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Dairy Sector Productivity Growth in Northern Ireland: Trends and Drivers

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1. Introduction

The dairy sector is one of the most important agricultural industries in Northern Ireland (NI). In 2019, the sector accounted for approximately 10% of total active farms, and contributed the largest share (31%) of total agricultural gross output in NI, a larger share than any other agricultural sector (DAERA 2019). The NI dairy sector is significant to agriculture in the United Kingdom (UK) as well, contributing approximately 15% of the total dairy output in 2015/2016, second only to England's share (AHDB 2016).

Despite the importance of this sector, it is still faced with a number of important challenges, including limitations to factors of production such as land and labour. Another pressure on the industry is that successive policy reforms of the Common Agricultural Policy (CAP) and World Trade Organisation (WTO) agreements have increased the exposure of domestic producers to world markets. The NI dairy sector may face even greater international competition as the UK negotiates Free Trade Deals across the globe in the post-Brexit era. Besides, there is a growing concern in recent years about the future performance of the sector in the face of falling farmgate milk prices and increasing input costs (AHDB 2016). Against this backdrop, it is important to gain a better understanding of the sector's performance to maintain and improve competitiveness in a changing national and international context. One approach is to benchmark the competitiveness of NI's dairy sector compared to other competing regions, such as England and Wales, Netherlands, and Estonia. A key indicator of competitiveness is productivity: a measure of how efficiently inputs are converted to outputs.

The productivity of NI agriculture as a whole is currently measured using aggregate data, however it is not disaggregated into individual sectors, so it is difficult to determine trends in dairy productivity specifically. The objective of this study is to gain an improved understanding of the patterns, and factors impacting the productivity of NI dairy. This is accomplished by combining three complementary analyses.

Computation of an aggregate dairy sector productivity measure

Measuring aggregate productivity enables trends to be examined over time and allows for comparison with national productivity indices using similar coverage and methods. Having access to an index that is already widely applied by national agricultural ministries provides information on the competitiveness of the NI sector compared to other regions. This is useful for developing government policy to support productivity by learning from more productive dairy sectors. If there are differences in policy approaches, then there may be an opportunity to adopt some of the more successful approaches within NI.

Decomposition of aggregate productivity into different components

Dairy sector-level productivity is attributed to three different impacts: productivity growth within farms; resource reallocation between farms; and farm entry & exit (Kimura & Sauer 2015; Sheng *et al.* 2017). Decomposition analysis enhances the policy conclusions that can be drawn as these components imply different pathways to improving productivity; i.e. on-farm innovation, resource reallocation between farms and structural change.

Regression analysis of farm-level productivity, farm and farmer characteristics

Analysis of the marginal impact (positive or negative) of different factors at farm level identifies the drivers of productivity and provides evidence for policy to tackle productivity constraints. Econometric analysis is a useful tool for exploring the links between productivity and farm-specific characteristics and choices.

2. Brief Review of Literature

Many empirical studies have investigated the factors that drive dairy productivity growth at farm and sector levels. These studies identified factors that are directly related to technology and those that are not directly related to technology. Studies such as Emvalomatis (2012) conducted for the German dairy sector, Kimura and Sauer (2015) for the Netherlands, England and Wales, and Estonia, Mackinnon *et al.* (2010) and Nossal and Sheng (2010) for the Australian dairy farm sector, report that productivity growth is largely driven by technical progress. In particular, Mackinnon *et al.* (2010) and Nossal and Sheng (2010) establish that changes in production practices and technologies, which include improved milking sheds and equipment, genetics, artificial insemination and use of automatic cup removers, largely drive productivity growth of dairy farm sector.

Farm management and farmer characteristics, such as farming experience, education and training, financial status and attitude towards risk condition farmers' capacity to innovate and adopt new technologies, land use intensity, specialisation and farm size have also been identified as important drivers of productivity levels of dairy farms (Mullen 2007; Zhao *et al.* 2009; Sauer & Latacz-Lohmann 2014; Kimura & Sauer 2015; Xayavong *et al.* 2016). For example, Sauer and Latacz-Lohmann (2015) note that investments in innovative technology for German dairy farms require a sufficient level of complementary education to trigger an increase in productivity, recommending that the quality of human capital in terms of educational training is crucial for a lasting increase in efficiency as a result of innovation. Kimura and Sauer (2015) find a positive relationship between productivity and stocking density, but the converse for intensity of purchased feed and labour input. With regards to farm size, Keizer and Emvalomatis (2014) find that larger and more intensive dairy farms in the Netherlands experience faster productivity growth than the smaller farmers.

At sector level, Kimura and Sauer (2015) examined the contribution of exit and entry of dairy farms to productivity growth in Estonia, the Netherlands and

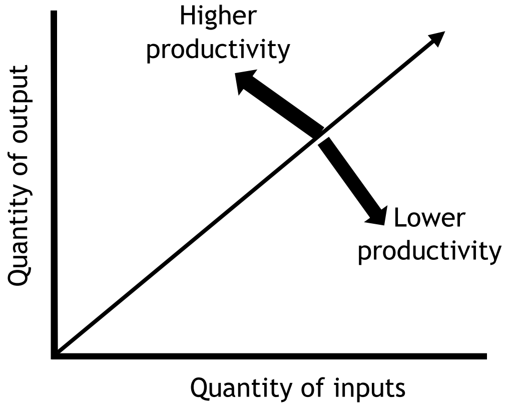
England and Wales over time. For the Netherlands and Estonia, the growth effect of entry and exit of farms was found negligible on average, which reflects a relatively low rate of farm exit in the Dutch and Estonian dairy farming sector. Contrastingly, for the English and Welsh dairy sector, the exit of less efficient farms and the resource allocation between continuing farms accounted for 0.2% of annual productivity growth in the sector. The direction of productivity growth also depends on agricultural policy reforms. For example, there is empirical evidence that decoupling policy support for Danish dairy farms, investment support for farms in Sweden, and milk quota reforms in Estonia and the Netherlands had significant positive effects on farm productivity (Kazukauskas *et al*. 2014; Kimura & Sauer 2015; Nilsson 2017). Conversely, Mary (2013) shows that coupled CAP payments (*i.e* set-aside, less favoured areas (LFA) payments and livestock payments) have a significantly negative effect on productivity. Other factors that drive productivity growth of the dairy farm sector include changing consumer preferences and incomes, resource qualities (such as labour and natural resources), dwindling milk prices, and land values (Zhao *et al*. 2008). While all the factors discussed in existing studies may have bearing on NI's dairy sector, it is important to empirically provide estimated impacts of the different drivers of productivity growth in a NI context. A comprehensive review of the literature on drivers of productivity growth has been conducted and submitted[1].

3. Measuring Productivity Growth of the Dairy Farm Sector

Essentially, productivity is the ratio of outputs to inputs. More technically, it is a farm's ability to convert production inputs into production outputs. As shown in Figure 1, a more productive farm has a higher ratio of output to input compared to a less productive farm. An increase in output/input ratios over time is referred to as productivity growth. Measuring productivity can be useful to evaluate the degree to which dairy farms have incorporated technological advances (e.g. through the adoption of new production practices and technologies such as modernising milking parlours). Productivity is also useful to assess the impact of wider factors such as policy, institutional, or market changes.

[1] Patton M., Olagunju K.O., Feng S., 2018. Key Drivers of Agricultural Productivity Growth: A Literature Review. *Report submitted to Department of Agriculture, Environment and Rural Affairs*.

Figure 1: Comparison of productivity



Adapted from Kimura and Sauer (2015).

There are two main measures of productivity: Partial Factor Productivity (PFP) and Total Factor Productivity (TFP). The former is simply the ratio of total outputs to a single factor input such as output per unit of labour, or labour productivity, and output per unit of land, or yields. Although these measures are simple to calculate and transparent, they can be misleading because they fail to capture changes in the use of other factors of production. The second measure, TFP, is more robust because it compares total outputs to all the productive inputs (land, labour, capital, material and services). TFP measures how efficiently a farm uses all inputs to produce outputs, which is a different concept to financial performance indicators such as gross margin, farm income and gross value-added. The improvements in TFP indicate changes in technological progress, farm production management and organisation, policy environment (for example the abolition of EU milk quota regime in 2015), and structure and composition of the dairy sector. TFP indices are quite sensitive to how components of outputs and inputs are aggregated. In particular, different aggregation methods may result in different estimations of TFP indices, depending on the production function assumption being relied upon (Kimura & Sauer 2015). The most common TFP indices employed by many national statistical offices and in the refereed academic literature include Laspeyres, Paasche, Fisher and Törnqvist-Theil indices *(Latruffe 2010)*.

