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Dynamics of dairy farm productivity growth

CROSS-COUNTRY COMPARISON

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Abstract

DYNAMICS OF DAIRY FARM PRODUCTIVITY GROWTH: CROSS-COUNTRY COMPARISON

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This report compares the dynamics of productivity growth in the last decade in the dairy farm sector of three EU Member States: Estonia, the Netherlands and the United Kingdom (England and Wales). The evolution of the dairy farm sector in these countries is characterised by a decline in the number of dairy farms and an increase in the average herd size per farm. Policy factors have a strong impact on productivity growth at the farm. In Estonia, the dairy farm sector has expanded significantly in recent years and the productivity growth of the sector is led largely by a resource reallocation in favour of a small number of large and productive farms. In the Netherlands, the dairy farm sector adjusted to the different policy environments over time and the productivity growth of the sector is driven largely by productivity improvement at the farm level through technological adoption and efficient resource use. In the United Kingdom, productivity growth comes from the exit of smaller farms and farm size expansion of the remaining farms.

Key words: Productivity, dairy farm, milk quota, resource allocation

JEL classification: D24, O33, Q12, Q18

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Executive summary

This report compares the dynamics of productivity growth in the dairy farm sector of three EU member states: Estonia, the Netherlands and the United Kingdom (England and Wales) in the last decade.

Overall, the productivity dynamics of dairy farms in the three countries show a several pathways to improving productivity, including technological adoption and extension, efficient management of inputs and structural change. This highlights the importance of adopting a comprehensive approach when analysing innovation system in agriculture. Understanding the heterogeneous productivity structure in the sector helps to identify a policy agenda tailored to the needs of different farms. Enhancing on-farm innovation through technological extension and efficient farm management is an important part of such policy agenda, but providing a sound policy environment to facilitate efficient resource reallocation between farms is found to be equally important. The exit of inefficient farms is one of the important drivers of productivity growth of the dairy farm sector in the countries analysed in this report. Thus, the government can play an important role in removing impediments to farm exit and facilitating resource reallocation to productive farms. While total factor productivity (TFP) is a measure designed to capture how efficiently a farm uses total inputs to produce outputs, it does not reflect the diverse concerns of policy makers such as environmental sustainability, low farm income, rural development, animal welfare and public acceptance of new technologies. Further analysis should investigate the link between productivity and other performance indicators of the sector including profitability, competitiveness and employment creation.

In this study total factor productivity is measured at both the sector and the farm levels using a non-parametric index method applied to an unbalanced panel of farm survey data and other complementary data.

The measurement of TFP growth at the aggregate dairy farm sector level indicates that improvement in labour productivity is the largest contributor to sector level productivity growth across the three countries. The evolution of the dairy farm sector in these countries can be characterised by a decline in the number of dairy farms and an increase in the average herd size per farm. Associated with this trend is a decline of labour input and an increase in capital inputs, notably machinery and equipment. Milk output has been relatively stable in the Netherlands and the United Kingdom due partly to the EU milk production quota system that was in operation between 1984 and early 2015. In the Netherlands, the EU milk quota system was a binding constraint for dairy farms to expand milk production. TFP growth before the phasing out of the milk quota is almost entirely driven by a decline in input use. However, the main driving force of TFP growth in the Dutch dairy farm sector became the expansion of milk output after the phasing out of milk quotas started. While the Dutch dairy farm sector achieved continuous productivity growth, the change in milk quota regime changed its dynamics. In Estonia, the rapid growth of milk output is associated with an increase in capital and purchased inputs, leading to little improvement in TFP levels in the dairy farm sector as a whole. In the United Kingdom, the evolution of the dairy farm sector has been less dynamic than in the two other countries. Specialisation in milk production increased and the sector became more capital intensive over time, but TFP at the sector level remained on average almost unchanged.

The distribution of TFP across farms shows that a significant difference continues to exist in farm-level productivity within countries. The evolution of farm-level TFP in four regions of Germany also shows persistent regional difference in average farm-level productivity. In Estonia, milk production is highly concentrated in large-farms so that the largest 25% farms accounted for 90% of milk production in recent years, while small farms remained in the sector. Under this dualistic sector structure, the evolution of sector-level productivity is largely driven by improvements in a small number of large farms. As a result, the productivity difference between large and small farms increased overtime. The analysis shows that resource reallocation towards more productive farms became more important in driving the sector level productivity in Estonia. In the Netherlands and the United Kingdom, there has been a significant herd size expansion in all size classes of dairy farms and larger farms on average continue to achieve higher levels of productivity. However, differences in productivity across farms have decreased overtime due to the diffusion of technology across farms as well as the exit of less productive farms. In the case of Germany, larger-size farms tend to expand their farm-size at a higher rate, the average productivity growth rate of the largest farm size class is not necessarily higher in some regions, narrowing the productivity gap between farms larger than middle farm size class overtime.

Farm-level productivity is related to farm characteristics such as farm management practice and natural conditions in the three countries. Productive farms tend to be more intensive in some input use, such as higher stocking density, and use more purchased feed per cow. A deeper analysis using a multivariate regression model confirms the positive relation between productivity and stocking density, but the intensity of the purchased feed input has a negative productivity impact. The direction of the impact of support payments on farm-level productivity is unclear as a whole, but the farms which obtain higher levels of non-farm income tend to have a lower productivity in the Netherlands and the United Kingdom. Those part-time farms may reduce the input intensity and may under-invest in productivity improving technology.

Decomposing sector level productivity growth into a set of productivity growth drivers shows that policy factors have a strong impact on productivity growth at the farm. In Estonia, the dairy farm sector has expanded significantly in recent years and the productivity growth of the sector is led largely by a resource reallocation in favour of a small number of large size and productive farms. Smaller farms continue to have a low productivity, but their share in milk output has become marginal so that they have a minor effect on aggregate productivity at the sector level. Productivity can be fostered by improving the productivity of larger farms, for example through providing tailored advice and diffusing appropriate technologies. In the Netherlands, the dairy farm sector adjusted to the different policy environments over time and the productivity growth of the sector is driven largely by productivity improvement at the farm level through technological adoption and efficient resource use. In the United Kingdom, productivity growth comes from the exit of smaller farms and farm size expansion of the remaining farms.

1. Introduction

Increasing the productivity, efficiency and competitiveness of agricultural industries, while conserving and enhancing natural resources, remain important objectives for many countries. Productivity growth and sustainable resource use are playing an important role in meeting growing food demand given limited land, water and other resources. It is the primary way by which countries can produce more output relative to the inputs used, reallocate resources to other economic activities and improve the sustainability of resource use in agriculture. As such, an improved understanding of productivity trends and drivers, and its role in explaining industry competitiveness and long-term global food supply, are goals shared by governments and the agriculture sector (Alston et al. 2010).

Work on Cross Country Analysis of Farm Performance (Kimura and Le Thi, 2013) carried out under the 2011-12 PWB finds significant differences in farm performance, as measured by cash income indicators, across farms and identifies the characteristics of high performing farms. This report is a result of continued efforts to measure the performance of agricultural innovation systems through the OECD Network for Farm-level Analysis. This report constitutes one element of the OECD work on “Increasing innovation and agricultural productivity growth”, including: 1) pilot country reviews applying the framework developed in OECD (2013) to analyse the role of the government in fostering innovation in the agricultural and agri-food sector; 2) co-operation between public and private actors in agricultural innovation systems; and 3) methods and indicators to evaluate the performance of agricultural innovation systems.

The primary purpose of this report is to investigate to which extent the productivity growth in the dairy farm sector is driven by farm-level innovation (including farm management practices), and changes in sectorial structure under various policy environment. It identifies the channels through which changes in productivity at farm level are translated into productivity growth at sector level. The report provides information for policy makers to assess the relative importance of different elements of innovation systems in driving productivity growth in the dairy farm sector. Although policy makers have diverse policy concerns such as environmental sustainability, low farm income, rural development and public acceptance of new technologies next to productivity growth, discussing the capacity of the agricultural innovation system to address such diverse concerns is beyond the scope of this report.

This report compares the dynamics of productivity growth in the dairy farm sector in three countries: Estonia, the Netherlands and the United Kingdom (UK).[1] It makes use of productivity measurement performed both at the sector and farm level. A non-parametric index method was applied to estimate total factor productivity (TFP) index based on an unbalanced panel of farm survey data and aggregate price index information. The contribution of different inputs and outputs to the estimated TFP growth in the dairy farm sector is analysed to identify the productivity drivers including various policy reforms in the dairy farm sector. The report further investigates the distribution of productivity measured at the farm level and identifies its drivers including farm management practice, characteristic of the operator, investment and technological choice, natural condition and the policy environment. Finally, the panel of farm-level TFP measurement is utilized to identify the link between the dynamics of sectorial structure, farm-level innovation and sector level productivity growth. A set of policy implications is drawn from the cross-country comparison presented in this report.

1. In this report the data (Farm Business Survey) for the United Kingdom covers only England and Wales and results need to be interpreted accordingly.

A comprehensive innovation system approach takes into account different dynamics of innovations including multiple actors and institutions (OECD, 2013). The cross-country comparison of the dynamics of productivity growth could be useful to identify a variety of pathways to enhance productivity growth of the sector under the innovation system framework. The productivity is decomposed into three components: productivity growth within farm, resource reallocation between continuing farms and farm exit and entry. The analysis assesses the extent to which productivity growth in the dairy sector is led by technological progress and adoption, and structural change in the sector of the three countries. TFP is a single measure designed to capture how efficiently a farm uses total inputs to produce output. Analysing the productivity growth dynamics of the sector can help policy makers to evaluate certain aspects of the sector's economic performance and to diagnose the constraints to productivity growth that the sector is facing, including policy constraints. This report attempts to identify the policy agenda tailored to the specificity of the agricultural innovation system in each country and concentrating on the dairy sector.

2. Recent developments of the dairy farm sector in selected OECD countries

The dairy sector offers interesting insights on the impacts of policy on productivity growth because it has undergone significant reforms in several OECD countries or continues to be regulated in others. In Australia, the milk marketing regulation was ended in 2000, introducing a structural adjustment package to facilitate adjustment. In Canada, the milk production quota system continues to exist, while the United States (US) maintains geographically-based price discrimination and pooling schemes. After a transition period, Switzerland ended milk production quotas in 2009. In the EU, the milk production quota system was phased out by early 2015.

During the time frame of this analysis EU milk production took place within the framework of milk quotas which were introduced in 1984 in order to address problems of surplus production. Under the EU milk quota system, every member state had a national production quota which is distributed to milk producers. Whenever a member state exceeds its quota, it has to pay a penalty (called "super levy") to the EU. However, the policy environment of the EU dairy farm sector evolved significantly during the 2000s. The 2003 CAP reform reduced price support to milk products and introduced a compensation payment for milk producers, which was subsequently incorporated into the single farm payment. As a result, the share of producer single commodity transfer (%PSCT) in value of milk production declined from 45% to 21% in 2003-06 and to nearly zero after 2007. The EU decided to increase milk quotas by 2% in 2008, followed by the Health Check decision of November 2008 to increase milk quotas by 1% annually over five years until they were abolished in 2015. Although the 2003 CAP reform decreased the level of intervention prices, the EU maintains public intervention purchase schemes for butter and Skimmed milk powder (SMP). While these schemes have not been activated since 2009, they remain in place to address so called 'exceptional market condition'.

