



Department  
for Environment  
Food & Rural Affairs

# Characteristics of high performing dairy farms in England

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Written by: Nicolas Jones  
Enquiries to: Clare Betts  
Department for Environment, Food and Rural Affairs  
Email: [FBS.queries@defra.gov.uk](mailto:FBS.queries@defra.gov.uk)

# 1 Contents

1	Contents .....	1
2	Executive summary .....	2
3	Introduction .....	3
3.1	Purpose and Definitions .....	4
3.2	Data and Methodology .....	4
4	Results .....	5
4.1	Breakdown of variation in performance .....	6
4.2	Farm characteristics related to farming performance .....	8
4.2.1	Business decisions .....	10
4.2.2	Farm characteristics .....	17
5	Conclusions .....	22
6	Appendix A .....	24
6.1	Methods .....	24
6.1.1	Geographical and temporal variation in performance .....	24
6.1.2	Factors related to farming performance .....	25
7	Appendix B .....	26
7.1	Spatial distribution of farm business output/input ratio .....	26
7.2	Model outputs .....	27
7.3	Model diagnostic plots .....	29
7.	References .....	29









## 2 Executive summary





This report studies the characteristics of high performing dairy farms. Performance is defined as economic performance measured by the efficiency with which inputs are turned into outputs. The analysis covers the period 2010/11 to 2016/17 for dairy farms in England.

The first section of the analysis ([section 3.1](#), below) compares the relative importance of temporal, geographic and idiosyncratic (i.e. farm specific) factors in explaining variation in the economic performance of dairy farms. Geographic factors, such as localised weather and land quality, contributed very little to variation in performance, accounting for only around 0.01% of variance. In contrast temporal (changes over time such as prices and weather) and farm specific factors explained the majority of the variation in the data, accounting for around 30% and 70% respectively. However, the influence of geographic factors may have been underestimated due to data limitations, further details are in [section 3.1](#).

The second section of the analysis ([section 3.2](#)) focuses mainly on farm specific factors related to the performance of the farm business as a whole, and to the agricultural portion of the business in isolation (i.e. excluding diversified income, direct payments and agri-environment schemes). The results were categorised by those which the farm has control over and those which are less controllable. Factors which were found to be related to performance are listed below in Table 1.

**Table 1. Factors which were found to be related to performance, ↑ indicates a positive relationship with performance, ↓ indicates a negative relationship, and ■ indicates no relationship. The size of the arrow indicates the strength of the evidence, larger arrows indicating more confidence in the result and smaller arrows indicating less confidence.**

Variable	Farm Business	Agriculture	Comments
Debt			For both short and long term debt, increasing indebtedness was related to decreasing performance.
Organic			Organic dairy farms tended to be better performers than non-organic dairy farms, for both the farm business and the agricultural portion of the business.
Agri-environment scheme payments			Increasing reliance on agri-environment scheme payments was associated with reduced agricultural performance, but this was compensated for by the rest of the farm business such that overall performance was not impacted.
Specialisation			More specialised dairy farms performed less well than those with a more varied agricultural enterprise, for both the farm business and the agricultural portion of the business.

Diversification		More investment in diversified activities was related to lower agricultural performance, but this was compensated for by the rest of the farm business such that overall performance was not impacted.
Unpaid labour		Unpaid labour was advantageous for performance. However, once the inherent advantage of receiving labour for free was removed by including an imputed cost, more unpaid labour was associated with reduced farm business performance.
Herd size		Farms which increased their herd size over the study period tended to be better performers than those whose herd has decreased.
Tenure		Tenanted, and in particular FBT (shorter) tenanted farms tended to have lower performance than FAT (more long term) and owner-occupied farms.

### 3 Introduction

There is substantial variation in the economic performance of farms in England, both across and within sectors. Better understanding the causes of this variation is key for the industry and policy makers to understand the drivers of productivity, competitiveness and profitability. Farm performance is also often related to environmental outcomes. The relationship between performance and farm characteristics is however often complex. This is part of a series of three reports analysing factors related to economic performance at the farm level.

Economic performance is a key measure of the productivity of farms and is defined as the ability of farms to turn inputs into outputs. The dairy sector has the lowest difference in performance between the best and worst performers of any agricultural sector in England and yet variation is still extensive. In 2016/17 the top 25% performing farms in England on average achieved £1.17 in outputs for every £1 spent on inputs whereas the lowest performing 25% of farms only managed to achieve 81 pence in outputs for every £1 spent on inputs<sup>1</sup>. In the same year only 46% of dairy farms broke even by achieving a return of at least £1 for every £1 spent on inputs. When considering purely inputs and outputs related to the agriculture aspect of the business only around 1 in 5 farms broke even.

The general trend in the structure of the dairy industry over the past decades has been towards fewer but larger farms. In the decade between 2008 -2017, the number of holdings, total land area and total cow numbers related to the UK dairy industry all fell; total land area by almost 20% (Defra, 2019). Despite this reduction in key inputs, production increased by around 11% over the same period, and the average land area per farm also increased, from 101 ha to 129 ha (Defra, 2019). At the industry level, the exiting of small farms from the industry, and the trend towards

<sup>1</sup> Farm Business Survey data 2016/17

larger farms has been presented as the key driver of industry productivity growth (Kimura and Sauer 2015); the suggestion being that larger farms are able to benefit from returns to scale. At the individual farm level however a number of factors are likely to explain the variation in the economic performance of dairy farms.

### 3.1 Purpose and Definitions

The purpose of this report is to provide an up to date assessment of the characteristics associated with economic performance for dairy farms in England. The analysis within this report was produced alongside (Betts, 2020) and (Jones, 2020) which analyse the grazing livestock and cereals sectors respectively.

Economic and financial performance of farms can be measured using a number of different indicators. This report focuses on efficiency; specifically technical efficiency. Technical efficiency is defined as how much output a farm can produce per unit of input. In this study outputs are measured as the monetary value of products produced by the farm. Inputs are measured as all monetary costs to the farm in addition to an amount representing unpaid family labour. Although unpaid labour does not appear on a farm's balance sheet, it represents a financial cost to the farm through forgone off-farm wages. Where a cost for unpaid labour was used this was done using the market rate and represents what a worker could have earned doing the same job elsewhere. This is not a perfect measure as many farmers have the skills and qualifications to earn a higher wage in another sector. On the other hand farmers receive a number of non-monetary benefits such as housing, and lifestyle benefits which they value highly. These benefits offset lost earnings to an extent.

Inputs and outputs were not deflated to account for changes in prices over time. This is to allow for a wider definition of efficiency which includes allocative as well as technical efficiency. Where technical efficiency considers how a product is made, allocative efficiency relates to which products should be made. Allocative efficiency is defined as the best mix of goods being produced. Price changes have an impact on allocative efficiency; if input prices change, the most appropriate combination of inputs and outputs also changes. For instance, if the cost of fertiliser falls in a given year, farmers may apply more fertiliser to benefit from cheaper production costs and achieve higher output. This may make allocative sense, however may lead to reductions in technical efficiency. In practice changes in price over time are captured within the model by the inclusion of a "year" variable.

### 3.2 Data and Methodology

A simplified explanation of the data and methods used in the analysis is presented here. A more detailed technical breakdown of data and methods used can be found in [Appendix A](#).

Data was taken from the Farm Business Survey<sup>2</sup> of England for 2010/11 – 2016/2017. Farms were included in the analyses if their farm type<sup>3</sup> was classified as dairy in at least

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<sup>2</sup> <https://www.gov.uk/government/collections/farm-business-survey>

<sup>3</sup> [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/365564/fb-s-uk-farmclassification-2014-21oct14.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/365564/fb-s-uk-farmclassification-2014-21oct14.pdf)

three of these years and they had at least 20 dairy cows. 328 farms met these conditions, of which 164 were surveyed in all seven years and 250 in at least five. The majority (96%) of farms were always classified as dairy, with the remainder classified as mixed or grazing livestock for some years.

Within the Farm Business Survey, each farm business is broken down into four 'cost centres'; agriculture, diversification, direct payments and agri-environment schemes. Costs and outputs are apportioned as appropriate between these cost centres. All the analysis in this report has been produced using both farm business costs and outputs (i.e. including all cost centres), and also for the agricultural portion of the business alone.

The analysis is split into two sections. The first section uses the ratio of outputs to inputs to understand how much of the variation in economic performance can be attributed to the location of each farm (i.e. large scale geography), changes in time (e.g. price changes from year to year, or agricultural policy changes) and how much can be attributed to 'idiosyncratic' factors which are specific to each farm.

The second section of the analysis uses generalised linear mixed models to further analyse the characteristics associated with farming performance. In this section putative relationships between a number of factors and performance are tested. Costs, herd size and land area were included in the model to take into account differences in farm size. Two separate models were run to determine factors affecting purely the agricultural part of the farm business and those affecting the business as a whole.

All results presented in the second section are in the form of model predictions, which allow us to draw conclusions about the relationship between a farm/farmer characteristic and economic performance, once the impact of other variables have been accounted for. Predictions of outputs (the response variable used) were then divided by inputs to convert the model predictions into estimates of performance. In all instances, predicted values should be treated with caution since they are an estimation made based on a combination of average values of the other variables, which may not be representative of actual farms, and it would be uninformative to compare absolute predicted values across different pieces of analysis (i.e. those relating to other farm types), instead, consider the directional relationships between significant variables and economic performance as an indicator of the nature of the relationships.

The analysis presented here is principally directed towards identifying correlations and patterns in the data, and **should not be used to infer causation**. That two variables are highly correlated to one another does not mean that one is driving change in the other. It is also possible that other factors not included in the model are driving the results, despite every effort being made to reduce this possibility. As well as the results from the data analysis, theory and external evidence must be used to build a narrative to explain possible causation. This is reflected in the interpretation of the results.