Historically, TFP indices published as national statistics used the Laspeyres and Paasche indices for aggregation, however, these two approaches have been widely replaced by the Törnqvist-Theil index and Fischer index, which satisfy 'axiomatic' and 'economic' tests more than any other indices as they are both commonly said to be "superlative indices" (Diewert 1992)[2]. However, the Törnqvist-Theil index cannot handle data with many zero values, a common feature within the NI Farm Business Survey (FBS). This is not the case for the Fisher index, as it can handle data with zeros, and therefore the estimation of TFP in this report uses the

[2] These two tests are used in selecting and assessing the quality of TFP index formulae.

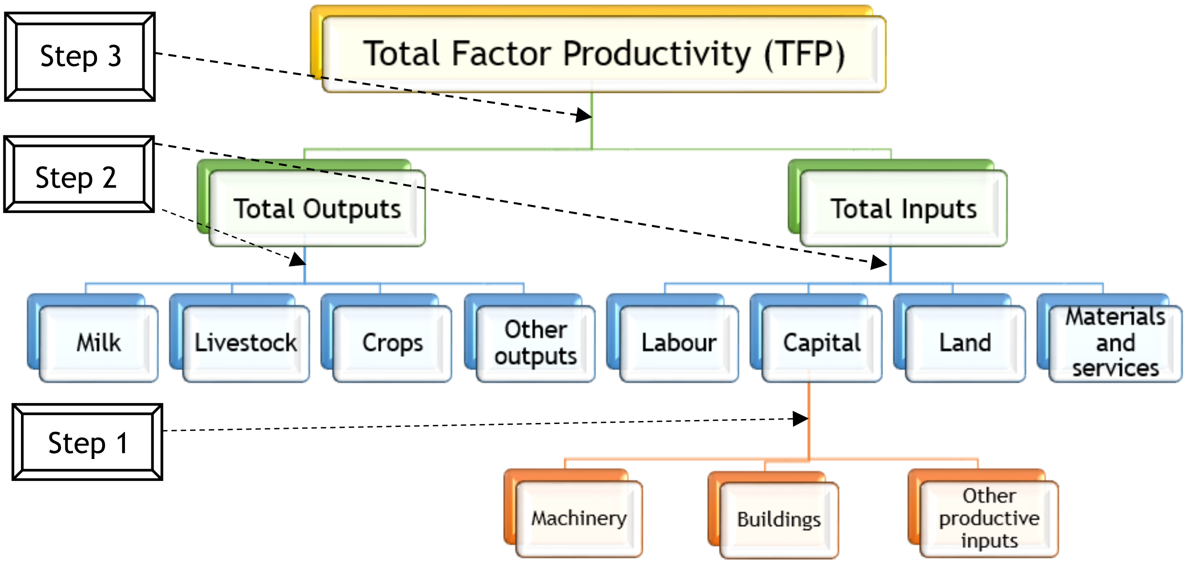
Fisher Index. The Fisher index can be adjusted using the Eltetö Köves Szulc (EKS) formula to ensure it is trans-temporal (can be compared over time) as well as compared across farms. Therefore, an EKS-adjusted Fisher index has been selected to estimate NI dairy farm sector productivity. A brief explanation of the methods employed for TFP estimation in this report is presented in the next section.

3.1 Methods for measuring a productivity index using FBS data

The simplest definition of TFP is the ratio of quantity index of all outputs divided by quantity index of all inputs. The changes in this ratio over time measures productivity growth which is a performance indicator of a production unit (for example farms, sector, region or a country). In estimating TFP, the physical quantities of both the outputs and inputs are needed, however, these items have different units of measurement (they are heterogeneous), and therefore cannot be aggregated directly. An attempt to aggregate these different categories of outputs and inputs requires the application of an INDEX FORMULA which uses either price or value as weights for each item. This is to enable comparison of items, for example, to compare a tonne of feed against a litre of milk.

Applying the aggregation framework employed by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), the TFP of NI's dairy sector can be estimated using three main steps (as shown in Figure 2). First, aggregating specific items of outputs and inputs into broad types of outputs (milk, livestock, crops and other outputs) and inputs (labour, capital, land, and materials and services). Second, aggregating the broad types of outputs and inputs into total outputs and total inputs, respectively. The third step calculates a ratio of total outputs and total inputs to obtain the TFP measure. Details of the specific input and output items in the aggregation steps are reported in the appendix section of this report.

Figure 2. Steps involved in aggregating inputs and outputs for estimating TFP in NI Dairy Farm Sector



Source: Zhao *et al*. (2012).

Similar to methods used by many National Statistical Offices, such as Department for Environment, Food and Rural Affairs (DEFRA), ABARES *etc*., the TFP index in this report is derived using a non-parametric formula called the **Fisher Index**. This index is applied to construct indices of total outputs and inputs.

The Fisher index is the geometric mean of the Laspeyres and Paasche quantity indices. The Laspeyres quantity indices for output and input are denoted as $Y_{t,t-1}^{L}$ and $X_{t,t-1}^{L}$ respectively while the Paasche quantity indices for output and input are represented by $Y_{t,t-1}^{P}$ and $X_{t,t-1}^{P}$ respectively. This Fisher index equation is specified as follows:

$$\text{Fisher output index} = Y_t^F = \left(Y_{t,t-1}^{L} \times Y_{t,t-1}^{P}\right)^{1/2} \quad (1)$$

$$\text{Fisher input index} = X_t^F = \left(X_{t,t-1}^{L} \times X_{t,t-1}^{P}\right)^{1/2} \quad (2)$$

with the Laspeyres output and input quantity indices specified as:

$$Y_{t,t-1}^{L} = \frac{\sum_{m=1}^{M} P_{t-1}^{m} Y_t^{m}}{\sum_{m=1}^{M} P_{t-1}^{m} Y_{t-1}^{m}} \quad (3a) \quad \text{and} \quad X_{t,t-1}^{L} = \frac{\sum_{n=1}^{N} W_{t-1}^{n} X_t^{n}}{\sum_{n=1}^{N} W_{t-1}^{n} X_{t-1}^{n}} \quad (3b)$$

and the Paasche quantity indexes defined as:

$$Y_{t,t-1}^{P} = \frac{\sum_{m=1}^{M} P_t^{m} Y_t^{m}}{\sum_{m=1}^{M} P_t^{m} Y_{t-1}^{m}} \quad (4a) \quad \text{and} \quad X_{t,t-1}^{P} = \frac{\sum_{n=1}^{N} W_t^{n} X_t^{n}}{\sum_{n=1}^{N} W_t^{n} X_{t-1}^{n}} \quad (4b)$$

The final Fisher TFP index, denoted by TFP_t^F can be estimated by dividing the Fisher output index Y_t^F by the Fisher input index X_t^F:

$$TFP_t^F = \frac{\text{Fisher output index}}{\text{Fisher input index}} = \frac{Y_t^F}{X_t^F} \quad (5)$$

The Fisher Index is a bilateral index and therefore when it is used to measure TFP for more than two observations (either of the same time or different periods) it might yield inconsistent results. To obtain a consistent measure of TFP across different dairy farms and points in time, several adjustment techniques have been developed to make the bilateral Fisher index transitive. Examples of these techniques include Minimum Spanning Trees, EKS, chaining the Fisher index *etc*. (Ball *et al*. 1997). In this report, the EKS adjustment was applied on the intransitive Fisher index to make it transitive thereby useful for consistently comparing TFP differences between farms and/or over time. The EKS formula applied to the Fisher index between farms A and B can be expressed as:

$$Q_{A,B}^{EKS} = \left(\prod_{r=1}^{N} Q_{AC}^{F} * Q_{CB}^{F}\right)^{1/N}, \quad (6)$$

where $Q_{A,B}^{EKS}$ is the transitive Fisher index between farm A and B when there are N dairy farms being compared. Q_{AC}^F is the Fisher bilateral Fisher index using farm *A* as the base farm, and Q_{CB}^F is the Fisher quantity index using farm *C* as the base farm.

To aggregate the farm-level inputs and outputs to obtain a measure of TFP at the sector level requires the application of specific sample weights. The application of these weights can take two forms. The first approach requires that the weights are applied *ex-ante*, that is, the sample weights are applied to aggregate the inputs and output at the sector level which are then used to measure the TFP of the NI dairy farm sector as the ratio of aggregated output and aggregated input. The second approach requires that the weights are applied *ex-post*, that is, the weights are applied after the TFP measures have been estimated at the farm level. Under this approach, sample weights and market share weights are applied *ex-post* to aggregate the farm-level TFP estimates consistent with the analytical objective of decomposing the TFP measures into different components (with particular emphasis to resource reallocation at sector level). In this report, the two weighting approaches are applied. It should be noted that these two approaches might produce different results because they are based on different economic concepts. The first weighting approach (*ex-ante)* defines dairy sector-level productivity in terms of efficiency of the sector in using inputs to produce outputs, while the second weighting approach (*ex-post*) defines sector-level productivity as the averaged farm-level productivity.

