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Decomposition of Dairy Productivity Growth in Northern Ireland

Kehinde Oluseyi Olagunju, Aurelia Samuel and Erin Sherry

30 April 2021

Evidence and Innovation project 170204 (48178)

Summary

The main objective of this brief is to examine the extent to which changes in total factor productivity (TFP) in the Northern Ireland (NI) dairy farming sector are driven by different elements. Understanding what is currently driving TFP growth at sector-level can help identify ways to help improve TFP in the future. Sector-level TFP is decomposed into three main components: productivity growth within farms; resource reallocation between farms; and all remaining factors (such as farm entry and exit).

The main findings are:

- Productivity growth within farms (in terms of technological progress and farm management practices) is the main contributor to TFP growth during the period 2005 to 2016
- Resource reallocation has also made a positive contribution to sector-level TFP, but to a much smaller extent than productivity improvements within individual farms
- There is almost no impact from remaining factors

Total Factor Productivity

TFP is the ratio of outputs to inputs used in production. A farm that produces more output from the same level of inputs as another farm is more productive. Equally, a farm that produces the same amount of output using fewer inputs is also more productive. Sector-level TFP is the aggregation of farm-level TFP using a weight, such as output, to represent how dominant a given farm is within the wider sector. Therefore, sector-level TFP can be increased by an improvement of average farm-level productivity, an increase in market share of relatively more productive farms, or both. Improving aggregate TFP may involve interactions between productivity improvement at the farm-level and structural change within the sector impacting the relative market share of productive farms (Kimura & Sauer 2015). Adoption of new technology (for example, robotic milking systems) can improve the efficiency of capital and labour on farm, and therefore TFP. Structural adjustments could lead to fewer, relatively larger scale, farms better positioned to take advantage of capital investment, such as robotic milking. Therefore, adoption of the new technology, and the associated productivity gains, could plateau unless structural adjustment increases the number of farms at sufficient scale to make the investment.

The structural trend in NI has been towards fewer larger scale dairy farms. The number of dairy farms has declined on average by 2.2% per year between 2004 and 2017, and the average herd size has increased on average by 0.73 % per year between 2004 and 2015. Decomposing aggregate productivity growth helps to reveal how the dynamics between technical progress and structural change have played out in recent history. In order to consider links between the pattern of TFP growth in NI and the broader market and policy context, the TFP decomposition profiles of three other dairy farming sectors are presented (Estonia, the Netherlands, and England and Wales) from a study by Kimura and Sauer (2015).

The NI analysis was conducted using a methodology called the dynamic Olley-Pakes (OP) decomposition approach that breaks down the change in sector-level productivity between two consecutive years into three main components[1]. A *within-farm effect* captures productivity change

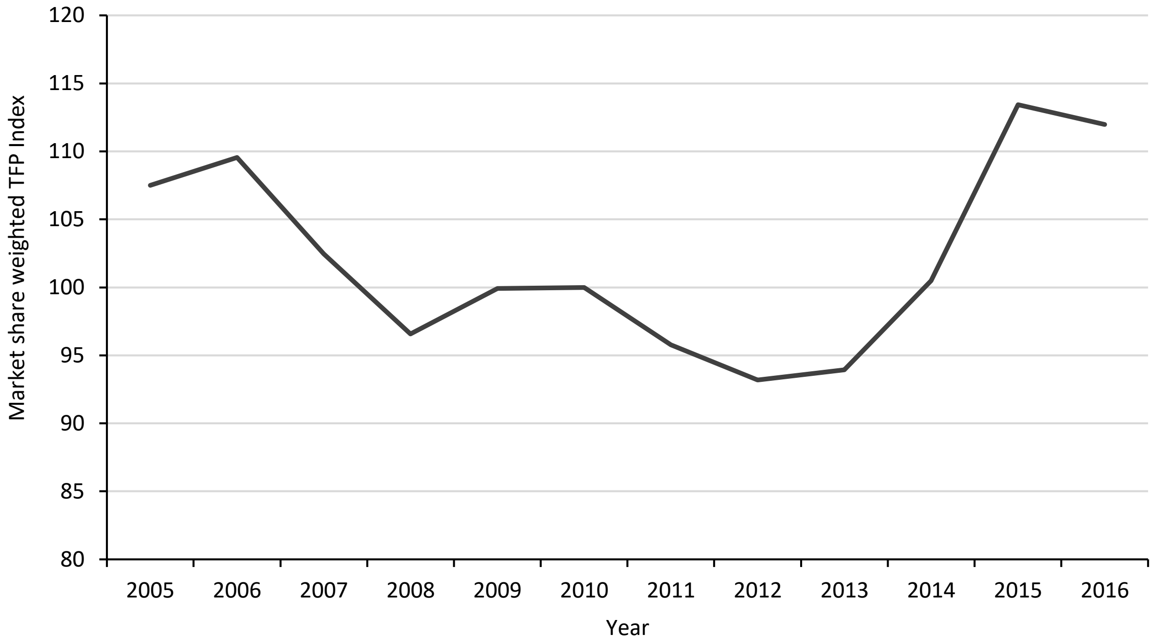
[1] Details on the methodology is presented in the Technical Appendix section.

