Agricultural and Food Economics

Literature review: Key Drivers of Agricultural Productivity Growth

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1. Introduction

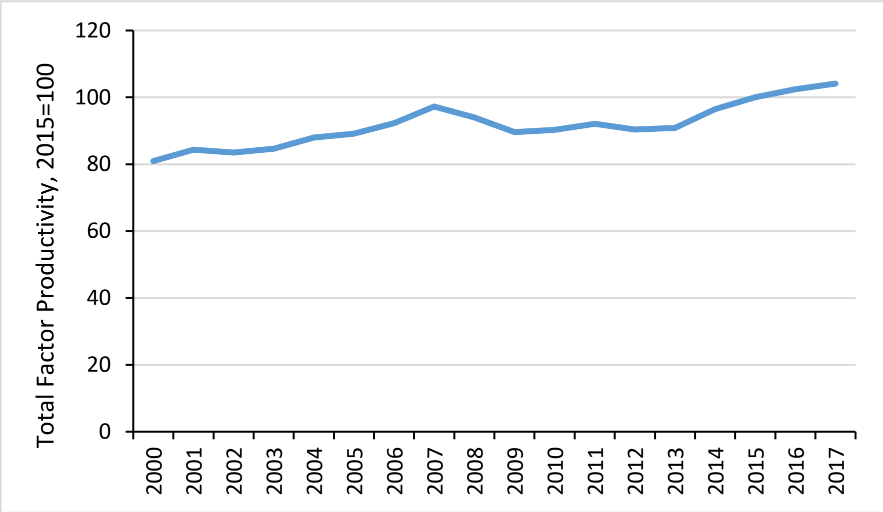
Agricultural productivity has gained renewed interest for a number of reasons. It is widely recognised as a key performance indicator of the agricultural sector since it captures increases in the efficiency of production processes over time (Zhao *et al.* 2012). The estimates of agricultural productivity growth are extensively used by industry bodies, government agencies and the wider research community for the purposes of informing decision makers about agricultural policies and analysing economic issues in the sector (Mullen & Crean 2007). In general, there is growing competition from outside agriculture for factors of production such as land, labour, water and other resources available to agriculture due to increasing food and industrial demand driven by demographic and disposable income changes. Given the increasing pressure on- and limitations to- these factors of production long term growth of agricultural sector largely depends on gains in productivity.

Previous studies have shown that productivity growth can be measured using two main approaches: partial factor productivity (PFP) and total factor productivity (TFP). PFP compares output to a single input, such as output per unit of labour, milk yields per cow. Although PFP measures are concrete and understandable, they can be misleading because they tend to hide underlying changes in the use of other inputs. For instance, implementation of an input subsidies scheme may increase labour productivity, but lead to a decrease in material productivity, resulting in a low level of overall productivity. As a result, an appropriate estimation of productivity growth should take into account the relationship between the change in output and the change in the use of all inputs, which is the case with TFP measure. TFP can be measured as a ratio of aggregate output produced relative to aggregate input used which accounts for all inputs used and, therefore, is more suitable for performance measurement and comparisons across farms and for a given farm over time (Coelli *et al.* 2005; Saikia 2014).

Gains in productivity provide a means for sectors to produce more output relative to the inputs used, reallocate resources to other economic activities and improve the sustainability of resource use (Kimura and Sauer, 2015). In proffering effective policy for the agri-food sector, policy makers require to understand the trends and main drivers of productivity growth. This requires estimation and decomposition of the TFP index into different economic components such as technological progress through innovation adoption or changes in production organisation, technical efficiency, scale and mix efficiency change, resource allocation between farms, changes in market environment, changes in institutional and regulatory arrangements *etc.* (O'Donnell 2012; Kimura & Sauer 2015; Darku *et al.* 2016; Sheng *et al.* 2017).

The Northern Irish agricultural sector has witnessed some gains in productivity in the last ten years (Figure 1). Despite this increase, statistics reveals the rate has slowed; on average TFP increased by 1.2 percent a year between 2007 and 2017, significantly lower than TFP growth between 1998 and 2006 (2.6 percent a year)(DAERA 2017b). This evidence of slow rate of productivity growth is a cause for concern given that increasing productivity gains are important for maintaining international competitiveness, which will become increasingly important in the post-Brexit era as the UK aims to negotiate Free Trade deals across the globe. Therefore, it becomes imperative to gain a better understanding of the main drivers of productivity growth, with particular attention on dairy sector considering its central role in Northern Ireland agricultural economy.

Figure 1: Total Factor Productivity (ratio of output at constant prices to all inputs (including labour and capital)) of the NI Agricultural Sector



Source: Statistical Review of NI Agriculture

The main purpose of this report is to review the empirical literature on the key drivers of productivity growth, with a particular emphasis on the dairy sector. The subsequent sections of this report are as follows. The next section provides an overview of the dairy sector in Northern Ireland (NI), which is followed by an empirical review of drivers of productivity growth.