The data used for the estimation are mainly obtained from the NI FBS data collected annually through the Department of Agricultural, Environment and Rural

Affairs (DAERA). The dataset covers the period 2005 – 2016. Data on price indices are obtained from the Office of National Statistics (ONS) and DEFRA.

4. Results

4.1 Trends of aggregate productivity growth in the dairy farm sector

This section presents trends in dairy sector TFP growth during the period 2005 – 2016, defined in terms of efficiency of the whole sector in converting inputs to outputs. The quantity of total output and input used is measured at the sector level which is then used to calculate the TFP index[3]. The estimated TFP index is adjusted relative to a reference year (2010) to make the index comparable across the study period. For interpretation purposes, annual changes in the growth of TFP estimates may be attributed to differences in the contributions of changes in output and input growth over time. For example, a positive annual growth rate of TFP may imply that the annual growth rate of output exceeds that of inputs[4]. It is important to state that there may be other factors, apart from technological progress, that may influence productivity growth. For instance, weather variability or a disease outbreak could affect the quantity or quality of input and output, resulting in annual fluctuations of the TFP index. Long-term trends in productivity growth estimates, instead of year-on-year comparisons, offer the most reliable indicator of sector performance because the effects of external shocks such as weather or disease will not change the overall direction of TFP when considered over many years (Zhao *et al*. (2012).

Table 1 and 2 present the average annual TFP growth, partial factor productivity, outputs, and inputs from the years 2005 to 2016. The NI dairy farm sector has experienced moderate productivity growth per year. Between 2005 and 2016, the sector-level TFP grew at 0.5% a year (as shown in Table 1). This growth indicates an improvement in how efficiently inputs are used to produce milk and other dairy products. There is a structural break in the time period examined. The sector experienced negative annual TFP growth of 1.8% between 2005 and 2009, but starting from the year 2010 this reversed to positive growth at 1.8% a year. During the entire period covered, the annual growth rate of output increased by 4.6% and that of inputs increased by 4.2% implying that the annual growth rate of output marginally outpaced the growth of input. This suggests that the moderate productivity growth in NI dairy sector is driven by output growth, with inputs also increasing over the period but not at the same pace with outputs. While NI has performed well in productivity growth when compared with England and Australia during 2005 and 2016 (see Table 3), the aggregate productivity growth level of 0.5%

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[3] The sample weight data for NI dairy farms obtained from DAERA was used to aggregate farm- level quantity of output and inputs at the sector. The sample farms in the FBS and their corresponding weights vary overtime in order to maintain the representativeness of the sector.

[4] Similar to Zhao *et al*. (2012), the average productivity growth rate in this report was estimated econometrically using the following regression equation: $\ln(TFP) = \alpha + \beta t$, where $\ln(TFP)$ is the logarithm of *TFP* and t is a linear trend. The coefficient β is the value of average productivity growth rate.

per annum is fairly modest suggesting that there is still room for improvement. The negative partial productivity of the materials input component appears to be an area of concern, suggesting that better and efficient use of material inputs may be key in championing productivity improvement of the sector.

The partial factor productivity growth for the four main factors of production used in the dairy farm sector is also reported in Table 1. Labour input increased the least (1.2% per year) compared to other inputs, making labour productivity growth (3.3% per annum) the most important partial factor productivity contributor to overall TFP growth. According to Kimura and Sauer (2015), the Netherlands experienced similar labour productivity growth of 3.3% while England and Wales experienced about 2.3% per year. This may suggest gradual and partial replacement of labour inputs with capital over the years[5]. The annual growth rate of output slightly exceeds that of capital input, resulting in a moderate positive growth of capital productivity of 0.9%. This suggests that output from the dairy sector outpaced the level of investment in capital items between 2005 and 2016. Specifically, capital input increased by 3.9% between 2005 and 2016 which suggests that farmers are increasingly investing in capital inputs. The use of land inputs in the dairy sector experienced an increase of 2.8% per year between 2005 and 2016. The rate of growth per year of land input between 2005 and 2009 was higher than the growth rate after 2009. Overall, the growth rate of land input is outpaced by output growth leading to positive land productivity of 1.8% per annum.

The results presented in Table 2 show that the largest component of material input in terms of cost share is feed/fodder which experienced annual average growth of 11.2%[6]. Similarly, the growth rate of fertilizer, chemical and fuel inputs was positive except for seed input. As a result, material input outpaced total output, thereby producing a negative annual material partial productivity growth rate (-3.6%) between 2005 and 2016. England and Wales also experienced a negative annual material productivity growth rate of -0.3% between 2000 and 2012 while Estonia recorded -1.6% between 2003 and 2012 (Kimura & Sauer 2015). The results also show that material inputs grew at a faster pace (by about 18%) before 2012, but fell by 8% per year from 2013 to 2016 (as shown in Figure 2). However, both England and Wales and the Netherlands experienced a negative growth rate (-0.4%) in material input use until 2012 (Kimura & Sauer 2015).

The dairy farm sector experienced expansion of output between 2013 and 2015, which slowed down in 2016. The output increase between 2013 and 2015 was accompanied by an improvement in productivity, but between 2015 and 2016 the sector experienced a reduction in productivity growth, suggesting that there was a more than proportionate reduction in total output produced than input used between 2015 and 2016. This is largely attributed to a significant reduction in

[5] The labour input might have been gradually replaced by capital inputs over the years which implies substitution of labour with capital input. The positive effect of this substitution effect on TFP, although is evident at sector level, may not necessarily translate to improvement in TFP at farm level especially in the short term. Further discussion on this is reported in section 3.6.

[6] By definition in this report, material input is same as variable costs which include feed/fodder, fertiliser, chemical, seeds and fuel.

farmgate milk prices between 2015 and 2016 which influenced farmers' production and cost-cutting behaviour. The results also show that the reduction in total input between 2015 and 2016 was significant in material and service (see Figure 4). Between 2015 and 2016, material and service inputs reduced by 8.6% and 0.84% respectively.

Figure 3 shows the trends of TFP, total input and output during the period 2005 to 2016, making the level in 2010 a reference level of 100. The annual TFP growth was positive in six years out of eleven years, while total output and input increased in eight out of eleven years. A decline in TFP by 4.5%, 2.4% and 3.2% was observed during 2007/2008, between 2010/2011-2012/2013, and 2015/2016 respectively. During 2015 and 2016, the sector experienced a reduction in TFP, driven by a 3.2% reduction in outputs and a persistent reduction in input growth by 1.3%. In contrast, TFP growth was positive between 2013/2014 and 2014/2015 production season which was mainly driven by growth in output and a decline in the growth of inputs, particularly material inputs such as feed, which lead to a reduction in total input growth per year of more than 5.5%.

Table 1. Average Annual Productivity Growth (Percentage) of the Dairy Farm Sector, 2005-2016

	2005- 2009	2010 - 2016	2005 -2016
Total Factor Productivity	-1.8	1.8	0.5
Partial Factor Productivity			
Labour	2.9	3.5	3.3
Land	0.7	2.5	1.8
Capital	-0.2	1.6	0.9
Material	-11.9	1.2	-3.6
Service	-3.0	0.6	-0.7

Table 2. Growth Rate of NI Dairy Farm Sector-level TFP, Outputs and Inputs, 2005-2016

	Average annual growth rate %	Average value or cost share %
Total outputs	**4.6**	**100**
Milk	3.9	73
Livestock	6.0	26
Total inputs	**4.2**	**100**
Labour	1.2	19.4
Land	2.8	7.2
Capital	3.9	22.8
Material	8.2	33.2
Feed/Fodder	11.2	77.7
Fertiliser	3.9	12.9
Chemical	5.3	0.9
Seeds	-1.8	0.9
Fuel	0.9	7.6
Services	5.4	17.4

Figure 3. NI Dairy Farm Sector TFP, Total Output and Total Input Indices (2010=100), 2005 – 2016