that has been driven by a change in average farm-level productivity in the sector. This could be on-farm productivity gains due to innovation or adoption of new technology. A *resource reallocation effect* captures productivity change that has been driven by a change in the allocation of available resources across farms. This is captured by measuring the change in sector-level productivity explained by changes in the relative market share of more or less productive farms. Productivity growth, not attributable to within-farm productivity gains, can be associated with relatively more productive farms having access to a larger resource base, and therefore taking over more market share within the sector. A r*esidual effect* captures the net impact of all factors not included in the *within-farm* or *resource reallocation* effects, such as farm entry and exit.

Northern Ireland Dairy Sector Total Factor Productivity

Figure 1 presents the trends in TFP for the NI dairy farming sector (defined as the sum of farm-level TFP weighted by each farm's share of total milk production) between the years 2005 and 2016[2]. The raw TFP is only of interest in terms of its relative difference over time, so it has been converted to an index with the year 2010 set to 100. The results show a downward trend until the year 2013, after which there is an upward trend, with a local peak in the year 2015. On average, the aggregate TFP growth is 0.4% per year over the period.

Figure 1. Trends in Sector Total Factor Productivity, 2005 – 2016 (2010=100)



TFP is decomposed and presented in Figure 2. The *with-in farm effect* dominates, in terms of the proportionate contribution to changes in productivity over the period, and also exhibits the most volatility. This may reflect periods of above or below average weather conditions, having a wide-spread impact on farm-level productivity, or conditions of high milk prices triggering revenue increasing management decisions, that reduce efficiency of production, and therefore productivity.

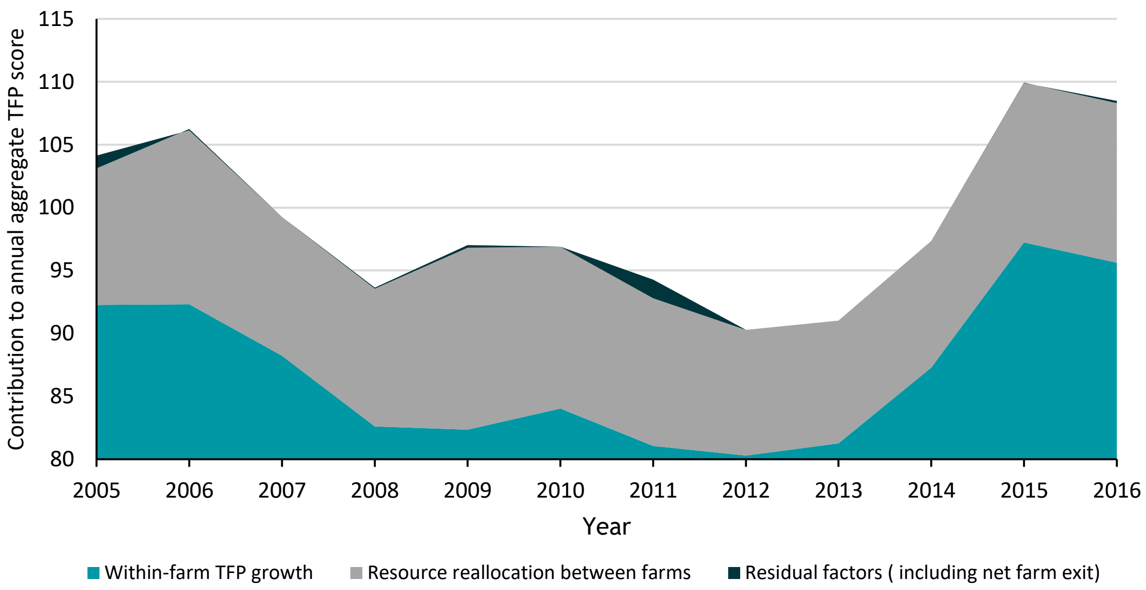
[2] The data used for the estimation are obtained from the Northern Ireland Farm Business Survey administered annually by the Department of Agricultural, Environment and Rural Affairs (DAERA).

