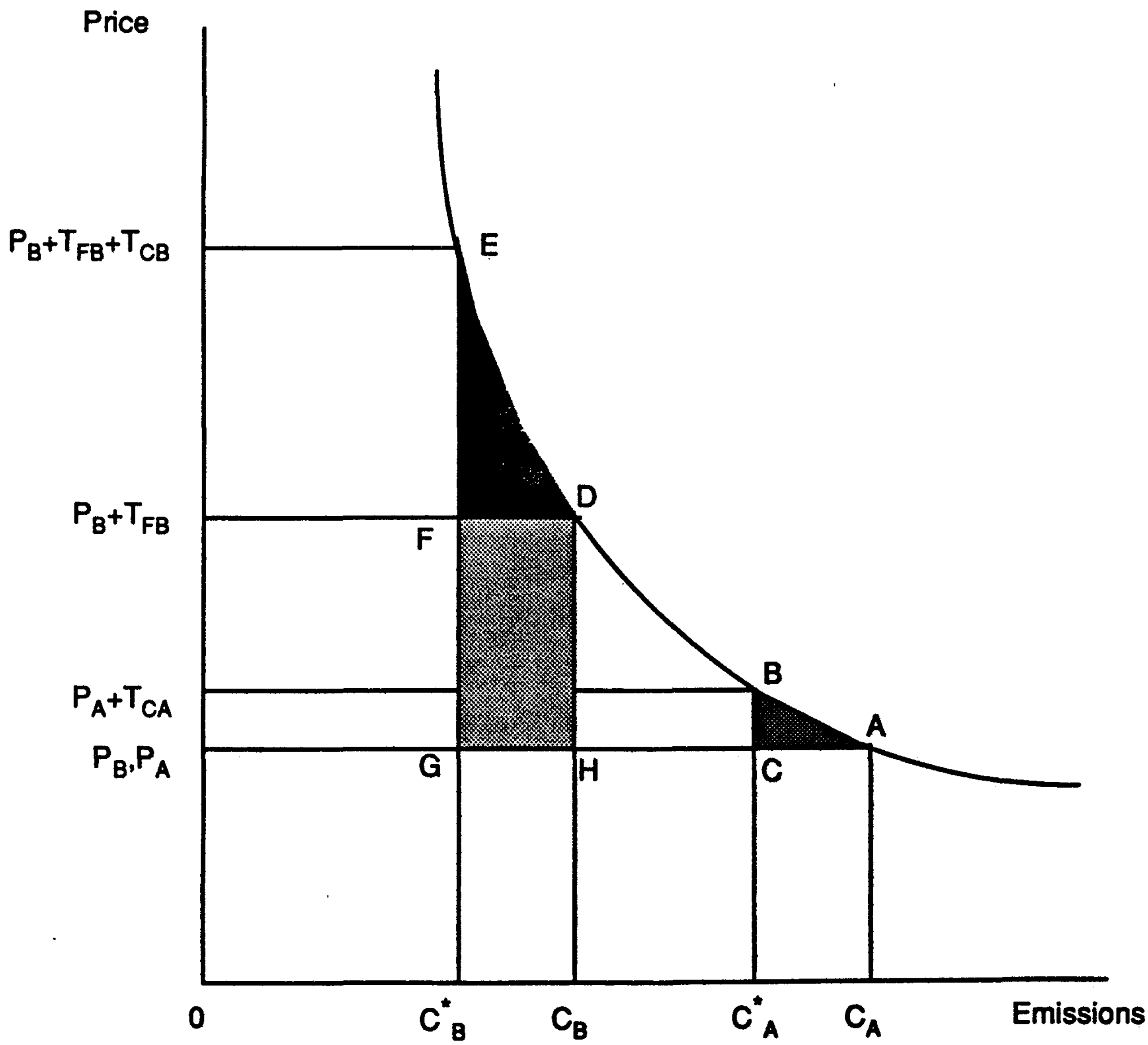
Chart 3. **Prices per ton of emission and emission intensities**
(Dollars 1988)



Source: Estimates based on IEA data.

Note: The relationship between carbon intensity and prices is adjusted for the average contribution from the hydro and nuclear energy share (HN). This affects in particular France, Norway, Sweden and Switzerland. Country codes which may not be obvious are ASL and OST which are respectively Australia and Austria.