## 4 Results

The analysis is in two sections; the first examines how much of the variation in economic performance can be attributed to the location of each farm (i.e. large scale geography), changes in time (e.g. price changes from year to year, or agricultural policy changes) and

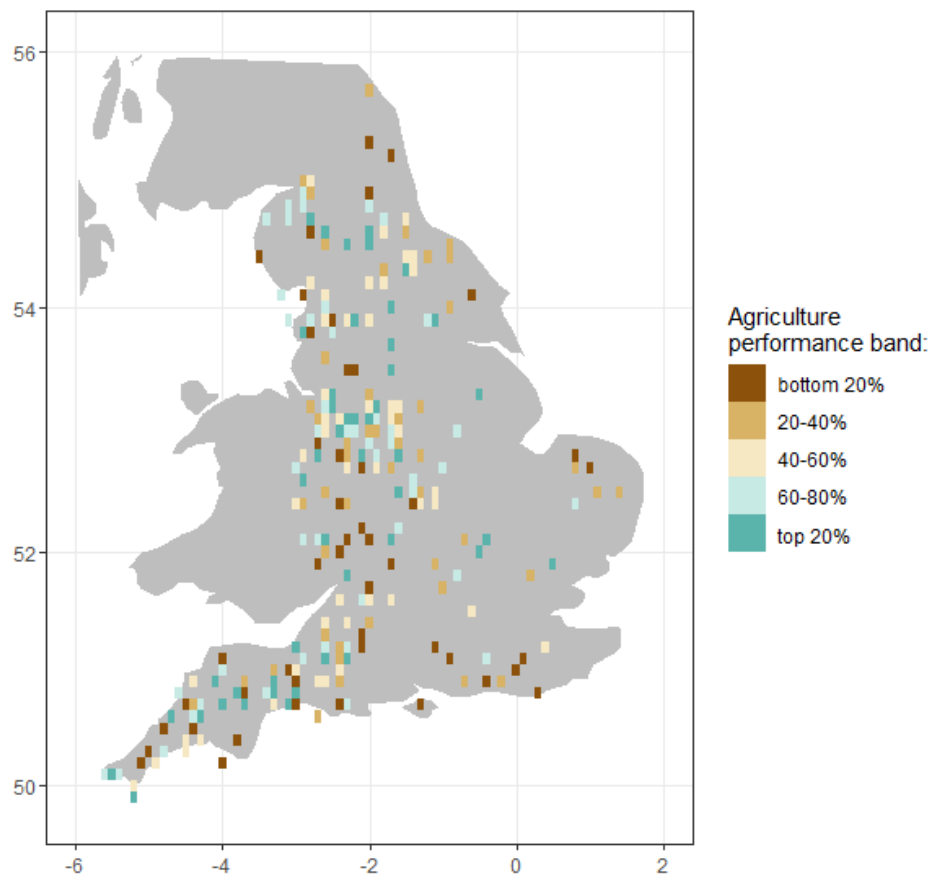
how much can be attributed to factors which are specific to each farm. This final driver of performance – farm characteristics – is further explored in the second phase of analysis.

## 4.1 Breakdown of variation in performance

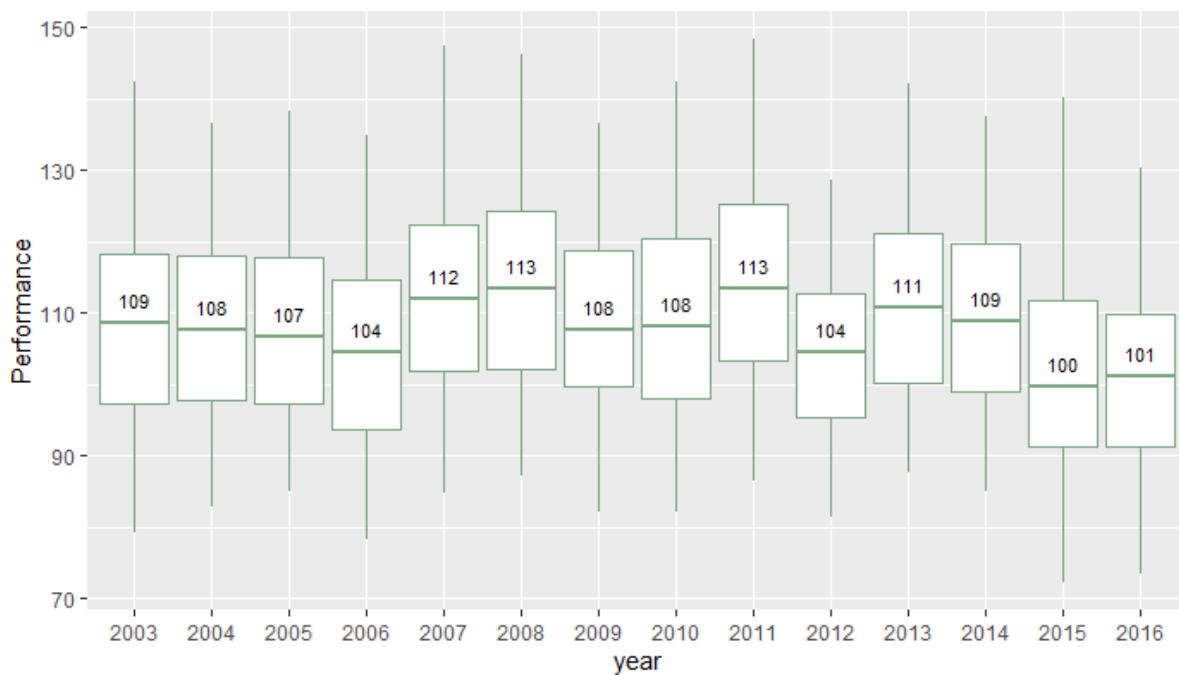
There are numerous factors which may explain the variation in economic performance of farms in England, however these can largely be categorised into three main groups: geographic, temporal and characteristics which are specific to each farm.

Geographic factors are those which are unique to farms in a particular region or area of the country. This could be regional differences in climate or land quality. Temporal variations are changes in performance occurring over time and explain why the same farm may appear to perform less well one year compared to the next. Temporal factors include changes in prices and extreme weather events. Lastly, characteristics which are specific to each farm explain why farms located in the same region, and compared within the same timeframe still show variation in economic performance. This can be due to decisions made by the farmer, as well as more local geographic differences such as grass quality. This section discusses the results from the first part of the analysis which determines the contribution of these three overarching sources of variation in economic performance within the data.

Figure 1 shows the spatial distribution of farm performance for dairy farms for the years 2010/11 – 2016/17 (see Figure 15, [Appendix B](#), for the farm business distribution). Here farms are grouped into quintiles based on their average performance. The overall distribution of points reflects the general trend for the highest density of dairy farms in England to be in the West, particularly in counties such as Devon, Cheshire and Lancashire. The distribution of performance is reflected by the colour of the points; the majority of areas appear to have a mix of high and low performing farms, again suggesting that geographic area only explains a minimal amount of the variation in performance. Some systematic differences in performance between years can be seen in Figure 2. This shows the annual average performance of dairy farms for the years within this study and with earlier years taken from Langton (2013).



**Figure 1. Spatial distribution of output/input ratios calculated from agricultural inputs and outputs only. Mean performance for farms falling within each 10km grid square are shown.**



**Figure 2. Farm business performance of dairy farms (calculated as the ratio of outputs to inputs (including an imputed costs for unpaid labour)) has not changed systematically over time. Previous work (Langton, 2013) covers the years 2003/04 – 2009/10, current analysis covers the years 2010/11 – 2016/17. Values shown are the median ratio for dairy farms in each year.**



The main source of variation in economic performance was found to be characteristics associated with individual farms (Table 2), making up 69% and 70% of variation in performance in the farm business and agricultural models respectively. Temporal factors were also important, with annual changes shown to contribute 31% to variation in farm business efficiency and 29% to agricultural efficiency. In contrast geographic factors were relatively inconsequential and only accounted for around 0.1% of variation. These will likely be underestimates due to the limited geographic information available for FBS farms; the location of FBS farms is only known to the nearest 10km, and small scale geographical differences such as elevation, or soil quality is poorly reflected by NCA designations and will instead be accounted for by the variation between farms variable. But the geographic variation it is nevertheless much lower than year to year variation within farms, and farm to farm variation. It is important to emphasise that this result does not necessarily mean that geographic differences in economic efficiency do not exist, but rather that the FBS dataset is not sensitive enough to pick them up. Indeed, the very fact that dairy farms tend to be concentrated in the West of the country reflects the fact that geography is important. Even where a few farms exist outside the core dairy areas, the geographic trend may be obscured if, as is likely, these dairy farms are highly motivated and manage to deliver profits despite the disadvantages of their geographic location.

**Table 2. Sources of variation within the dataset**

Component	Farm business		Agriculture	
	Variance	% of total	Variance	% of total
Geographical variation (NCA)	0.07	0.1	0.07	0.1
Farm to farm variation	54.87	69.1	54.45	70.6
Year to year variation within farms	24.43	30.8	22.64	29.3

## 4.2 Farm characteristics related to farming performance

In the previous section the relative importance of farm specific differences in explaining variation in economic performance was demonstrated. This section takes a more detailed look at the farm specific factors to better understand the characteristics of higher performing farms. For the modelling in this section, the relationship between monetary inputs and monetary outputs was considered, alongside other variables which may influence that relationship. A variety of variables and their interactions were used in the modelling, chosen largely on the basis of theory, or for data quality. For instance, it was not possible to include some variables relating to business management practices (e.g. the use of financial plans) because these data was not collected for all farms, resulting in a very small sample size. For a full list with descriptions see Table 5 in [Appendix A](#).

Two different models are used here. The first includes all farm business costs and outputs, whereas the second only includes inputs and outputs related to agricultural production. The former gives an indication of the overall economic and financial performance of the farm business and includes income related to subsidies and diversified parts of the business. By also including the latter model, comparison can be made between factors which impact agricultural performance, and those which have an impact on the performance of the business as a whole. Many of the variables considered have a similar

relationship with performance in both models; more so than in the cereals (Jones, 2020) and grazing livestock (Betts, 2020) studies. This is explained by the fact that dairy farms tend to receive a high proportion of their income from agriculture rather than other income types such as diversified enterprises. This is worth keeping in mind when interpreting the results.

The results in this section are structured so as to make a distinction between those factors which are within the control of the farmer and those that are less controllable. This is a somewhat arbitrary dichotomy as most of the factors are not fully controllable or uncontrollable, however categorising in this way is useful for understanding the application of the results. The variables included in the model are limited to those found in the Farm Business Survey (FBS), which although a vast dataset, does not include all variables which may be worth considering.