2. Brief Overview of Northern Irish Dairy Sector

Livestock-based enterprises mainly predominate NI agricultural sector, making up 92 percent of all farming undertaken in the region (DAERA 2017a). The dairy sector plays a central role in overall NI agricultural economy, accounting for 11% of the total active farms, as well as contributing the largest share (32%) of the total gross output of NI agriculture in 2017 (DAERA 2017b). The NI dairy sector contributed approximately 15% of the total dairy output in the UK in 2014, which was second only to England (AHDB, 2015). In this context, the dairy sector is of relative more importance to the NI agricultural economy compared to the UK agricultural economy as a whole.

The total milk output produced in 2017 was 2,283 million litres, up by 85 million litres from 2016 – about 4.0% increase. The average annual percentage change of milk output in NI between 2004 and 2017 (2.0 %) is higher than the average increase witnessed between these periods in the UK (0.49%). In addition, NI milk output as a percentage of the total UK milk output increased steadily between 2004 and 2017, although there was a slight decrease in this trend between 2008 and 2010.

The NI dairy sector has been subjected to structural change in the last few years. As shown in Table 1 below, the number of dairy farms in NI have declined steadily, falling annually on average by about 2.2% between 2004 and 2017. In 2017, there were 3,428 dairy farms in NI, which is smaller compared to 3,537 in 2014. In addition, the number of dairy cows increased annually on average by 0.73 % between 2004 and 2015 and has risen annually by 1.3% over the last 7 years. As a percentage of the UK total in 2004, NI dairy cows constitute13.7% while this percentage increased steadily up to 16.9% in 2017. This clearly signifies expansion in the NI dairy sector in terms of number of dairy cows over the years relative to the UK. Considering the average herd size in NI, an annual increase of 3.1% was witnessed between 2004 and 2015, while the increase has slowed after 2015 with an increase of 2.3% between 2015 and 2017. Overall, the average herd size has been on increase in the last 13 years.

There have been substantial changes in NI milk yield per cow, a partial productivity measure. Average milk yield per cow in 2016 stood at 6970 litres per cow per annum, which rose by 250 litres per cow in 2017(about 4% change). Between 2004 and 2017, the annual average milk yield per cow grew by 1.0%, which was lower than the overall UK annual average change during that period.

Table 1: Overview of Dairy Sector in NI and the UK

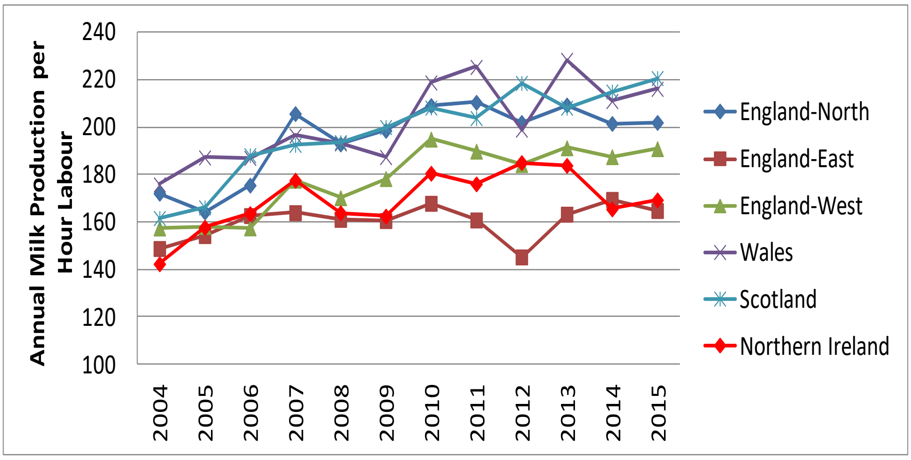
	2004	2010	2015	2016	2017	[1]Average annual change 04-17
Northern Ireland						
Milk output ('000)	1,783.96	1,849.82	2,266.39	2,198.32	2,283.85	+ 2.00%
Number of farms	4,577	3,647	3,537	3,529	3,428	-2.17%
Number of dairy cows ('000)	288	281	312	317	316	+0.73%
Average herd size	63	77	88.1	90	92	+3%
Average Milk yield per cow (litre per annum)	6,380	6,740	7,390	6,970	7,220	+1.03%
UK						
Milk output ('000)	13,893.69 (12.8%)	13,321.50 (13.9%)	14,753.20 (15.4%)	14,372 (15.6%)	14,708.0 (15.6%)	0.49%
Number of dairy cows ('000)	2,102 (13.7%)	1,844 (15.2%)	1,865 (16.7%)	1,866 (16.9)	1,860 (16.9%)	-0.91%
Average Milk yield per cow (litre per annum)	6,609.75	7,224.49	7,910.24	7,567.93	7,905.47	+1.42%

Source: DAERA 2017a, 2017b, DEFRA 2017, AHDB 2015; own calculation; values in parenthesis are percentage of NI in UK;
[1] Average annual change for the period 2004 – 2017 estimated.