Over the last decades, the dairy farm sector in OECD countries has undergone a significant structural change. The expansion of average farm size and the decline in the number of dairy farms are widely observed features across OECD countries. In the United States, the number of farms with dairy cows fell by 88% in 1970-2006. The total number of dairy cows declined by 24% in the same period, but total milk production increased due to the rapid increase in milk yield. Moreover, milk production has been concentrating towards larger farms so that the share of milk produced by farms with more than 100 cows increased from 71% to 80% between 2000 and 2006 (Macdonald et al., 2007). A similar structural trend can be observed in the EU dairy farm sector. The number of farms with dairy cows and the total number of cows declined during the period 1983 to 2007, while the average farm size increased in each of the 9 EU member states, which together accounted for 85% of EU-27 milk production in 2009 (Jongeneel, 2010).

Dairy productivity growth has been driven by changes in production practices and technologies, including improved milking sheds and equipment, genetics, artificial insemination, use of automatic cup removers and increased soil testing (Mackinnon et al., 2010). The average milk yield per cow has been increasing in most of the countries due partly to improvements in cattle breeds and feed quality. Nossal and Sheng (2010) find that the adoption of new technologies and management systems has been the major driver for growth in milk yields in Australia between 1977 and 2008. The labour intensive nature of the milking process induced technological progress towards labour-saving technologies such as automated milking parlour. The labour-saving technological progress allows managing more dairy cows with fewer operators, creating economies of scale in dairy farming. For example, MacDonald et al. (2007) find a substantial cost advantage of large size dairy farms in the United States. On the other hand, Tauer and Mishra (2006) find that the higher cost of production on many smaller dairy farms in the United States is caused by economic inefficiency rather than technology.

Overview of the dairy farm sector in Estonia, the Netherlands and the United Kingdom (England and Wales)

Dairy farming is a significant part of agriculture in all three countries, accounting for more than 15% of the total value of gross agricultural output. According to EU FADN data, the combined share of the three countries in the milk production of the EU27 was 17% in 2011. Milk production in the three countries is characterised by a higher concentration of production in specialist dairy farms.[2] In 2011, specialist fairy farms accounted for more than 90% of total milk production in the three countries analysed: 91% in Estonia and 96% in both the Netherlands and the United Kingdom (European Union, 2014). This is not necessarily the case in other EU member states. For example, the share of specialist dairy farms in total milk output was 70% in France and 45% in Romania in 2011.

The specialised dairy farm sector in the three countries analysed in this report shows similar trends of declining numbers of specialist dairy farms and expansion of average farm-size, in particular the number of dairy cows per farm, while total milk output remains relatively stable (Tables 1 and 2). The rate of decline in the number of specialised dairy farms between 2003 and 2012 is the highest in the United Kingdom (46%), followed by Estonia (25%) and the Netherlands (19%).[3]

Estonia experienced more than two decades of economic transition since its independence in 1991. Breaking up collective farms changed the farm structure to a small number of large size corporate dairy farms and a large number of small family dairy farms (Viira et al., 2009). Prior to its accession to the European Union in 2004, Estonia introduced a milk quota system in April 2003. Since then the milk quota has been filled only up to 85-94%, farmers can obtain milk quotas by registration without cost. The milk quota system has not been a significantly binding factor for milk producers to expand production in Estonia. Since EU

2. In this report, the farm type of “specialised dairying farm” (TF41 before 2010 and TF45 after 2010) in FADN database is selected to represent the population of the specialised dairy farm sector.

3. Cattle Tracing Scheme data suggest that the number of holding with at least 10 dairy cows fell by around 600 each year in 2005-08 (around 7% of annual rate of reduction), while 150-200 holdings are new to commercial production in each year (DEFRA 2009).

accession, Estonia has also applied the CAP simplified area payments scheme and rural development programme.

The Netherlands is one of the largest milk producers in the European Union and accounted for 8% of milk production in EU27 in 2011. The dairy production is mainly oriented to export markets, where the Netherlands has around 5% of world dairy product market. Due to its limited land endowment, milk production is more intensive in the use of capital and purchased inputs, achieving one of the highest milk yields per cow in the European Union. In contrast to Estonia, the EU quota system has been constraining milk output in the Netherlands until the quota started to be relaxed after 2007. As a consequence of the increase in milk quota, milk output increased by 12% during the 2007-12 period. In the Netherlands, milk deliveries continued to exceed the national quota marginally, resulting in the payments of surplus levies in the last ten years, except for 2005/06 and 2012/13. The Netherlands developed a well-functioning quota sales and lease market, which facilitated structural change leading to the concentration of milk production in large and productive farms through quota trade (Jongeneel and Tonini, 2008). Although the quota price shows an overall declining trend for most of the EU member states, the quota price in the Netherlands remained relatively high even after the announcement of milk quota reform. The price of milk quotas fell from EUR 40 per kg of fat to EUR 18 in one year from July 2006 and further decreased to nearly EUR 10 in 2013. The quota system has been a constraint to expanding production for the Dutch dairy farms.

The United Kingdom is the third largest producer of milk in EU27 after Germany and France, accounting for 9% of total milk production in 2011. Dairy farming in the United Kingdom has been dominated by large-size specialist milk farms in the last decade. As a result, the average number of dairy cows, hectares and labour units per specialist milk farm is one of the largest in the European Union. The total milk output has been fairly static until 2005 when it started to decrease. Although milk quotas were tradable across different regions, the national quota has not been exceeded recently and the quota price has come down to nearly zero in recent years.

Table 1. Evolution of the specialised dairy farm sector

	2003	2006	2009	2012
Estonia				
Number of specialised milk farms (thousand)	2.0	2.0	1.5	1.5
Milk output (million tonne)	0.4	0.5	0.6	0.6
Netherlands[1]				
Number of specialised milk farms (thousand)	20.6	18.7	17.7	16.8
Milk output (million tonne)	10.2	10.3	11.2	11.4
United Kingdom (England and Wales)				
Number of specialised milk farms (thousand)	15.6	14.1	10.1	8.5
Milk output (million tonne)	9.6	10.2	9.4	9.3

1. The Dutch Data used in this report stems from the Dutch FADN system as collected by the Dutch Agricultural Economics Research Institute (LEI). The Centre of Economic Information (CEI) has provided access to these data. Results shown are and remain entirely the responsibility of the author(s); neither they represent LEI / CEI views nor constitute official statistics.

Source: National FADN Database.

Table 2 compares the characteristics of specialised dairy farms in the three countries considered. The average number of dairy cows continued to be the largest in the United Kingdom and the smallest in Estonia.[4] The average herd size increased in all three countries by around 25% during the 2004-11 period. The average utilised area of land increased until 2009, but to a lesser extent. It is the largest in Estonia, where dairy farming is grass-silage-based, and the smallest in the Netherlands, where it is feed intensive. The average labour input is the largest in Estonia, where family labour accounts for 19% of total labour input in the specialised dairy farm sector in 2011. The majority of labour input is provided by family labour in the Netherlands (89%) and the United Kingdom (63%), resulting in relatively smaller labour input per farm.

Dutch dairy farms continue to achieve the highest milk yield among the three countries considered. Milk yields follow an increasing trend in all countries, with the highest pace being in Estonia, where average milk yields in 2011 are 30% higher than in 2004.

Table 2. Characteristics of the average specialised dairy farm

	2004	2006	2009	2011
Estonia				
Number of dairy cows	49	51	72	61
Full-time equivalent labour input	5.5	5.5	6.0	4.5
Utilised Area of Land (ha)	193	196	253	202
Milk yield per cow (kg per cow)	5 655	6 613	7 312	7 445
The Netherlands				
Number of dairy cows	65	68	81	82
Full-time equivalent labour input	1.6	1.6	1.7	1.7
Utilised Area of Land (ha)	43	44	49	50
Milk yield per cow (kg per cow)	7 473	7 749	7 837	7 984
United Kingdom				
Number of dairy cows	95	99	119	121
Full-time equivalent labour input	2.3	2.3	2.6	2.6
Utilised Area of Land (ha)	89	91	107	106
Milk yield per cow (kg per cow)	6 812	6 904	7 036	7 429

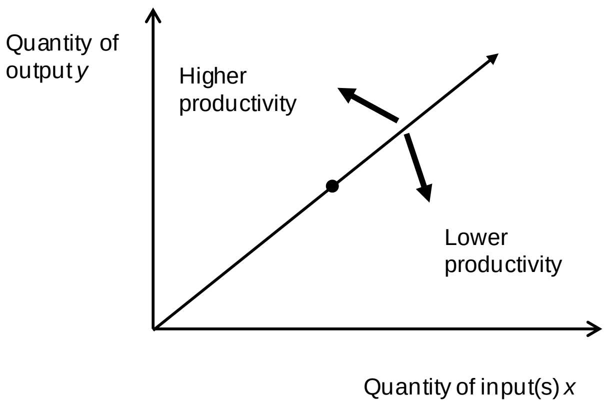
Source: EU FADN Database.

4. The number of milk quota owners in Estonia was 1 681 in 2006 and 975 in 2011, which is lower than the specialised dairy farm population in the national FADN data. A large number of small dairy farms keep a few dairy cows. They are estimated to be subsistent farms which do not market milk. The milk output measured in the national FADN data includes milk which is not marketed. In the FADN survey, those farms which exceed a certain economic size are defined as commercial are included. The threshold applied to Estonia (EUR 4 000 in standard output) is much lower than the Netherlands and the United Kingdom (EUR 25 000). Therefore, the sample in Estonia includes smaller size dairy farms than the other two countries.

3. Productivity growth of the dairy farm sector

Generally speaking, productivity represents a farm's ability to convert production inputs into production outputs. A more "productive" farm has a higher ratio of output to input than a less productive farm. Productivity growth refers to the change in output/input ratios over time (Figure 1). Productivity measurement can evaluate the extent to which dairy farmers have made use of technological advances through innovation adoption or changes in production organisation and resource use. It can also evaluate the influence of other off-farm factors, including the changes in market environment, new process technologies, and changes in institutional and regulatory arrangements. It mustbe noted that the concept of productivity is conceptually different from financial performance indicators such as revenue, income and profit, in particular in the short run. The improvement in productivity would not necessarily be associated with higher farm profits and *vice versa*.