Table 3 lists the variables in each model along with their respective f-values and p-values. A more detailed results table and variable definitions can be found in Appendices [A](#) and [B](#).

**Table 3. Variables found to be related to either farm business or agricultural performance. See Table 5 in [Appendix A](#) for the full list of variables considered and their descriptions. P-values are in bold where variables were found to be related to either farm business or agricultural performance.**

	Farm business performance		Agricultural performance	
	F-value	P-value	F-value	P-value
Specialisation	23.5	<0.001	23.8	<0.001
Diversification			3.38	0.009
Organic	8.11	0.004	6.32	0.012
Long term debt	18.1	<0.001	26.6	<0.001
Short term debt	9.87	0.002	9.29	0.002
Unpaid labour	5.10	0.024		
Agri-environment scheme			8.47	0.004
Tenancy	7.31	0.001	4.29	0.014
Herd size	79.4	<0.001	88.9	<0.001
Cow trend	7.52	<0.001	10.9	<0.001
Area	4.42	0.036	4.68	0.031
Costs/herd size interaction	17.6	<0.001	18.7	<0.001
Costs	305.5	<0.001	293.1	<0.001
Year	109.5	<0.001	105.8	<0.001

Of those variables which were found to have a relationship with either farm business or agricultural outputs, each is discussed in turn in the following section. To visualise the results, predictions have been made using the fitted models, and those predictions of monetary outputs converted to output/input ratios, those farms with higher output/input ratios can be considered to be better performers. Absolute predicted values should be

treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.

## **4.2.1 Business decisions**

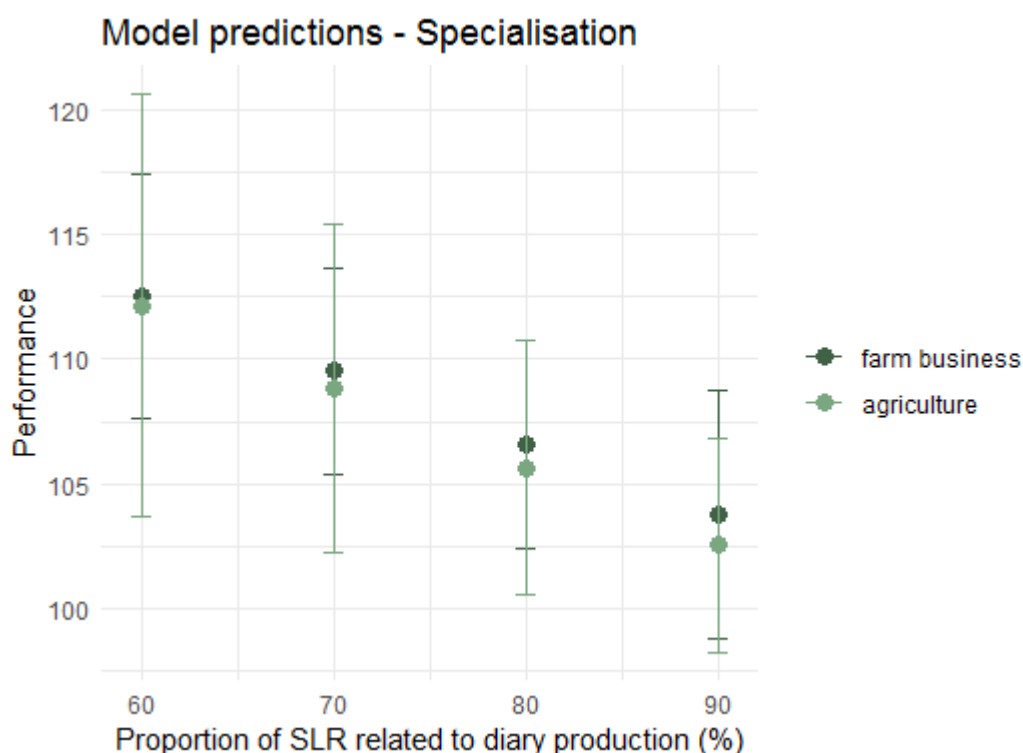
This section concentrates on variables which may affect economic performance, which are particular to each farm in each year. Here we concentrate on variables which might be thought of as business decisions and which are amenable, at least in theory, to change. Further on we consider some variables which are largely beyond the scope of a farmer to change.

### **4.2.1.1 Dairy Specialisation**

Specialisation was calculated using the percentage of total Standard Labour Requirement (SLR) attributed to dairy production. There was a negative relationship between specialisation and performance for both the farm business and agricultural portion of the business (see Figure 3).

This was similar to findings by (Langton, 2013) as well as other UK studies (Hadley, 2006) but is in contrast to Barnes et al (2010) and Redman et al (2018) who find that specialisation increases performance in dairy farming. Arguably, the latter relationship is as expected due to the increasing requirement to use specialised machinery and workers within the dairy sector (Barnes, et al., 2010). The results in this study do not necessarily contradict previous analysis, however contrasting results across studies suggest there may be a complex relationship.

Redman et al. (2018) propose that farms who produce their own inputs such as forage and youngstock may perform better than those who do not as inputs will be more bespoke and appropriate for the specific characteristics of that farm. Inputs may also be better quality as farms are likely keep the best for themselves and sell the excess. The calculation of specialisation in this study uses a narrow definition of dairy production which does not include input production, thus it is possible that some of those less specialised farms which are better performers, may devote more resources to producing their own inputs. Alternatively, less specialised farms may be more buffered to changeable markets and so generate higher incomes on average.

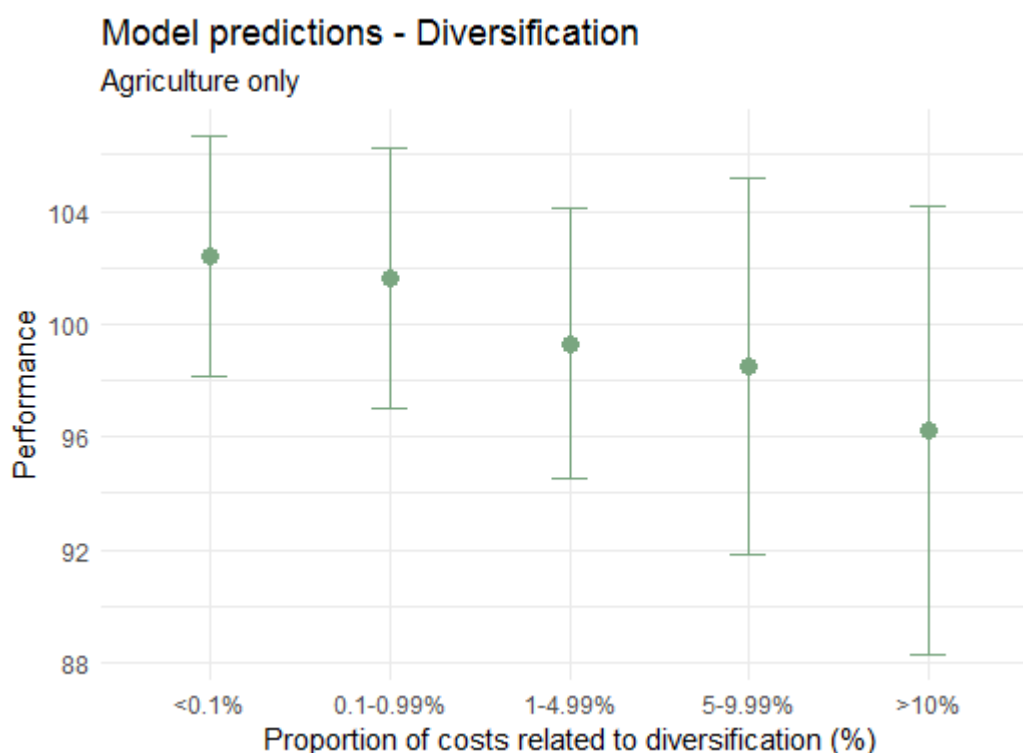


**Figure 3. The relationship between specialisation and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

#### 4.2.1.2 Diversification

Whereas specialisation refers to specialising within agriculture, diversification relates to activities outside of the core agricultural business, such as tourism or renting out farm buildings, but which utilise the farm's resources. Diversification was calculated as the percentage of farm business costs related to diversified activities.

Increasing diversification was related to slightly lower agricultural performance, and no relationship was found between diversification and farm business performance (see Figure 4). It is possible that diversifying pulls focus and resources away from the agricultural share of the business, which then suffers as a result. That there was no relationship between diversification and farm business performance suggests that any lost agricultural output is made up for through diversified activities. Alternatively poor performing farms may be forced to seek diversified income to remain competitive.

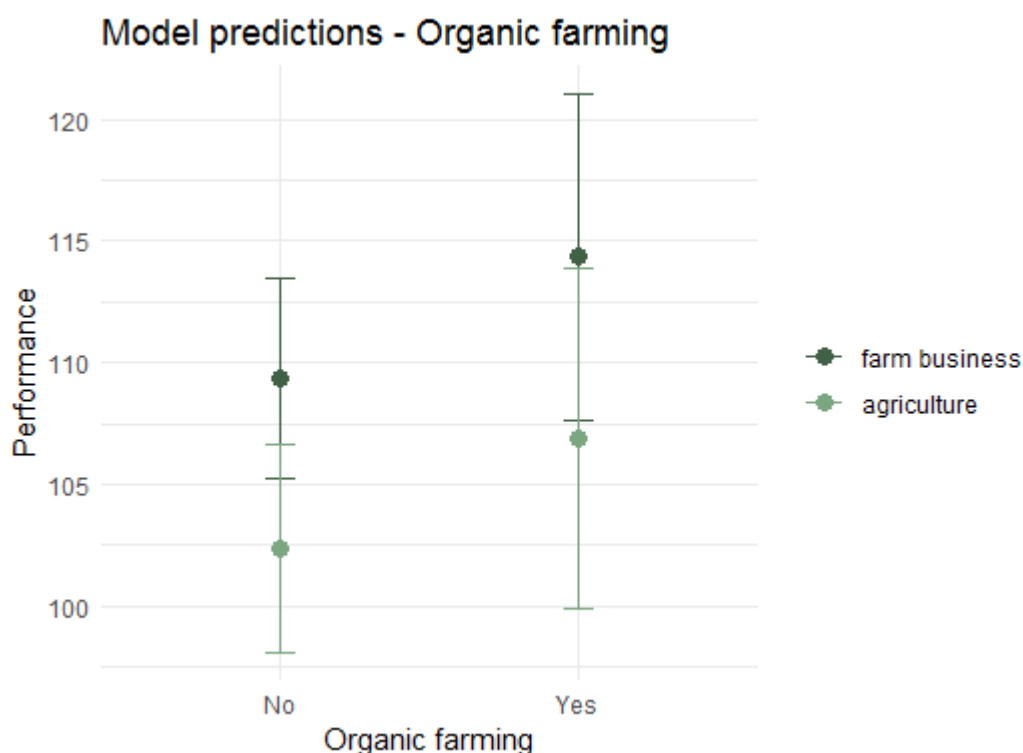


**Figure 4.** The relationship between diversification and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.

#### 4.2.1.3 Organic

Organic farms were defined as those with 50% or more of farmed land under organic certification. In practice however, dairy farms tend to be highly specialised as organic or non-organic. Within the sample 75% of farms in the organic category used at least 96% of their land for organic purposes. In contrast, the average non-organic farm in the sample used less than 1% of their land to produce organic output.