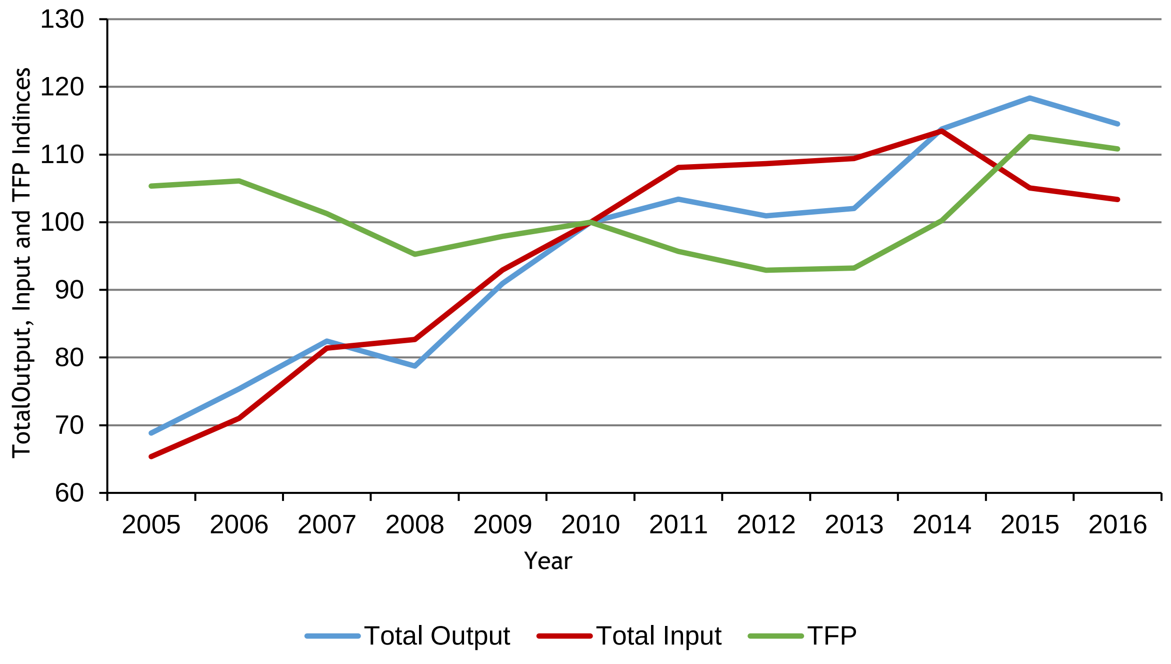
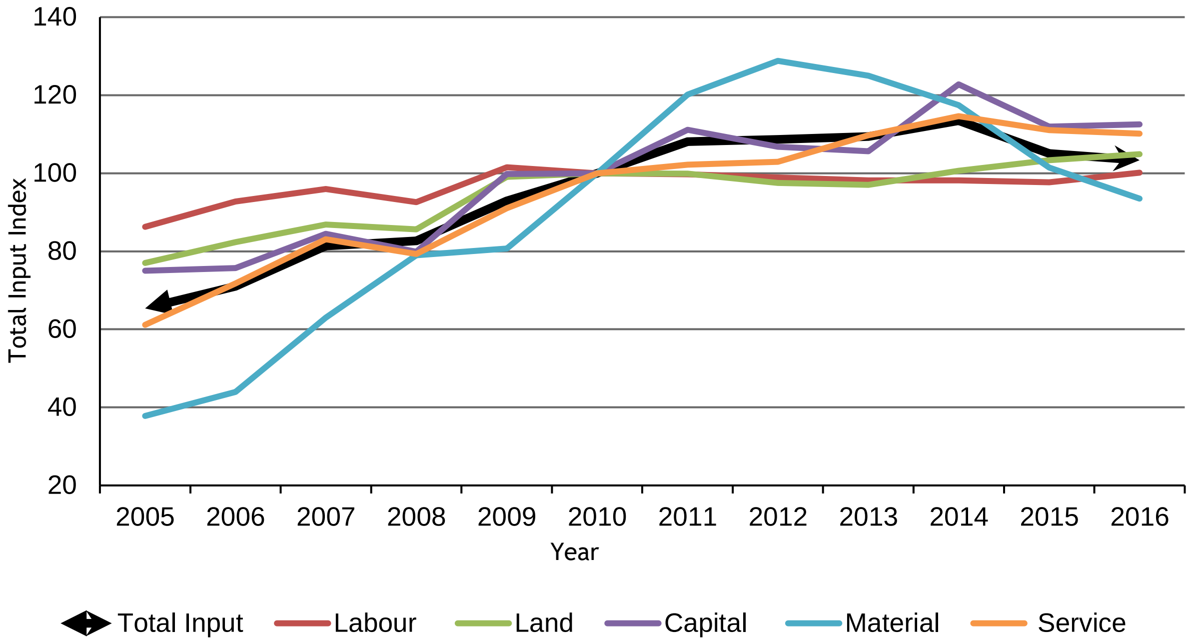


Figure 4. NI Dairy Farm Sector Total Input Index (2010=100), 2005 – 2016



4.2 Comparison of NI TFP Growth with England and Australia's Dairy Sector

Table 3 compares the TFP growth rate of NI's dairy farm sector with England and Australia between 2005 and 2016. During this period, on average NI witnessed the highest TFP growth rate of 0.5% followed by England, while the Australian dairy sector experienced a negative annual growth rate of -0.1%.

Table 3. Comparison of NI TFP Growth with English and Australian Dairy Sectors

Year	**TFP Growth Rate (2005-2016)**		
	NI	England[a]	Australia[b]
2005/2006	0.7	-0.5	-10.0
2006/2007	-4.7	-6.9	4.1
2007/2008	-6.1	0.5	1.3
2008/2009	2.7	-2.6	4.6
2009/2010	2.1	1.7	5.0
2010/2011	-4.4	2.3	0.6
2011/2012	-3.0	-6.4	-18.5
2012/2013	0.4	1.9	7.7
2013/2014	7.2	3.7	-1.4
2014/2015	11.7	7.6	4.0
2015/2016	-1.6	0.3	1.3
Average annual productivity growth (%)	0.5	0.1	-0.1

**Note that the estimation techniques employed in different countries differ slightly, therefore estimates are only suggestive.* [a] TFP growth estimates for England are obtained from DEFRA (https://www.gov.uk/government/statistics/total-factor-productivity-for-england-by-farm-type). [b] TFP growth estimates for Australia are obtained from ABARES (https://www.agriculture.gov.au/abares/research-topics/productivity/agricultural-productivity-estimates#dairy).

4.3 Distribution of productivity and resource use at the farm level

The TFP index presented in the previous section measures productivity improvement in the dairy sector. Albeit, this measure is unable to provide insights into the relative contribution of farm-level innovation (that is how farmers may apply existing technology more efficiently) and resource reallocation between farms (including farm entry and exit behaviour) to productivity growth in the dairy sector. To empirically examine the contribution of resource reallocation between farms and farm-level innovation on dairy sector productivity, it is important to employ a measure of farm-level productivity which could be used for decomposing sector-level productivity into different components. The TFP estimated here defines sector-level productivity as the averaged farm-level productivity. See Box 1 for the description of the methodology.

Table 4 reports the evolution of the unweighted average farm-level TFP and the market-share-weighted average productivity[7]. It is noteworthy to state that these two TFP measures are different in their absolute terms and growth rate which suggests that productivity and market share vary across farms. Throughout the entire period (2005 – 2016), the level of market-share-weighted average productivity is higher than the unweighted average productivity, suggesting that dairy farms with large market shares (defined as their proportion of total output) have a higher level of productivity. This means, as shown in Table 5, larger farms, on average, have higher levels of productivity across years than small and medium farms.

The market share weighted TFP continues to be close to the average productivity of large farms, reflecting further on the trend in the concentration of output towards large farms. The market share weighted productivity grew at 0.37% annually on average, whereas the average annual growth rate of unweighted productivity grew at 0.48%.

Milk production is found to be concentrated in large farms and this degree of concentration has increased over time. As shown in Table 6, the largest 25% of farms (categorized as large farms) account for the greater share of milk output. In particular, the large farms are responsible for about 55% of milk production between 2005 and 2016 although there was a slight reduction from 54% to 52% in 2016.

The average farm size has increased steadily between 2005 and 2015, but there was a reduction across all the farm class sizes between 2015 and 2016. The average annual productivity growth rate was positive in all the farm sizes, but the growth rate was higher in smaller farms. This may be attributed to improvements in productivity of smaller farms (for example through the use of improved technology) or the exit of small and inefficient farms. Notably, in 2015 and 2016, there was a reduction in the productivity growth rate of large and medium-sized farms. This may be attributed to falling milk prices during this period, to below average long-term levels, which might have triggered farmers to adopt cost-costing measures

[7] Both FBS sample weights and market share are applied to calculate the market share weighted average productivity while only FBS sample weights are applied to calculate the unweighted average farm-level productivity.

(postponement of investment and reduction other production inputs like feeds) that may have an impact on short-run productivity differentials.