Chart 4. **Marginal and average cost of carbon taxes**



Notes

1. An earlier version of this paper was presented to the OECD Workshop on Fee and Charge Systems for Reducing GHG Emissions, 5-6 November 1991. We are grateful for comments and suggestions by Andrew Dean, Jorgen Elmeskov, Robert Ford, Constantino Lluch, John Martin, David Newbery, Ronald Steenblik and Workshop participants without implicating them in the views expressed here. Special thanks are due to Anne Chergui, Trellis Huahn, Janet Law, Anick Lotrous and Francette Koechlin for technical assistance.

2. These are methane, nitrous oxide and chlorofluorocarbons. CO_2 is the most important greenhouse gas (GHG) and 75 per cent of man-made CO_2 emissions arise from the burning of fossil fuels.

3. Concerning relative energy prices, PPPs may be a good proxy for the relative prices households face in different countries. The magnitude, however, of price level differences in energy-intensive industries and electricity generation is likely to be lower. As they are very capital intensive, what matters most for relative prices is the user cost of capital. Investment goods are traded internationally and capital markets are largely integrated. Therefore, price level dispersion for these two sectors which generate two thirds of emissions, should still be well reflected in energy prices converted by market exchange rates.

4. In most OECD countries the energy PPPs and the GDP PPPs are greater than in the reference country. In Portugal and Spain, however, GDP relative prices are lower than in the United States while relative energy prices are higher. In the case of Portugal where the energy PPP is twice that of the United States and GDP PPP about half, the price of carbon in PPPs is four times greater than when measured in U.S. dollars.

5. For the United Kingdom, the residual wedge on coal is substantially lower, if the actual import price and not the average import price for the European countries is used. The higher price reflects the lack of large bulk-handling import terminals, which itself is the result of past restrictions on imports of coal. The U.K. and Irish import prices are the only European import prices which differ substantially from the average.

6. The amount of assistance due to price support measures, as calculated by Steenblik and Wigley (1990), is smaller than the residual wedges calculated here. The difference largely stems from the use of different reference prices.

7. In mid-1991 the Finnish authorities relaxed import restrictions on oil products and since 1 January 1992 all import licences for fuel were abolished effectively ending the monopoly structure on oil products. Since the changes gasoline prices exclusive of tax have come closer to the OECD average.

8. In Japan, a large amount of crude oil is burnt directly for power generation and is absent from the calculations. Since the taxation of crude oil is low, the inclusion of crude oil burnt directly would lower the non-tax wedge.

9. The regulated structure of the gas industry in Europe makes it extremely difficult to identify relevant gas prices since they are linked in many countries to the price of the nearest competing fuel. Indeed, published information is very patchy and is not necessarily representative of the marginal opportunity cost.

10. Difficulties in modelling gas markets are well explained in Bjerkholt *et al.* (1990).

11. For the reference country, the United States, a relative aggregate energy price cannot be established. Concerning household expenditure the price level for heat and light was 15 per cent below the aggregate price level in 1985.

12. This approach has frequently been used. See, for example, Griffin (1977) who analyses fuel substitution in the power-generating sector, or Hogan (1989) who uses it to analyse inter-fuel substitution in the United States and Japan.

13. For small price changes, the economic cost of taxation is approximated by the Harberger triangle:

$$W = 1/2\ t\ \Delta E \qquad [1]$$

where W represents economic cost, t the tax and ΔE the change in energy consumption. Base energy consumption is computed from simulating the removal of existing energy taxes. If,

$$\Delta E = (t/p_0)\ \mu\ E_0 \qquad [2]$$

then,

$$W = 1/2\ t^2\ \mu\ E_0/p_0 \qquad [3]$$

where p_0 and E_0 are baseline prices and energy consumption respectively, and μ is the price elasticity of demand for energy.

Note that the calculations are partial in nature and the assumptions for computing Harberger triangles need to hold. If energy supply prices fall, for instance, because of the imposition of carbon taxes, there could be a welfare gain for energy-importing countries and a loss for energy producers.

Annex 1

Data Construction Methods

The data base underlying the tables, charts and simulation scenarios have been constructed from IEA energy price and tax data (1990). Price and tax numbers are subdivided into three sectors: industry, households and power generation. Included within industry are the products heavy fuel oil, light fuel oil, diesel, natural gas, steam coal and coking coal. The household sector includes light fuel oil, gasoline and natural gas. Within power generation the three fossil-fuel oil, natural gas and coal are covered. Hydro, nuclear and other renewables are excluded from the analysis.