The net effect over the entire period is positive, averaging 0.31% productivity growth per year. This suggests that continuous uptake of new technologies and more efficient management of inputs at the farm level has enhanced productivity overall.

The *resource reallocation effect* has also made a net positive contribution to sector TFP over the period, averaging 0.16% growth each year. This finding suggests that on average, resource is moving from low productivity dairy farms to high performing dairy farms. This could be an indication that on average, relatively more productive dairy farms are more likely to be leasing in additional land. As more resources flow to relatively efficient farms, the overall efficiency of the industry increases. Worthy of note is that the decomposition results are specific to the time periods under consideration. Changes to barriers to resource reallocation in the future could potentially strengthen the importance of this source of productivity growth.

The *residual effect* is negligible between 2005 and 2016. On average, this component accounts for -0.08% of aggregate TFP. This category includes farm entry and exit, however, the structure of the dataset makes it impossible to measure this directly (more details are provided on this in the technical appendix). Therefore, the result does not provide strong evidence on how this may or may not be impacting sector productivity.

Figure 2. Decomposition of Sector Total Factor Productivity, 2005 -2016



Comparison with other dairy farming sectors

Previous research by Kimura and Sauer (2015) decomposes dairy farming sector TFP growth in Estonia, the Netherlands, and, England and Wales. A summary of their findings are presented in Figure 3 showing the average contribution of *with-in farm*, *resource reallocation*, and *farm entry and exit* components on TFP over the study period[3].

[3] Table 1 compares NI decomposition results with Estonia, Netherlands, and England and Wales. The time periods considered are different.

The Estonian dairy sector experienced a dramatic restructuring in the 1990s, during which the state-directed system transitioned to private enterprise, followed by radical liberalisation exposing the sector to subsidised imports. Agricultural policy was aligned with the Common Agricultural Policy in anticipation of joining the European Union (EU) in 1996.[4] Estonia implemented milk quotas in 2003, but these have not been binding, with at most 94% filled, and farmers allowed to acquire quota without any cost. Estonia implemented Pillar I (area payment scheme) as well as Pillar II (rural development) in 2004. Given the degree of institutional and policy change preceding and during the study period, it follows that on average *resource reallocation*, linked to structural changes (who has access to factors of production) was the dominant component.

In the Netherlands, milk production is strongly oriented to export markets, accounting for approximately 5% of the global dairy product market. Due to constraints on the land endowment dairy production is mainly intensive, especially in the use of advanced technology and purchased feed, attaining one of the highest levels of milk output per cow in the EU. Unlike in Estonia, the milk quota was significantly binding and therefore constrained milk production in the Netherlands until the relaxation of quota started post 2007. In response to the increase in quota, milk output rose by about 12% between 2007 and 2012. The largest positive impact on TFP over the periods was due to productivity gains *with-in farm*. Although of lower magnitude, *resource reallocation* also contributes positively to TFP. Given the Netherlands has the highest level of TFP amongst the three case studies, there is an indication that these two components work in a complementary fashion (e.g. scale and technology).

In England and Wales, dairy farming is mainly dominated by large farms, and consequently the average number of dairy cows, hectares, and labour units per dairy farm is one of the largest in the EU. Milk quota could be traded across devolved regions in the UK, but the national quota was not binding, and similar to Estonia, there was almost no cost to farmers to increase their share. On average productivity gains were due to *resource reallocation*, and *farm entry and exit*. The negative impact of *within farm* productivity indicates that efforts to decouple agricultural support from production has encouraged some restructuring within the sector. However, market and policy conditions were not triggering changes on-farm to the extent that average farm-level productivity improved within the study period.

[4] For more information see ‘Competitiveness of the Estonian Dairy Sector, 1994 – 2014’ https://www.researchgate.net/publication/287982280_Competitiveness_of_the_Estonian_dairy_sector_1994-2014/link/567ae09e08ae197583812116/download

Figure 3. Decomposition of average Dairy Sector Total Factor Productivity for Estonia (2003-2011), the Netherlands (2001 – 2011) and England and Wales (2000-2011)