The weighted averaged TFP obtained in this section will be used for the decomposition of aggregate productivity into different components: productivity growth within farms; resource reallocation between farms; and farm entry and exit. The results of the full decomposition analysis, including farm entry and exit will be provided in separate technical brief during September 2020.

Box 1. Measuring Sector-Level Productivity based on Market Share

An index of dairy farm sector productivity based on market share is defined as a weighted sum of farm-level productivity, where individual farms' share of gross sector output is used as the weight. This can be denoted as:

$$TFP_t = \sum_f s_{it} \, TFP_{it}, \tag{7}$$

where TFP_t is the index number of dairy farm sector-level productivity, s_{it} is the weight of farm f in dairy sector *I*, and TFP_{it} as an index of farm-level productivity provided by the non-parametric productivity measurements outlined in Section 3.1. The weight s_{it} can be based on either milk output or herd size. In this report, the share of milk output in the sector is used as the weight. The sector productivity index described is based on the farm-level productivity measurement and can be decomposed into different components.

Table 4. Evolution of Farm-Level TFP

Year	Unweighted average TFP		Market share weighted average TFP	
2005	90.9		104.15	
2006	91.3	0.42	106.14	1.90
2007	88.4	-3.26	99.26	-6.70
2008	83.2	-6.02	93.56	-5.91
2009	83.6	0.51	96.81	3.41
2010	85.4	2.11	96.88	0.08
2011	82.5	-3.53	92.79	-4.31
2012	80.8	-2.00	90.28	-2.74
2013	80.6	-0.34	91.01	0.81
2014	87.7	8.43	97.36	6.74
2015	97.5	10.62	109.89	12.11
2016	95.8	-1.69	108.49	-1.28
Average growth rate (%)		0.48		0.37

Table 5. Market Weighted TFP by Farm Size

Farm size class	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average TFP growth %
	All farms	104	106	99	94	97	97	93	90	91	97	110	109	0.4
Typology based on number dairy cows	Large	115	120	108	102	106	105	100	96	97	104	117	116	
			4.4	-10.7	-5.5	3.9	-1.2	-4.8	-3.4	1.0	6.1	12.5	-1.1	0.1
	Medium	96	92	91	86	81	87	86	85	88	93	105	103	
			-4.4	-1.5	-5.5	-6.0	6.9	-1.1	-1.2	3.3	6.1	12.3	-2.0	0.6
	Small	76	77	76	72	71	70	68	68	67	76	79	83	
			2.7	-2.2	-5.5	-1.4	-2.2	-1.9	-0.7	-1.7	13.4	4.1	4.3	0.8

Large – the largest 25%, small – the smallest 25%, Middle – the remaining 50%.

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

		Number of dairy cows						Market share in %				
		2005	**2008**	**2012**	**2015**	**2016**		**2005**	**2008**	**2012**	**2015**	**2016**
Typology based on number dairy cows	Large	159	179	200	226	222		53	55	57	55	52
	Medium	67	73	82	94	91		37	35	37	37	40
	Small	28	32	35	42	37		10	9	7	8	7

Large – the largest 25%, small – the smallest 25%, Middle – the remaining 50%.

4.4 Farm characteristics and productivity

This section of the report examines the relationship between farm productivity and the characteristics of the farm and farmer. The characteristics considered are grouped into six main categories including farm size (herd size), farmer characteristics, farm management, farm investment and technology choices, farm location, and income sources. By employing K-means cluster analysis, productivity levels are grouped into three clusters. The units are continually arranged, such that they are clustered in a way that they are as similar as possible within cluster and as different as possible between clusters. The resulting groups identified by this analytical technique represent groups of farms characterized by similarity in terms of productivity level. For ease of comparison, farms within the first cluster are classified as low-productivity farms (average TFP level of 64.4; range of 33.8 to 76.8); the farms that fall in the second cluster are grouped as middle-productivity farms (average TFP level of 89.2; range of 76.9 to 102.1) and the farms in the third cluster are the high-productivity farms (average TFP level of 115.2; range of 102.2 to 160.0).

4.4.1 Characteristics of sample farms productivity by productivity class

The summary of the average farm characteristics disaggregated by three productivity categories between 2005 and 2016 is presented in Table 7. The results show that there are significant differences in productivity between the three clusters. The productivity level of the most productive farms, on average, is about 1.8 times higher than the average productivity level of low productivity farms. Similarly, the average TFP level of middle productivity farms is on average about 1.2 times higher than the low productivity farms. Additional analysis will be run whereby alternative groupings of farms by productivity will be looked at to check the sensitivity of results to how farms are clustered. Table 7 also shows that farms with large herd size have higher productivity levels, indicating that there is a positive correlation between farm size and productivity. This suggests that economies of scale in dairy farming is likely to be relevant for improvement in farm productivity. (A correlation means it could be related or is likely related, but we don't know if it is causal until regression is run, also that we can show we have controlled for confounding factors.)

Considering farm management variables, the amount of some inputs used tends to be positively associated with productivity level. On average, the low productivity farms have lower stocking density and vice versa. The high productivity farms are observed to be more intensive in the use of purchased feed and achieve higher milk yield. Conversely, the use of labour inputs is found to be negatively correlated to productivity level suggesting that high productivity farm uses less labour input. Although high productive farms have been able to manage larger herd sizes, relying more on hired labour for production, these farms have been able to simultaneously reduce labour input use while increasing herd size. Also, larger farms have been able to replace labour input with capital, including the increasing popularity of automatic milking technology. This is a large capital investment, but it significantly eliminates daily milking time thereby releasing a lot of labour due to decreased labour demand per cow.

There appears to be no large difference between the ages of operators of high and low productive farms. This may be attributed to the fact that other variables have not been adjusted for. With regards to the education level of farmers, the rates of A levels, agricultural colleges, and university education are highest among high productive farms. Moreover, the majority of dairy farmers (about 63%) have GSCE and school only education.

Farms that use more capital relative to labour tend to have higher productivity. The net investment per cow tends to be lowest in high productivity farms. The negative correlation of investment per cow variable with productivity level may likely be attributed to the fact that these farms are able to obtain scale and therefore investment is spread more thinly over each dairy cow, making it more economically viable to invest (*i.e* improving returns per each pound of capital invested per cow).

Regarding the location of farms, high-productivity dairy farms are likely to be located in lowlands while low productive farms are likely to be located in regions that tend to be classified as naturally disadvantaged or constrained. The total direct payments per hectare received by farms are larger for high productive farms. The difference may be linked to the intensity of production in the past (a basis for the amount of subsidy received by farms) which would correlate with productivity. High-productivity dairy farms, on average, tend to participate less in off-farm activities while low productive farms participate most. This is likely linked to relative scale, such that smaller farms may be optimising available time by allocating less to the farm and opting to operate a less intensive unit to facilitate off-farm employment in order to maximise overall economic welfare.

Table 7. Characteristics of Farmers and Farms Disaggregated by Productivity Category

Productivity category	Low	Middle	High
TFP score	64.4	89.2	115.2
Farm size			
Number of dairy cows	55	98	159
Farm Management			
Milk yield (litres per cow)	5334	6262	7095
Stocking density(*LU per ha)	1.6	2.0	2.2
Purchased feed per cow (GBP)	540	565	619
Labour input per cow(hour)	100	60	41
Hired labour share (%)	1.5	2.0	6.0
Characteristics of farmer			
Age (years)	56	54	58
School & GSCE (%)	66.8	64.7	55.7
A levels (%)	0.0	0.6	2.8
College (%)	27.2	25.9	33.6
Degree & Postgraduate qualification (%)	0.5	1.5	1.4
Investment and technological choice			
Net investment per cow (GBP)	366	369	341
Capital and labour ratio	0.9	1.2	1.5
Land quality			
Severely disadvantaged area (%)	53.5	39.7	32.5
Disadvantaged area (%)	22.4	34.7	32.5
Lowland area (%)	24.0	25.6	34.9
Payment and other sources of income			
Total payment per area farmed (GBP/ha)	285	301	320
Off farm participation ratio (%)	31.5	28.5	26
Number of observations	289	617	437

*LU = Livestock unit

4.4.2 Factors influencing farm productivity

The majority of farmer and farm characteristics highlighted in Table 7 are potentially correlated. As an example, farms with large herd size will likely invest more in improved technologies, realise higher milk yield and perhaps operate in lowlands. In this section, we perform an econometric estimation that incorporates both observed and unobserved factors that influence farm productivity. The estimation was carried out by employing a panel fixed-effect approach and the results are presented in Table 8[8]. We specify two different models: the first model

[8] The model specification is based on fixed effect panel regression: $TFP_{it} = \beta_0 + \beta_1 X_{it} + \delta_i + \psi_t + \varepsilon_{it}$, where TFP_{it} is Productivity level of Farm i, year t, X_{it} is set of covariates/explanatory variables (including farm size, farm and farmers characteristics, investment *etc.*), and δ_i denotes the farm fixed effect which controls for

contains net investment per cow variable at the current time (that is, at time t) while the second model incorporates the variable in its lagged form (three-year lag, that is, t-3). The purpose of the first model is to capture recent capital investments while the second model incorporates past farm capital investments. The estimated coefficients from both models for all the variables have the same signs but different levels of significance, except for the net investment per cow variable.

