Department for Environment Food & Rural Affairs

Characteristics of high performing cereal farms in England

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1. Contents

2. Executive Summary

Performance in this report refers to economic performance, measured as the ability of a given farm to turn monetary inputs into monetary outputs. This analysis covers cereal farms in England for the years 2010/11 – 2016/17.

There is a great deal of variation in performance for cereal farms. Under 0.1% of the variation in farm business performance is related to large-scale geographic factors (e.g. regional differences in soil and climate). In contrast around 44% is attributed to temporal variation, such as adverse weather events and price fluctuations. 56% is contributed by the characteristics of the farm business itself, such as differences in management ability and local geographic effects.

Farm specific variables relating to performance were examined further, summarised 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	↓	↓	Farms with greater debt tended to have reduced agricultural and farm business performance.
Diversification	↑	↓	Farms which devoted more resources to diversified enterprises tended to perform less well in the agricultural portion of the business, but better at the farm business level.
Agricultural specialisation	–	–	There isn't a clear relationship between agricultural specialisation and performance.
Agri-environment scheme payments	↓	↓	Farms which received a greater proportion of their income from agri-environment schemes tended to have poorer farm business and agriculture performance.
Unpaid labour	–	↑	When including an imputed cost for unpaid labour, farm businesses which utilise large proportions of unpaid labour tended to have better performance in the agricultural portion of the business, while this had no impact on the farm business performance.
Contract work	↑	↑	Those farms which used and/or engaged with more contracting work tended to have better agricultural performance and farm business performance.
Tenure	↑↓	↑↓	Owner occupied farms tend to perform slightly better than tenanted farms.
CEH Code	–	–	There is not a clear pattern to the impact of land classification on business performance.

Land area	↑	↑	Larger farms tended to be better performers in both the farm business overall and the agricultural portion.
Farmer education	–	–	There is not a clear pattern to the impact of the education level of the principal farmer on business performance.

3. Introduction

Financial returns received by farm businesses in England vary widely. Though farms with similar characteristics; sector, size or location for example, might be expected to achieve similar incomes, this is often not true. The 'performance' of farm businesses here refers to the ability to convert monetary inputs into outputs, thus, a higher performing farm generates higher monetary outputs from a given level of inputs in comparison to a less well performing farm business.

The variation in the performance of cereal farms in England in 2016/17 can be seen in Figure 1, where performance is calculated as the ratio of outputs to inputs and shown for the farm business as a whole (see Figure 1a) and for the agricultural portion of the business[1] (see Figure 1b). Only 55% of farms broke even overall (those that achieved £100 or more of outputs, for every £100 of inputs, shaded in light green in Figure 1a). This proportion drops dramatically (to 18%) when considering only the agricultural portion of the business.

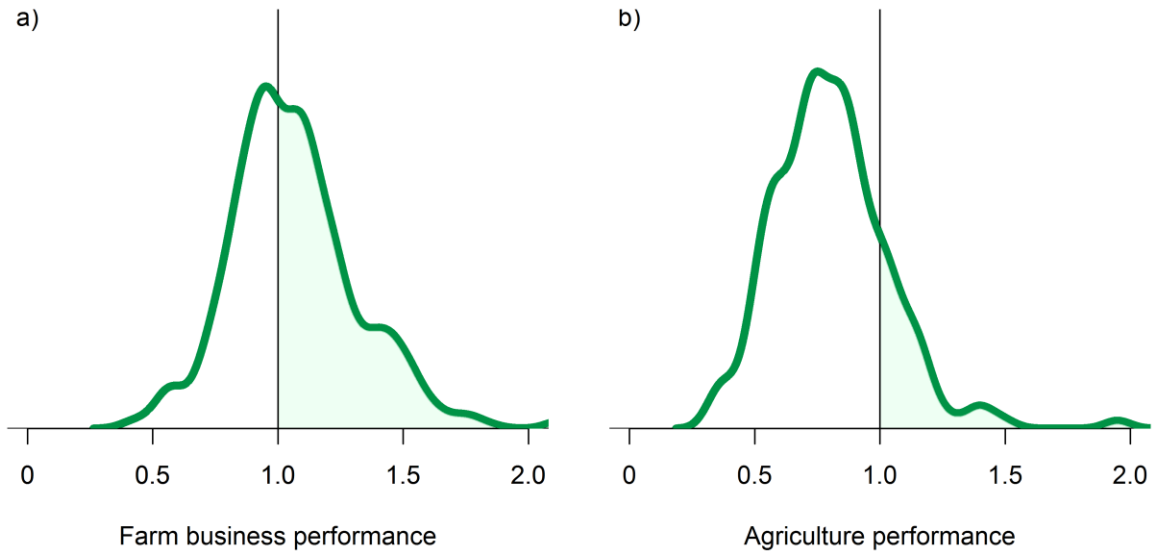

Figure 1. The distribution of farm performance scores for cereal farms in England in 2017/18, calculated as the ratio of outputs to inputs (including an imputed costs for unpaid labour). (a) The farm business as a whole and (b) the agricultural portion of the business only.

[1] The agricultural portion of the business excludes income from diversified enterprises, Agri-environment schemes and Direct Payments.

Across all countries and farm types, Kimura and Le Thi (2013) found that low performers relied much more on support as a source of farm income than the high performers, a pattern which is true of English farms too (Defra, 2018). For many farmers farming is not only a business but a lifestyle, so economic performance may not be the main driver of their on-farm decisions. Often independence, status, work satisfaction and access to housing are cited as the dominant reasons for accepting lower financial incomes (Wilson, et al., 2013; Redman, et al., 2018). In summary, while there may be a great potential for improvement, not all of this potential will be realised because many will not have the capacity or willingness to change.

3.1. Purpose

The purpose of this report is to provide a current assessment of the characteristics associated with economic performance for cereals farms in England. This work was done alongside analysis looking at the characteristics associated with economic performance for dairy (Jones, 2020) and grazing livestock (Betts, 2020) farms.

3.2. Definitions

In this report, by 'performance' we are referring to the economic performance of a farm. For many farmers this might describe only one aspect of what farming performance means to them, since other benefits and lifestyle choices might be just as, if not more important than the financial aspects of running a farm business. However, for the purposes of this report we are concerned with the ability of farm businesses to turn monetary inputs into monetary outputs, which can be expressed as a ratio:

$$\frac{\text{income generated by the farm}}{\text{costs associated with it}}$$

This ratio has been used to explore the geographical and temporal variation in farming performance across England. In order to explore in more detail the variables which are associated with farming performance, performance was defined as the linear relationship between inputs, influencing variables and outputs (see Appendix A for methods).

Throughout the analysis presented here, an imputed cost for unpaid labour using the market rate has been included as a cost, removing the economic advantage of receiving labour for free.

Within the Farm Business Survey of England[2], 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.

[2] https://www.gov.uk/government/collections/farm-business-survey

3.3. Data and Methodology

Data was taken from the Farm Business Survey of England for 2010/11 – 2016/17. Farms were included in the analyses if they were classified as having a farm type[3] of cereals in at least three of these years. 401 farms met this condition, with 209 of these surveyed in all seven years, and 312 providing data in at least five years. Most (77%) of the farms were always classified as cereals, with the remainder being classified predominantly as general cropping or mixed farms in a minority of years.

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 performance was defined as the linear relationship between inputs, influencing variables and outputs. Costs 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. A detailed breakdown of data and methods used can be found in Appendix A.

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 should not be used to infer causation. A significant relationship between two variables does not give any indication of which drives the other, if at all. But understanding the characteristics of high performers will allow farmers and policymakers to make informed decisions on improving the performance of farm businesses. It is of course possible that other factors not included in the model influence a farm's performance, though we included all plausible candidate variables that we consider could be explanatory.

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3 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/365564/fbs-uk-farmclassification-2014-21oct14.pdf

4. Results

Analysis was separated into two distinct 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. Sources of variation in performance

This section describes the analysis of farm performance across farms in England, and how variation in performance may be attributed to geography, changes over time and farm characteristics.

To do this the output/input ratio[4] of each farm in each year was analysed. The National Character Area[5] (NCA) which each farm was predominantly located in is used to represent the geography of each farm. NCAs are a natural subdivision of England based on a combination of landscape characteristics, biodiversity, geology and economic activity. There are 159 National Character Areas and they follow natural, rather than administrative, boundaries.