Figure 1. Graphical illustration of productivity growth



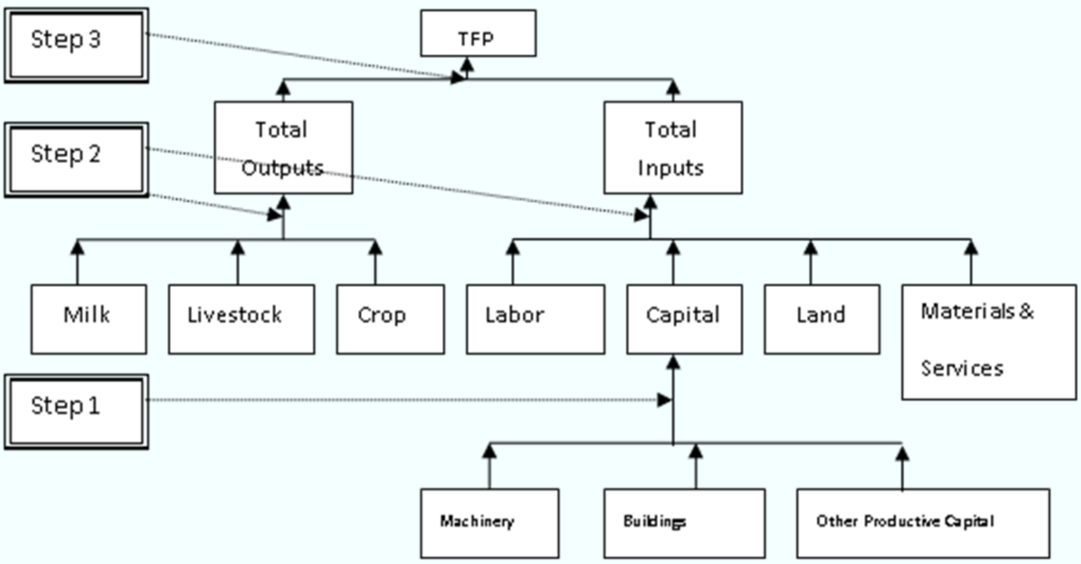
For measures of partial factor productivity, an index of output over a particular input is used to measure how output per unit of a particular input changes over time. While partial factor productivity measures are useful for some purposes, for example to examine labour markets or land markets, they can be misleading indicators of technological progress because they do not reflect changes in the use of other inputs. For example, a programme that heavily subsidises fertilisers may increase both land and labour productivity, but reduces material productivity, leading to lower level of overall (total factor) productivity.

Total Factor Productivity (TFP) can be defined as an index of total outputs over an index of total inputs (in quantity terms). As such, TFP is a single measure designed to capture how efficiently a farm uses total inputs to produce outputs, which is a different concept than financial performance indicators such as gross margin, farm income and gross value-added. Improvements in TFP reflect changes in technology, production organisation and scale, operating environment (including policy settings) and industry composition (through farm entry and exit) (Nossal and Gooday, 2009). TFP indices are sensitive to the way that various outputs and various inputs are aggregated, different aggregation approaches may lead to different estimations, each being consistent with the specific assumption made on the underlying production function. As described by Latruffe (2010), the main TFP indices used in the literature include Laspeyres, Paasche, Fisher and Törnqvist-Theil indices among others.

Box 1. A non-parametric approach to measure a productivity index using farm survey data

TFP is defined as a quantity index of total outputs over total inputs. However, items of outputs and inputs observed in farm survey data are heterogeneous so that the physical quantity of different items cannot be aggregated directly. An index formula is applies to aggregate different categories of outputs and inputs, using price or value as weights. Figure 2 describes the steps of aggregation applied in measuring TFP in Australian broadacre agriculture. First, specific output and input items are aggregated to broad types of outputs and inputs. These broad outputs and inputs are further aggregated to total output and input. Finally, TFP is measured based on a ratio of total outputs to total inputs. In this report, the broad outputs and inputs in dairy farm sector constitute milk, livestock, crop and other output in the output side, and labour, land, capital, material and service in input side. The definition of specific outputs and inputs items are documented in the Dairy Farm Productivity Measurement: Technical background report.

Figure 2. Aggregation steps for measuring TFP in Australian broadacre agriculture



Source: Zhao et al. (2012).

In this report, non-parametric Fisher type quantity indexes have been used to aggregate total output and input quantities in the case of multiple categories in order to enable the measurement of total factor productivity (TFP) at farm level Based on well-documented axiomatic tests (e.g. Diewert et.al, 1996 or Balk, 1995) these index formulas are regarded as superior to alternative methods. Fisher type quantity indexes are constructed by calculating the geometric mean of the corresponding Laspeyres ($Y^L_{t,t-1}$and $X^L_{t,t-1}$) and Paasche ($Y^P_{t,t-1}$and $X^P_{t,t-1}$) quantity indexes:

$Y_t^F = (Y^L_{t,t-1} * Y^P_{t,t-1})^{1/2}$ [1a] and $X_t^F = (X^L_{t,t-1} * X^P_{t,t-1})^{1/2}$ [1b]

with the Laspeyres output and input quantity indexes defined as:

$Y^L_{t,t-1} = \frac{\sum_{m=1}^{M} P^m_{t-1} * Y^m_t}{\sum_{m=1}^{M} P^m_{t-1} * Y^m_{t-1}}$ [2a] and $X^L_{t,t-1} = \frac{\sum_{n=1}^{N} W^n_{t-1} * X^n_t}{\sum_{n=1}^{N} W^n_{t-1} * X^n_{t-1}}$ [2b]

as well as the Paasche indexes defined as:

$Y^P_{t,t-1} = \frac{\sum_{m=1}^{M} P^m_t * Y^m_t}{\sum_{m=1}^{M} P^m_t * Y^m_{t-1}}$ [3a] and $X^P_{t,t-1} = \frac{\sum_{n=1}^{N} W^n_t * X^n_t}{\sum_{n=1}^{N} W^n_t * X^n_{t-1}}$ [3b]

The final Fisher productivity index TFP_t^F can then be constructed as a ratio of the Fisher output index Y_t^F and the Fisher input index X_t^F:

$TFP_t^F = \frac{Y_t^F}{X_t^F}$ [4]

In order to consistently measure TFP differences between more than two different observations (either different farms or the same farm at different time points) various adjustments can be applied to assure the transitivity, equi-characteristicity, and partitioning invariance of the bilateral Fisher index: chaining the Fisher index formula, GEKS and rolling GEKS (Ball et al., 1997).

In the context of this report the rolling GEKS procedure (see Szulc, 1983, Diewert, 1988 or Ivancic et al., 2011) is used for the Fisher index to multilaterally compare TFP differences between farms and/or time periods. It should be noted that non-market inputs or non-commodity outputs such as rainfall, climatic condition as well as positive and negative environmental externality or landscape are not taken into consideration in the productivity measurement in this report. Productivity estimates in this report only reflect variables under the control of farm managers. On-going work on environmentally adjusted multifactor productivity overviews the methods to estimate TFP and to incorporate environmental external impacts in the measurement of agricultural. It also, attempts, for illustrative purposes, to apply one of the methods – the nutrients balance approach – to estimate and decompose traditional and environmental TFP for 32 OECD countries from 1992 to 2008.

There are a number of issues to be considered for the measurement of inputs and outputs, using farm survey data. Dairy Farm Productivity Measurement: Technical background report discusses these issues and the selection of the methods applied in this report. For example, capital inputs (including land) are measured as a concept of stock variable in farm survey data, but the contribution of capital input in the production is through unobserved flows of capital services, not the observed stock of capital (Syverson, 2011; Xu and Sheng, 2012). The stock variables need to be converted to flow variables to measure its flow of service. The measurement of quality of inputs and outputs is another issue. TFP estimates should account for the different quality of inputs and outputs entering production through the price weight used to aggregate different inputs and outputs. If some workers are more educated or experienced, they typically hold a higher productive capacity. This quality difference should be captured through the price weight used in the input index. However, the quality differences of some items are difficult to capture, particularly where only average wage rates or aggregate price index are used. Similarly, the value of farm-owned input factors (e.g. family labour input) is difficult to measure correctly. The productivity measurement could be biased in case an appropriate price data to account for quality difference or to estimate the return to farm owned factors is not available. Although output includes livestock sales, crop production and other output from on-farm activities in addition to milk output, the government subsidies are excluded from output assuming that they are independent from the production process.

Aggregating farm level measurement of inputs and outputs based on farm survey data into industry (or regional) level TFP measures requires the application of specific sample weights. Either such weights are applied *ex post*, i.e. after the TFP measures have been calculated at the farm level, or these weights are applied on aggregated inputs and outputs before the actual indexes are built from which then industry (or regional) level TFP measures are calculated. This report applies both methods. Sample weights are applied *ex ante* to aggregate output and input at the sector level to measure the TFP of the dairy farm sector as a ratio of total output and input of the sector. Alternatively, sample weights and market share weights are applied *ex post* to aggregate the farm-level TFP estimates consistent with the analytical interest of further decomposing the TFP measures into different components (especially with respect to resource reallocation at industry). However, it has to be noted that the TFP measures obtained by the two methods might vary to a certain extent based on different economic concepts. The *ex post* weighting method explains the sector level productivity as the averaged farm-level productivity while the *ex ante* weighting method explains the sector level productivity as the efficiency of the sector using inputs to produce outputs.

While earlier studies employed the Laspeyre and Paasche indices, these methods have largely been replaced by the Törnqvist-Theil index, which is consistent with a more flexible translog production function, and by the Fischer index, which is proved by Diewert (1992) to be a superlatie index. The Eltetö Köves Szulc (EKS) formula, when combined with the Fisher index, help to impose transitivity to ensure comparability of estimation results between countries, regions or farms. For this reason, it has been considered as the best option for this comparative analysis. Box 1 above briefly explains the method used in this report to estimate TFP using farm survey data.

Trends of aggregate productivity growth in dairy farming

This section compares the productivity growth of the dairy farm sector by measuring the efficiency of the dairy farm sector as a whole to convert input to produce output. The quantity of total input and gross output in the specialised dairy farm sector is measured at the country level to compute a TFP index.[5] The index is normalized relative to a reference year so that the level of productivity is comparable across years within the country. The indices are not comparable across countries, but its growth rate is comparable. The annual growth rate of TFP is positive if the annual growth rate of output exceeds that of input. The year to year change in TFP is influenced by a number of factors apart from technological progress. For example, risk factors such as weather variability or incidence of livestock diseases outbreak could have a temporary impact on the output and input leading to the year to year fluctuation of the TFP index.[6] Longer trends in productivity growth provide the most reliable indicator of sector performance as the unexplained effects of year to year fluctuations are softened (Nossal and Sheng, 2010).[7]

Tables 3 and 4 compare the average annual growth of TFP, partial factor productivity, outputs and inputs in the three countries in the last 9 to 12 years. Average annual TFP growth rate was the highest in the Netherlands (1.3%), followed by the United Kingdom (0.0%) and Estonia (-0.2%). While total input decreased on average both in the United Kingdom (-0.7%) and the Netherlands (-0.2%), the average annual growth rate of output was positive in the Netherlands (1.1%) and negative in the United Kingdom (-0.7%). In Estonia, the growth of total output was the highest of the three countries, but it was outpaced by the growth rate of input on average, leading to lower TFP.