Model 2 is extended to include some transformed versions of variables to try and capture non-linear relationships, such as with farmer age, and interaction effects, such as with education and investment. The results of the extended estimation, or Model 3, is presented in Table 9.

The findings are as follows:

- The estimated coefficients show that herd size has a positive and significant impact on the productivity level. This suggests that larger farms are more competitive and have been able to take advantage of economies of scale. This result is consistent with the rising market share of these farms.

- Higher milk yield is associated with higher farm productivity and is statistically significant. This result may reflect the importance of genetic improvement as an embodied technology in improving productivity.

- Consistent with the findings obtained in the summary statistics, a higher stocking density has a positive and significant relationship with farm productivity. The finding suggests that dairy farms operating intensive systems are more productive.

- Contrary to the summary statistics, the intensity of purchased feed input (GPB per cow) has a negative and significant impact on productivity after controlling for other factors. A possible explanation for this is that diminishing marginal returns to purchased feedstuffs may set in for some farmers, at which point higher feed input will not enhance productivity but rather constitute additional cost for the farmer. In the NI context, this suggests that better utilization of grassland combined with optimal use of concentrate inputs has potential for achieving productivity improvements.

- In line with expectations, labour intensity per cow has a significant and negative impact on productivity. This implies that labour-intensive dairy farming is less productive.

unobserved farm characteristics that do not change over time but may affect TFP level. ψ_t represents year fixed effect which controls for shocks common to all the farms, e.g. price volatility, weather. ε_{it} is the error term.

- In Model 1, the variable hired-labour-share was found to be positive and significant, indicating that farms with a relatively larger share of hired labour are more productive. This result further points to the relevance of scale in influencing productivity.

- The impact of age on productivity is complex. In Model 1 and 2, farmer age is positive, but not statistically significant. The insignificance of the variable could reflect the multi-generational nature of many dairy farms in NI and the need to know the role of all family members involved to better establish the influence of age on farm business performance. For example, dairy farm owners may hand over management responsibilities to their children who take charge of all production decisions. When age as well as age-squared (quadratic form) is included in Model 3, age is still positive, but significant, and age-squared is negative and significant. To illustrate the non-linear relationship between age and TFP, the predictive margins graph was constructed (see Figure 5). The predictive margins graph plots the response of TFP when age is allowed to vary from 19 years to 84 years) and other remaining variables in the model are fixed at their mean values[9]. The graph shows that the average effect of age is negative, but the negative impact increases in size as farmers get older. It may suggest that the negative sign of the quadratic term of age dominates the age -TFP relationship.

- Education variable (A levels, agricultural college or above) consistently has a positive impact on productivity across all the models. The results support the literature that indicates that additional years in education, including A levels, specialist agricultural training or above, have a positive impact on farm management performance[10][11]. However, as with the results from the 'age' variable, estimating the true impact of education would require information on the education of the farm manager, in cases where the owner and manager are not the same. The interaction effect of age and education variable in Model 3 is also negative suggesting that dairy farms with younger farmers that have attained at least A levels or agricultural college level

[9] Margins are statistics estimated from prediction of the already fitted model at fixed values of one/more explanatory variable(s) and averaging over other explanatory variables (Rising 2012).

[10] Preferably, dummy variables for each of the education qualification categories should have been used, but the number of observations are few, and hence the amalgamated education variable – 'A levels, agricultural college or above' was used in the main analysis. Majority of the observations within the amalgamated variable have agriculture college qualification. As a result, a supplementary regression was conducted with 'Agriculture college' dummy variable (operators with agricultural college qualification takes value of 1, and 0 if otherwise). This is presented in Model 2a of Table 1A in the appendix section.

[11] Model 2a of Table 1A tests the relevance of agricultural college education variable by allowing it to be the sole education variable in Model 2. The results show that agricultural college has a positive and significant effect on productivity, providing evidence for the important role of agricultural college educational attainment in improving farm performance.

qualifications tend to have greater productivity. This may imply that because younger farmers have completed agricultural education more recently, they may have access to more up to date information than a farmer with the same level of qualification, but at a time when industry standards and technological options were different.

- In Model 1, net investment variable was found to have a negative impact on productivity. This may reflect a short term impact of farm-gate milk price movements on productivity level. For example, when milk prices increase above the long-term average, dairy farmers may increase their level of investment in pursuit of short term additional output, thereby resulting in a short term negative impact from investment on productivity. In addition, this result also suggests that the productivity-enhancing effect of investment is likely to be delayed. However, when the variable was lagged by 3-years (as in Model 2), the relationship between investment and productivity turned positive. This affirms that the returns on capital investments in terms of productivity may not be immediate but may take some time before the impact may show, thereby reflecting a long-term impact of investment on productivity. These results are consistent with findings by Kimura and Sauer (2015) that the short term impact of investment on dairy productivity was negative across Netherlands, Estonia, and England and Wales. Also, Sauer and Latacz-Lohmann (2015) reported that it took two years for capital investment to manifest in productivity gains for dairy farms in Germany.

- When lagged net investment interacts with education in Model 3, the results show that education has a complementary effect on net investment by increasing the positive effect of long term net investment on productivity. This clearly suggests the complementary role of education in influencing the long term positive effect of investment in technology on productivity.

- As expected, being located in less-favoured areas is associated with lower TFP, but this is statistically insignificant. This suggests that natural conditions could be a constraint for productivity growth. This result may also be linked with the fact that dairy farms in less-favoured areas are typically smaller and may attain lesser productivity level.

- After controlling for other factors, the share of payments in total farm output has a significant and negative relationship with productivity in Model 2. This could suggests that farms with higher share of payments in total output or those that are highly reliant on direct payment are less productive. This result may also indicate the level of specialisation of some dairy farms given that direct payments are based on historic activities, and farms with sizeable beef enterprises (mostly low productive) had larger payments, thereby suggesting that specialised dairy farms (compared to mixed farming activities) are more productive. To provide empirical support for this result, after controlling for level of specialisation of dairy farms (as in Model 2b of Table 1A), the share of payments in total farm output still retains its negative sign.

- The estimated results show that participation in more off-farm activities may have a negative impact on productivity, but this is not statistically significant. This suggests that dairy farmers engaged in off-farm activities are optimising available time by allocating less to the farm and choosing to run a less intensive unit in order to maximise overall economic welfare.

Table 1A comparing all three main models plus the supplementary model (the model that accounts for specialisation) is available in the Appendix.

Table 8. Estimated coefficients of the effects of farm characteristics on farm-level productivity

Variables	Model 1 (contains 1-in year capital investment)	Model 2 (contains 3-in year lagged capital investment)
Number of dairy cows	0.078***	0.196***
Milk yield	0.516***	0.544***
Stocking density	0.073***	0.101***
Purchased feed per cow	-0.068***	-0.087***
Labour input per cow	-0.337***	-0.134***
Hired labour share	0.114*	0.066
Age	0.086	0.138
Education - A levels, Agric. college or above	0.030*	0.052**
Net investment per cow	-0.065***	-
Net investment per cow *(3-year lagged)*	-	0.012**
Severely disadvantaged area	-0.012	-0.052
Disadvantaged area	-0.033	-0.014
Share of payments in farm outputs	-0.093	-0.181**
Off farm participation ratio	-0.008	-0.022
Observations	1,343	866
Number of farms	169	137

Notes: Model 1 represents model with net investment per cow variable at the current time (that is, at time t); Model 2 incorporates net investment per cow variable in their lagged form (three-year lag, that is, t-3) *** p<1%, ** p<5%, * p<10% denote significance at 1%, 5% and 10% levels respectively.

Figure 5: Predictive margins graph showing age variable within the productivity equation.