Figure 2 shows the spatial distribution of farm performance based on agricultural inputs and outputs for cereal farms for the year 2010/11 – 2016/17 (see Figure 12, Appendix B, for the farm business distribution). There is little sign of any wider regional effects, with most areas having a mix of high and low performers. This is reflected in Table 2, where NCA accounts for 0.04% of the total variability in the output/input ratio for the farm business, and less than 0.02% of total variability in the output/input ratio for agriculture. This figure will likely underestimate the true figure due to the limited geographic information available for FBS farms, but it is substantially lower than year to year variation within farms, which accounts for 44%% and 39% of variability in output/input ratios for the farm business and agriculture respectively. Year-on-year variation can be caused by factors such as poor weather or price fluctuations. Gradual changes in efficiency over the seven years of data will also contribute to the year to year variation.

The variability between farms, due to farm characteristics such as management practices or farm size, accounts for 56% of total variation in the farm business output/input ratio, and 60% of the total variation in agricultural output/input ratios. Variability between farms could be due to factors which a farmer might be able to influence, such as choice of crops or debt taken on, as well as factors which are more difficult or impossible to change, such as local geographic factors or farm size. These sources of variation are explored further in the following stage of analysis.

These patterns are very similar to those found previously (Langton, 2011), and to that of the accompanying analyses of grazing livestock (Betts, 2020) and dairy (Jones, 2020)

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[4] The output/input ratio is the ratio of outputs (either farm business or agriculture outputs) to inputs (either farm business or agriculture inputs. Both inputs include an imputed cost for unpaid labour calculated at the market rate).

[5] Formerly known as Joint Character Areas (JCAs). See https://www.gov.uk/government/publications/national-character-area-profiles-data-for-local-decision-making

farms, where year-to-year and farm-to-farm variation are similarly dominant over that coming from large scale geographic effects.

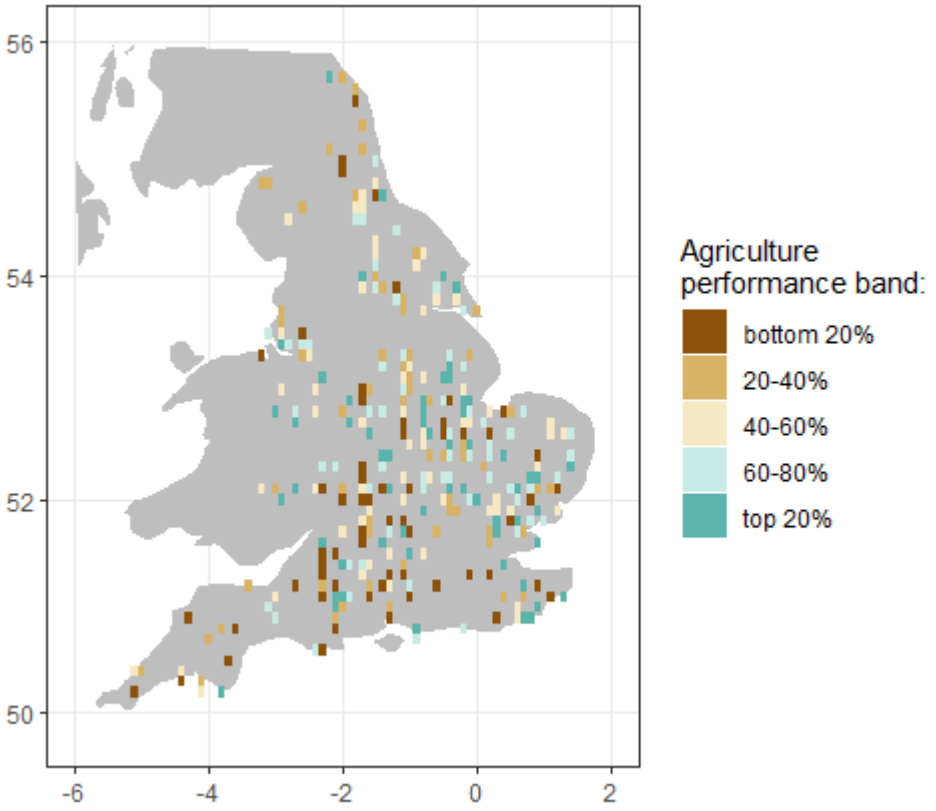

Figure 2. Spatial distribution of output/input ratios calculated from agricultural inputs and outputs only. Mean performance for farms falling within each 10km grid square are shown.

Table 2. Sources of variation within the dataset

	Farm business		Agriculture	
Component	Variance	% of total	Variance	% of total
Geographical variation (NCA)	0.04	0.02	0.03	<0.02
Year to year variation within farms	71.30	43.70	61.05	39.46
Farm to farm variation	91.83	56.28	93.65	60.52

4.2. Farm characteristics related to farming performance

This section of the analysis considered variables which are particular to a farm. 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 issues. Some variables had to be removed from the outset due to insufficient data quality or quantity, for example; information on the business management practices was not collected for all farms, and the resultant sample size was too small to robustly infer trends. Additionally, for cereals farms in particular, some variables were not investigated due to their distribution in the data. Across the seven years of data only 6% of farms had any organic land, and only 20 farms are classed as Less Favoured Area (LFA), so these variables were discounted at a preliminary stage of analysis.

A summary of the variables found to be related to farm business or agricultural performance is in Table 3. Full model outputs (see Table 5, Table 6), diagnostic plots (see Figure 15) and the results showing the general relationship for year (see Figure 13) can be found in Appendix B.

Table 3. Variables found to be related to either farm business or agricultural performance. 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
Costs (farm business or agriculture)	2082	**<.0001**	1188	**<.0001**
Land area	265	**<.0001**	163	**<.0001**
Year	144	**<.0001**	139	**<.0001**
Agricultural specialisation	54.0	**<.0001**	24.6	**<.0001**
Diversification cost	18.1	**<.0001**	21.6	**<.0001**
Contracting costs	17.1	**<.0001**	18.7	**<.0001**
Income from agri-environment schemes	13.8	**0.0002**	110	**<.0001**
Proportion of SLR arable	53.5	**<.0001**	24.6	**<.0001**
Tenancy	5.6	**0.0037**	4.4	**0.0129**
Debt	5.6	**0.0183**	4.7	**0.0308**
Education	2.4	**0.0183**	-	-
CEH land code	-	-	2.7	**0.0001**
Unpaid Labour	-	-	8.5	**0.0035**
Specialisation	2.4	0.1248	4.5	**0.0342**
Land area and specialisation interaction	3.8	**0.0500**	-	-
Costs and debt interaction	6.04	**0.0141**	9.2	**0.0024**

The variables from Table 3 are grouped into two categories: 'farm characteristics' and 'business decisions', on the basis that, at least in principle, it may be easier for a farm business to make changes to its management decisions than to the characteristics of the farm. These variables are discussed in turn in the following section. To visualise the results, predictions have been made using the fitted models, such that the impact of each variable on predicted performance can be assessed. Absolute predicted values of performance should be treated with caution however, since they are estimated using 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. Debt

'Indebtedness' in this case was measured as total interest payments as a proportion of total costs. Farms with greater levels of debt will pay higher interest charges, and larger

farms will tend to take on more debt (Defra, 2019). Making this measure proportional to total costs provides an indicator of debt which is independent of the economic size of the business. Farms with greater indebtedness tended to have slightly lower than average performance for the farm business as a whole, and more pronounced reduced performance for the agricultural part of the business (see Figure 3).

This finding contrasts with that of Kimura and Le Thi (2013) who, as part of a large cross country piece of analysis, found that higher performing cereal farms tended to have larger debt ratios. Other studies concentrating on English farms report broadly similar findings to that here, including English farms across all farm types (Hadley, 2006) as well as English cereal (Langton, 2011) dairy (Langton, 2013; Jones, 2020) and grazing livestock farms (Langton, 2012; Betts, 2020). It is possible that indebted farms face greater financial constraints which limits their ability to adjust to shocks or make investments and thus reduces their performance. Conversely, it is also possible that poorer performing farms are forced to take on greater levels of debt in order to cover unexpected shortfalls in income.