The comparison of partial factor productivity growth across countries indicates contrasting dynamics of productivity contributions across inputs. In all three countries, the labour input declined at the highest pace, making labour productivity growth the most important partial factor productivity contributor to overall TFP growth. On the other hand, there is a clear trend towards the partial replacement of labour input by capital input in all three countries.[8] The growth rate of capital input outpaced the growth in output, leading to negative growth of capital productivity. Capital input increased by 113% in Estonia (2003-12), 38% in the Netherlands (2001-12) and 9% in the United Kingdom (2000-12).

In Estonia, plant and machinery input increased by 3.6 times in 2003-12, following the low level of investments during the early transition period of 1992-2001. Purchased fodder input also increased to 15% total cost of input in 2012. The use of contract service increased rapidly. As a result, an increase in capital, material and service input outpaced the increase in output, making partial factor productivity of these inputs negative. In the Netherlands and the United Kingdom, capital input increased particularly after 2008. While overall capital input grew at 2.9% per year in the Netherlands and 0.7% in the United Kingdom, it grew at a faster

5. Sample weight information is used to aggregate farm-level quantity of output and input at the country level. The sample farms and their weights change overtime to maintain the representativeness of the specialist dairy farm sector in each country.

6. Zhao et al. (2008) analyse the total factor productivity development in the Australian dairy industries for the period 1997 to 2006. They find a high variability of the growth rate on a year-to-year basis but generally a positive trend, with annual growth rates averaging about 1.2% between 1998 and 2006. Nossal and Sheng (2010) investigate trends and drivers of productivity growth in Australia between 1977 and 2008. They argue that the temporary slowdown found in dairy productivity is likely an outcome of poor seasonal conditions and limited resources as well as a decline in input quality.

7. Average TFP growth rate $= {}^{1}/_{N} * \sum_{t=1}^{n} \ln(\frac{TFP_t}{TFP_{t-1}})$

8. Although the trend of substituting labour with capital input and its positive impact on labour productivity is evident at the sector level, the substitution does not necessarily lead to an improvement in TFP at the farm level in the short term. See Section 5 for more discussion of this issue.

pace during 2008-12 (5.0% in the Netherlands and 5.6% in the United Kingdom). In particular, capital input in building, and plant and machinery has increased. Capital investment is likely to be in response to anticipated expansion of milk production both in the Netherlands and the United Kingdom as a result of the abolition of the EU milk quota regime.[9]

Table 3. Average annual % growth rate of productivity of the specialised dairy farm sector

	Estonia	**Netherlands**	**United Kingdom (England and Wales)**
	2003-12	2001-12	2000-12
Total factor productivity	**-0.2**	**1.3**	**0.0**
Partial factor productivity			
Labour	11.9	3.3	2.3
Land	5.0	1.0	1.2
Capital	-4.0	-1.8	-1.4
Material	-1.6	1.4	-0.3
Service	-4.2	1.1	-0.9

Table 4. Annual % growth rate of TFP, output and input at the sector level of the specialised dairy farm sector

	Estonia 2003-12		**Netherlands** 2001-12		**United Kingdom (England and Wales)** 2000-12	
	%Annual growth rate	%Value share	%Annual growth rate	%Value share	%Annual growth rate	%Value share
Total output	**4.4**	**100**	**1.1**	**100**	**-0.7**	**100**
Milk	4.7	74	1.1	88	-0.2	79
Livestock	-7.2	11	0.7	6	-2.4	15
Crop	19.7	8	-3.6	8	-3.5	4
Other output	8.0	7	7.5	6	-4.6	2
Total input	**4.6**	**100**	**-0.2**	**100**	**-0.7**	**100**
Labour	-7.5	26	-2.3	27	-3.0	16
Land	-0.6	2	0.1	9	-1.9	12
Capital	8.4	18	2.9	15	0.7	17
Material	6.0	34	-0.4	21	-0.4	38
Service	8.6	20	0.0	29	0.1	17

Figure 3 compares the evolution of TFP and total input and output in the three countries, making the level in 2003 a reference level of 100. In Estonia, annual TFP growth was positive

9. The impact of market regulation on the trend of dairy productivity growth is observed in Australia. The Australian dairy industry has achieved productivity growth of 0.3% a year from 1978-79 to 2009-10. There was virtually no growth before major deregulation in 2000. Strong growth in dairy output (4.5% a year) has been driven mostly by input growth (4.1% a year), rather than productivity gains (Gray et al. 2012). The removal of industry price support moved the trend of industry output and input downward as input contracting more rapidly than output (Gray et al., 2014)

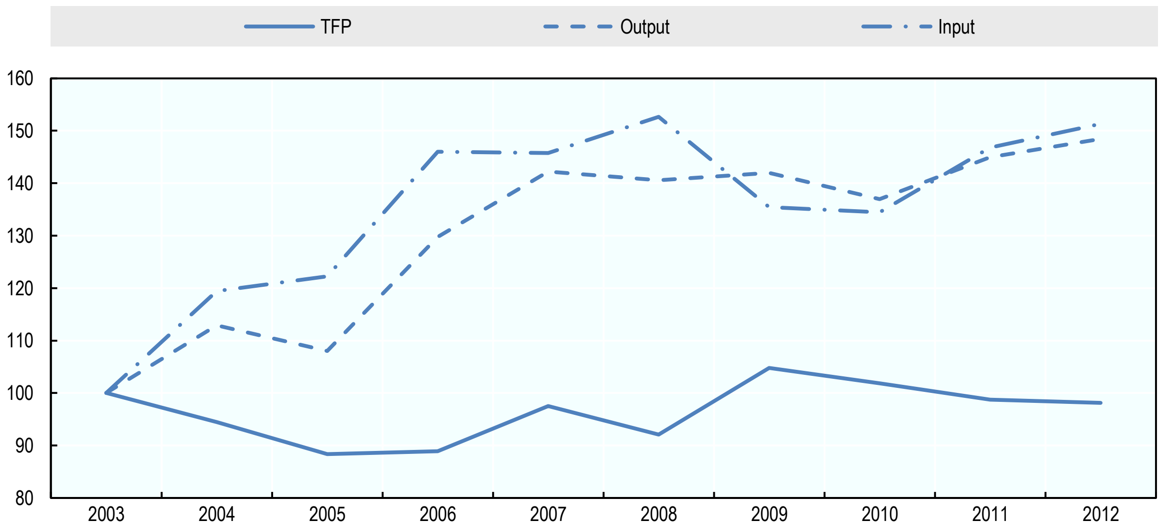
in three out of nine years, while total input and output increased in six out of nine years. The expansion of the dairy sector mainly takes place during the period 2003-08, following EU accession, and it slowed down in recent years. The evolution of TFP indicates that the expansion of the sector was not accompanied by an improvement of productivity of the sector as a whole.

In the Netherlands, TFP growth was positive eight out of 11 years, showing a more steady TFP growth path than the other two countries. The growth path differs, however, between the two period 2001-07 and 2007-12. Due to the quota constraints, milk output could not increase before 2007, and TFP growth was driven by a reduction in input. The reduction of input in 2001-07 was also significant in material and service input. Material and service input declined at -2.8% and -1.9% annually respectively, leading to the average annual increase in material and service productivity at 2.9% and 1.9%, respectively. In contrast, after the announcement of the milk quota reform in 2007, the growth in output outpaced that in input, following the increase in national milk quota. Public policies and regulations influence producers' decisions regarding resource allocation. They may also distort firms' competition. The literature suggests that milk quotas tend to slow down structural change of the sector and maintain inefficiencies. However, to what extent this occurs depends on the flexibility of quota transfer mechanisms (Huettel and Jongeneel, 2011). The evolution of TFP in the Netherlands implies that the productivity improvement could occur under the milk quota regime with a well-functioning quota market.

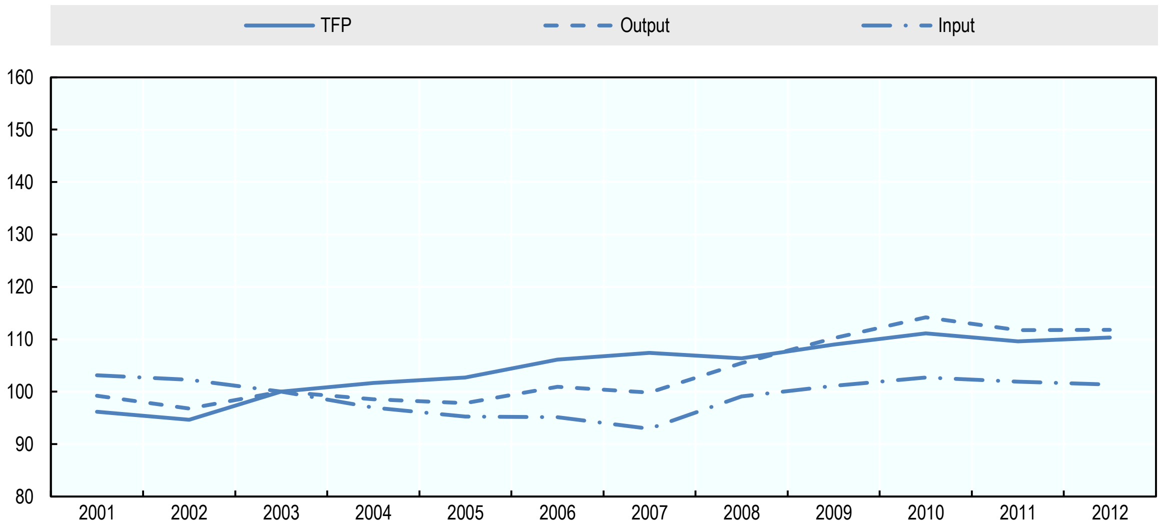
In the United Kingdom, the annual TFP growth was positive in seven out of 12 years. A decline of over 5% in TFP was observed in 2009 and 2012 when the decline in total output is associated with an increase in total input. In 2009, total output declined marginally, but the increase in capital input such as building, and plant and machinery, and material input such as fodder led to more than 5% increase in total input. In 2012, poor weather conditions in the second half of the year impacted both on quantity and quality of forage, resulting in low milk yield and milk production (DEFRA 2013).