Feng and Patton (2018) computed the evolution of another measure of PFP for the dairy farm sector over time, namely Dairy Farm Labour Productivity (Annual milk production (kg) per hour labour). Within the context of the UK, this shows that Northern Ireland was bottom in ranking in terms of this indicator at the start of the period, 2004 (Figure 2). Dairy farm labour productivity in Northern Ireland improved between 2010 and 2013, but deteriorated in 2014 and 2015. The underlying data demonstrates that during this time period the Northern Irish dairy sector performed well in terms of milk yield growth, but less so in terms of labour productivity.

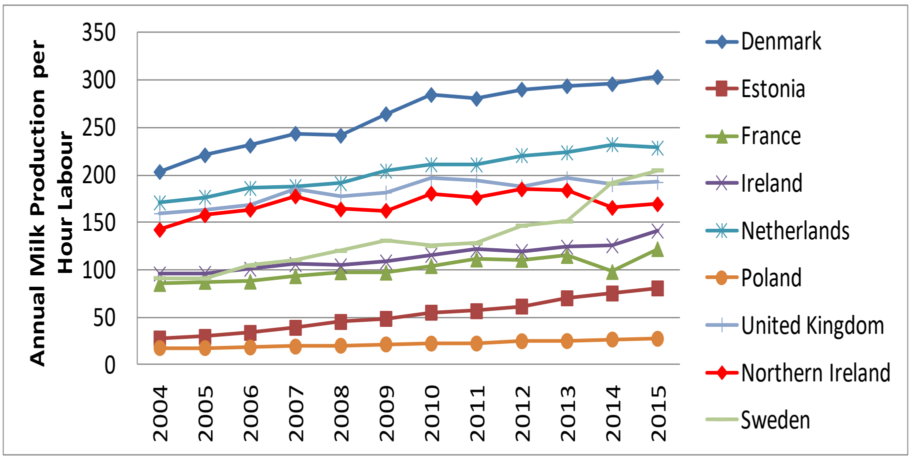
There is considerable variation in dairy farm labour productivity across the EU (Figure 3). At the end of the reference period (2015), one hour of labour produced 303 kg of milk in Denmark compared to 18kg in Lithuania. Northern Ireland lies in the middle of this range, with one of labour producing 169 kg of milk. In general, productivity is markedly lower in eastern European countries that only entered the EU in 2003. Nevertheless, it is clear that some of these eastern European countries have progressed very quickly during the reference period, with Estonia in particular performing strongly. In contrast, Northern Ireland displayed the second lowest growth rate in labour productivity across the EU, including both old and new Member States.

Figure 2: Dairy Farm Labour Productivity across the UK (Annual milk production (kg) per hour labour)



Source: Feng and Patton (2018)

Figure 3: Dairy Farm Labour Productivity across the EU (Annual milk production (kg) per hour labour)



Source: Feng and Patton (2018)

3. Drivers of Agricultural Productivity Growth

This section details the main driving factors of productivity growth that have been empirically examined in the literature.

As a starting point, Zhao *et al.* (2012) provided a background for change in productivity, a shift in the input-output relationship, stating that productivity change in the dairy sector is driven by factors that are directly related to technology and those that are not directly related to technology[1]. Some of these factors are at the discretion of the farm manager and depend on his/her management skills, such as some efficiency improvements, improved seeds, breeds or a new type of machinery, while others go beyond the individual farm manager, such as the natural environment, investment in research and development, the advisory system and infrastructure, applied policy framework *etc*.

3.1 Farm level innovation/technical progress

One of the main drivers of productivity highlighted in the literature is farm level innovations which may be in the form of introducing new technologies, new products and ways of working (OECD 2001). Mackinnon *et al.* (2010) conclude that changes in production practices and technologies, which include improved milking sheds and equipment, genetics, artificial insemination, use of automatic cup removers and increased soil testing, largely drive productivity growth in Australian dairy sector. Similarly, Nossal and Sheng (2010) note that increase in milk yield per cow in Australia is attributed to adoption of new technologies and management systems, such as improved quality of feed and breed of cattle and labour saving technologies. The explanation for the above is that the technical progress encompasses innovations which enable the use of labour-saving technologies which allows more dairy cows to be managed with fewer operators, allowing economies of scale in dairy farming. Key *et al.* (2008) found that technical progress was an important driver of productivity growth for the pig sector in the US.