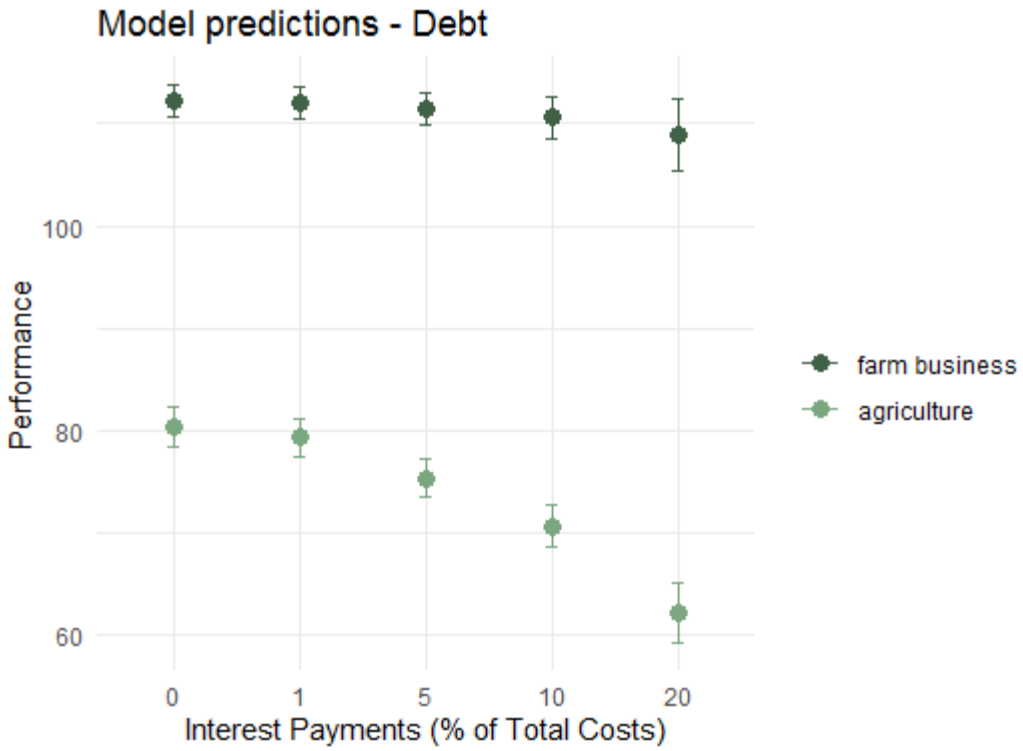

Figure 3. The relationship between debt and performance for both the farm business and agriculture models. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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.

For both the farm business as a whole, and the agricultural portion of the business, while higher inputs were always correlated with higher performance, the negative impact of increased indebtedness was larger for those with higher inputs; and therefore a higher absolute level of debt. Figure 14 in Appendix B shows this relationship.

4.2.1.2. Diversification

Diversification refers to enterprises that a farm business undertakes outside agriculture, such as tourism or renting out farm buildings, but which utilise the farm's resources. The extent of diversification was measured by looking at the proportion of business costs associated with diversified enterprises.

Greater diversification was associated with lower agricultural performance, but greater farm business performance (see Figure 4). This might be expected as time and resources diverted away from agriculture might be expected to reduce the outputs from agriculture, i.e. most farms will not hire more staff to set up/run diversified enterprises and so they necessarily divert management capacity away from agriculture. This loss of agricultural output is then more than compensated for such that the overall farm business performance is greater.

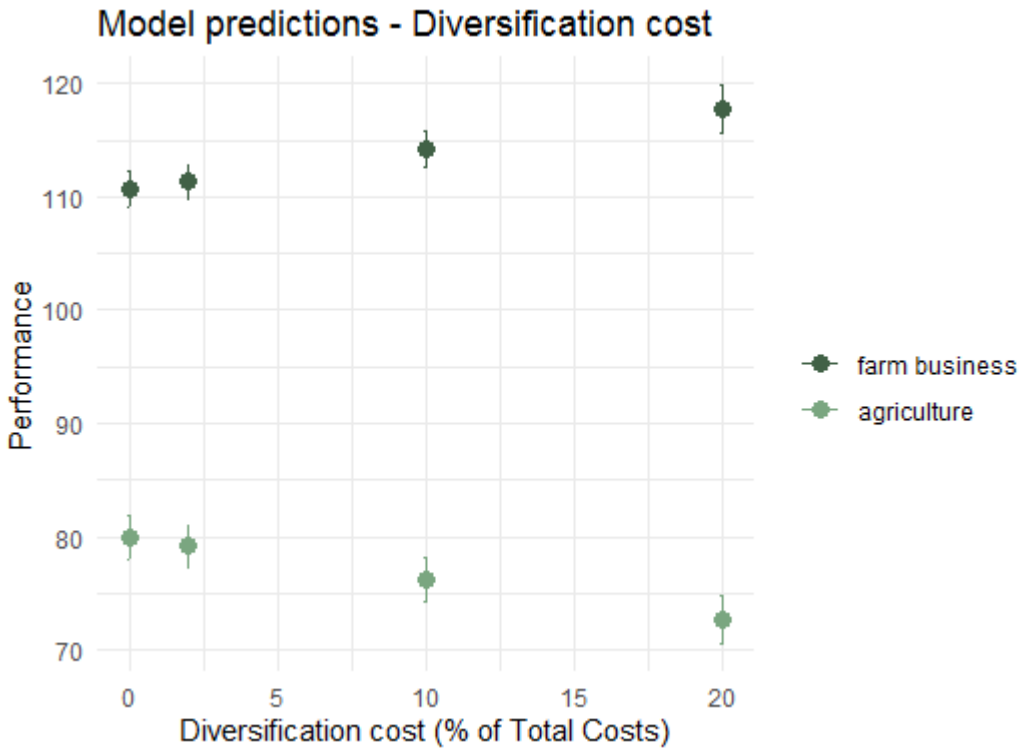

Figure 4. The relationship between costs associated with diversified enterprises and agricultural outputs. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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. Agricultural specialisation

No convincing trend between farm business or agricultural performance and agricultural specialisation was found. Although some significant relationships emerged from the modelling, upon closer inspection these were found to be extremely weak.

The level of specialisation in cereals farms was assessed using the Standard Labour Requirement (SLR) of the various agricultural enterprises on each farm. The SLR of a farm represents the normal labour requirement for all the enterprises on a farm under typical conditions. The SLR for a farm is calculated from standard coefficients applied to each enterprise on the farm, these standard coefficients representing the input of labour required per head of livestock or per hectare of crops for enterprises of average size and performance.

Using SLR, the level of specialisation of each farm was measured in two ways: Firstly by looking at the proportion of total SLR which was attributed to the arable enterprise, of which there are nine out of a total of 34 agricultural enterprises recorded. Secondly, by assessing the diversity of SLR across all 34 agricultural enterprises. This is similar to the approach used in previous analysis (Clothier, et al., 2008; Langton, 2012). This measure is an index, where 100 represents a fully specialised farm which engages in only one agricultural enterprise (of the possible 34) and 0 represents a very un-specialised farm engaging in many agricultural enterprises. For a full list of the 34 possible agricultural enterprises see Appendix A.

4.2.1.4. Agri-environment schemes

Those farms with a greater proportion of their income derived from agri-environment scheme payments tended to have lower performance, for both agriculture and the farm business (see Figure 5). This suggests that agri-environment scheme payments received do not compensate for the loss in agricultural output for an average cereals farm. Dairy and grazing livestock farms also saw a negative relationship between agri-environment payments and agricultural performance, but no relationship was found for dairy farms at the farm business level, and a positive relationship was found for grazing livestock at the farm business level. This suggests that the impact of agri-environment scheme payments on overall farm business performance is quite different across different sectors of agriculture.