Figure 3. Evolution of TFP, output and input indices of specialised dairy farm sector

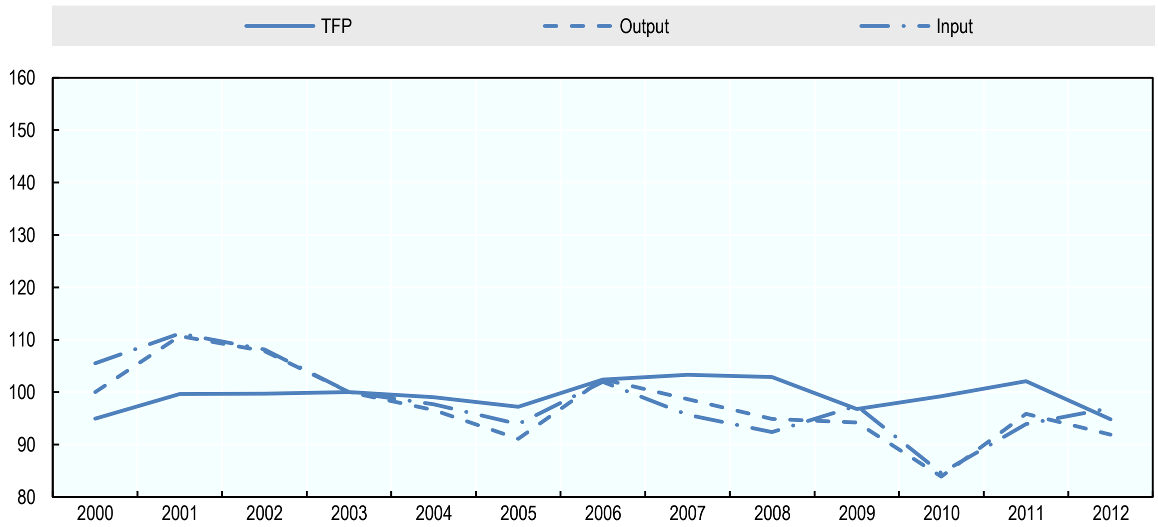
Estonia (2003 = 100)



Netherlands (2003 = 100)



United Kingdom (England and Wales) (2003 = 100)



4. Distribution of productivity and resource use at the farm level

The evolution of TFP and other indices at the sector level could measure the improvement in the sector-level productivity. However, it is not able to provide insights on how farm-level innovation and resource reallocation between farms (including farm entry and exit behaviour) contribute to the productivity change at the sector level. To empirically investigate the relative magnitude of resource reallocation between farms and its effects on sector-level productivity, the measurement of farm-level productivity is needed and it could be used for decomposing sector-level productivity into various components.

The productivity decomposition analyses have been developed in different areas of the wide field of productivity and efficiency measurement. They include formulas based on the parametric total factor decomposition literature focusing on the firm level (for a comprehensive overview see Coelli et al., 2005; or Kumbhakar and Knox-Lovell, 2001) and measures stemming from the non-parametric industry or sector level productivity decomposition literature (e.g. Olley and Pakes, 1996; Petrin and Levinsohn, 2012). Sector level decomposition methods are nearly always based on a constructed index for sector-level productivity. Accordingly, the index of productivity level (LP) of the dairy farm sector can be denoted as:

$$LP_t = \sum\nolimits_f s_{it} LP_{it}$$

with s_{ft} as the weight of farm f in dairy sector i and LP_{it} as an index of farm-level productivity provided by the non-parametric productivity measurements outlined in Box 1. The weight s might be based on milk output or herd size. In this report, the share of milk output in the sector is used as a weight. While the productivity index computed in the previous section is a ratio of total output and input at the sector level, the proposed productivity index of the sector is based on the farm-level productivity measurement and requires different economic interpretation.

Table 5 presents the evolution of farm-level productivity in the three countries. The productivity index is normalized so that the unweighted average farm-level productivity in 2003 is 100 in each country.[10] The unweighted average productivity and market share weighted average productivity is different both in terms of absolute level and growth rate, indicating differences in productivity and market share across farms. In all three countries, the level of market share weighted average productivity is higher than the unweighted average productivity, indicating that the farms with large market shares have a higher productivity level. Table 5 shows that on average, larger farms have higher levels of productivity in all three countries across years. The productivity difference between different size classes was the largest in Estonia.

Milk production is highly concentrated in large farms and the degree of concentration increased over time in Estonia (Table 6). The market share weighted TFP continues to be close to the average productivity of large farms, reflecting on the trend in the concentration of output towards large farms. In Estonia, market share weighted productivity grew at 0.85% annually on average, whereas average annual growth rate of unweighted productivity is negative. The positive growth rate of market share weighted productivity is led by a productivity improvement of a small number of extremely large farms.

In Estonia, small subsistent dairy farms tend to remain in the sector and the national FADN data shows that the number of dairy farms reduced only moderately compared to the other two countries. The rate of productivity decline was the largest in smaller farms. The divergence between large and small farms increases both in farm size and productivity. However, the impacts of lower productivity of a large number of small and middle farms on the sector level productivity became smaller as their market share declined to only 9% in 2012. The distribution of productivity and market shares implies that improving the productivity of larger farms could have larger impacts on sector level productivity.

In contrast, the specialised dairy farm sector has a more homogenous structure in the Netherlands and the United Kingdom. The largest 25% of farms account for around 50% of milk production in 2012, but the concentration of production in large farms has increased in the Netherlands and declined in the United Kingdom. Average farm size increased continuously both in the Netherlands and the United Kingdom for all size classes of farms, but the rate of farm size expansion increased after 2007 particularly for larger farms. The

10. Sample weights in farm survey are applied to estimate unweighted average farm-level productivity. Both sample weights and market share are applied to estimate market share weighted average productivity.

announcement of phasing out the milk quota by 2015 could have induced larger farms to expand their operational size.

Table 5. Evolution of farm-level TFP

	Average TFP 100 = unweighted average in 2003				Average TFP growth (%)
	2003	2006	2009	2012	
Estonia					(2003-12)
Unweighted average	100	87	94	96	-0.48
Market share weighted average	121	113	139	131	0.85
Large farms	127	119	141	126	-0.11
Middle farms	95	83	89	91	-0.41
Small farms	85	69	62	76	-1.25
Netherlands					(2001-12)
Unweighted average	100	105	109	110	1.18
Market share weighted average	108	114	119	120	1.17
Large farms	116	123	125	127	0.79
Middle farms	102	108	112	111	1.23
Small farms	79	83	89	89	1.74
United Kingdom (England and Wales)					(2000-12)
Unweighted average	100	101	100	99	0.32
Market share weighted average	110	110	104	102	-0.26
Large farms	117	117	108	105	-0.36
Middle farms	101	100	98	99	0.05
Small farms	78	80	84	83	0.75

The three farm size classes are ranked by the number of dairy cows (the largest 25%, the smallest 25% and the remaining 50% of farms)

Table 6. Average number of dairy cows and market share by three farm size class

	Number of dairy cows				% market share			
	2003	2006	2009	2012	2003	2006	2009	2012
Estonia								
Large farms	132	141	186	202	83	86	89	92
Middle farms	11	12	14	12	13	11	10	8
Small farms	7	6	5	2	4	3	1	1
Netherlands								
Large farms	107	118	138	153	42	43	45	46
Middle farms	60	64	70	75	46	45	45	44
Small farms	32	33	35	37	12	11	11	10
United Kingdom (England and Wales)								
Large farms	186	207	248	273	54	56	51	49
Middle farms	74	79	108	130	38	37	41	43
Small farms	34	38	50	57	8	7	8	8

Box 2. Dynamics of dairy farm-level productivity growth in four regions of Germany

Kleinhanss (2015) analyses the dynamics of farm-level TFP growth of German dairy farms, applying the same framework of TFP measurement based on the German FADN data and aggregate price index information. A balanced panel of 2 904 dairy farms with a minimum farm size of 25 dairy cows was selected for the period of the economic years 2005/6 to 2012/13. The sample farms cover about half of the farms with milk production and two-thirds of milk production in Germany, They are clustered into five size categories (based on the quantity of milk production) and four regions (North/West, Centre, South and East), where respectively 33%, 6%, 36% and 24% of national milk production is located. About 25-27% of milk production is produced in each size category <250 thousand tonnes (smallest), <500 thousand tonnes (small) and > 1 000 thousand tons (largest), while 15% is produced in category <750 thousand tonnes (middle) and 7% in <1 000 thousand tonnes (large).

The development of milk production is quite diverse in Germany due to different quota trading schemes and scale effects across regions (Table 7). The two largest farm size classes expended production at a higher rate than smaller farms, indicating more resource allocation to large farms. Smallest farms lowered their production sharply in 2012/13 shortly before the phasing out of the milk quota regulation began. The farm size expansion is most pronounced in North/West and South regions, the two largest size classes of farms in North/West and South increased milk production up to 80% in 2006-13. The situation is less dynamic in the East, where very large farms dominate the sector. Small farms reduced milk production and large farms increased their size only by 15%. This might be the effect of competition on the land market, where large scale arable production is favoured by decoupled direct payments – against dairy and (other) cattle production (Kleinhanss, 2012).

Table 7. Evolution of average milk output per farm in four regions of Germany

	All farms	By farm-size class				
		Smallest	Small	Middle	Large	Largest
Average milk output (thousand kg per year)						
North/West	403	145	374	603	864	1277
Center	294	121	354	618	853	1175
South	190	134	337	568	861	1188
East	1884	126	388	623	858	3577
Average annual growth rate of milk output (%)						
North/West	4.0	-0.1	3.0	4.3	6.3	7.7
Center	2.3	-0.7	2.1	3.6	4.8	4.4
South	2.6	1.0	4.3	4.5	8.3	3.9
East	2.0	-2.3	0.0	1.5	2.1	2.1

TFP levels show a positive correlation between farm-size and productivity up to middle size class of farms in all the regions (Table 8). However, average farm-level productivity declines as the farm size become larger than middle size in the East region. In the North/West and Centre regions, the largest farm size class of farms achieves the highest productivity. The average farm-level productivity is the lowest in the East region and the highest in in all size classes. In particular the productivity difference is the largest for the largest farm size class in the East region, where former collective farms dominate the largest size class of farms. The average productivity of farms in the largest farm size class in East region is 57% lower than the same farm size class of farms in the North/West region.

Average farm-level TFP growth was 0.5% across the four regions of Germany. The evolution of TFP shows similar tendencies for most size classes: a slight upward trend in 2007, followed by a significant decrease in 2008. TFP continued to rise in 2009 and 2010, reaching highest TFP growth in 2010, driven mainly by a decrease in inputs. A continuous decrease of TFP was observed after 2011, despite a slight increase in 2013 in a few cases. The average TFP growth rate was the highest in the South region in all the farm size classes except for the largest size class. The average TFP growth rate of the largest farm size class was positive only in the East region and negative in the Centre and South regions, implying that the economy of scale has been exploited in these regions. Similarly, the TFP growth rate of the smallest farms tends to be lower than larger farm size classes in most of the regions. The large size class of farms achieved the highest TFP growth in the North/East and Centre regions, while the TFP growth was the highest for the middle and small size classes in the East and South regions, respectively.

Farm-level productivity in four regions of Germany shows different productivity growth dynamics across regions. Structural change in dairy farms is more dynamic in the North/West and South regions and these regions are achieving higher level of average farm-level productivity. In general, milk production is more concentrated in large size productivity farms, which is leading to a higher level of productivity at the industry level. The productivity gap between farms larger than middle farm size class tends to be shrinking overtime due to the lower productivity growth rate of the largest farm size class. The economies of scale in milk production seem to be declining as the farm size becomes very large.