Organic farming was associated with higher farm business and agricultural performance (see Figure 5). In general, organic farms tend to have lower yields than non-organic farms (Seufert, 2012). This means that an organic farm would produce less milk than a non-organic farm with the same herd size. The results in this study suggest that even if the volume of milk produced by organic farms is lower than a non-organic farm, the total value of milk output is higher than non-organic farms of the same size, this is unsurprising given that organic milk commands a higher price than non-organic milk, which compensates organic farmers for the extra inputs needed to produce a litre of milk.



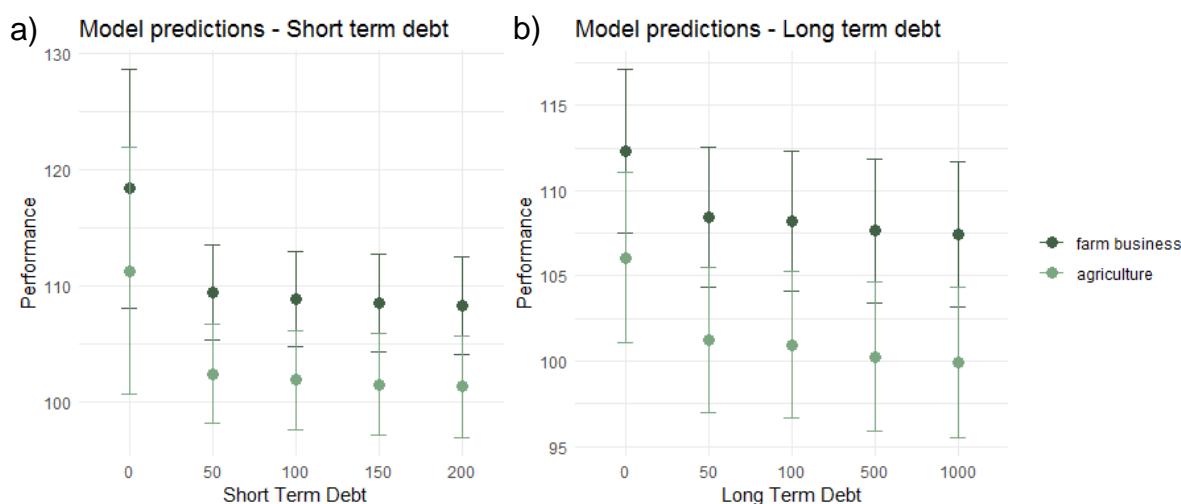
**Figure 5. The relationship between organic farming and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

#### 4.2.1.4 Debt

Debt was disaggregated into short and long term debt, to distinguish between borrowing for long term investments (such as bank and family loans) and borrowing to pay short term bills (e.g. overdrafts, hire purchase and leasing costs).

Greater levels of debt were associated with poorer performance, for both short and long term debt, and for both the farm business and the agricultural portion of the business (see Figure 6). It is possible that the financial constraints faced by indebted farms restrict their ability to adjust to changing markets or make investments and thus reduces their performance. It is also possible that poorer performing farms are forced into greater levels of debt to their cover unexpected shortfalls in income. The degree of variability in the data is an important consideration here: there were many instances of farms with moderate levels of debt performing well, and equally of farms with very little debt which were amongst the poorest performers.

Previous studies have found contradictory relationships between debt and performance. Langton (2013) found that farms with higher levels of debt tended to be poorer performers. In contrast, Barnes et al. (2010) found a positive relationship between debt and performance. Theoretically debt is likely to have two main purposes: farms borrow to make efficiency boosting investments or to expand; or borrowing is used to supplement earnings where cash flow is an issue. The former would be expected to lead to increased efficiency, whereas the latter could be a sign of a poor performing farm.



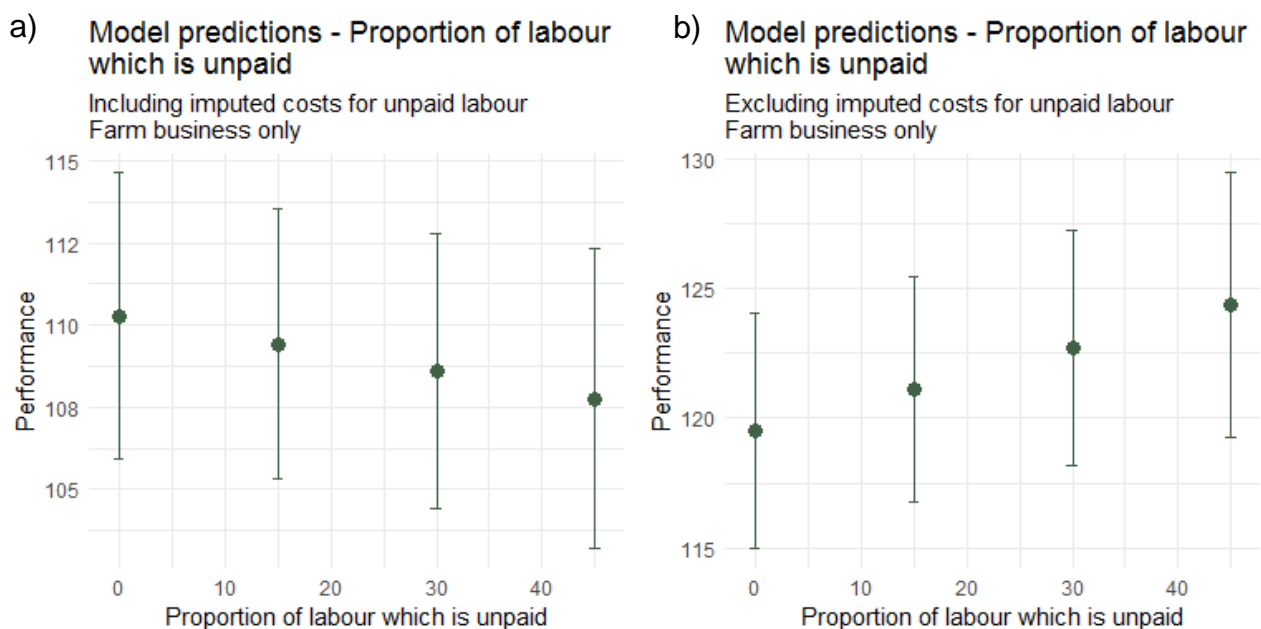
**Figure 6. The relationship between short term (a) and long term (b) debt, and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

#### 4.2.1.5 Unpaid Labour

Unpaid labour was included as a cost and calculated using the market rate for similar agricultural work off the farm. This removes the inherent advantage of receiving labour at no cost and acknowledges the true cost to the farm of unpaid labour. The percentage of labour which was unpaid was also included in the analysis. As the percentage of unpaid labour increased the performance of the farm business decreased (see Figure 7a). This is in line with findings by Barnes et al. (2010) but contrasts to those by Langton (2013). Langton (2013) found that unpaid labour has a positive relationship with agricultural performance only when calculated at the minimum wage. When the market rate is used the relationship no longer exists.

When the imputed cost for unpaid labour was removed from the analysis, a greater reliance on unpaid labour was associated with increased farm business performance (see Figure 7b). This relationship makes sense as without removing the advantage gained by free labour, those with more unpaid labour will appear to be more efficient.

The relationship between unpaid labour and performance is a complicated one. Barnes et al. (2010) propose that paid labourers may be more specialised leading to greater labour efficiency, and Redman et al. (2018) suggest that unpaid labour may be more likely to do low-value work, and hence have low productivity. In contrast Langton (2012), in the context of grazing livestock farms, argued that family labourers have more of a stake in the success of the business which could lead them to be more productive than paid labourers. The true relationship is likely to be more nuanced with the relationship depending on other factors such as the skill level of paid and unpaid workers. As pointed out by Barnes (2010) the FBS is unable to provide enough detail to further explore this fully.