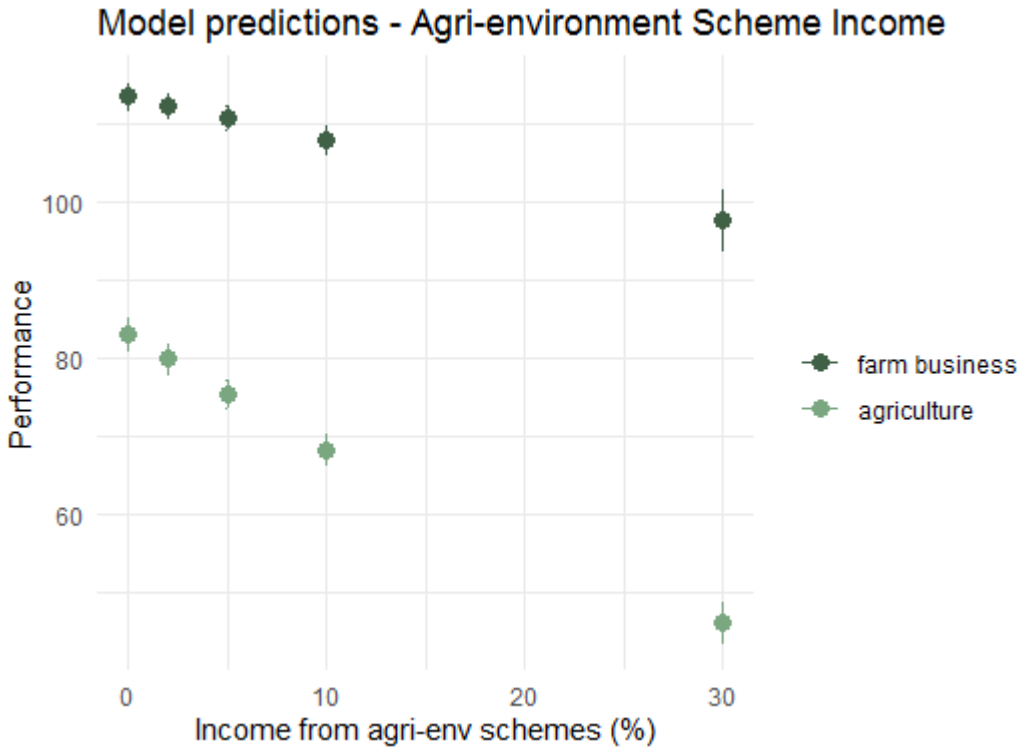

Figure 5. The relationship between the proportion of farm income from agri-environment schemes and performance. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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 (usually from the farmer and family members) was costed using the market rate, and included as a cost in the modelling in order to remove the inherent advantage of receiving labour at no cost.

When an imputed costs for unpaid labour was included in the modelling there was a positive relationship between unpaid labour and agricultural performance (see Figure 6a). This suggests that there is some added value which unpaid labour contributes to the agricultural portion of farm business. Unpaid labour may be more productive; it usually comes from the family, who are likely to be more personally invested in the business and might be more dedicated than hired labour. Perhaps this dedication is realised within the agricultural portion of the business, but not at the farm business level.

When the imputed costs for unpaid labour were excluded from the modelling the pattern remained unchanged and was apparent at the farm business level also (see Figure 6b) suggesting, unsurprisingly, that the monetary benefit of receiving labour at no cost is also a benefit to performance.

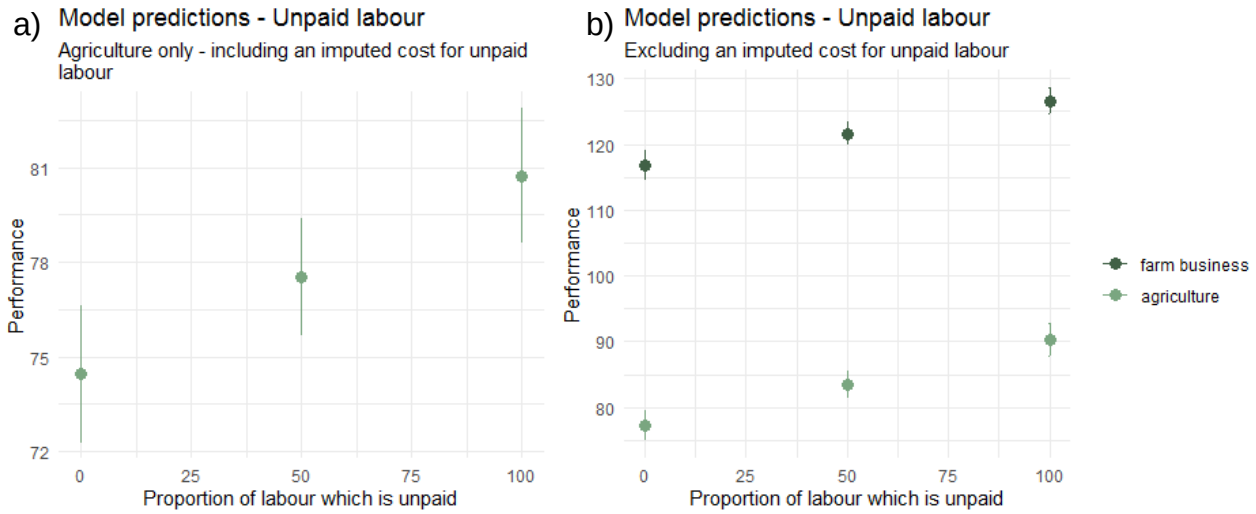

Figure 6. The relationship between unpaid labour and performance, including an imputed cost for unpaid labour using market rates (a) and excluding imputed costs (b). Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most 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. Contract work

The use of equipment and machinery on a contract basis was associated with increased farm business and agricultural performance (see Figure 7); farms which had a greater proportion of their machinery related costs associated with renting rather than buying and repairs tended to be better performers. This suggests that for the average cereal farm it is more efficient to hire machinery and its associated labour rather than own that machinery.

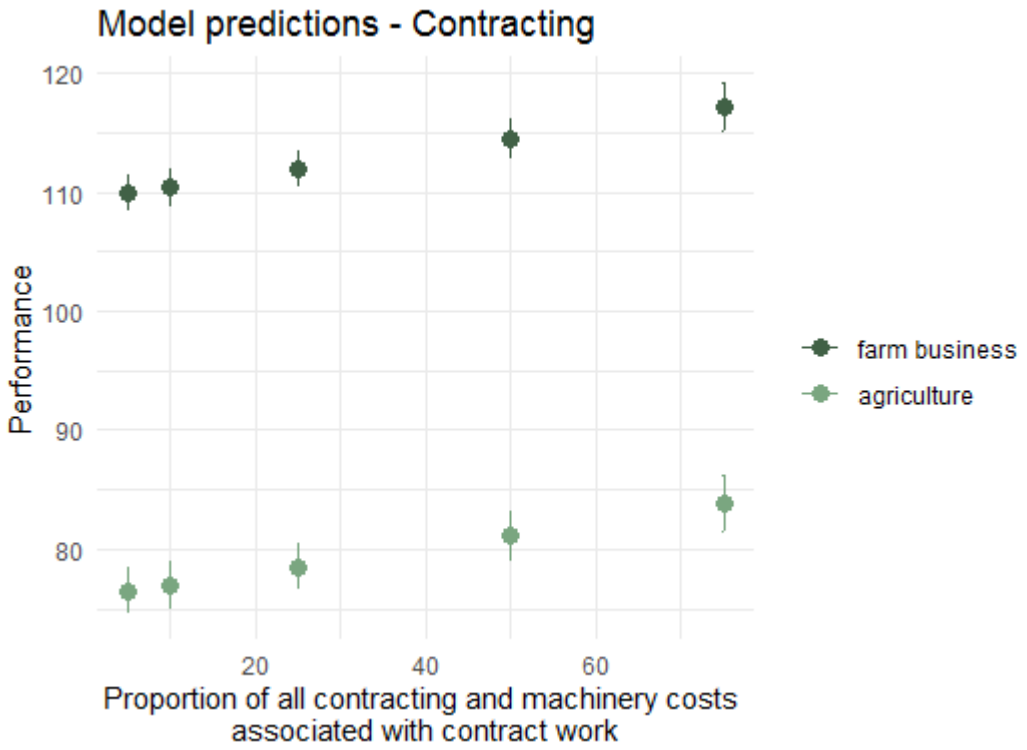

Figure 7. The relationship between contracting costs and performance. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard error. Absolute predicted values should 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 and are largely beyond the scope of a farmer to change.

4.2.2.1. Tenancy

Here farms were grouped into mainly owner occupied or mainly tenanted based on their farmed area. Those in the tenanted category were then spilt 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, owner occupied farms performed slightly better than tenanted farms for both farm business and agricultural performance (see Figure 8). The differences in average performance between owner-occupied and tenanted farms is small, and may solely be due to the fact that the costs included in the models did not include an imputed rent for owner-occupiers, but did include the actual rent paid by tenants.