Table 8. Evolution of farm-level TFP in four regions of Germany

	All farms	By farm-size class				
		Smallest	Small	Middle	Large	Largest
Average productivity (100= average in 2006)						
All regions	105	93	120	133	141	115
North/West	122	102	128	138	148	149
Center	102	88	113	124	129	132
South	98	92	118	128	140	138
East	94	74	100	109	106	95
Productivity growth rate (% per year)						
All regions	0.5	0.4	0.9	0.4	0.4	0.3
North/West	0.1	0.0	0.4	0.3	0.5	0.0
Center	0.4	0.4	0.2	0.1	0.7	-1.0
South	0.7	0.4	1.2	0.9	0.7	-0.4
East	0.4	0.0	0.2	0.5	0.2	0.4

The average annual growth rate of productivity is higher for the smaller size class of farms both in the Netherlands and the United Kingdom, indicating the convergence in productivity levels across farms. This is either due to productivity improvement in smaller farms (e.g through technological adoption) or the exit of small and less efficient operations. The rate of decline in the specialised dairy farms was the largest in the United Kingdom. The exit of small less efficient farms most likely resulted in an increase of the average size in smaller size classes of farms.

The effect of resource allocation on productivity

The sector level productivity could be improved without any productivity improvement at the farm level. If resources are reallocated to more productive farms, overall productivity level of the sector could be higher. Olley and Parkes (1996) developed a decomposition method of sector-level productivity to measure allocative efficient of the sector. This measurement can show the extent to which resource allocation across farms contributes to the sector-level TFP. The evolution of the allocative efficiency can be compared across countries, and related to the different policy settings (e.g. Olley-Pakes, 1996, or Foster et al., 1998). This decomposition method is applicable to measure the efficiency in resource allocation in the dairy farm sector.

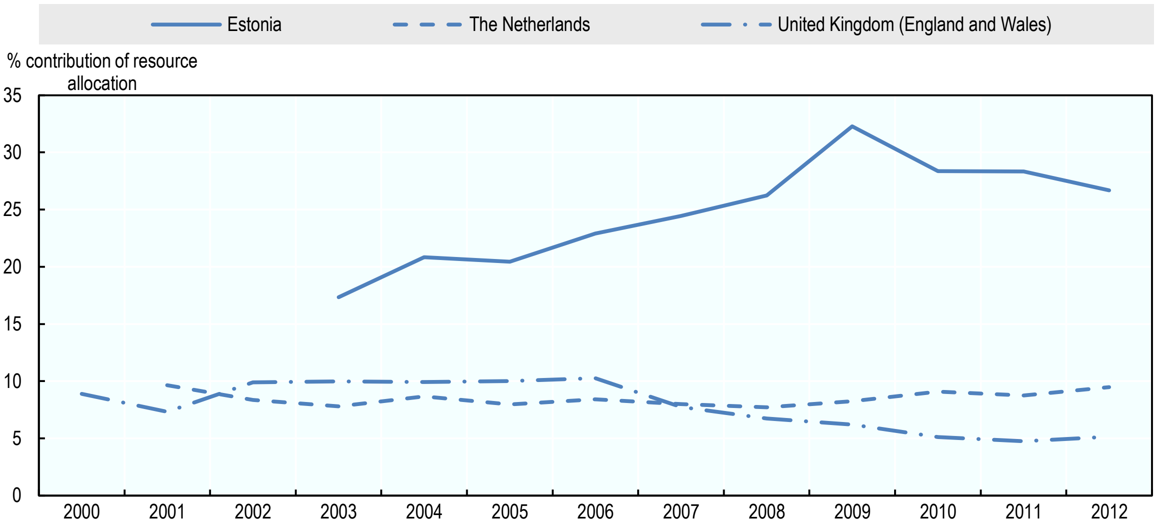
Given the estimates of TFP index (LP_{it}) and market share ($\mathrm{s_{it}}$) of farm *i* at year *t*, the industry level productivity (LP_{t}) can be computed as market share-weighted average of farm-level productivity ($\mathrm{LP_{it}}$). It can be rewritten as the unweighted average of farm-level productivity plus a cross term that reflects that farms with higher productivity have a higher weighting factor, which can be considered as a measurement of the contribution of allocative efficiency to the aggregate productivity level.

$$LP_t = \sum_f s_{it} LP_{it} = \overline{LP}_{it} + \sum_f (s_{it} - \bar{s}_{it})(LP_{it} - \overline{LP}_{it})$$

If the resource is allocated randomly (zero correlation between productivity and market share), the market share weighted productivity would be equal to the unweighted productivity.

However, the market share weighted productivity is higher than the unweighted average productivity if productivity and resource allocation are positively correlated. Figure 4 compares the resource allocation effect on dairy farm sector level productivity in the three countries shown as a percentage increase in productivity compared to the case where resource allocation is random. In Estonia, the contribution of resource allocation is relatively large and increasing between 2003 and 2009. The productivity gain from the resource allocation to sector level productivity is estimated to be more than 30% in 2009. The increased contribution of resource allocation indicates that more productive farms increased their market share, reducing that of less productive farms. In the Netherlands and the United Kingdom, resource allocation effect on productivity is relatively small, but it still generates between 5% and 10% of productivity gain. In the United Kingdom, the resource allocation effect has declined since 2007 due to the convergence of productivity between farms.

Figure 4. Contribution of resource allocation to productivity



5. Farm characteristics and productivity

This section investigates the characteristics of farms associated with different levels of productivity. In total six categories of farm characteristics variables were chosen from the farm survey data: herd size, farm management, characteristics of the operator, investment and technological choice, natural conditions, and support payments and other sources of income. Three productivity classes are defined according to farm-level TFP measurement: the top 25% most productive farms as high productivity farms, the bottom 25% least productive farms as low productivity farms and the remaining 50% of farms as middle productivity farms.

Table 7 summarises the average farm characteristics by three productivity classes in the three countries during the available years. The TFP of the most productive farms is on average 55% higher than that of the middle productivity farms in Estonia, followed by 27% in the Netherlands and 26% in the United Kingdom. The low productivity farms are on average 30% less productive than the middle productivity farms in the Netherlands and the United Kingdom, and 36% less productive in Estonia. As observed in the distribution of farm-level TFP, farm size and productivity have a positive correlation in all three countries.[11]

11. Reaping economies of scale in dairy farming is regarded as the main driver for aggregate productivity growth. Mosheim and Knox-Lovell (2009) investigate scale economies in US dairy farming for the year 2000 based on more than 600 farms. The results of this empirical study

Regarding farm management practices, intensities of some inputs are correlated positively with the productivity level. The high productivity farms have on average higher stocking density. They tend to use purchased feed more intensively and achieve higher milk yield. However, labour input intensity is negatively correlated with the level of productivity. Although productive farms manage larger herd sizes, depending more on hired labour, they succeed in reducing labour input intensity and increasing herd size at the same time.

The profile of the farm operator shows that the operators of productive farms tend to be younger in Estonia, but there seems to be little difference in average age and rate of completing university education between the three productivity classes of farms in the Netherlands and the United Kingdom.[12] The corporate organised farms tend to be more productive than family farms in Estonia. In general, productive farms tend to have a larger size of net investment in all three countries, but net investment per cow is lower for more productive farms in the Netherlands. The investment in milk robot and milk parlour equipment is not necessarily correlated with productivity levels in the Netherlands without controlling for other factors. On the other hand, less productive farms are more likely to be located in geographically less favourable areas in Estonia and the United Kingdom.

The amount of support payments tends to be larger for more productive farms most likely because of the payments are linked to the large land area of productive farms. However, the share of support payments in farm income is higher for the farms with lower productivity. A clear negative correlation exists between off-farm income and productivity in the Netherlands and the United Kingdom. Lower productive farms obtain on average higher off-farm income to offset the lower productivity of the farming enterprise. These are consistent with previous findings in the OECD report on farm performance (Kimura and Le Thi, 2013). Similarly, Lien et al. (2010) also find a significant negative effect of farm output on farmers' off-farm work hours based on an unbalanced panel of Norwegian grain farms during 1991 to 2005.

Many of the farm characteristics described in Table 9 are potentially highly correlated with each other. For example, large farms tend to invest more, receive more payments and operate in more geographically favourable areas. On the other hand, higher educational attainment and the younger age of the operator may not be correlated with large farm size, but it could be an important factor of high performing farms. An econometric model, incorporating the influence of observed and unobserved factors on TFP is performed to estimate the impact of each farm characteristic variable on TFP as well as the milk quota reform implemented in the European Union. The factors for varying total factor productivity over dairy farms are investigated by means of censored regression models (Tobit) in a random effect specification.[13]

point to significant productivity effects by economies of scale confirming the observed long-term trend of an increase in average dairy farm size. Rasmussen (2010) finds an improvement of scale efficiency for dairy and other farms for the period 1985 to 2006.

12. Farmer’s age and education attainment are defined as the main operator’s age and education attainment.

13. The econometric model can be specified as the following equation, where LP_{it} is the level of TFP of farm *i* at time *t.* X represents the vector of *K* farm characteristic variables. D is a time dummy variable differentiating the period before and after the beginning of the implementation of the EU milk quota reform in 2008. The unobserved error term is composed of time invariant factors or farm-specific effects (μ) and time variant factors (φ) affecting the level of TFP. The random effect model allows controlling farm –specific unobserved variables in the error term. $LP_{it} = \alpha + \sum_K \beta^K X_{it}^K + \sum_t \gamma^t D^{quota\ reform} + \mu_i + \varphi_{it}$.

Table 9. Farm characteristics by productivity class

	Estonia (2003-2012)			The Netherlands (2001-12)			United Kinddom (England and Wales) (2000-12)		
Productivity class	Low	Middle	High	Low	Middle	High	Low	Middle	High
TFP	57	89	139	74	104	132	70	100	128
Farm size									
Number of dairy cow	8	29	128	45	70	100	70	104	154
Farm management									
Milk yield	68	74	75	99	99	99	78	80	79
Stocking density (per ha)	0.4	0.5	0.7	2.2	2.3	2.5	1.2	1.5	1.7
Purchased feed per cow (EUR/GBP)	146	182	254	493	554	556	382	428	431
Labour input per cow (hour)	815	414	278	90	61	45	81	54	43
Hired labour share (%)	1	14	51	3	5	9	24	27	37
Characteristics of operator									
Age	58	53	51	46	46	46	53	51	52
Completion of university education (%)	na	na	na	10	8	12	33	35	37
Corporate Organization (%)	3	8	37	na	na	na	2	2	3
Investment amd technological choice									
Net investment per cow (EUR)	-24	213	229	882	718	685	265	258	322
Capital and labour ratio	0.2	0.5	0.8	0.5	0.5	0.6	0.9	1.2	1.6
Adoption of organic practice (%)	20	17	6	8	12	12	36	31	26
Milk robot (%)	0	0	1	9	9	11	na	na	na
Milk palour-rotation (%)	na	na	na	5	5	5	na	na	na
Milk palour-fish bone (%)	na	na	na	68	60	71	na	na	na
Milk palour-side by side (%)	na	na	na	9	9	8	na	na	na
Natural condiction									
Less favoured area (%)	68	71	57	na	na	na	15	9	5
Payments and other source of income									
Total payment (EUR/GBP)	5197	18618	66414	15754	19332	27080	8195	9688	10524
Off-farm income (EUR/GBP)	na	na	na	15659	11672	9520	14440	11386	9709

1. Less favoured area indicates % of farms located in less favoured area.

2. Total payment includes all types of support payments.

3. United Kingdom: off-farm income = diversified income + non-farm income.

4. na: not available.