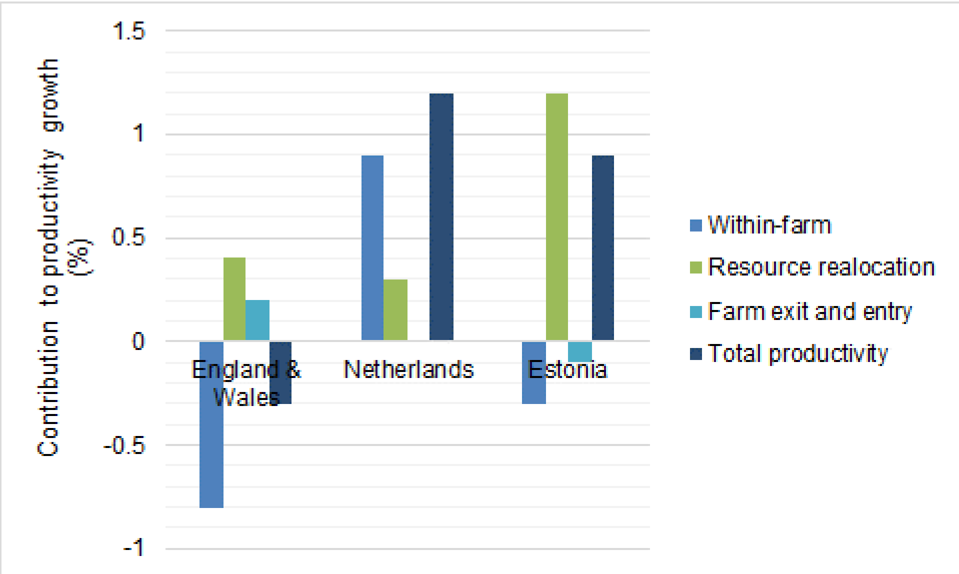
Kimura and Sauer (2015) report similar findings for Dutch dairy sector, with productivity growth of continuing farms making the largest contribution to total productivity growth. In contrast, within England & Wales the authors found that declines in farm-level productivity of continuing farms had a considerable negative impact on productivity, resulting in a decline in total productivity growth for England & Wales between 2001 and 2012. Further details on the decomposition of productivity growth in this study are provided in Box 1.

[1]Technology related drivers, commonly referred to technological progress, are embodied in the capacity of famers to adopt new technologies and findings from scientific research (O'Donnell 2012) while factors that are not directly related to technology include changes in the technical efficiency within firms (Coelli *et al.* 2005; O'Donnell 2014), efficiency gains resulting from resource allocation between firms and industries (Kimura & Sauer 2015; Frick & Sauer 2018), accumulation of human capital *etc* (Reilly *et al.* 2005). See details in Zhao *et al.* (2012).

Box 1: Decomposition of Productivity Growth per Year in England & Wales, Netherlands and Estonia by Kimura and Sauer (2015)

Kimura and Sauer (2015) decompose sector level productivity growth into three different components, namely productivity growth within farm; resource allocation between farms; and farm entry and exit. This approach enables a deeper understanding of the different factors that underlie productivity growth dynamics. A comparison of these growth dynamics is made between England & Wales, the Netherlands and Estonia (Figure 4). The time period of analysis is 2000 to 2012.

Figure 4: Decomposition of annual productivity growth per year in England & Wales, the Netherlands and Estonia



The results demonstrate contrasting productivity dynamics in each of the countries. In England & Wales, the decomposition indicates that productivity growth comes from the exit of smaller farms and farm size expansion of the remaining farms. In contrast, within-farm productivity of continuing dairy farms exhibited a substantial downward impact, resulting in overall annual productivity falling over the period of analysis.

In Estonia, productivity growth of the dairy sector is driven by resource reallocation towards a small number of large and productive farms. In contrast. In contrast, within-farm productivity growth is the main driver of overall productivity growth in the Netherlands, indicating the importance of on-farm innovation such as technological adoption and efficient resource use in this country.

Using a state-level data from 1990 – 2011, Khan *et al.* (2015) find a clear movement towards slower TFP growth in Australia broadacre agriculture largely driven by declining growth in production innovations in the sector. In the same vein, Emvalomatis (2012) estimate the average TFP growth rate of German dairy sector (1995 to 2004) to be 1.1%, with the largest component of this growth attributed to technical progress, albeit farms are found to become less efficient over time. The adjustment-cost theory is used to provide a reasoning for this combined finding: as farmers are adjusting the production process to new technological developments they incur learning costs associated with using new techniques.

Employing an output distance function framework, Brümmer *et al.* (2002) decomposed dairy sector TFP growth index between 1992 and 1994 for three European countries (Germany, the Netherlands, and Poland). They find that the change in the productivity growth index in Germany (+6%) is driven by technical progress, Poland (−5%) dictated by technological regress, while the Netherlands (+3%) is mainly influenced by allocative efficiency components.