In contrast to dairy farms (Jones, 2020), farms with the shorter FBT (Farm Business Tenancy) agreements performed better than those with the longer FAT (Full Agricultural Tenancy) agreements, though again the difference is only slight.

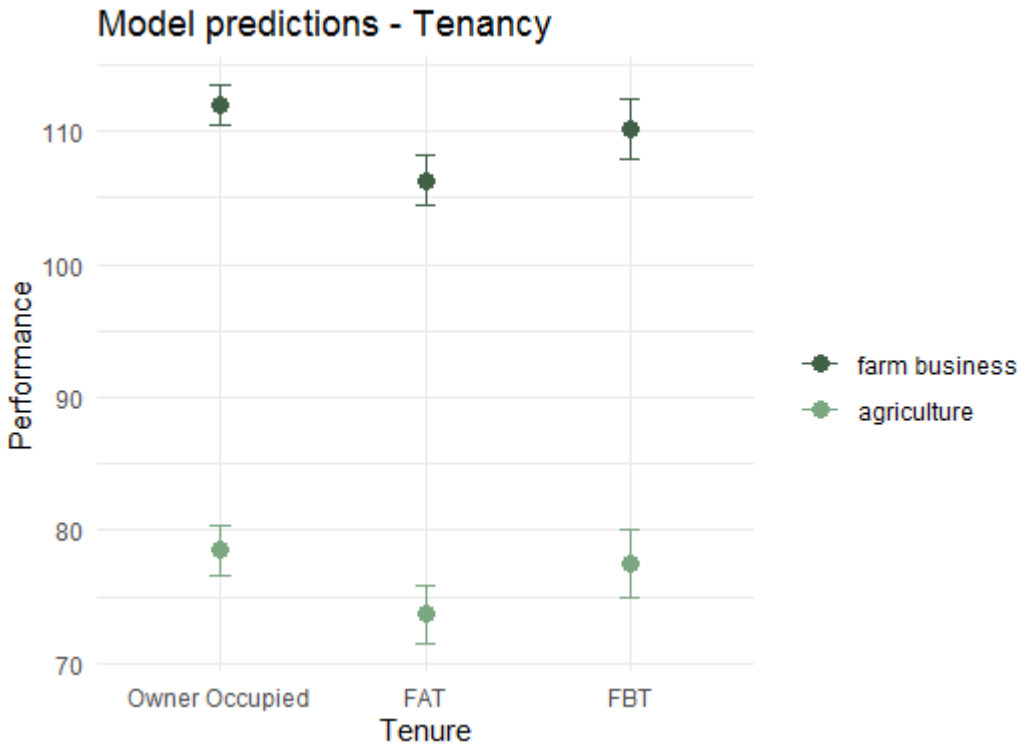

Figure 8. The relationship between tenancy and performance for both the agriculture and farm business models. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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. Land Area

Of course, unlike geographic location or soil quality for example, land area is not an entirely immutable property of a farm. Some farmers may have the ability or willingness to either rent or buy additional land or to rent out or sell their own land. However, for the purposes of this analysis we consider it to be closer to an intrinsic property of a farm than it is to the more “day-to day” farm business decisions described in section 4.2.1.

Farms which utilised a larger land area tended to be better performers, at both the farm business level and the agricultural portion of the business (see Figure 9). Crucially predictions were made whilst holding inputs the same and varying only the land area variable, and whilst is it highly unlikely that two farms which are 50 and 500 hectares respectively could function on the same input costs, the overall pattern is probably representative. Direct Payments and agri-environment scheme payments, which are paid at least in part on a per area basis, are excluded from the agriculture model but included in the farm business model and yet the relationship is very similar for both. The predicted performance of otherwise “typical” farms with land area much lower than the average figure of 200ha is far below breaking even. This may suggest that economies of scale are at play.

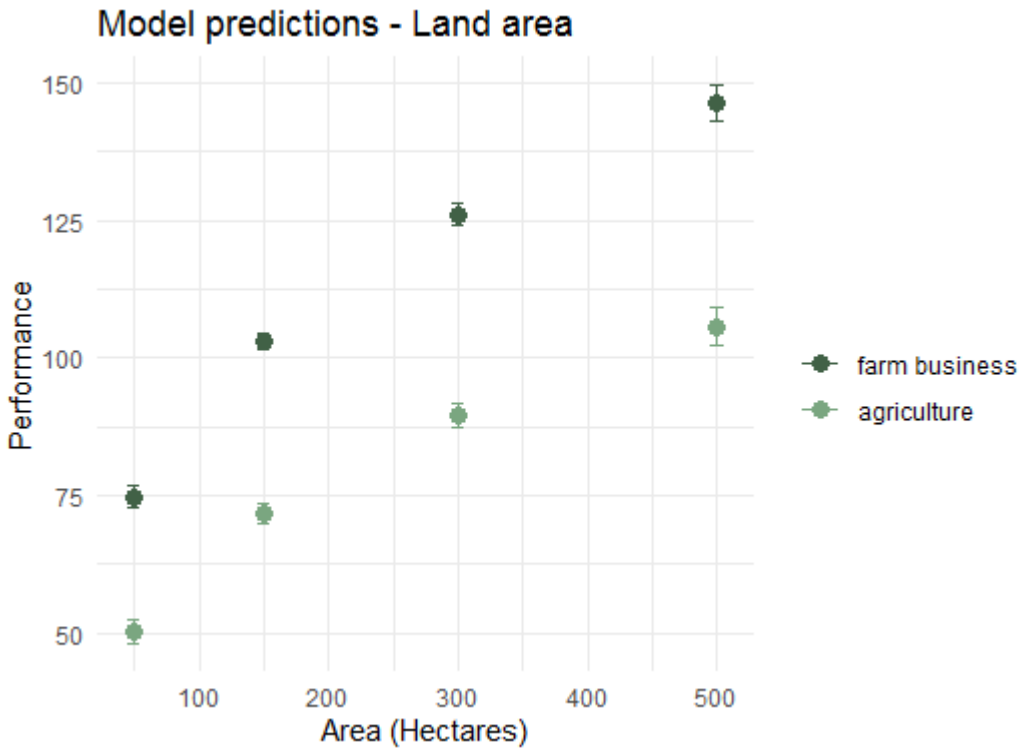

Figure 9. The relationship between farm size (in hectares) and performance, for both the farm business and agriculture models. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars 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.

4.2.2.3. Farmer education level

Similarly to section 3.2.2.1, though a farmer may choose to undertake training or study for a qualification and therefore change this property, this does not fall under day-to-day farm business decisions and so for the purposes of this analysis we consider it to be closer to an intrinsic property of a farm than those variable described in section 4.2.1.

There was a relatively small positive relationship between farm business performance and education level (up to College/Diploma level, see Figure 10). There are indications that vocational study (Apprenticeship) had a positive influence, but the sample sizes are small and so further investigation is needed.

Similarly to the discussion of farmer age in the accompanying report on grazing livestock farms (Betts, 2020) only the education level of the principal farmer is recorded in the Farm Business Survey, often this is the most senior family member. Often more than one generation of a family work together to manage a farm. Under these circumstances the details of the most senior family member will be recorded, while in reality the skills and knowledge of all the people involved in managing the business contributes to the overall performance. This includes non-family members such as workers, advisors or contractors, making the interpretation of this variable extremely limited.