Source: National FADN Database.

Table 10 summarises the estimated signs of the coefficients found for various factors with respect to total factor productivity at the farm level. The estimated coefficients show that the herd size has positive impacts on the productivity level in all three countries after controlling for other farm characteristics. Higher milk yield is apparently associated with higher farm productivity. As found in the descriptive statistics, higher stocking density is correlated with a higher level of farm productivity. Similarly, the labour input per cow has a negative correlation with productivity. Contrary to the descriptive statistics, the intensity of purchased feed input has a negative correlation with productivity in all three countries after controlling for other factors. The efficient management of labour and feed inputs could be one of the determinants of dairy farm productivity.

Table 10. Estimated coefficients of the Impacts of farm characteristics on farm-level TFP

	Estonia	Netherlands	United Kingdom (England and Wales)
Farm size			
Number of dairy cows	++	++	++
Farm management			
Milk yield	++	++	++
Stocking density (per ha)	++	++	++
Purchased feed per cow (EUR)	--	--	--
Labour input per cow (hour)	--	--	--
Hired labour share (%)	++	++	--
Characteristics of manager			
Age	-	++	0
University education	na	--	--
Corporate organisation (%)	0	na	--
Investment and technological choice			
Net investment per cow (EUR)	--	--	--
Milk robot	0	++	na
Milk parlor	na	++	na
Adoption of organic practice (%)	--	--	++
Natural condition			
Less favoured area (%)	--	na	--
Payments and other source of income			
Share of payments in farm income	-	++	0
Non-farm income	na	--	--
Milk quota reform	++	++	-

* Na: not available; ++ -- positive/negative and significant at 1% + - positive/negative and significant at 5%

** Model quality measures can be obtained upon request.

In Estonia, a higher age of the farm manager is found to have a negative relationship with productivity, but the opposite is the case in the Netherlands. Post-university level educational attainment is found to have a significant and negative impact on productivity in the Netherlands and the United Kingdom. Table 6 indicates that high productivity farms in Estonia tend to be corporate farms, but the choice of farm organisation is found to be insignificant in determining productivity in Estonia after controlling for other factors such as herd size. In the United Kingdom, family farms are found to be more productive.

The adoption of milking equipment such as milk robot and milking parlour is found to have significant and positive impacts on the productivity level. This determines the productivity growth path at the farm-level; more investment in labour saving technology with increasing herd size. Net investment is found to have a negative impact on TFP in all three countries, but the productivity enhancing effect of investment is likely to be delayed. Sauer and Latacz-Lohmann (2014) investigate the link between innovative investments and productivity using a large scale panel dataset for German dairy farms (1996 to 2010). They find that investments in innovative technology increase the productivity of dairy production by shifting out the production frontier. The findings further imply that investments in innovative dairy technologies require a sufficient level of complementary education to also trigger an increase in efficiency at farm level.

The adoption of organic production technology reduces productivity in Estonia and the Netherlands, but it has an opposite impact in the United Kingdom.[14] Sauer (2010) finds that the productivity effects of policy deregulation on dairy production systems in Denmark suggest that the deregulation in the quota allocation mechanism led to an increased allocative efficiency of milk production as well as a relative shift of the production frontier in favour of the production of organic milk. In general, organic farms are less intensive in using material and capital inputs and aim to obtain higher milk price. In this sense, lower productivity of organic farms does not necessarily indicate lower profitability.

The random-effects Tobit models revealed that being located in less favoured areas is associated with a lower total factor productivity both in Estonia and the United Kingdom, implying that natural conditions could be a constraint for productivity growth. The estimated result shows that a higher level of non-farm income is associated with a lower level of productivity. The farm households with a higher level of non-farm income may reduce the input intensity of farming and reduce investment in productive technology to improve productivity, while receiving payments decoupled from production. Similarly, the share of payments in farm income has a significant and negative relation with productivity in Estonia, keeping other factors constant. In the Netherlands, the relationship was found positive after controlling for other factors. According to the study by Sauer and Park (2009) on the productivity development in Danish organic dairy farming in the period 2002 to 2004, a positive relationship is found between subsidy payments and an increase in farm efficiency, technology improvements and a decreasing probability of organic market exit which was also confirmed for off-farm income.

Finally, the coefficient on the time dummy to identify the period after the milk quota reform is implemented in 2008 implies a positive impact of reform on farm-level productivity both in Estonia and the Netherlands. Siplilaeinen et al. (2014) explore the profitability and productivity development of Finnish and Norwegian dairy farms in the period 1991 to 2008 by decomposing into various potential sources for change. The results provide evidence that the stronger liberalisation of agricultural policy in Finland has provided greater flexibility for farmers to change and thus has created better scope for productivity and profitability improvements compared with Norway.

6. Decomposition of productivity growth in dairy farming

The decomposition performed in Section 4 is static and cross-section and does not take into account the effect of farm entry and exit. Separating out within-farms and between-farms' effects from cross-farms' influences (i.e. covariances related) and also considering the effects by farms entering or exiting the sector requires a decomposition method. Several methods of decomposition have been proposed in the literature. Foster et al. (1998) based on Baily et al. (1992) and Haltiwanger (1997) suggest to apply a formula to decompose industry level productivity growth making use of deviations between farm level TFP estimates and market shares and the initial sector TFP and average market share. Using this method, a dairy farm with a continuous increase in market share contributes positively to the between-farm component only if its productivity is higher than initial average sector productivity. An exiting (entering) dairy farm contributes positively if its productivity is lower (higher) than the initial average sector productivity. Melitz and Polanec (2012) extended the static

14. The productivity and efficiency of organic and conventional dairy farms in the United States was investigated by Mayen et al. (2010). Based on propensity score matching and stochastic frontier techniques and using a cross-section for 2005 the authors reject the homogeneous technology hypothesis and find that the organic dairy technology is approximately 13% less productive.

decomposition proposed by Olley-Pakes to allow for entry and exit, which is called dynamic Olley-Pakes (OP) decomposition.

Change in the level of TFP between *t-1* and *t* can be decomposed as follows:

$$\begin{aligned}\Delta LP_{it} = {} & \left[\overline{LP}_{cont,t} - \overline{LP}_{cont,t-1}\right] + \sum\nolimits_{cont} [(s_{it} - \bar{s}_t)(LP_{it} - \overline{LP}_t) \\ & - (s_{it-1} - \bar{s}_{t-1})(LP_{it-1} - \overline{LP}_{t-1})] \\ & + \sum\nolimits_{entry} [s_{entry,t}\left(LP_{entry,t} - \overline{LP}_{cont,t}\right)] \\ & + \sum\nolimits_{exit} [s_{exit,t-1}\left(\overline{LP}_{cont,t-1} - LP_{exit,t-1}\right)]\end{aligned}$$

where *Cont* refers to continuing (non-exiting) dairy farms, *Entry* refers to entering (new) dairy farms, and *Exit* refers to exiting (non-continuing) dairy farms. The first term represents the within-farm component of productivity growth based on changes in average farm level productivity in the sector. The trend of this term measures the change in sector level productivity level due to on-farm innovation such as technological adoption. The second term indicates the change in resource allocation effect between the continuing farms (covariance term of the OP decomposition). It measures to which extent resource reallocation between continuing farms contributed to the productivity growth at the sector level. The final two terms relate to the contribution of farm entry and exit to the sector level productivity growth.

The accurate identification of entering and exiting dairy farms in farm survey data is challenging in practice. The farm survey data used in the report do not record farm exit and entry and the farm sample changes overtime are independent from farm exit and entry.[15] Similarly, the sample farms that existed both at *t-1* and *t* do not necessarily represent the population of farms continued between *t-1* and *t*. [16] Given the limitation of the available dataset, some assumptions are imposed to apply the dynamic OP decomposition. First, the sample farms which appeared both at *t-1* and *t* are assumed to represent the population of continuing farm between *t-1* and *t*. Second, a part of population of continuing farms which is missing in the survey had the average market share and productivity level both at *t-1* and *t* so that the covariance terms are zero for the missing population of continuing farms. The net effect of farm entry and exit is calculated as a residual of the changes in market share weighted productivity. The measurement of net entry and exit effects could have an upward bias when the resource reallocation effect between farms is underestimated due to the missing part of the continuing population.

Figure 5 compares the average contribution of three productivity growth components in the three countries considered. The decomposition results indicate contrasting productivity growth dynamics of the dairy farm sector between the three countries.[17] In Estonia, the

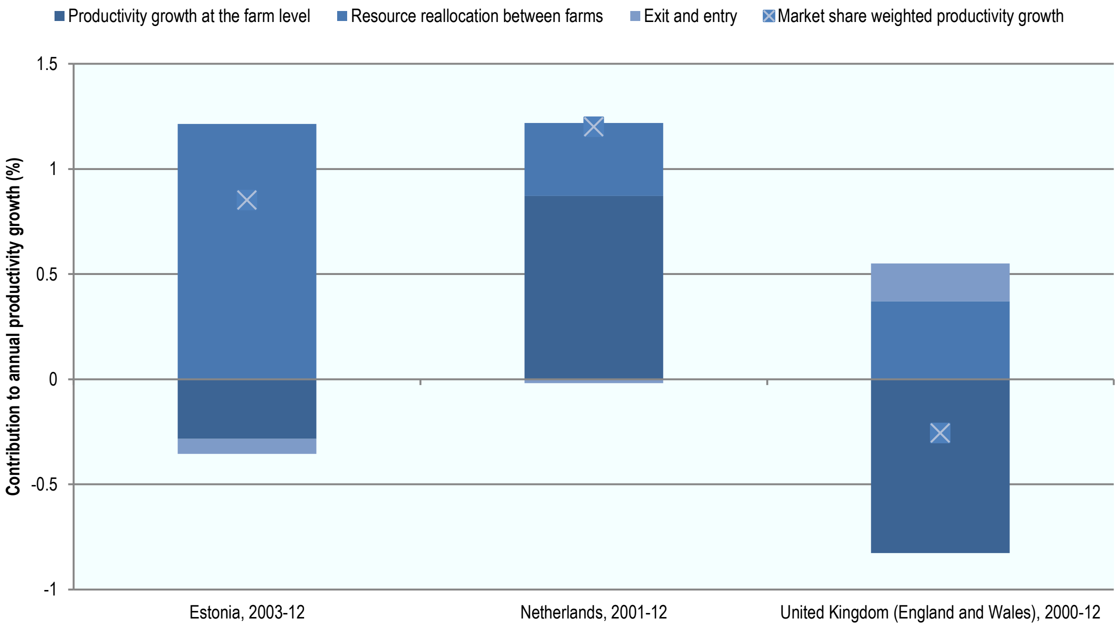
15. Although official data on the number of dairy farm entry and exit does not exist, farm exit is estimated to account for most of the decline in the population of specialist dairy farms in the three countries. Entry in the dairy farm sector has been limited because the EU milk quota policy restricted entry of new younger dairy farmers while maintaining existing producers (Dillion et al., 2005). However, care must be taken in interpreting the estimated impact of farm exit and entry. The farm exit and entry in this report includes a change in farm type between specialist dairy farm and other types of farms such as mixed farm. It does not necessarily mean the exit from and entry to the agricultural sector.