3.2 Farm management and farmer characteristics

Farmer characteristics, such as experience, education and training, financial status and attitude towards risk condition farmers' capacity to innovate and adopt new technologies (Mullen 2007; Xayavong *et al.* 2016). At the farm-level, Kimura and Sauer (2015) find that age has opposing impacts on productivity in Estonia and the Netherlands, while it is insignificant in England & Wales (see Box 2 for estimated signs of coefficients within this study). Surprisingly, the results indicate that post-university education has a statistically negative impact on productivity in the Netherlands and the UK. Nevertheless citing Sauer and Latacz-Lohmann (2015), the authors argue that there may be a complementary relationship between investments in innovative technologies and education. In particular, Sauer and Latacz-Lohmann (2015) examine the relationship between innovative investments and productivity for German dairy farms (1996 to 2010). They find that investments in innovative technology 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.

Box 2: Results of Farm-Level Productivity Analysis by Kimura and Sauer (2015)

In addition to the decomposition of sector-level productivity outlined in Box 1, Kimura and Sauer (2015) also investigated the farm and farmer characteristics that help to explain different levels of farm-level productivity using regression model. The estimated signs of coefficients within this regression analysis for three countries (England & Wales, the Netherlands and Estonia) are shown in Table 2 below.

Table 2: Estimated signs of coefficients

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

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

** Model quality measures can be obtained upon request.

Kimura and Sauer (2015) also consider the effect of farm management on productivity, finding a positive relationship between productivity and stocking density, but the converse for intensity of purchased feed and labour input. At the same time it is notable that milk yields has a statistically significant positive influence on productivity. This finding in combination with that for purchased feed indicates that lower purchased feed should not be pursued to the detriment of milk yields. The results imply that the efficient management of inputs is crucial for dairy farmers to become more productive. They also found that the choice of farm organization significantly influences productivity. In particular, family farms are found to be more productive in England & Wales. Similarly, Zhao *et al.* (2009) suggested that work experience, formal education, farm size, land use intensity, crop specialisation, management and farming practices are important factors influencing farm-level TFP performance in the Australian grains industry.

Another important characteristic is the extent of specialisation of farms. This may reduce the complexity of farm management by allowing farmers to focus their skills on few enterprises, improving production control and efficiency, and allowing farms to become more organised, contributing to lower transaction costs (Alexander & Kokic 2005; Rada *et al.* 2018). Conversely, Kim *et al.* (2012) examine the productivity effects associated with farm specialisation/diversification, finding positive but small productivity gains from farm diversification. They argue that the productivity gains come from complementarity effects across farm outputs.

In addition, studies reveal that participation in off-farm activities tend to reduce productivity, by changing the time line of farming activities in ways that reduce agricultural productivity (Ahearn *et al.* 2005); by reducing farmers' opportunities to research and implement more efficient farming practices and technologies (Alexander & Kokic 2005); and by reducing input intensity of farming and investment in productive technology to improve productivity (Kimura & Sauer 2015).

3.3 Farm size

In recent years, farm size has gained prominence in the literature as one of the important drivers of productivity. Keizer and Emvalomatis (2014) find that larger and more intensive dairy farms in the Netherlands experience faster productivity growth than the smaller farmers. They argue that larger farms are possibly becoming more productive by exploiting economies of scale inherent in production technology. In addition, they asserted that larger farms are in a better position to benefit from new technologies because they are easier to implement on a larger scale. The explanation for the disparities in the productivities of small and large farms was further provided by Sheng and Chancellor (2018).They support the previous argument that improved productivity can be achieved by acquiring new technologies, such as new machinery and improved species, however, large farms have the resources to acquire improved technology by increasing returns to scale and, thereby, enabling large farms to benefit from technology related productivity gains. By contrast, small farms often lack the willingness and financial ability to invest in similarly advanced and expensive capital equipment, limiting potential benefits from increasing returns to size. Similarly, Kimura and Sauer (2015) find that farm size has a positive effect on productivity in England & Wales, the Netherlands and Estonia.

In the same vein, Sheng and Chancellor (2018) show that there is a positive relationship between farm size and TFP in an Australian farm level context. Moreover, they proceeded in their study to analyse the potential to bridge the productivity gaps between large and small farms. Based on their findings, capital outsourcing appears to provide a successful avenue to lift the productivity of small farms in the Australian grains sector thereby unlocking additional productivity gains by allowing them to access more advanced technologies. The implication of their findings is that identifying and addressing market and institutional barriers to capital outsourcing would assist small farms in moving towards the productivity levels achieved by their larger counterparts.

In contrary to the direct farm size-productivity relationship established above, Jha *et al.* (2000) find an inverse relationship between farm size and productivity growth for wheat farmers in India. They argue that small farms tend to use more of family labour lower labour transaction costs than larger farms.