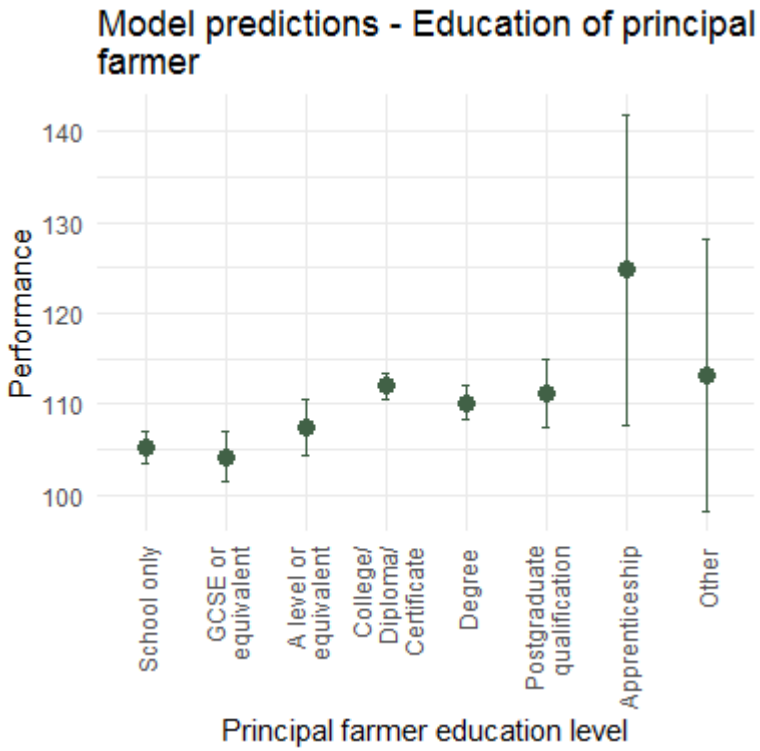

Figure 10. The relationship between farmer education level and performance for both the farm business model. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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.

4.2.2.4. CEH land classification

While large scale geographic effects contribute very little to the variation in the performance of farms (see section 4.1) that is not to say that the geography of a given farm does not influence its performance.

A relationship was found between the Centre for Ecology & Hydrology (CEH) Land Classification Code recorded for a farm and the performance of the agricultural portion of the business of that farm (see Figure 11). Unsurprisingly, farms with the majority of their land in areas which favour agriculture, such as fertile lowlands, tended to be better performers. Conversely those with the majority of their land in land types which are less favourable for agriculture, such as upper mountain slopes, tended to be poorer performers. However there was a great deal of variation within and between each land classification.

The location of farms in the FBS data is only known within a 10km grid square, and soil quality varies on much smaller scales than CEH code or JCA can capture, and even within farms. The influence of localised geography on performance is complex and highly specific to a given farm. The fact that this relationship is not present in the farm business model suggests that possibly poor land quality is in some way compensated for by the rest of the business. However it is equally plausible that there is an impact of land quality on farm business performance but the FBS sample lacks the statistical power to detect it. While it is not in the scope of this report to comment in any great detail on the effect of geography and soil type on performance, it is useful to consider that any potential gains in efficiency a

farm may be able to make through business decisions will be sensitive in some way to the type of land a farm sits on.

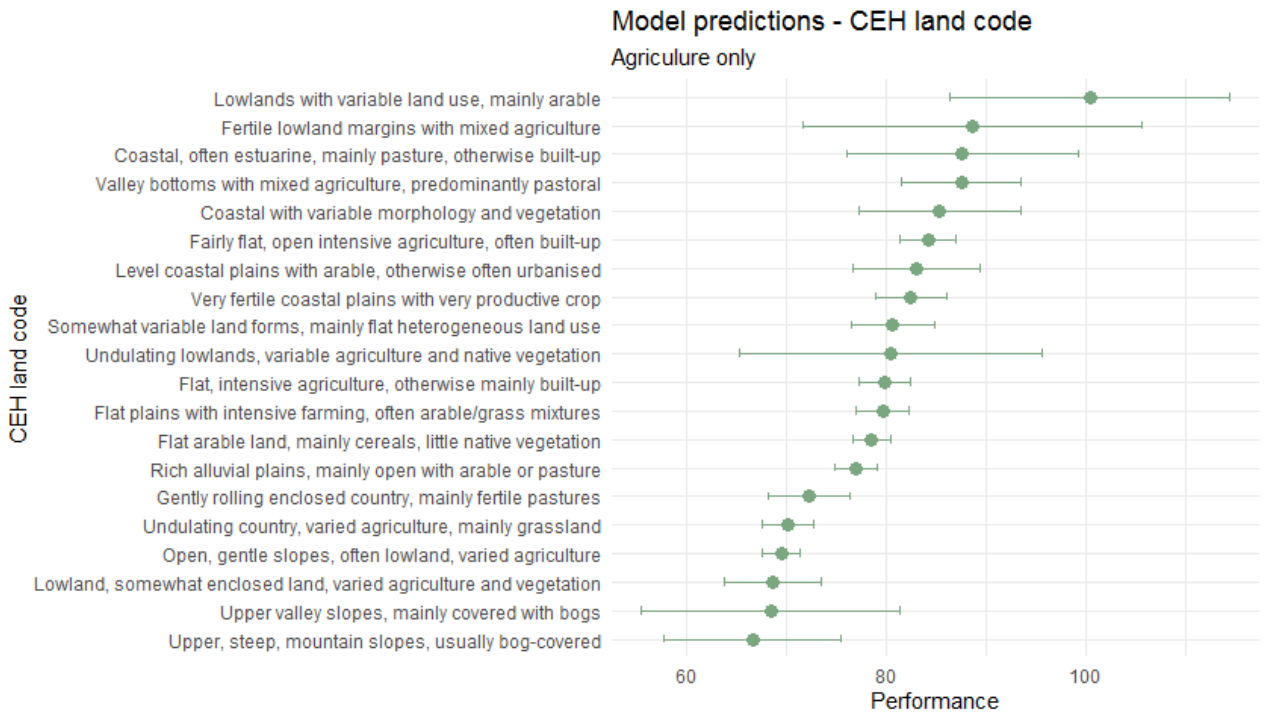

Figure 11. The relationship between CEH land classification and performance for the agriculture model. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard error. 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.

5. Conclusions

This work fits into an active area of research and similar research questions have been asked of different farming systems within England, in particular the work of Betts (2020), Jones (2020) and Langton (2011; 2012; 2013), as well as farming systems across the rest of the world. A summary of the results found here are in Table 4.

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

Variable	Evidence Strength	Comments
Debt	Strong – this pattern has been found across many systems and studies.	More indebted farms tended to have reduced agricultural and farm business performance.
Diversification	Moderate – similar patterns have been found in other systems and previous studies.	Farms which devoted more resources to diversified enterprises tended to perform less well in the agricultural portion of the business, but better at the farm business level.
Agricultural specialisation	Weak – no convincing trend was found	There isn't a clear relationship between agricultural specialisation and performance.
Agri-environment scheme payments	Strong - this pattern has been reported elsewhere.	Farms which received a greater proportion of their income from agri-environment schemes tended to have poorer farm business and agriculture performance.
Unpaid labour	Moderate – similar and contrasting patterns have been reported elsewhere.	When including an imputed cost for unpaid labour, farm businesses which utilise large proportions of unpaid labour tended to have better performance in the agricultural portion of the business, while this had no impact on the farm business performance.
Contract work	Moderate – similar patterns has been reported elsewhere.	Those farms which used and/or engaged with more contracting work tended to have better agricultural performance and farm business performance.
Tenure	Moderate - similar patterns have been found in other systems and previous studies.	Owner occupied farms tend to perform slightly better than tenanted farms.
CEH Code	Weak – the quality of the underlying data is poor.	There is not a clear pattern to the impact of land classification on business performance.
Land area	Strong – a well-established pattern due to the impact of area-based payments.	Larger farms tended to be better performers in both the farm business overall and the agricultural portion.
Farmer education	Weak – the quality of the underlying data is poor.	There is not a clear pattern to the impact of the education level of the principal farmer on business performance.

Many other variables were considered and included in the analysis here but did not appear to have a relationship with performance. This does not mean necessarily that these variables are unrelated to performance. All statistical analysis is limited by the sample size of the data considered, and with more data comes more power to detect relationships. Subtler, or more complex, relationships may not be picked up by the models.

It is important to recognise that economic performance is not the only consideration for many farmers, and for those who it is important, they are likely to place more onus on the performance of the farm business as a whole as opposed to purely agriculture. Farmers also 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.

6. Appendix A

Data was taken from the Farm Business Survey[6] of England for 2010/11 – 2016/17. Farms were included in the analyses if they were classified as having a farm type[7] of cereals in at least three of these years. 401 farms met this condition, with 209 of these surveyed in all seven years, and 312 providing data in at least five years. 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.

Anomalous data were excluded from the analysis, this included one farm with missing data for its tenure status.

Statistical analysis was broken up into two sections; the first using two models to assess the spatial and temporal variation in farm output/input 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 (Pinheiro, et al., 2018) package 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. Breakdown of variation in performance

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

$$performance\ ratio \sim \mathrm{Farm/Year} + \mathrm{NCA}$$

Where performance ratio refers to the output/input ratio for the farm business and agriculture respectively, and NCA refers to the National Character Area. Each dependant variable was fitted as a factor.