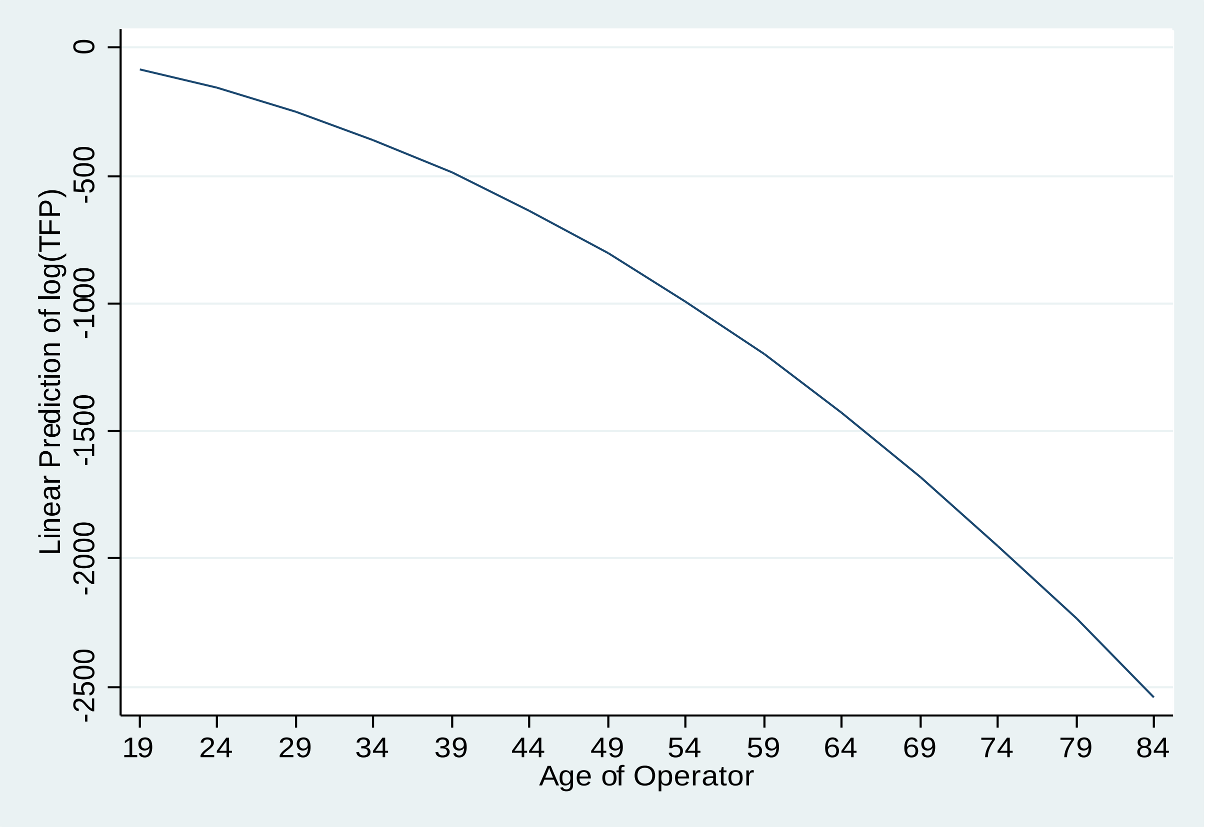


Table 9. Extended model Estimates (with interaction terms) of the effects of farm characteristics on farm-level productivity

Variables	Coefficient
Number of dairy cows	0.197***
Milk yield	0.541 ***
Stocking density	0.108***
Purchased feed per cow	-0.092***
Labour input per cow	-0.123***
Hired labour share	-0.077
Age	3.082***
Age squared	-0.396**
Education - A levels, Agric. college or above	0.784***
Age * Education - A levels, Agric. college or above	-0.199***
Net investment per cow *(3-year lagged)*	0.015***
Net investment per cow *(3-year lagged)* * A levels, Agric. college or above	0.059*
Severely disadvantaged area	-0.006
Disadvantaged area	-0.020
Share of payments in farm outputs	-0.164**
Off farm participation ratio	-0.019
Observations	866
Number of farms	137

Note: *** p<1%, ** p<5%, * p<10% denote significance at 1%, 5% and 10% levels respectively.

5. Summary and conclusions

- Increasing productivity growth remains an essential element in sustaining international competitiveness of NI's dairy farm sector. In light of limitations to factors of production as well as changes in policy and market developments, it is important to gain a better understanding of the sector's performance to maintain and improve competitiveness in a changing national and international context.

- This policy brief examines productivity trends and drivers in NI's dairy sector, by employing a productivity index measurement approach at both the farm and sector level. A non-parametric approach was used to measure productivity indices based on an unbalanced panel of FBS data and aggregated price index information for the period 2005 -2016.

- Our results show that the sector experienced moderate growth in productivity (0.5% a year) between 2005 and 2016. This slight improvement in productivity has been driven by output growth, with inputs also increasing over the period but not at the same pace as outputs. This implies that the expansion in output from dairy farms, primarily milk, relative to input used was the main driving force of productivity growth.

- Comparing the productivity growth experienced in NI with England and Australia which experienced growth rates of 0.2% and -0.1% respectively during the period 2005-2016, it is evident that the dairy sector in NI has performed better. To maintain and or further improve the competitiveness of dairy sector, it is important to understand the strengths and weaknesses within the mix of factors that influence productivity, exploring innovative approaches to further enhance strengths and address weaknesses so that productivity growth is further enhanced.

- Productivity measurement at 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 supports the existence of economies of scale. Larger farms tend to achieve higher levels of productivity suggesting that while policy should support improvement at all farm scales, different approaches may be needed for larger and smaller farms. This may be particularly relevant when considering strategies involving investment and education.

- The estimation of farm-level productivity also allows investigation of the factors influencing productivity using an econometric approach. The results show that herd size and stocking density have a positive impact on productivity, but purchased feed input per cow tends to have a negative impact. This result is consistent with the interpretation that purchased feeds may be increased to drive yields in the short-term in response to prices, but that there is a diminishing return (there is a greater impact on profit for the first few units of extra feed with less and less of a benefit as more feed is used). The analysis also shows that more productive farms have a lower intensity of labour input per cow. These results suggest that policy strategies aimed at efficient management of inputs are key for NI dairy farms to become more productive. This may involve optimising labour input as part of the labour, capital and land resource mix. For example, adoption of zero-grazing systems in larger herds could be an effective management option.

- Also, the results show that education variable has a positive impact on productivity, suggesting that additional years in education, including A levels, specialist agricultural training or above, have a positive impact on farm management performance. However, to understand the more nuanced and complex role of education in productivity, additional information on both farmer, and farm family managers and co-managers would generate richer results, and the ability to generate more detailed policy guidance. Consideration should be given to phasing in additional data points within the FBS.

- Finally, our results show that capital investment is a significant factor in improving productivity, although this impact may be delayed. The findings echo the relevance of providing support for dairy farmers to invest in equipment and machinery that will help realise improvements in efficiency and overall competitiveness and sustainability of the sector. In addition, our findings also highlight the role of education in the relationship between investment in innovative technology and productivity. The findings reveal that innovative dairy technologies require a sufficient level of complementary education to trigger an increase in productivity at farm level.

Appendix

A1. Measurement and Definition of Outputs and Inputs used in the Estimation of TFP

The measurement of TFP in NI dairy farm sector is based on Fisher index method defined as the ratio of Fisher quantity indices of total outputs and total inputs. This requires the construction of broad output and inputs. To construct these indices, quantity and prices variables are identified for each output and input items as shown in Figure 1. But when physical observations are not available, implicit quantities/prices derived from the corresponding revenues/costs are used as substitutes (Zhao *et al*. 2012). The specification of output/input quantities and prices are described below.

Output measure:

In this report, output is defined in terms of good and services that are produced on the farm by using economic resources at the disposal of dairy farmers. The outputs of NI dairy farm sector consist of 15 items which are divided into 4 major groups: milk output, livestock sales, crops, and other outputs.

Milk

The most important output of the dairy sector is milk and the production of milk is for sales or production of other dairy products. The measure of the quantity of milk output is milk produced on the farm. To aggregate milk output, the prices of milk are needed as weights. In the Farms Business Survey (FBS), the value of milk produced are readily available and to derive milk prices, value of milk produced was divided by volume of milk produced by farms.

Livestock sales

This component consists of four main output items including livestock sales of dairy cattle, beef, sheep and other livestock. The information required for each of the items includes sales of livestock, net natural changes (births and deaths), and net transfers.

The Fisher index is employed to calculate the outputs for dairy cattle, beef, sheep and other livestock. In the FBS, the quantity of the sales of livestock, net natural changes (births and deaths), and net transfers are available and are applied to calculate the quantity indices. However, the prices are obtained by dividing the value variable of these items (sales plus the value of natural changes (births and deaths) and net transfers) by their corresponding quantities.