3.4 Resource allocation

Another important driver of productivity growth at the sector level established in the literature is resource allocation within a sector. On-going resource allocation between farms within a sector characterises a well-functioning market economy (Andrews & Cingano 2014). The movement of productive input or resources from less productive farms tends to raise aggregate productivity, even though various adjustment costs may be incurred.

Sheng *et al.* (2017) decomposed industry-level productivity into within-farm technology progress and between-farm resource reallocation. Resource reallocation is estimated to account for around half of the industry-level productivity growth that occurred between 1978 and 2010 in Australian Broadacre agriculture, and its contribution appears to have increased over time. Moreover, they also show that resource reallocation effects vary across different inputs, partly due to their different mobility. The analysis of how resource allocation influences productivity may provide improved understanding of how reforms targeting structural adjustment. Gray *et al.* (2014) also examined productivity dynamics in the Australian broadacre agriculture in the context of policy reforms. These authors concluded that, facilitated by comprehensive policy reforms, resource reallocation account for significant component of influenced sectoral productivity growth, and partly helped offset the effect of the declining on-farm producivity.

Similar to Sheng *et al.* (2017) and Gray *et al.* (2014), Kimura and Sauer (2015) also decomposed dairy sector–level productivity growth (from 2001-2012) in the Netherlands, United Kingdom and Estonia (Box 1). In Estonia, the contribution of resource allocation is relatively large, indicating that the more productive farms increased their market share, reducing that of less productive farms. In the Netherlands and England & Wales the resource allocation effect on productivity is relatively small. In the latter, the reallocation effect was negative in 2009 and 2011 due to the convergence of productivity between farms in these years (that is decreasing productivity gap between farms).

The relative importance of resource allocation is not only limited to the agricultural sector, Dabla-Norris *et al.* (2015) note that aggregate TFP in an economy depends not only on the efficiency of individual firms or industries but also on how inputs are allocated across them. For instance, Dias *et al.* (2016) find that a better allocation of resources across firms within services industries in Portugal could boost measured productivity by about 40%.

3.5 Exit and entry

One important form of resource allocation is exit and entry, which is discussed separately in this section. The contribution of exit and entry of dairy farms to productivity growth in Estonia, the Netherlands and England and Wales over time was examined by Kimura and Sauer (2015). For the Netherlands and Estonia, the growth effect of entry and exit of farms was found to be negligible on average, which reflects a relatively low rate of exit of farm exit in the Dutch and Estonian dairy farming sector. Contrastingly, for the UK 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 authors argued that these results highlight the importance of government initiatives to remove barriers to farm exit and facilitate resource allocation to productive farms.

Similarly, in the US dairy sector, Dong *et al.* (2013) found that smaller and less efficient farms are more likely to exit, and more efficient dairy farms are less likely to exit as higher efficiency increases farm's competitive performance and enables farm to survive, resulting in an overall increase in sector level productivity. Jang and Du (2014) in the US showed that while higher productivity leads to a low probability of exit in traditional dairy regions, productivity is positively associated with exit probability in non-traditional dairy regions.

3.6 Agricultural policies

The direction of productivity growth also depends on agricultural policy reforms. However, whether policy reform enables or disables productivity growth depends on the policy objectives pursued and the policy instruments chosen. For example, policy objectives targeted at improving market orientation can be related with a drive towards production efficiency, while increased regulation might result in the opposite effect.

Using a dynamic Generalized Methods of Moments (GMM) estimation technique, Mary (2013) analysed the impact of Pillar 1 and Pillar 2 components of Common Agricultural Policy (CAP) subsidies on TFP of French crop farms between 1996 and 2003. This study showed that not all CAP payments have a significantly impact on TFP. More specifically, the study revealed that coupled CAP payments (i.e. set-aside premiums, Less Favoured Area (LFA) payments, and livestock subsidies) had a significantly negative effect on TFP. In contrast, selective (targeted) subsidies which are not automatic but subject to project approval, such as agri-environmental payments and investment subsidies were found to have no significant impact on TFP.

In an EU-wide study, Rizov *et al.* (2013) investigated the impact of CAP subsidies on the TFP of farms in the EU-15 countries for the period 1990 to 2008. They showed that subsidies had a negative impact on farm productivity before the implementation of the decoupling reform. They argue that coupled subsidies distort farm behaviour (for example production structure and or input allocation) resulting in productivity loss. In addition, due to the allocative and technical inefficiencies, monitoring costs and payment uncertainty, coupled subsidies tend to stimulate less credit and hence also enhanced less productive investment. However, after the introduction of decoupling the picture is different as the impact of subsidies on productivity is more nuanced and, in most of the EU-15 countries, this impact becomes significant and positive except for Greece and Sweden. They explained that decoupled subsidies may impact farm productivity through the “credit channel”, with these subsidies allowing farms to improve their credit position and/or reduce cost of borrowing for investments, thus boosting their productivity. Furthermore, they argued that the positive effect could also be due to these subsidies decreasing risk aversion which ensures that the farm productivity adjustment is stronger as farmers may be more willing to expand capital and adopt novel technologies.