Table 1. Comparison of Decomposition of Total Factor Productivity Growth for Northern Ireland (2005 – 2016), Estonia (2003-2011), the Netherlands (2001 – 2011) and England and Wales (2000-2011)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Northern Ireland																	
Market share weighted productivity	-	-	-	-	-	2.0	-6.9	-5.7	3.2	0.1	-4.1	-2.5	0.7	6.3	12.5	-1.4	**0.40**
Within-farm productivity growth	-	-	-	-	-	0.1	-4.1	-5.6	-0.3	1.7	-3.0	-0.8	1.0	6.0	10.0	-1.6	**0.31**
Resource reallocation	-	-	-	-	-	3.0	-2.9	0.0	3.6	-1.8	0.4	-3.2	-0.2	0.3	2.6	0.0	**0.16**
Residual factors (including Farm entry and exit)	-	-	-	-	-	-1.1	0.1	-0.1	-0.1	0.2	-1.5	1.5	0.0	0.0	0.0	0.2	**-0.08**
Estonia																	
Market share weighted productivity	-	-	-	-3.2	-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 entry and exit	-	-	-	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 productivity 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 entry and exit	-	-0.3	-0.6	-0.2	0.3	-0.2	-0.4	-0.3	1.8	-0.1	-0.8	0.6	-	-	-	-	**0.0**
England &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	-	-	-	-	**-0.7**
Within-farm productivity 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	-	-	-	-	**-1.7**
Resource reallocation	-1.9	1.5	1.4	-2.2	-2.1	0.6	0.6	0.1	-0.5	1.3	-0.2	0.3	-	-	-	-	**0.3**
Farm entry and exit	0.4	-0.3	-2.1	0.7	-0.5	1.7	0.9	-0.5	0.5	0.0	0.0	1.4	-	-	-	-	**0.6**

Conclusions

This brief decomposes TFP for the NI dairy farming sector between 2005 and 2016. The findings show that in NI, productivity gains were mainly achieved due to with-in farm factors such as new technology and resource efficiency. This suggests that enhancing on-farm innovation through technology and efficient management are important for improving aggregate productivity. Although on average this component increased aggregate productivity over the period, it is also quite volatile, reflecting that conditions outside of farm managers control, such as weather, or, steep changes in prices that shift management approaches, can have a considerable impact on farm-level productivity across the sector. While more modest, there was a steady benefit to TFP from the shifting of available resources towards relatively productive farms. Considering this, as well as the experience of the Netherlands, there is a good case to consider these components complementary. Therefore, how the synergies between them may be maximised could be a fruitful avenue for further investigation in the formulation of the next generation of agricultural policy.

Technical Appendix

Total factor productivity (TFP) at farm level is defined as the ratio of outputs to all inputs used in production. It measures how efficiently a farm uses all inputs to produce outputs. It can be measured by dividing the physical quantities of outputs by inputs. Because these items have different units of measurement, an aggregation formula which uses either price or value to weight each item is required, and therefore the resulting farm level TFP measure has no unit. Details on the formula used are available in Olagunju *et al.* (2020).

Sector-wide or aggregate productivity refers to as a weighted sum of farm-level productivity in which each individual farm's share of gross industry output is used as the weight (Melitz & Polanec 2015). Mathematically, this can be expressed as follows

$$TFP_t = \sum_i s_{it} \, TFP_{it}, \tag{1}$$

where TFP_t represents aggregate sector productivity, s_{it} denotes farm i's sample share of physical milk output in year t ($s_{it} \geq 0$ and sums to 1 over all *i*) and TFP_{it} is individual farm-level TFP in year t.

Following Olley & Pakes (1992), aggregate productivity TFP_t can be decomposed according to

$$TFP_t = \overline{TFP}_t + \sum_i (s_{it} - \bar{s}_t)\ (TFP_{it} - \overline{TFP}_t) \tag{2}$$

where a bar over a variable denotes the unweighted mean for all farms in the sector. The first term on the right-hand side of equation (2) is the unweighted mean productivity in year t and accounts for sector productivity growth generated within farms ("within-farm effect").

The second term on the right-hand side represents a covariance-type term (*cov*) since it resembles the calculation of the sample covariance without division by sample size. It accounts for the contribution to sector productivity by resource reallocation effects ("between effect"). Specifically, this component measures the contribution of market share changes between farms. As an example, dairy farms that cannot keep up with competitors tend to reduce their market share and subsequently release resource bound by their production activity, for instance, leasing land out to another farmer that is more productive. This process contributes to more efficient production at the sector level (i.e., aggregate productivity), which is captured by the "between effects/resource reallocation" components.

A major criticism of the OP method is that it cannot separate the impact of farm entry and exit from the market share changes between continuous farms. This downside was addressed by Melitz & Polanec (2015) by decomposing the covariance term into components related to continuous farms' restructuring, and the entry and exit of farms. Therefore, the modified approach allows for accommodating the net impact of farm entry and exit. The extended model is often referred to as the 'dynamic OP decomposition approach'.