The price and tax data cover approximately 65 per cent of all commercial energy consumed in 20 OECD countries. In Ireland peat represents about 15 per cent of total energy needs. Data on average peat prices is not available but it has been possible to calculate average milled peat prices for power generation. Due to lack of data Greece, Iceland, Luxembourg and Turkey are excluded. There is variation in data coverage among countries largely depending on the relative share of nuclear and hydro in total energy consumed. For France, a significant nuclear producer, the coverage is slightly less than 50 per cent whereas in Italy it is around 80 per cent. Among fossil fuels under-coverage is mainly in the business sector. Price data are not available, for instance, for agriculture, service sectors or railways.

Tax numbers include excise taxes and VAT for households. A split between household and business consumption of diesel and gasoline consumption is not possible. The calculations assume that all gasoline is consumed by households (includes VAT) and all diesel is used by businesses (excludes VAT). For the United States, local taxes on fossil-fuel use are not available in IEA (1990). An estimate for import duties for the United States and Japan is included. Small import duties in Austria, Finland and Portugal are not taken into account. In a few instances, such as taxes on natural gas for residential use in the United States, taxes on steam coal for industrial use in Canada and taxes on natural gas and steam coal for electricity generation for most countries tax numbers were not available. In these cases a zero tax was assumed. Where tax or price numbers were available in previous years, but not for 1988, an estimate for the tax and price numbers has been made.

In order to estimate end-use prices each products pre-tax numbers are the starting point. The tax wedge is then added on. This implies that the products not included are assumed to have a zero tax rate. This is likely to provide a good approximation for end-use prices as under-coverage of products is mainly in the business sector.

All quantity data is originally expressed in terms of tons of oil equivalent. To compute pre-tax prices per ton of carbon equivalent expenditure on a specific fuel is divided by the carbon emitted by the consumption of that fuel. The following emission factors were applied to the TOE data:

Heavy Fuel Oil	0.89
Gasoline	0.81
Diesel	0.84
Light Fuel Oil	0.84
Natural Gas	0.60
Steam Coal	1.09
Coking Coal	1.09
Peat	1.23

As under-coverage is likely to be of little importance for tax data, tax revenue is directly related to IEA emission numbers and pre-tax prices and taxes per ton of carbon added to form the end-use price per ton of carbon.

Reference prices for each of the fuels are based on world market prices or prices close to world market prices. For oil products the simple average of U.S. and German domestic prices are employed. Both countries have a deregulated domestic market and imports are not constrained. For coal the European import price is taken as a benchmark. For natural gas in power generation a price somewhat above the pipeline price is used. For households and industry an average of the low price countries is employed. In the case of Japan which consumes mostly LNG sourced from distant producers the reference prices are adjusted upwards to account for the additional transport and revaporisation costs. Specifically, the following reference prices in terms of TOE are taken.

Industry	
Heavy Fuel Oil	91
Light Fuel Oil	166
Diesel	207
Natural Gas	125
Steam Coal	78
Coking Coal	79
Households	
Light Fuel Oil	203
Gasoline	231
Natural Gas	250
Power Generation	
Oil	101
Coal	78
Natural Gas	100

In the case of Japan the natural gas reference prices for industry, households and power generation are 185, 310 and 160 respectively. When a domestic price is lower than the reference price the lower price is taken.

End-use prices are converted into a common currency by the U.S. market exchange rate, GDP PPPs and energy PPPs. Table 6 lists the rates of conversion. The energy PPPs are calculated using the price and quantity data detailed above in the same manner as the GDP PPPs. For a description of how PPPs are estimated see OECD (1987).

Table 6. **Exchange rates and purchasing power parities**

1988

	$US	GDP PPP	Energy PPP
United States	1.00	1.00	1.00
Japan	128.15	204.00	364.49
Germany	1.76	2.12	3.40
France	5.96	6.69	13.13
Italy	1 301.62	1 342.00	3 342.90
United Kingdom	0.56	0.58	1.17
Canada	1.23	1.31	1.61
Australia	1.28	1.34	1.66
Austria	12.35	14.30	26.80
Belgium	36.77	39.40	64.36
Denmark	6.73	9.52	16.41
Finland	4.18	6.16	8.64
Ireland	0.66	0.72	1.67
Netherlands	1.98	2.23	3.82
New Zealand	1.53	1.60	2.82
Norway	6.52	9.54	13.22
Portugal	143.45	86.60	358.12
Spain	116.49	102.60	235.77
Sweden	6.13	8.57	12.90
Switzerland	1.46	2.16	3.38

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