Using Irish, Danish, and Dutch farm-level data, Kazukauskas *et al.* (2014) also provide evidence that the decoupling policy had significant positive effects on farm productivity and behavioural changes related to farm specialisation, arguing that the decoupling policy is aimed at aligning farmer’s production decisions with demands of the market. However, the authors only find a positive and significant relationship between the decoupling variable and productivity for Irish cattle and Danish dairy farms. The productivity improvement related to subsidy decoupling for Irish cattle farms was explained by the fact that this sector was the least profitable agricultural sector in Ireland prior to decoupling and therefore had greater scope for reducing inefficiencies. A possible explanation for why decoupling is not found to have an effect on Dutch farmers (apart from the fact that Dutch farmers were highly productive even before the decoupling policy was implemented) is that they depended less on coupled subsidies before the reform and so the impact in practice may not have been that great. In contrast to Dutch dairy farms, Danish dairy farms increased their productivity due to decoupling even though they have a high productivity level prior to the implementation of the policy.

Kimura and Sauer (2015) showed that the share of direct payments in farm income had differing impacts on farm level productivity in Estonia, the Netherlands, and England & Wales. The relationship was found negative in Estonia, positive in the Netherlands and insignificant in England & Wales. While this study covers the period 2001 to 2012, the definition of direct payments does not consider the move from coupled to decoupled payments during this period.

Nilsson (2017) finds a positive and significant effect of investment support on farm productivity, but only for small farms. They revealed that an increase in the size of the support in relation to farm income has a negative and significant impact on productivity for all farms, suggesting that this type of support can improve its efficiency if targeted on small farms.

With regards to milk quota reforms, previous studies revealed that production quotas negatively impact productivity in the sector; however, the negative effect is reduced with increasing quota tradability. For example, Gillespie *et al.* (2015) explore a panel of Irish dairy farmers with findings that revealed high productivity growth rates before the quota implementation, low growth rates in the first years of the quota regime, and increasing growth rates following policy reforms. Turning to tradability of milk quota, Colman (2000) revealed that the tradability of quota rights reduced sector inefficiency by facilitating allocative efficiency in the United Kingdom as quota levels could be transferred from less-efficient to more efficient farms. This is further supported by Kimura and Sauer (2015) who showed that although milk quota reforms in 2008 had a positive impact on productivity in Estonia and the Netherlands, this was not the case in England & Wales, implying that the flexibility of quota transfer in the UK diminished the productivity constraining effect of quotas.

Using a sample of specialised dairy farms in southeast Germany, Frick and Sauer (2018) provide empirical evidence that the reallocation of resources toward more productive farms increased gradually during the phasing-out of the EU milk quota, implying that deregulation is an important driver of resource allocation.

In the same vein, Sheng and Jackson (2016) examined the impact of deregulating the milk market in Australia on industry-level productivity growth by comparing the pre- and post-reform periods. They find that the reforms contributed to sector-level productivity growth not only by raising average within-farm technology progress but also through the exit of relatively inefficient farms in some states and by shifting resources between farms operating different production systems with inherent productivity differences. They further argued that although deregulation may have an impact on the productivity of individual farms, it is more likely to affect farmers' decisions about entering and exiting the industry and the size of their operations and will thereby contribute to industry-level productivity growth through the dynamics generated by structural adjustment and the resource reallocation between farms that this induces. Further, Kirwan *et al.* (2012) examined the effect of the termination of production quotas in the tobacco sector in Kentucky. After the sudden elimination of quotas, these authors found considerable resource reallocation flows accompanying the restructuring process in the sector and showed their positive effect on aggregate productivity.

3.7 Public investment in research and development (R&D)

Investments in agricultural R&D result in the creation of new knowledge and technological breakthrough and is thereby considered as one of the leading drivers of productivity growth (Coe & Helpman 1995). Agricultural R&D activities take place in private, public and farmers' organisations, as well as on-farm (Piesse & Thirtle 2010). Economic evaluations suggest that returns to pubic investment in R&D are high. For instance, Zhang *et al.* (2015) from their empirical study find that approximately two-thirds of the of average annual broadacre productivity growth between 1952-1953 and 2006-2007 is driven by public investment in agricultural R&D. This suggests that increasing public investment in agricultural R&D and extension and maintaining agricultural R&D policy stability are important to sustain long-term agricultural productivity growth.