16. On average the majority of farms observed at *t* appear at *t-1*. The shares of such panel farms are 67% in Estonia, 90% in the Netherlands and 74% in the United Kingdom.

17 . Gray et al. (2014) performs Olley-Pakes decomposition of Australia’s broadacre industry productivity. They find that efficiency gain from the resource reallocation accounts for over a

productivity growth of the dairy farm sector is on average entirely driven by resource reallocation between farms. The resource reallocation contributed positively to the productivity growth in all the periods except the 2007-08 and 2009-10, leading to an average 1.2% of productivity growth contribution annually (Table 11). This implies that the main driver of productivity in the Estonian dairy farm sector is farm size expansion and increasing milk yield by a few numbers of productive large farms. The annual contribution of within-farm productivity growth and farm exit and entry was negative on average: -0.3% and -0.1%, respectively. Relatively low farm-level productivity growth at the farm level reflects the lower productivity growth of the majority of small farms. The negligible average impact of farm entry and exit effect reflects relatively slower pace of farm exit as well as the very small market share of the exiting small farms in Estonia compared to the other two countries.

Figure 5. Decomposition of productivity growth in dairy farm sector



In the Netherlands, both within-farm productivity growth and resource reallocation contributed positively to the productivity growth in the dairy sector, while the growth enhancing effect of farm exit and entry was found negligible on average. The productivity growth of continuing farms is the largest factor contributing the productivity growth, accounting for 0.9% out of 1.2% of average annual growth at the sector level. This indicates a trend of strong on-farm innovation in the sector such as technological adoption and more efficient management of inputs at the farm level. Resource reallocation between farms contributed positively to productivity growth, accounting for 0.3% of annual productivity growth on average. The slightly negative average contribution of farm entry and exit is reflecting on the relative lower rate of farm exit in the Dutch dairy farming sector.

third of TFP growth between 1989-90 and 1999-2000 and two-thirds between 1999-2000 and 2009-10, partly offsetting the effects of declining on-farm productivity.

In the UK dairy farm sector, the exit of less efficient farms and the resource reallocation between continuing farms are the driving factors of productivity growth. The net exit and entry effect and resource reallocation account for on average 0.2% and 0.4% of annual productivity growth in 2000-12, respectively. The rate of decline in specialised dairy farms in the United Kingdom is the largest among the three countries: the population of farms declined by 46% during 2003-12 compared to declines of 25% and 18% in Estonia and the Netherlands in the same period, respectively.[18] However, the decline in the average farm-level productivity of continuing farms offsets the positive contribution of the two other productivity growth factors, resulting in a 0.3% reduction in overall annual productivity growth in the sector. The large declines in farm-level productivity in 2008-09 and 2011-12 reduce the overall productivity growth over the whole period.

Table 11. Decomposition of productivity growth by year

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Estonia													
Market share weighted productivity				-3.1	-6.2	2.7	8.2	-1.5	13.8	-2.4	-1.6	-2.4	**0.9**
Within-farm productivity growth				-8.3	-3.8	3.2	3.7	2.5	5.7	-4.3	0.0	-1.3	**-0.3**
Resource reallocation				2.5	0.5	0.4	4.0	-2.2	1.9	-0.8	0.5	4.2	**1.2**
Farm exit and entry				2.3	-2.8	-0.8	0.7	-1.9	6.8	2.6	-2.2	-5.5	**-0.1**
Netherlands													
Market share weighted productivity		-2.9	5.2	1.6	0.5	3.6	1.5	-0.5	2.9	2.0	-1.5	0.8	**1.2**
Within-farm producitvity growth		-2.6	5.5	1.0	0.2	2.9	1.7	-0.1	1.0	1.2	-0.7	-0.5	**0.9**
Resource reallocation		0.1	0.4	0.8	0.1	0.9	0.2	-0.1	0.0	0.9	-0.1	0.6	**0.3**
Farm exit and entry		-0.3	-0.6	-0.2	0.3	-0.2	-0.4	-0.3	1.8	-0.1	-0.8	0.6	**0.0**
United Kingdom (England and Wales)													
Market share weighted productivity	2.6	1.7	0.7	-1.3	-1.5	3.0	1.7	-1.5	-6.6	4.3	1.7	-7.8	**-0.3**
Within-farm producitvity growth	4.0	0.5	1.4	-2.2	-2.1	0.8	0.2	-1.2	-6.5	3.0	1.8	-9.7	**-0.8**
Resource reallocation	-1.9	1.5	1.4	0.2	1.0	0.6	0.6	0.1	-0.5	1.3	-0.2	0.3	**0.4**
Farm exit and entry	0.4	-0.3	-2.1	0.7	-0.5	1.7	0.9	-0.5	0.5	0.0	0.0	1.4	**0.2**

7. Conclusion

This report compared the dynamics of productivity growth in the dairy farm sector in three countries: Estonia, the Netherlands and the United Kingdom (England and Wales), using productivity measurement at both the sector and the farm level.[19] A non-parametric index method was applied to estimate productivity indices based on an unbalanced panel of farm survey data and aggregated price index information. The report intends to shed light on the extent to which productivity growth in the dairy farm sector is driven by changes in the policy environment and dairy farm structure as well as farm-level innovation and other farm management practices.

18. DEFRA (2013) analyses 66 farms ceased dairying between 2003 and 2010 in England. It finds that 47 out of 66 farms converted farm types to grazing livestock farms and cereals or general cropping farms. Of the remaining 19 farms, seven farms are confirmed to be retired or sold up. Land of exiting farms tends to be used for other farming types and seldom transferred to other dairy farms in England. Table 4 also shows the decline in total land input in the sector.

19. Measurement of productivity in this report does not take into account non-markets inputs and non-commodity outputs such as rainfall, climatic condition as well as positive and negative environmental externality or landscape.

The total factor productivity of the dairy farm sector is first estimated by aggregating inputs and outputs to the sector level to compare the dynamics of productivity growth of the sector. The trend in productivity growth in the three countries reveals that labour productivity is the largest contributor to productivity growth in the dairy farm sector in all three countries. The decline in labour input is associated with an increase in capital inputs, notably machinery and equipment. The increase in capital inputs even exceeded the increase in the value of outputs, leading to negative growth of capital productivity. Trends in productivity growth are also influenced by a policy environment in which dairy farms are operating. In the Netherlands, the EU milk quota system continues to be a binding constraint for dairy farms to expand production. The productivity growth before implementation of the milk quota reform begins is almost entirely driven by a decline in input use. However, the expansion in milk output relative to input used became the main driving force of the Dutch dairy farm sector after the phasing out of milk quotas started.

The measurement of TFP at the farm level allows the distributional analysis of productivity and its linkage to sector level productivity. The distribution of productivity measured at the farm level shows significant differences in the level of productivity between farms. The comparison of productivity between different herd size classes of farms in the countries studied in this report shows the existence of economies of scale. Larger farms tend to achieve higher levels of productivity across in the countries analysed in this report. The decomposition of aggregated productivity index based on farm-level productivity measurement revealed that the productivity at the sector level is determined by the structural characteristics of the sector such as the distribution of farm-level productivity and resource allocation. In Estonia, milk production is highly concentrated in larger farms so that the largest 25% farms accounted for 90% of milk production in recent year. In this dualistic structure, the evolution of sector-level productivity is largely driven by the productivity of a small number of large farms. The analysis shows that the efficient resource reallocation towards more productive farms became more important in driving the sector level productivity in Estonia. In the Netherlands and the United Kingdom, there has been a significant herd size expansion in all size classes of dairy farms, however differences in productivity across farms has decreased overtime due to the diffusion of the existing technology across farms as well as the exit of less efficient farms.

The productivity measurement at the farm level also allows analysing the relationship between the level of productivity and the characteristics of farms such as farm management practice and natural conditions. The descriptive analysis shows that productive farms in three countries studied in this report tend to be more intensive in some inputs such as higher stocking density and larger use of purchased feed per cow. However, the results of the multivariate regression model indicate a positive relation between productivity and stocking density, but the intensity of the purchased feed input has a negative impact on productivity. The analysis shows that productive farms have a lower intensity of labour input per cow. These results indicate that efficient management of inputs is the key for dairy farms to become more productive. This involves decreasing labour input and increasing the efficiency of feed use, while increasing herd size. The introduction of milking equipment such as milk robots and milk parlours is also found to have a positive impact on the productivity of farms in the Netherlands. The analysis indicates that unfavourable geographical conditions tend to reduce the productivity at the farm level. The direction of the impact of support payments on farm-level productivity is unclear as a whole, but the farms which obtain higher levels of non-farm income tend to have a lower productivity in the Netherlands and the United Kingdom. It may be the case that those farms may reduce the input intensity of farming as well as investments in productivity improving technology. The estimated coefficient of the time dummy variable shows that the milk quota reform enhanced farm-level productivity growth both in the Netherlands and Estonia.

Finally, the panel of farm-level TFP measurement is utilized to identify the link between the dynamics of farm structure, farm-level innovation and sector level productivity growth. The decomposition of productivity growth indicates different growth dynamics in the three countries studied in this report. In Estonia, the dairy farm sector has expanded significantly in recent years and the productivity growth of the sector is led by a resource reallocation in favour of a small number of large size and productive farms. The low productivity of smaller farms persists, but their share in milk output has become marginal so that they have a minor effect on sector level productivity. In view of enhancing the productivity at the sector level, policy priority could be put on improving the productivity of larger farms, providing tailored advice and diffusing appropriate technologies. In the Netherlands, the dairy farm sector adjusted to the different policy environments over time and the productivity growth of the sector is driven largely by on-farm innovation such as technological adoption and efficient resource use. In the United Kingdom, productivity growth is led by the exit of smaller farms and farm size expansion of the continuing farms.

Overall, the cross-country comparison of dairy farm productivity growth shows a variety of pathways to enhance productivity growth of the sector, implying the importance of the comprehensive innovation system approach. Analysing the productivity growth dynamics of the sector can help policy makers to evaluate certain aspects of the sector’s economic performance and to diagnose the constraints to productivity growth that the sector is facing, including policy constraints. Understanding the heterogeneous productivity structure in the sector helps to identify the policy agenda tailored to the needs of different farms. Enhancing on-farm innovation through technological extension and farm management is an important part of such policy agenda, but providing a sound policy environment to allow and facilitate efficient resource reallocation between farms is found to be equally important. The exit of inefficient farms is one of the important drivers of productivity growth of the dairy farm sector in the countries analysed in this report, indicating the potential role of the government in removing impediments to farm exit and facilitating resource reallocation to continuing productive farms. Sector performance has more dimensions than productivity and more comprehensive policy recommendations to enhance performance of the dairy sector requires further deepening of the understanding of links between productivity and other performance indicators of the sector.

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