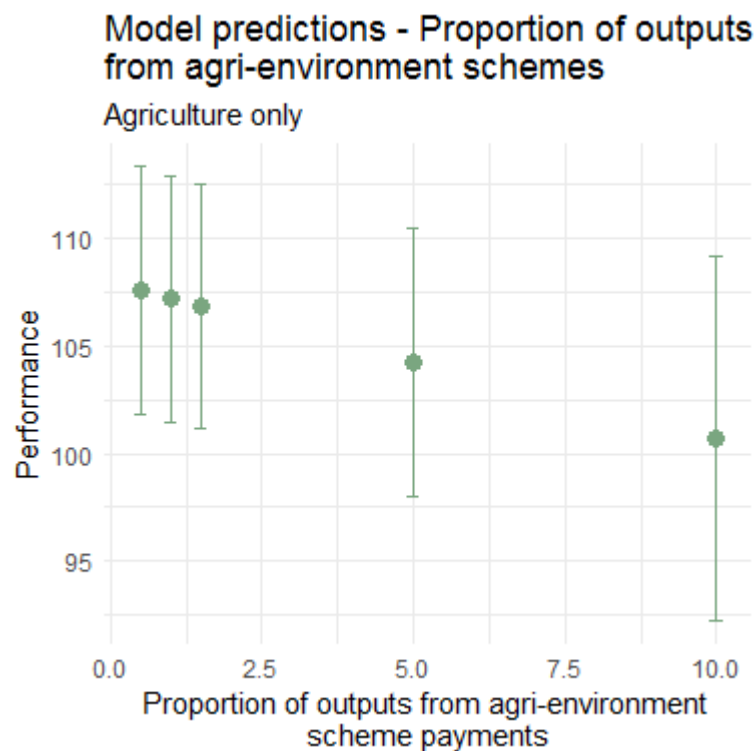


**Figure 7. The relationship between unpaid labour and agricultural performance including an imputed cost (a) and excluding an imputed cost (b). Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

#### 4.2.1.6 Agri-Environment Scheme Payments

Payments from agri-environment schemes as a percentage of income was related with lower agricultural performance (see Figure 8). This is unsurprising as by design agri-environment schemes encourage farmers to forgo a certain amount of output to produce environmental outcomes. No relationship was found between agri-environment scheme payments and farm business performance. This suggests that agri-environment payments are priced at the correct level so to act as income forgone and not disadvantage farms financially for participating.



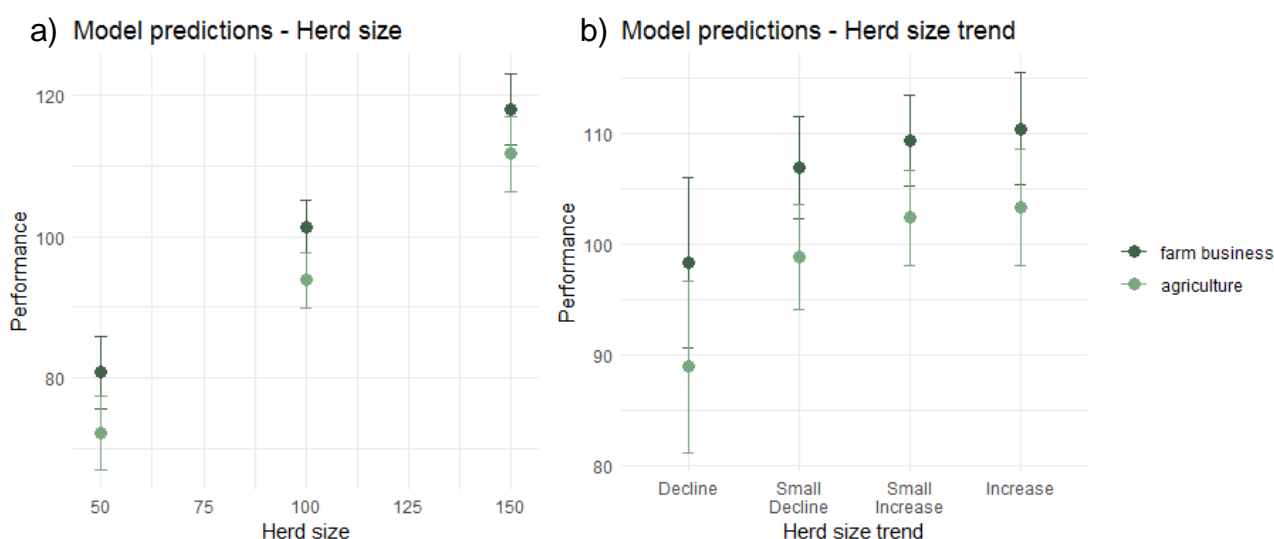


**Figure 8.** The relationship between agri-environment scheme payments and agricultural performance. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.

#### 4.2.1.7 Herd size

Herd size was found to have a positive relationship with both farm business and agricultural performance (see Figure 9a), suggesting that a farm with more dairy cows but the same land area and costs, produce farm business and agricultural output more efficiently.

A variable for the trend in herd size was also included in the analysis. This variable measures whether farms have generally expanded or reduced their herd size over the period studied. Farms which had expanded their herd size tended to have higher performance than those who had reduced their herd size (see Figure 9b). It is not clear whether increased performance is attributable to expanding the business or whether those with higher performance are better positioned to expand.



**Figure 9. The relationship between herd size (a) and the trend in herd size (b) and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

## 4.2.2 Farm characteristics

This section concentrates on variables which may affect economic performance, which are particular to each farm in each year. Here we concentrate on variables which are largely beyond the scope of a farmer to change.

### 4.2.2.1 Tenancy

Here farms were grouped into mainly owner occupied and mainly tenanted. Those in the tenanted category were then split into those renting mainly under Full Agricultural Tenancy (FAT) and those under Farm Business Tenancy (FBT) agreements.

Tenure type was related to both farm business and agricultural performance. On average, FBT farms performed less well than owner occupied and FAT farms for both farm business and agricultural performance (see Figure 10). This could be because the costs included in the models do not include an imputed rent for owner-occupiers, but do include the actual rent paid by tenants. When an imputed rental value for owner-occupied land was included in the models, a similar but less pronounced pattern emerged, suggesting that the differences were driven by more than just the cost of renting land. Some of this effect could also be due to the relative security of the two tenancy types. FATs tend to come with lifetime tenure and often include succession rights. In contrast FBT contracts tend to be much shorter. The Central Association of Agricultural Valuers (CAAV) for example estimate that the average new FBT agreement in 2016 was under 5 years<sup>4</sup>. Farms with a greater security of tenure may be more willing to make long term efficiency boosting investments as they are better able to appropriate the full benefits of these investments.

<sup>4</sup> When contracts under 1 year are excluded this rises to around 6 years. The CAAV also acknowledge that this is likely to be an underestimation however it still serves the purpose of demonstrating the vast difference in contract length between FAT and FBT agreements on average.

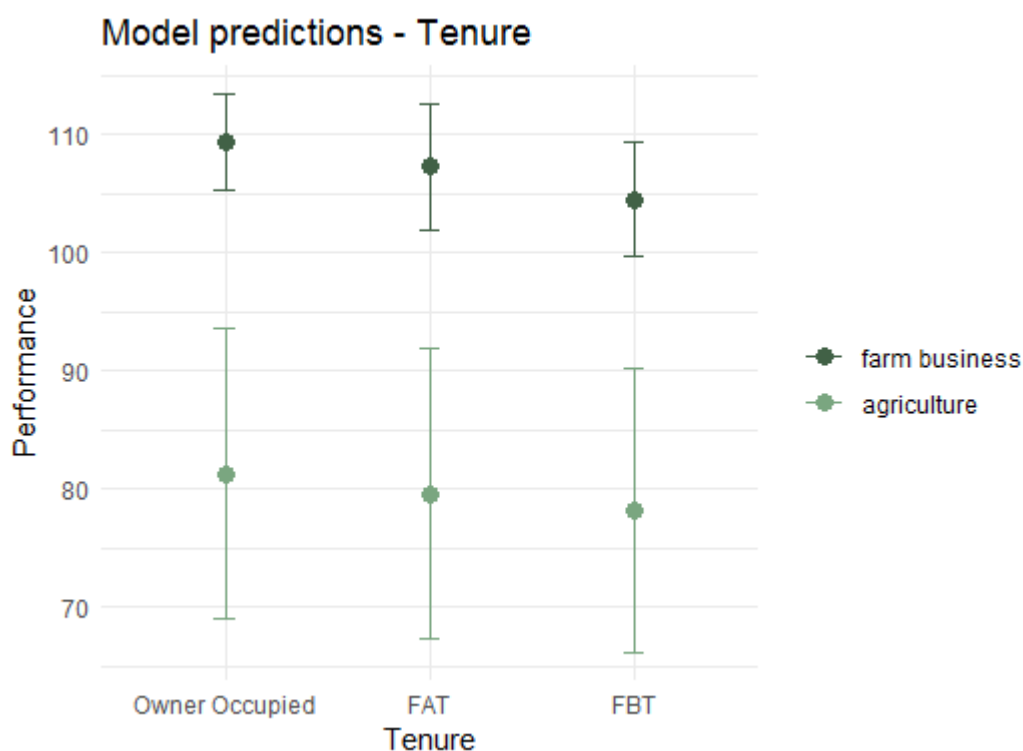
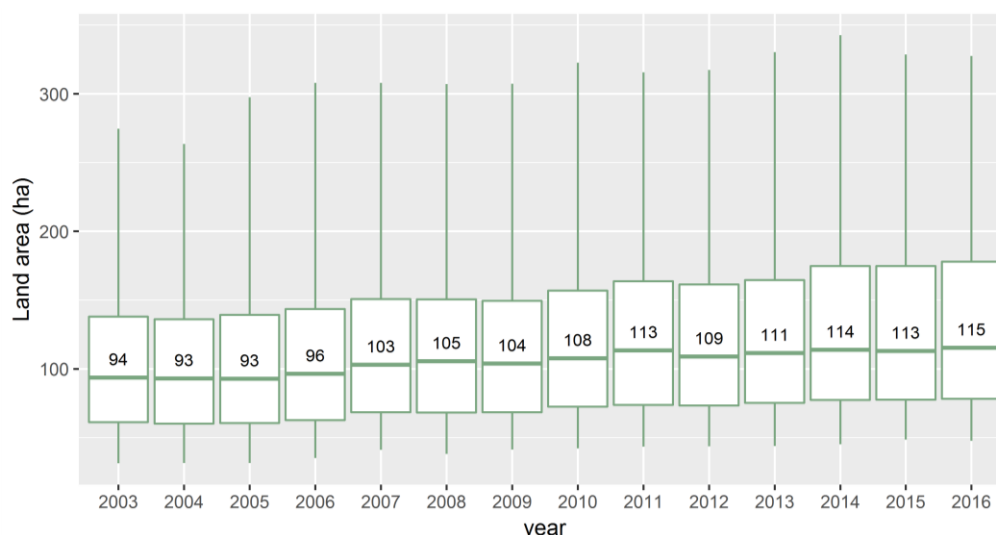


Figure 10. The relationship between tenure and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.