Apart from the public investment in agricultural R&D within a country, Piesse and Thirtle (2010) find that agricultural productivity is also likely to be driven by spillovers of technology from other countries. In their study, they report that R&D conducted overseas, when combined with domestic extension for localisation, can generate spill-in technology that can deliver productivity gains, whether as ideas gained from the research of others or through foreign technology adapted to suit local conditions. Similarly, Mullen (2007) estimates the contribution of spillovers of R&D to be approximately 0.8 percentage points a year in broadacre agriculture, while Gutierrez and Gutierrez (2003) find that TFP is strongly influenced by domestic as well as foreign public R&D spending in the agricultural sector for the 47 countries examined. They argue that productivity gains from external R&D are greater when the technology or knowledge is sourced from regions (or countries) that have similar agro-ecological conditions, as less investment in adaptive research is needed.

3.8 Climatic and environmental factors

Aside the observable determinants of productivity growth, differences in climatic and environmental conditions, such as changes in air pressure, sea temperatures, average rainfall and the frequency of extreme weather events which are beyond the control of farmers and government, can also influence productivity (Zhao *et al.* 2012). This effect, for example, is confirmed by early studies by Islam *et al.* (2014) and Zhao *et al.* (2008). Islam *et al.* (2014) found across varying rainfall environments that efficiency gains play an increasingly important role in influencing productivity as growing season rainfall increases. Islam et al. (2014) report that the reduction in the productivity in dairy sector in Victoria province in Australia is attributed to weather that was less favourable in the 1990s. Kokic *et al.* (2006) and Zhao *et al.* (2009) altogether find that agricultural productivity is significantly influenced by the amount of moisture retained in the soil and the various natural resource management practices adopted by farmers. Those findings suggest that the productivity of this sector is particularly sensitive to climate variability and the condition of natural resources, such as land quality. Kimura and Sauer (2015) show that being located in the less favoured area for dairy farms is associated with lower TFP in Estonia and England & Wales.

Similarly, findings from the study of Deep *et al.* (2013) show that heat stress have a significant nonlinear negative effect on milk production of dairy farms in Florida and Georgia, US indicating that future milk production and productivity growth in dairy farming can be hampered by a warmer environment. They suggested a need for research that facilitates farmer adaptation to reduce the impact of heat stress. It is important to note that heat stress can also have an adverse effect on herd reproduction. Key and Sneeringer (2014) note that in the United States, climate change is likely to increase average daily temperatures and the frequency of heat waves, which can reduce meat and milk production in dairy animals. The role of natural resources as driving factors of productivity is not limited to agriculture. Topp (2008) found that the quality of mineral had influenced the productivity of Australia's mining industry and Kompas *et al.* (2009) revealed that fish stocks were an important determinant of the productivity of a fishery.

3.9 Other factors

Other determinants of productivity include factors that are outside agricultural economy and are vital in creating conducive conditions to productivity growth. According to Gray *et al.* (2014), factors such as macroeconomic settings and stability, and the broader institutional architecture (such as the rule of law; workplace bargaining arrangements; corporate governance) affect farmers' costs of production and costs of doing business, and shape economic capabilities. Some other factors suggested by these authors include changing consumer preferences and incomes, quality of resources, milk prices and land values. In particular, Stokes (2006) provided evidence for the impact of milk price volatility on productivity growth. This study showed that increasing milk price volatility is a deterrent to entry for small dairies and also increases the exit probability of small farms, resulting in the reallocation of resources, thereby increasing sectoral productivity growth in the dairy sector in the US. This is further supported by Zimmermann and Heckelei (2012), who found an overall negative effect of price volatility on investments by farms, and especially small farms. These authors showed that by increasing milk price variation, the probability of exit was increased for small farms and decreased for large farms. Similarly, Frick and Sauer (2018) find empirical evidence that an interplay of deregulation and price volatility drove efficient resource reallocation in the dairy sector in southeast Germany.

4. Conclusions

Productivity growth is an essential element in sustaining international competitiveness of the Northern Irish agri-food sector. In light of the evolving challenges facing this sector, including increasing pressure on- and limitations to- the factors of production, climate change and rising cost of inputs, growing competition from outside agriculture for the same production factors, long term growth of agricultural sector largely depends on continues gains in productivity.

This brief has provided insights into the factors that can influence agricultural productivity growth. In summary, the previous research has identified factors that are directly related to technology and those that are not directly related to technology. These include: farm level innovation, farm management and farm managers' characteristics, farm size, resource allocation within sector, exit and entry, agricultural policies, public investment in research and development and climatic and environmental factors. Other factors such as changing consumer preferences and incomes, resource qualities, prices and land values were also highlighted in literature. The trends and drivers of productivity in NI dairy sector has not been previously examined. While all the factors discussed in early studies may have bearing on the Northern Irish dairy sector it is important to empirically measure and examine the drivers of productivity growth in the context of Northern Ireland.

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