The dynamic OP decomposition approach allows for changes in sector-level TFP (ΔTFP_t is the difference between $t - 1$ and t) to be decomposed into three main components as follows:

$$\Delta TFP_t = [\overline{TFP}_{cont,t} - \overline{TFP}_{cont,t-1}] + \sum_{cont} [(s_{cont,t} - \bar{s}_t)(\overline{TFP}_{cont,t} - \overline{TFP}_t) - (s_{cont,t-1} - \bar{s}_{t-1})(\overline{TFP}_{cont,t-1} - \overline{TFP}_{t-1})] + \sum_{entry} [s_{entry,t}(\overline{TFP}_{entry,t} - \overline{TFP}_{cont,t})] + \sum_{exit} [s_{exit,t-1}(\overline{TFP}_{cont,t-1} - \overline{TFP}_{exit,t-1})] \quad (3)$$

Where *Cont* represents dairy farms that are continuing (non-exiting), *Entry* refers to entering (new) dairy farms, and *Exit* refers to exiting (non-continuing) dairy farms.

The first term $[\overline{TFP}_{cont,t} - \overline{TFP}_{cont,t-1}]$ represents the within-farm component of productivity growth based on changes in average farm-level productivity in the sector, measuring the contribution of productivity improvements within continuing farms. It captures the effects of on-farm innovation such as technological adoption on the change in sector-level productivity.

The second term $\sum_{cont}[(s_{cont,t} - \bar{s}_t)(\overline{TFP}_{cont,t} - \overline{TFP}_t) - (s_{cont,t-1} - \bar{s}_{t-1})(\overline{TFP}_{cont,t-1} - \overline{TFP}_{t-1})]$ represents the change in resource allocation effect between the continuing farms, captures the contribution of market share changes between continuing farms on productivity growth at the sector-level.

The last two terms measures the contribution of structural changes in terms of farm entry and exit to sector-level productivity. Intuitively, the third term ($\sum_{entry}[s_{entry,t}(\overline{TFP}_{entry,t} - \overline{TFP}_{cont,t})]$) measures the contribution of new farms to aggregate productivity. The contribution of entrants can only be positive if they have higher productivity than the incumbent farms. The fourth term ($\sum_{exit}[s_{exit,t-1}(\overline{TFP}_{cont,t-1} - \overline{TFP}_{exit,t-1})]$) measures the loss or gains in productivity attributed to farms that have exited the sector. Exiters can only contribute positively to aggregate productivity if they have lower productivity than the remaining dairy farms. The relative magnitude of these two terms tell us if farm entry and exit have increased aggregate productivity or not, if the net value is positive then the sector has improved its TFP score, whereby if the net value is negative, then the sector has lower productivity than before the change happened.

One main challenge with implementing this model is related to accurate identification of entering and exiting dairy farms within the Farm Business Survey (FBS). This is because the FBS does not capture exit and entry and the farm because sample changes overtime are independent from entering or exiting the sector.

It is important to state that the sample farms that appeared at $t-1$ and t do not necessarily represent the population of dairy farms that continued between $t-1$ and t.

In respect of this limitation of the available dataset, it is imperative to impose some assumptions in order to apply the dynamic OP decomposition formula to FBS. The assumptions are as follows:

(1) Dairy farms within the FBS which appeared both at *t-1* and *t* are assumed to indicate the population of continuing farm between *t-1* and *t*. The majority of dairy farms (98%) within our sample at time *t* appeared at *t*-1.

(2) The net contribution/effect of farm entry and exit cannot be directly estimated because of the structure of the dataset. Therefore, the third component of the decomposition is a

residual, that includes entry and exit, but also all other factors not captured by the first two components. For the purpose of the study, our estimation formula can be written as

$$\Delta TFP_t = \left[\overline{TFP}_{cont,t} - \overline{TFP}_{cont,t-1}\right] + \sum\nolimits_{cont} [(s_{cont,t} - \bar{s}_t)\left(\overline{TFP}_{cont,t} - \overline{TFP}_t\right) - (\ s_{cont,t-1} - \bar{s}_{t-1})\left(\overline{TFP}_{cont,t-1} - \overline{TFP}_{t-1}\right)] \ + \ RES \qquad (4)$$

Where RES represents the residual of the changes in market share weighted productivity. This was operationalised by subtracting the first and second terms from ΔTFP_t, measuring the net impact on aggregate productivity of all factors *other than* on-farm innovations and resource reallocation between continuing farms.