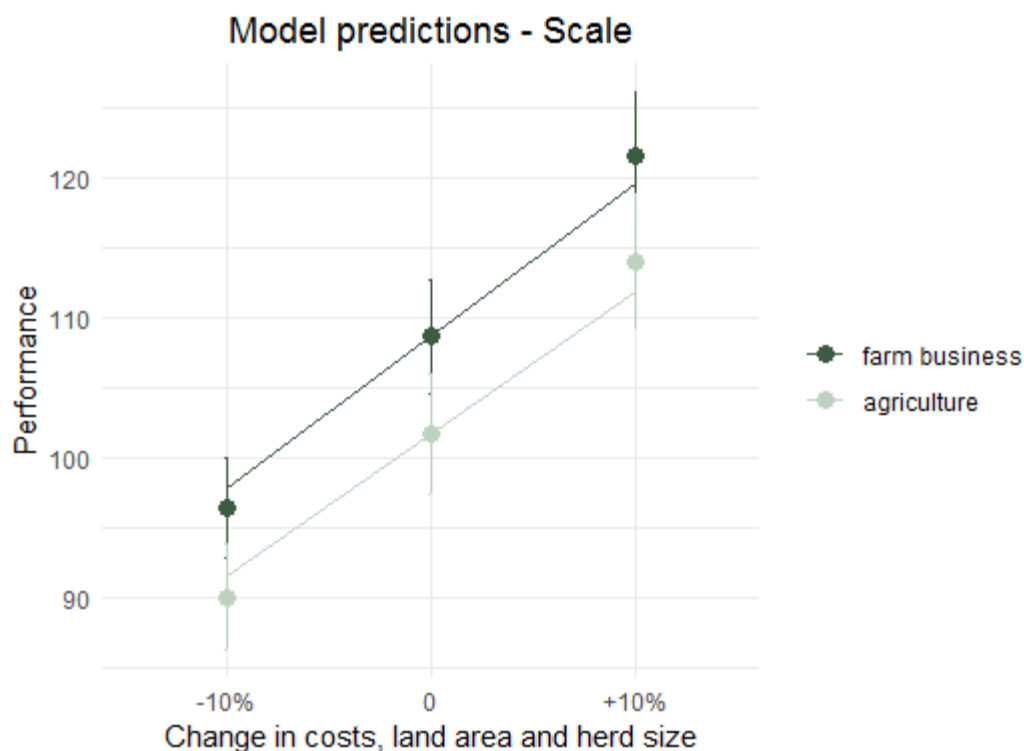
#### 4.2.2.2 Returns to scale

The recent trend in the UK dairy industry is of increasing average land area and herd size, while yields have also increased. Over the same period the number of holdings has declined. The industry is therefore characterised by fewer, larger farms producing more milk. This is reflected in the FBS sample used in this analysis. Figure 11 shows that median farm size has generally increased over time within the sample. Previous analysis suggests that these structural changes have been a key contributor to increased efficiency in the industry. Kimura and Sauer (2015) propose that the increase in average farm size and the exit of smaller farms from the industry has been the most important factor in explaining productivity growth in the UK dairy industry over the past two decades. Studying the agricultural sector as a whole, Thirtle et al. (2004) found that a 1% increase in average farm size led to a 0.2% increase in UK agricultural productivity.



**Figure 11. Box plot of land area (Ha) for dairy farms in the FBS from 2003/04 – 2016/17.**

Although farms of a similar size will vary in their levels of costs, land area and herd size, a significantly larger farm will have more of all three. A useful way of understanding the true relationship between scale and performance is to consider the impact of a proportionate increase in these variables concurrently. This gives an indication of whether there is increasing returns to scale in the industry. Figure 12 shows the predicted change in performance from a change in land area, herd size and costs of 10%. Constant returns to scale, a scenario where output changes proportionately with inputs, is represented by the line. The graph shows that performance changes by more than 10% if the scale variables are changed by 10% which suggests the existence of increasing returns to scale.



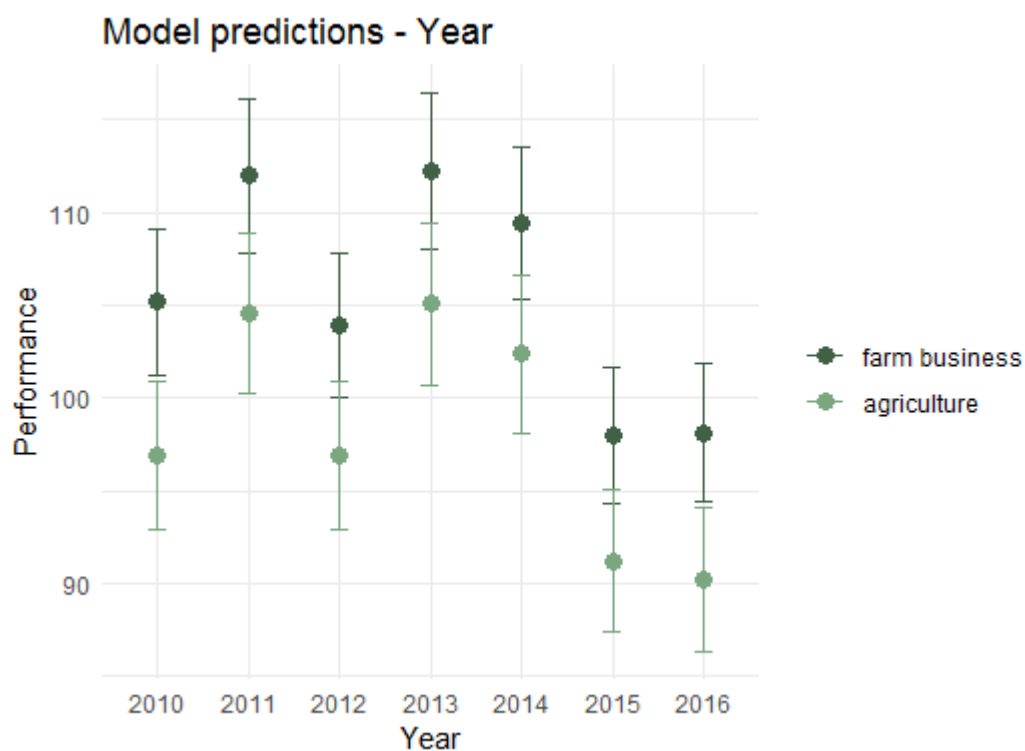
**Figure 12. Predicted performance change from decreasing and increasing land area, herd size and costs by 10%. The line represents constant returns to scale. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

Previous work (Langton, 2013) has also found evidence of increasing returns to scale for all but the largest dairy farms suggesting that an optimum size exists at which further growth will no longer lead to increased performance. It is worth noting however that other past studies have found mixed results when analysing whether increasing returns to scale exists in the UK dairy industry. For example Hadley (2006) found slight increasing returns to scale, whereas Barnes et al. (2010) found constant returns, suggesting farms are already operating at their optimum level on average, and Barnes (2008) found diminishing returns to scale for dairy farms in Scotland.

#### 4.2.2.3 Year

The year variable was included in the analysis to control for annual fluctuations in performance across farms due to in year impacts, such as changes in prices or extreme weather events.

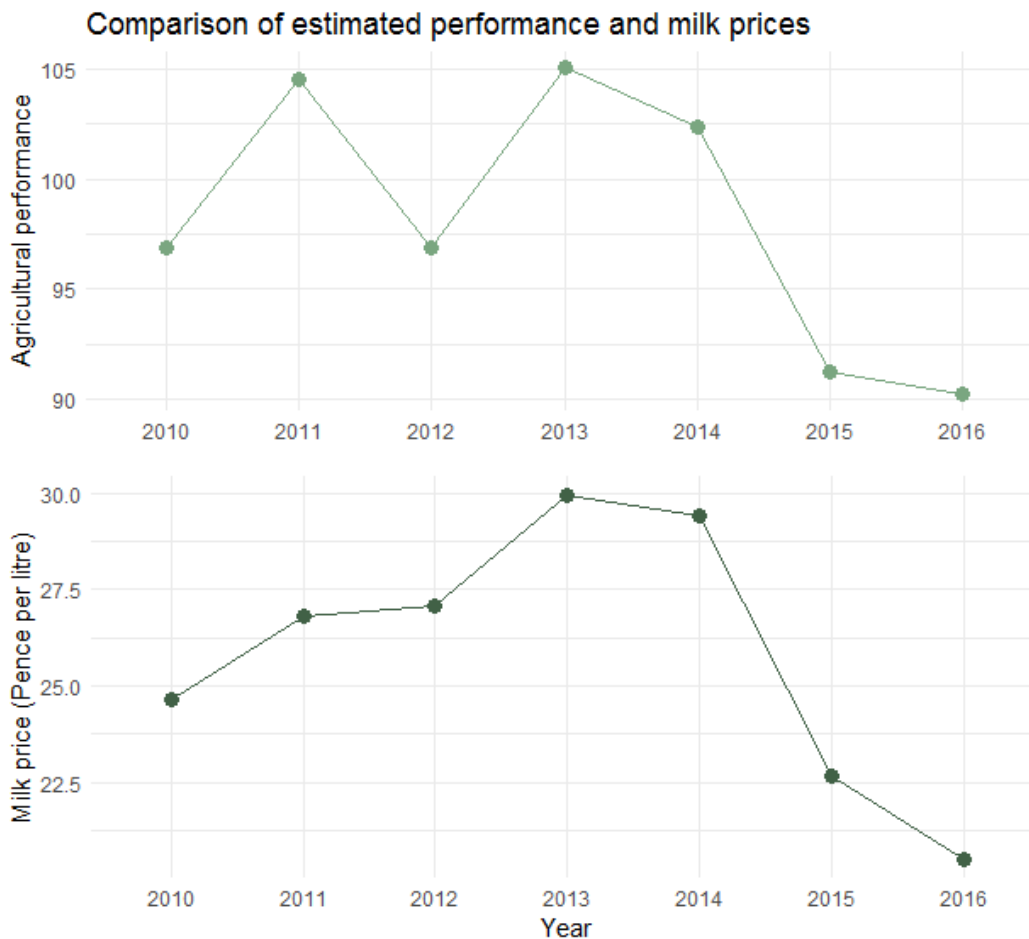
The annual fluctuations in farm business and agricultural performance across farms is shown in Figure 13. 2011 and 2013 appear to be particularly good years for the industry with relatively high performance. In contrast performance is particularly low in 2015 and 2016. Farm business and agricultural performance follow similar trends reflecting the importance of agricultural income to total farm income.