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.

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[6] https://www.gov.uk/government/collections/farm-business-survey

[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/365564/fbs-uk-farmclassification-2014-21oct14.pdf

6.2. Farm characteristics related to farming performance

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

$$\log(outputs) \sim \beta_0 + \log(costs) + \text{year} + \text{type} + \log(area) + variable_1 + \cdots + variable_n + \text{farm} + \varepsilon$$

Where;

- log(outputs) and log(costs) are log transformed outputs and costs in whole thousands of pounds.
- β_0 is a global intercept
- year is a categorical variable denoting each year
- log(area) is log transformed total area, including woodland, buildings etc.
- $variable_1$ … $variable_n$ are additional variables
- farm is fitted to have a random effect on the intercept
- ε is residual error

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.

The full list of agricultural enterprises which feed into the specialisation index calculation are:

- Cereals
- Oilseeds
- Hops
- Sugar Beet
- Field peas & beans
- Main crop Potatoes
- Early Potatoes
- Outdoor Vegetables
- Other peas & beans
- Vining Peas
- Top soft fruit
- HNS
- Vegetables under glass
- Flowers under glass
- Mushrooms
- Set aside
- Dairy cows
- Beef cows
- Other cattle
- Ewes and rams
- Other sheep
- Sows

- Finishing rearing pigs
- Piglets
- Table fowl
- Laying hens
- Growing pullets
- Other poultry
- Fodder crops
- Horses
- Goats
- Deer
- Grassland
- Rough grazing

Arable enterprises are

- Cereals
- Oilseeds
- Sugar Beet
- Field peas & beans
- Main crop Potatoes
- Early Potatoes
- Outdoor Vegetables
- Other peas & beans
- Vining Peas

7. Appendix B

7.1. Spatial distribution of farm business output/input ratio

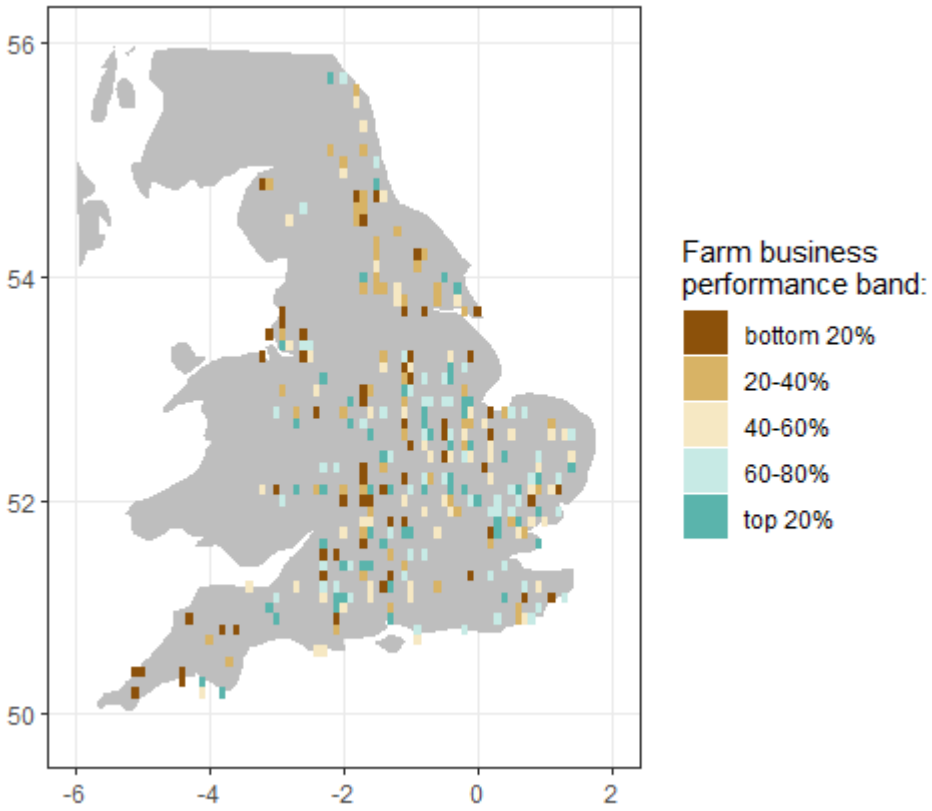

Figure 12. Spatial distribution of output/input ratios calculated from farm business inputs and outputs. Mean performance for farms falling within each 10km grid square are shown.

7.2. Relationship between other variables and performance

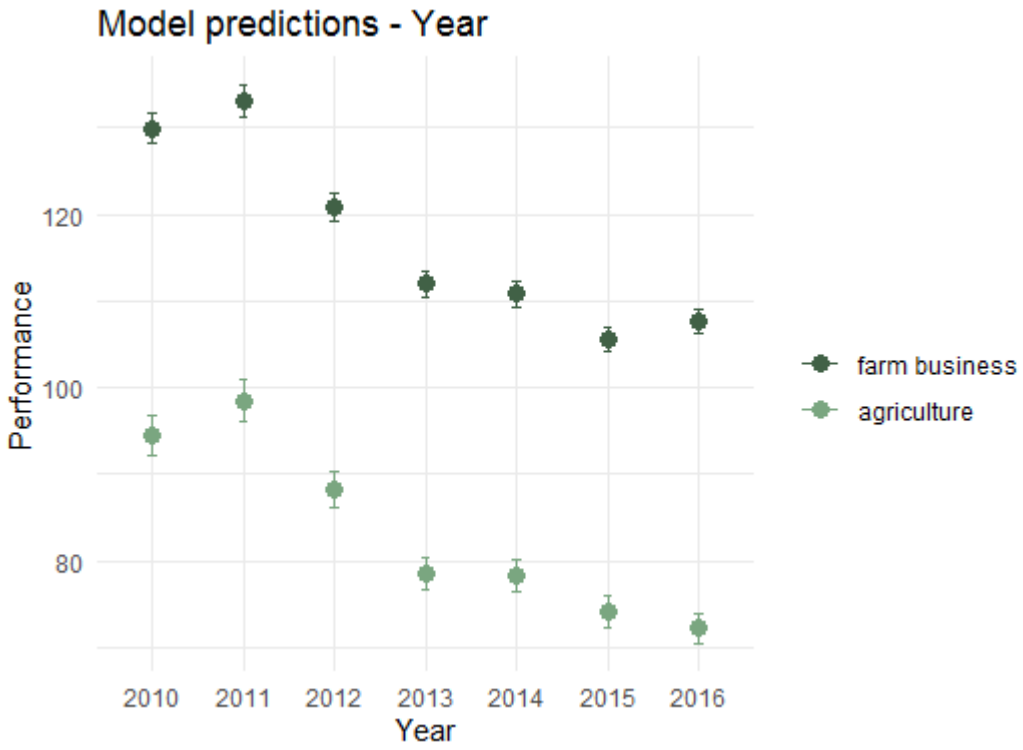

Figure 13. The relationship between year and performance for both the farm business and agriculture models. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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.