Crop output

Some dairy farms produce crops to feed their milking animals, and therefore crop output is included as part of the output categories. Crops are split into wheat, barley, potatoes, and other cereal crops. To obtain the quantity and price variables, implicit quantities of the crops are derived by dividing the value of crop output by an appropriate price index, that is, the value of each of the crops is deflated by their corresponding prices indexes. For aggregation purpose, the prices (or values) of each of the crops are employed as weights.

Other outputs

This category of output refers to other streams of income that the dairy farmers receive which include income received from contract work done, rents to other farmers, secondary activities. It should be noted that direct payments is not included in this category as they are not directly related to on-farm production. The FBS contains value variables from other on-farm activities which are used as weights. In other to obtain the implicit quantities, the value variables are deflated using appropriate price indices.

Input measure:

The input measure consists of all resources used in the production of output by dairy farms. It includes 28 items, and are categorised into three major groups: capital (comprising land, physical capital and livestock purchases), labour, and material and services. Land input is however classified as a separate input which is distinguished from capital because of its importance in agricultural production. On this basis, this report groups inputs into four main categories: land, labour, capital, and material and services (also known as the intermediate inputs).

Land

Based on the data available in the FBS, the quantity variable used for land is the area farmed. The area farmed is used as a measure for the quantity of services "provided" by land during the production period. Unfortunately, there is no information on the market value in the FBS that may be used for productivity estimation. As a substitute, the opportunity cost of investing funds in land input is used. This reflects the value of services provided by land as an input to production. The opportunity cost of land is the rent the owner would have to pay if the land were rented. On this basis, the average rent paid per hectare was applied as the price of land input to production. In the case that farmers do not rent, the average rent per hectare in the region was used for these groups of farmers. A similar approach was adopted by Kimura and Sauer (2015) and Zhao *et al*. (2012).

Labour

Different approaches have been adopted in literature to measure labour inputs, including number of employees, number of hours spent on farm production. In this report, a standard practice which involves the use of actual time spent on farm production is adopted to measure labour input. It should be noted that labour input in this report does not factor in 'quality adjustment' because the data required for its computation are not available in FBS. Labour inputs consist of two main items - family labour and hired labour. The decision to separate family labour from hired labour is because they are being paid differently. To construct a Fisher index for labour inputs, hours worked are used to measure the quantity of labour for hired workers and family members. The price of hired and family labour is also obtained from the FBS by dividing the total cost of these labour items by their corresponding quantity used (number of hours worked)[12].

Capital

In the construction of the index for capital inputs for productivity estimation, capital should be treated with some caution. This is because capital is a stock variable, but should be measure as capital service (the flow of productive service from a cumulative stock of investment) for productivity analysis. In reality, it is difficult to measure or observe the flow of capital services and therefore in most cases they are proxied by assuming that service flows are proportional to the 'productive stock', which is defined as the sum of capital assets of different vintages after adjusting for 'retirement' (the withdrawal of assets from service) and 'decay' (the loss in the productive capacity as capital goods age known as 'depreciation'), and thus converting quantities to a standard 'efficiency' unit.

Productive stock is a measure of the physical capability of capital stock used in production and it is practically impossible to construct a measure of the productive capital for individual dairy farms from FBS. The estimation of productive capital stock is a very data-demanding that requires longer time series data on the value of investment in different types of capital goods over the entire life span of an asset which may span to more than 20 years for plant and machinery or more than 50 years for farm buildings. It is difficult to collect such data in the FBS.

In other to circumvent this measurement problem with productive capital, the report employs market value of the productive capital stock as a substitute. The use of this proxy adjusts for economic depreciation. The estimate of capital input consists of four main groups of capital items: plant and machinery, existing stock and purchases of dairy cattle, other livestock and their changes.

The value and quantity variable for existing stock of dairy cattle is calculated as the average value and number of the dairy cattle at the opening and closing of the financial years. The changes in this variable reflect the operating gains and net transfers-in during the production year. The quantity purchased dairy cattle and their values are available in FBS. The corresponding price of purchases was obtained by dividing the value of purchase by quantity.

To estimate the capital service flow for other livestock (beef, sheep and other livestock), the average value and number of other livestock at the opening and closing of the financial years was used to calculate the quantity and the value. The changes in this variable measure the operating gains and net transfers-in during the production year. As a relevant input in production process, the 'livestock' changes when farmers purchase additional sheep or beef for breeding or restocking.

To calculate the Fisher quantity index for specific capital inputs, prices (values) of capital services are needed as weights in the aggregation. The usual

[12] The labour variables used within FBS are CD278 – CD282 measured in annual labour units (1 annual labour unit = 2200 hours). Hence, to obtain the equivalent of these labour variables in annual hours, they are multiplied by 2200.

practice is to use the market rental prices (as used for land input). However, many of the dairy farmers are owners of the capital assets used for production and are not involved in market transaction for capital, which makes it impossible to observe the 'prices' of capital services. The approach employed is the 'user costs' approach which produces the implicit amount of rents that would have been charged to cover the cost of using an asset. Following OECD (2001)'s approach, the user cost formula is defined as:

$$\widehat{UC}_t = \hat{q}_t \, (r_t + d_t) \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where $\widehat{UC}_t$ is the user cost of capital asset at time t; $\hat{q}_t$ is the market value of capital asset at time t; r_t is the interest rate and d_t is the depreciation rate. The user cost formula does not take into account the capital gains or losses as it is based on the assumption that dairy farmers in the FBS may have implicitly incorporated losses or gains when they are responding to the survey question on the market value of their capital items. The depreciation component in Equation 6 was obtained from the FBS (the variable on depreciation on fixed capital including plant and machinery, and buildings is available in FBS). The depreciation rate was calculated for each of the farms. It should be noted that depreciation or appreciated of dairy cattle and other livestock is included as part of the value of output, therefore are excluded for the user cost formula used for measuring capital inputs for livestock. Lastly, the interest rate component of the user cost formula is calculated by farm, with the assumption that the cost of capital differs by farm.

Material and services

Material and services used in the dairy sector are also known as intermediate inputs. This input category covers numerous inputs and can be broadly divided into two: material and services. There are seven items in the materials group - fertiliser, fuel, crop chemicals, livestock materials, seed, fodder and other materials; and eight items in the services group – rates and taxes, administrative costs, repairs and maintenance, veterinary expenses, motor vehicle expenses, insurance, contracts and other services. For some reasons, it is impossible to measure the physical quantities of material and services inputs. For example, the inputs of service such as insurance, contract services and administrative services are quite difficult to quantify. In this report, the inputs of each of the items are measured using quantity indices. To obtain the implicit quantity index, data from the FBS on the expenditure on these inputs and relevant price indexes from secondary sources are needed. Specifically, the quantity variables are derived by deflating the expenditure on each by the corresponding prices paid index. For example, farmers insure their farmhouses, livestock and some other insurable assets. The quantity input of insurance service is obtained by dividing farm's total expenditure on insurance by price paid index for insurance.

Data sources for prices indexes used in this report are obtained from DEFRA, DAERA and ONS.

Table 1A. Estimated coefficients of the effects of farm characteristics on farm-level productivity across various models

Variables	Model 1 (contains 1-in year investment)	Model 2 (contains lagged investment)	Model 2a (contains lagged investment and includes only agric. college)	Model 2b (contains lagged investment and controls for specialisation)	Model 3 (extended model with interaction terms)
Number of dairy cows	0.078***	0.196***	0.196***	0.247***	0.197***
Milk yield	0.516***	0.544***	0.542***	0.662***	0.541***
Stocking density	0.073***	0.101***	0.103***	0.098***	0.108***
Purchased feed per cow	-0.068***	-0.087***	-0.086***	-0.101***	-0.092***
Labour input per cow	-0.337***	-0.134***	-0.135***	-0.150***	-0.123***
Hired labour share	0.114*	-0.066	-0.065	-0.054	-0.077
Age	0.086	0.138	0.127	0.115	3.082***
Age squared					-0.396**
Education - A levels, Agric. college or above	0.030*	0.052**		0.048**	0.784***
Education - Agric. college only			0.047**		
Age* Education - A levels, Agric. college or above					-0.199***
Net investment per cow	-0.065***				
Net investment per cow *(3-year lagged)*		0.012**	0.011**	0.012**	0.015***
Net investment per cow *(3-year lagged)* * Education - A levels, Agric. college or above					0.059*
Share of payments in farm outputs	-0.093	-0.181**	-0.180**	-0.147**	-0.164**
Share of milk in farm outputs (specialisation proxy)				0.420***	
Off farm participation ratio	-0.008	-0.022		-0.022	-0.019
Severely disadvantaged area	-0.012	-0.052	-0.052	0.042	-0.006
Disadvantaged area	-0.033	-0.014	-0.014	0.011	-0.020
Observations	1,343	866	866	866	866
Number of farms	169	137	137	137	137

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