**Figure 13. The relationship between year and performance for both the farm business and agriculture models. Predictions were made for an average farm with £320k inputs per annum, 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

A number of factors will contribute to annual fluctuations in the income of a dairy farm however milk prices are arguably the most important for the dairy industry. The importance of milk prices can be seen clearly in Figure 14 which compares agricultural performance to

average annual UK milk prices. Predicted output and milk prices follow a very similar trend, travelling in the same direction for all but one year. This suggests that milk prices are important in explaining yearly variation in the model. Disentangling the causes of variations in milk prices is complex however weather, livestock disease, foreign trade and consumer tastes are all likely to contribute. Arguably one the most important influencers of milk prices over the period studied however are EU milk quotes which ceased in 2015 leading to falls in milk prices over the subsequent years. This is likely to explain much of the fall in output of farms within the study in 2015 and 2016.



**Figure 14. The relationship between year and agricultural costs (top) and annual UK milk prices (bottom). Predictions were made for an average farm with £320k inputs per annum, such that differences in the y-axis (outputs) can be interpreted as difference in performance. The ‘average farm’ also had 130 cows and 100 ha of land, remaining variables were averaged or the most common factor level used. Absolute predicted values should be treated with caution since they are estimated at a combination of average values of the other variables which may not be realistic in practice.**

## 5 Conclusions

The first section of the analysis aimed to determine the relative importance of three main groups of factors in explaining the variance in economic performance of dairy farms in England. The results suggested that geographic factors are relatively unimportant, however this may be partly due to limitations in the data. Temporal factors had a clear impact on variation, and farm specific factors explained the majority of variation in economic performance within the sample analysed.

In the second, and main, section of the results, farm specific factors were tested to better understand the characteristics of higher performing farms. The conclusions are summarised below.

**Table 4. A summary of the results with comment on the strength of the evidence.**

Variable	Evidence Strength	Comments
Specialisation	Moderate – similar and contrasting patterns have been reported elsewhere.	Agricultural specialisation was associated with lower performance
Diversification	Moderate – similar patterns have been found in other systems and previous studies.	More investment in diversified activities was related to lower agricultural performance, but this was compensated for by the rest of the farm business such that overall performance was not impacted.
Organic	Strong - this pattern has been reported elsewhere.	Farms which had a larger proportion of land under organic certification tended to better performers.
Debt	Strong – this pattern has been found across many systems and studies.	For both short and long term debt, increasing indebtedness was related to decreasing performance.
Unpaid labour	Moderate – similar and contrasting patterns have been reported elsewhere.	Unpaid labour was advantageous for performance. However, once the inherent advantage of receiving labour for free was removed by including an imputed cost, more unpaid labour was associated with reduced farm business performance.
Agri-environment scheme payments	Strong - this pattern has been reported elsewhere.	Increasing reliance on agri-environment scheme payments was associated with reduced agricultural performance, but this was compensated for by the rest of the farm business such that overall performance was not impacted.
Herd size	Strong - this pattern has been reported elsewhere.	Farms which had larger herd sizes tended to be better performers.
Change in herd size	Moderate - similar patterns have been found previously.	Farms which increased their herd size over the study period tended to be better performers than those whose herd has decreased.

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Tenure	Moderate - similar patterns have been found in other systems and previous studies.	Tenanted, and in particular FBT (shorter) tenanted farms tended to have lower performance than FAT (more long term) and owner-occupied farms.
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Farm specific factors were categorised into those which farmers are to some extent able to control, and those that are more difficult to change. Although this categorisation is not perfect, it does demonstrate that there are a number of key factors related to performance which are under the control of the farmer. This suggests that there is at least some potential for lower performing farms to improve their performance.

This conclusion must however be accompanied by some key caveats. Firstly, just because a variable considered here doesn't appear to have a relationship with performance, does not necessarily mean that it is unrelated. All statistical analysis is limited by the sample size of the data considered, with more data comes more power to detect relationships. Subtler, or nuanced, relationships may not be picked up by the models.

Secondly, it is important to recognise that economic performance is not the only consideration for farmers. From a financial perspective farmers may be more interested in farm business income (net profit) as this is likely to more directly impact their personal consumption. More significantly, financial incentives may not be the primary concern to farmers. Farmers gain a number of non-monetary benefits from farming, such as ability to live a particular lifestyle. Maintaining this lifestyle may be more of a concern than cultivating an efficient, profit making business. Therefore while it may be possible for farmers to improve the economic performance of their farm, they may not have the desire to do so.

Policy makers must also be aware of the complex relationships between efficiency and productivity gains and other policy aims such as improving environmental outcomes. Much historic productivity growth in agriculture can be attributed to the substitution of labour for energy intensive machinery, as well as growth in the use of fertilisers and pesticides. These inputs tend to have a number of negative environmental consequences associated with them. Depending on the nature of gains, the move towards greater efficiency on farms has the potential to either exacerbate or mitigate environmental degradation. Foster et al. (2007) show that there are often trade-offs between reducing one negative input and another. For example using less fertiliser will have positive environmental impacts but will require the use of more land to produce the same amount of output. Using more land for agriculture can have negative impacts on biodiversity and also represents the loss of land which can be used for carbon capture through woodland. There are indications however that increased efficiency will also lead to environmental benefits in the dairy sector. Shortall and Barnes (2013) found that more efficient Scottish dairy farms also produce less greenhouse gasses per litre of milk produced, although they acknowledge that how efficiency gains are achieved is hugely important. Previous work has been done to widen measures of productivity to include environmental outcomes however these measure as not yet mainstream<sup>5</sup>.

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<sup>5</sup> For example see (Thirtle & Holding, 2003) paper 5 which calculates a Total Social Factor Productivity (TSFP) index for the UK farming industry. Alternatively Total Resource Productivity (TRP) – see (Gollop & Swinand, 2001).



## 6 Appendix A

### 6.1 Methods

Data was taken from the Farm Business Survey of England for 2010-2016. Farms were included in the analyses if they were 'robust' type dairy farms in at least three of these years, of which 329 fit this criteria. Farms were also required to have more than 20 cows to be included in the sample. This left a sample of 328 farms. 164 of these farms were surveyed in all seven years, with 250 surveyed in at least five of the seven years. 96% of farms were always classified as dairy, with the remainder classed as either grazing livestock or mixed for some years.

The data was checked for anomalies and no further farms were removed.

Unpaid labour was given an imputed cost equivalent to the amount that the unpaid staff could earn in similar work elsewhere. Rent was not imputed for owner occupied farms.

Statistical analysis was broken up into two sections; the first using two models to assess the spatial and temporal variation in farm input/output ratios, the second assessing variables which might be associated with the economic performance at the farm business level, and agricultural portion of the business only. The farm business accounts includes costs and outputs from traditional farming sources, as well as diversified activities (such as tourism or renting out buildings), direct payments from government and payments from agri-environment schemes.

All statistical analyses were done in R (R Core Team, 2018), using the lme function in the nlme package (Pinheiro, et al., 2018) to fit mixed effects models. For both the farm business and agriculture models, farm ID was fitted to have a random effect on the intercept. Models were fitted using Maximum Likelihood during model simplification, and Restricted Maximum Likelihood to obtain final coefficient estimates.

Response variables were either log transformed farm business outputs, or log transformed agricultural outputs (both in whole £000s).

#### 6.1.1 Geographical and temporal variation in performance

To partition the variation in performance between geographical (using Joint Character Areas), temporal (year) and idiosyncratic (farm ID) sources, a simple ANOVA was used taking the form:

$$performance\ ratio \sim Farm/Year + NCA$$

Where performance ratio refers to the input/output ratio for the farm business and agriculture respectively, and NCA refers to the National Character Area. Each dependant variable was fitted as a factor. Government Office Regions (GOR) were also used in the place of NCA but this made no meaningful difference to the results.

To visualise the spatial distribution of performance, for each 10km grid square across England, an average performance score was calculated, where data existed. These scores were then categorised into bands (bottom 20%, 21-40%, 41-60%, 61-80% and top 20%) and plotted.

## 6.1.2 Factors related to farming performance

### 6.1.2.1 Fixed effects structure

Generalised linear mixed models were used to assess other putative explanatory variables associated with farm business and agricultural performance, taking the general form:

$$\log(\text{outputs}) \sim \beta_0 + \log(\text{costs}) + \text{year} + \log(\text{area}) + \text{variable}_1 + \dots + \text{variable}_n + \text{farm} + \varepsilon$$

Where;

- $\log(\text{outputs})$  and  $\log(\text{costs})$  are log transformed outputs and costs in whole thousands of pounds.
- $\beta_0$  is a global intercept
- year is a categorical variable denoting each year
- $\log(\text{area})$  is log transformed total area, including woodland, buildings etc.
- $\text{variable}_1 \dots \text{variable}_n$  are additional variables
- farm is fitted to have a random effect on the intercept
- $\varepsilon$  is residual error

The full list of variables used:

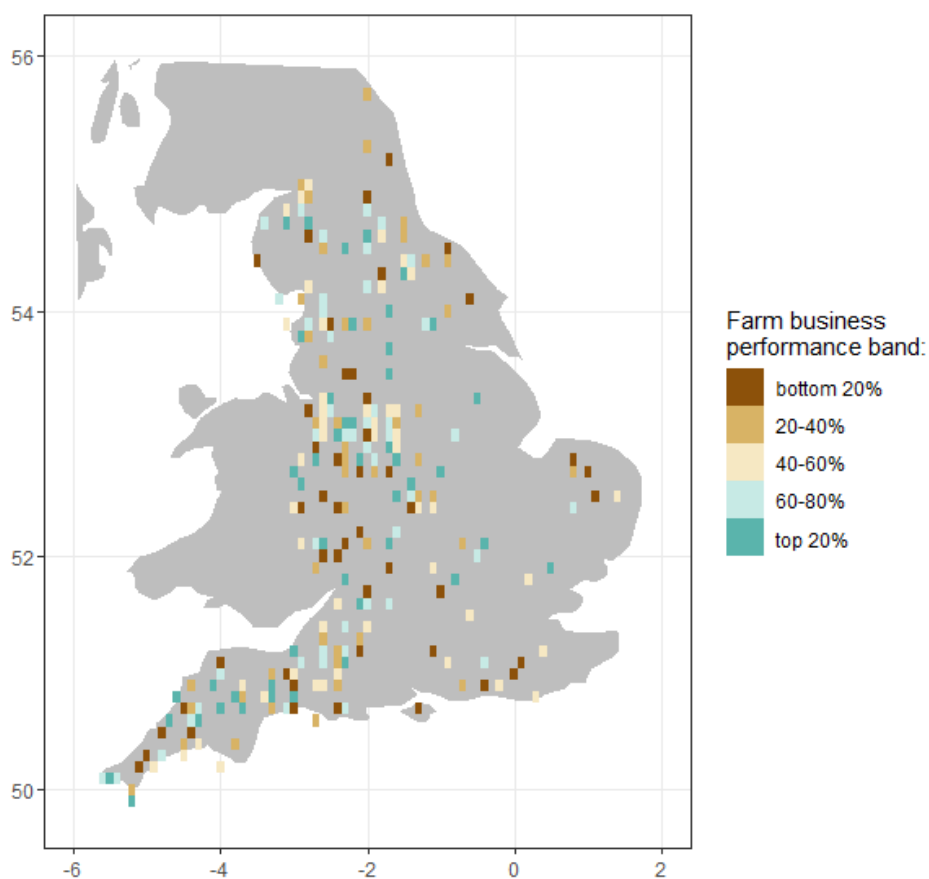
**Table 5. List of variables with summary statistics.**

Variable	Description	Min	Max	Mean/mode
<b>(log) output</b>	Log <sub>10</sub> farm business (agricultural) output	1.6(1.55)	3.34(3.29)	2.54(2.49)
<b>(Log) costs</b>	Log <sub>10</sub> farm business (agricultural) costs	1.73(1.73)	3.32(3.3)	2.53(2.52)
<b>(log) area</b>	Log <sub>10</sub> land area	1.37	3.1	2.06
<b>(log) herd size</b>	Log <sub>10</sub> dairy cow herd size	1.4	2.82	2.1
<b>Dairy cow trend</b>	Trend in herd size			Small Increase
<b>Unpaid labour</b>	Percentage of labour which is unpaid	0	73.58	15.78
<b>Tenure</b>	Owner occupied if 50% or more of land owned, otherwise tenanted. For tenanted, FAT if 50% of tenanted land under FAT, otherwise FBT.			Owner Occupied
<b>Specialisation</b>	Percentage of SLR related to dairy production	31.45	96.92	70.48
<b>Diversification</b>	Percentage of costs related to diversification			<0.1%
<b>Scheme payments</b>	Percentage of income from Agri-Environment schemes	0	15.55	1.16
<b>Organic</b>	Organic if 50% or more of area farmed is organic. Otherwise non- organic			Non Organic
<b>(log) Long term debt</b>	Log <sub>10</sub> long term debt	0	6.54	3.56
<b>(log) Short term debt</b>	Log <sub>10</sub> short term debt	0	6.05	4.7

The same maximal model was fitted to both the farm business data and the agricultural data, and potential fixed effects were assessed on the basis of stepwise model simplification (Crawley, 2013), model AIC and model performance. No automated model simplification or variable selection procedures were used.

## 7 Appendix B

### 7.1 Spatial distribution of farm business output/input ratio



**Figure 15. Spatial distribution of output/input ratios calculated from farm business inputs and outputs. Mean performance for farms falling within each 10km grid square are shown.**

## 7.2 Model outputs

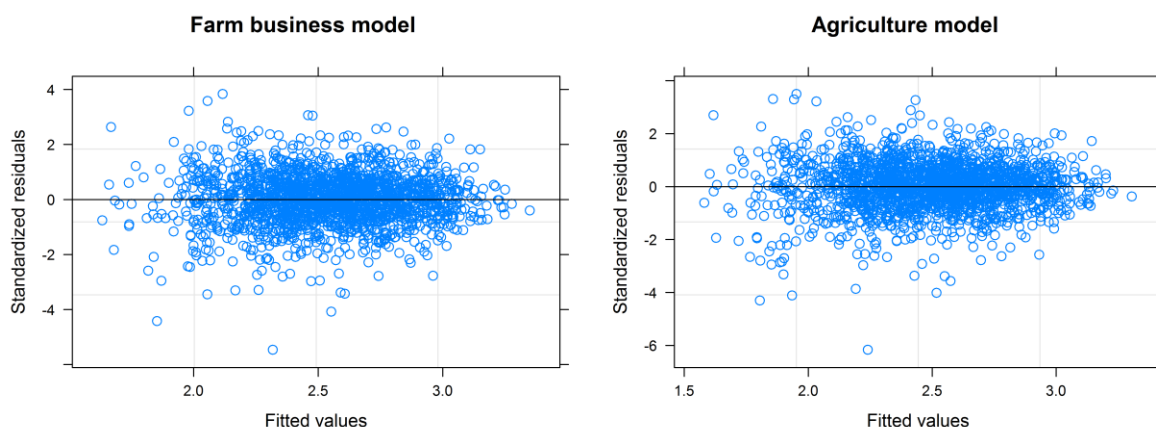
Table 6. Table of results for the farm business model.

Farm Business Model	Coefficient (Std error)	P-Value
<b>Costs</b>	1.020 (0.137)	<0.001
<b>Year</b>		
2011	0.027(0.003)	<0.001
2012	-0.005(0.003)	0.114
2013	0.028 (0.003)	<0.001
2014	0.017(0.003)	<0.001
2015	-0.031(0.003)	<0.001
2016	-0.030(0.003)	<0.001
<b>Dairy cows</b>	0.598 (0.067)	<0.001
<b>Dairy cow trend</b>		
Small Decline	0.036(0.011)	0.001
Small Increase	0.046(0.011)	<0.001
Increase	0.050(0.011)	<0.001
<b>Area</b>	0.032(0.015)	0.036
<b>Tenure</b>		
FAT	-0.008(0.006)	0.153
FBT	-0.020(0.005)	<0.001
<b>Specialisation</b>	-0.001(0.0002)	<0.001
<b>Organic</b>		
Organic	0.019 (0.007)	0.005
<b>Unpaid Labour</b>	-0.0002(0.0001)	0.024
<b>Long term debt</b>	-0.003(0.001)	<0.001
<b>Short term debt</b>	-0.007(0.002)	0.002
<b>Costs * Dairy cows</b>	-0.107 (0.026)	<0.001
<b>(Intercept)</b>	-0.699(0.138)	<0.001

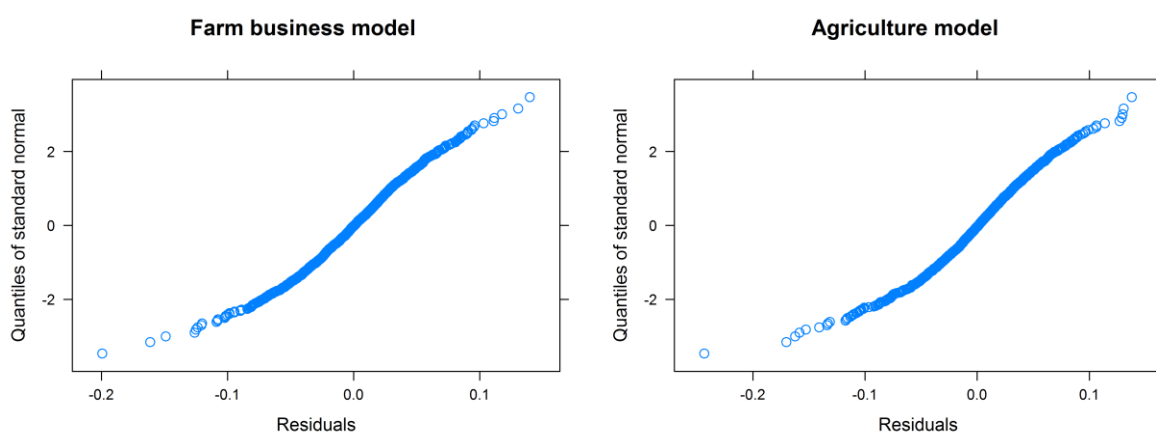
**Table 7. Table of results for the agriculture model.**

<b>Agriculture Model</b>	<b>Coefficient (Std Error)</b>	<b>P- Value</b>
<b>Costs</b>	1.086(0.063)	<0.001
<b>Year</b>		
2011	0.033(0.003)	<0.001
2012	-0.0001(0.004)	0.989
2013	0.035(0.004)	<0.001
2014	0.024(0.004)	<0.001
2015	-0.026(0.004)	<0.001
2016	-0.031(0.004)	<0.001
<b>Dairy cows</b>	0.679 (0.072)	<0.001
<b>Agri – environment payments</b>	-0.003(0.001)	0.004
<b>Dairy cow trend</b>		
Small decline	0.046(0.012)	<0.001
Small increase	0.061(0.012)	<0.001
Increase	0.065(0.012)	<0.001
<b>Area</b>	-0.036(0.006)	0.031
<b>Tenure</b>		
FAT	-0.009(0.006)	0.166
FBT	-0.016(0.006)	0.004
<b>Specialisation</b>	-0.001(0.0002)	<0.001
<b>Organic</b>		
Organic	0.019(0.008)	0.012
<b>Diversification</b>		
0.1 – 0.99%	-0.003(0.004)	0.336
1 - 4.99%	-0.013(0.004)	0.003
5 – 9.99%	-0.017(0.008)	0.037
> 10%	-0.027(0.010)	0.009
<b>Long term debt</b>	-0.004(0.001)	<0.001
<b>Short term debt</b>	-0.008(0.003)	0.002
<b>Costs * dairy cows</b>	-0.120(0.028)	<0.001
<b>(Intercept)</b>	-0.867(0.148)	<0.001

## 7.3 Model diagnostic plots



**Figure 16. Standardised residuals plotted against fitted values for the farm business and agriculture models**



**Figure 17. Quantile-quantile plot for the farm business and agriculture models.**

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