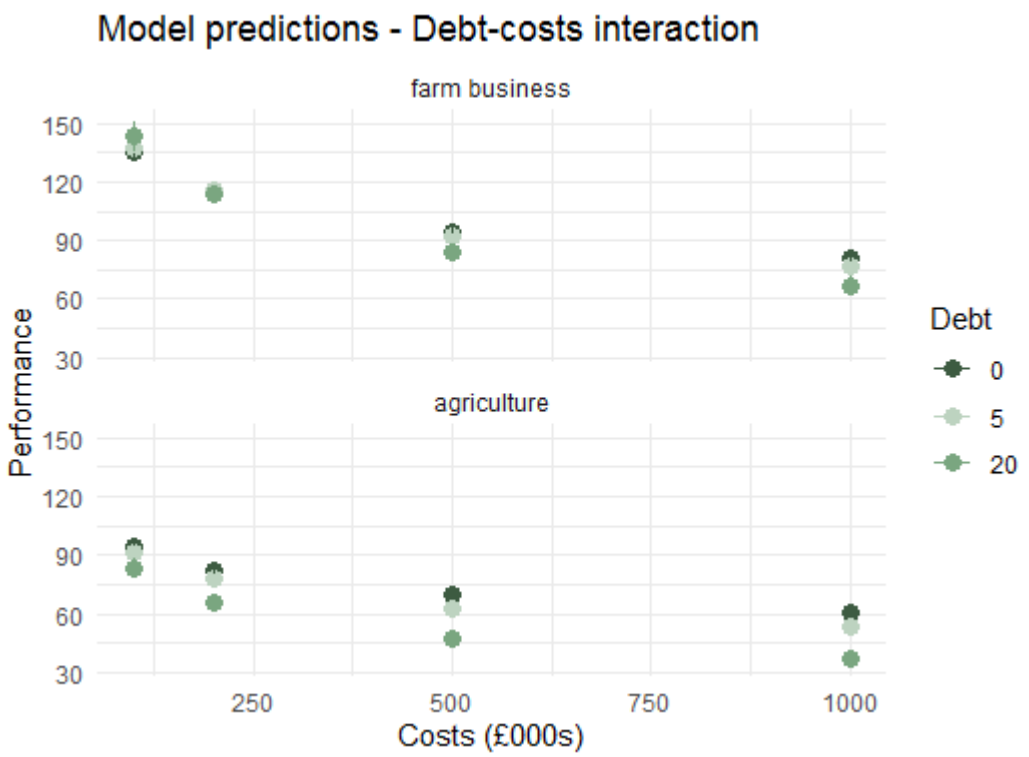

Figure 14.The relationship between debt (interest payments as a proportion of costs) and costs with performance. Predictions were made for an average farm with £230,000 inputs per annum and 200ha of land. Remaining variables were averaged or the most common factor level used. Error bars represent standard 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.

7.3. Model diagnostic plots

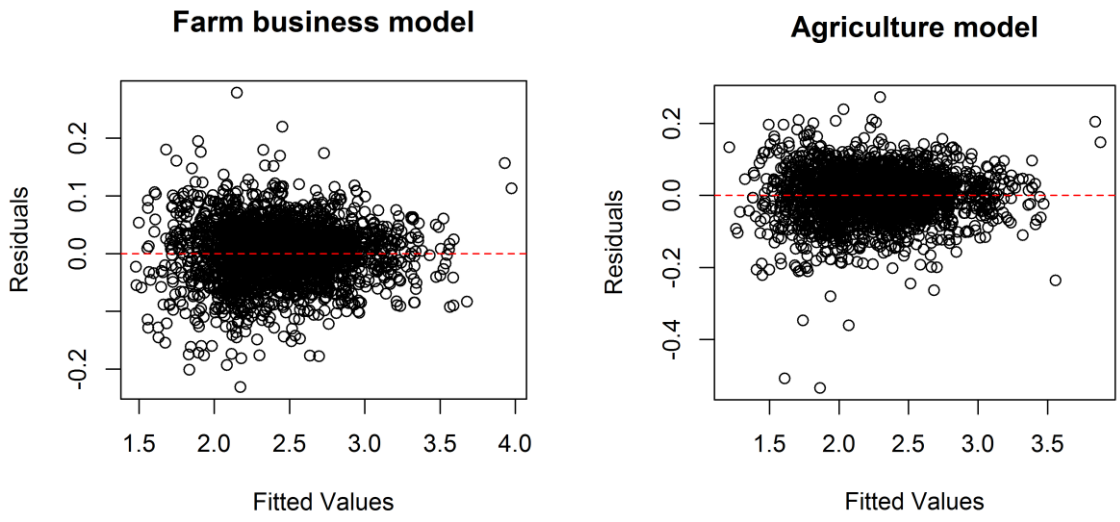

Figure 15. Model residuals plotted by their fitted values for the minimum adequate farm business performance model (left) and minimum adequate agriculture performance model (right).

7.4. Model coefficient estimates

Table 5. Coefficient estimates for terms in the farm business performance model.

Predictors	Estimates	CI
Costs		
log FBC full	0.77629	0.74299 – 0.80960
Tenancy		
Reference group: Owner-occupied		
FAT	-0.0225	-0.03547 – -0.00952
FBT	-0.00687	-0.02264 – 0.00889
Land Area		
LADJAREA	0.32188	0.27503 – 0.36874
Year		
Reference group: 2010		
Year 2011	0.01061	0.00212 – 0.01910
Year 2012	-0.03112	-0.03980 – -0.02244
Year 2013	-0.06461	-0.07335 – -0.05588
Year 2014	-0.06894	-0.07782 – -0.06005
Year 2015	-0.08989	-0.09899 – -0.08080
Year 2016	-0.08164	-0.09103 – -0.07224
Contracting		
Conrat	0.00039	0.00021 – 0.00058
Debt		
interest	0.01195	0.00161 – 0.02229
Farmer Education		
Reference group: School only		
GCSE or equivalent	-0.00404	-0.02858 – 0.02050
A level or equivalent	0.00958	-0.01675 – 0.03592
College/National Diploma/certificate	0.02721	0.01192 – 0.04251
Degree	0.02026	0.00271 – 0.03781
Postgraduate qualification	0.02443	-0.00604 – 0.05489
Apprenticeship	0.07422	-0.04159 – 0.19003
Other	0.03199	-0.08087 – 0.14485
Diversification		
Diversified costs	0.00135	0.00072 – 0.00197
Proportion of outputs from Agri-environment schemes		
Prop Agri	-0.00217	-0.00333 – -0.00102
Agricultural specialisation		
Special	0.10564	-0.02929 – 0.24056
Proportion of SLR arable		
Parable	0.00084	0.00062 – 0.00107
Costs and debt interaction		
lfbcosts1 * Interest	-0.00533	-0.00959 – -0.00108
Land area and specialisation		
Logarea * Special	-0.06004	-0.12055 – 0.00047

Table 6. Coefficient estimates for terms in the agriculture performance model.

Predictors	Estimates	CI
Land Area		
Logarea	0.32332	0.27356 – 0.37309
Costs		
lagcosts1	0.81136	0.76520 – 0.85752
Tenure		
Reference group: Owner Occupied		
FAT	-0.02741	-0.04566 – -0.00916
FBT	-0.00566	-0.02748 – 0.01616
Year		
Reference group: 2010		
2011	0.01806	0.00678 – 0.02934
2012	-0.02958	-0.04117 – -0.01800
2013	-0.08046	-0.09210 – -0.06881
2014	-0.08181	-0.09369 – -0.06994
2015	-0.10521	-0.11734 – -0.09308
2016	-0.11683	-0.12934 – -0.10431
Contracting		
Conrat	0.00056	0.00031 – 0.00082
Debt		
Interest	0.01359	0.00125 – 0.02593
Diversification		
Divcost	-0.00206	-0.00292 – -0.00119
Proportion of outputs from Agri-environment schemes		
PropIncomeAgri	-0.00851	-0.01010 – -0.00692
Proportion of SLR arable		
Parable	0.00079	0.00048 – 0.00110
Agricultural specialisation		
Special	-0.03354	-0.06457 – -0.00251
Unpaid labour		
Unpaid	0.00035	0.00012 – 0.00059
Costs and Interest interaction		
lfbcosts1 * Interest	-0.00812	-0.01336 – -0.00288
CEH Code		
CEH [2]	-0.00441	-0.04037 – 0.03155
CEH [3]	0.04841	0.01309 – 0.08372
CEH [4]	0.05588	0.01585 – 0.09592
CEH [5]	-0.00966	-0.07570 – 0.05638
CEH [6]	0.0127	-0.04202 – 0.06743
CEH [7]	0.08476	-0.00011 – 0.16964
CEH [8]	0.09614	-0.01885 – 0.21114
CEH [9]	0.07863	0.03911 – 0.11815
CEH [10]	0.05458	0.01531 – 0.09385
CEH [11]	0.03978	0.00328 – 0.07629
CEH [12]	0.0698	0.02372 – 0.11587
CEH [13]	0.05997	0.00842 – 0.11152
CEH [14]	0.07255	0.00089 – 0.14421
CEH [15]	0.0955	0.03129 – 0.15972
CEH [16]	0.0588	-0.10055 – 0.21814
CEH [21]	-0.01085	-0.16984 – 0.14815
CEH [24]	-0.02251	-0.13810 – 0.09309
CEH [25]	0.15495	0.03417 – 0.27573
CEH [27]	0.10095	-0.06022 – 0.26212

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