Stability of farm income: the role of agricultural diversity and agri-environment scheme payments

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Abstract

Instability (or variability) in farm income represents a significant challenge for farm management and the design of public policies. Identifying farming practices which can increase the stability of farm income may help farms to cope with shocks such as extreme weather events and economic challenges. Farming practices associated with increasing agricultural diversity and agri-environment schemes are considered to improve ecological functions and landscape resilience, however, their effect on the stability of farm income is not well known. Using a multilevel model, we analyse the effect of a range of farming practices and subsidies on the stability of farm income, and their relative importance, using four different measures of stability. We examine data for 2,333 farms in England and Wales, from 2007 to 2015, and use separate multilevel models for a range of different farm types to provide targeted recommendations for farmers. Here we show that greater agricultural diversity (i.e. lower degree of specialisation in different crop and livestock activities) increases the stability of farm income, in dairy, general cropping, cereal and mixed farms. Agricultural diversity is a particularly important factor for general cropping farms; increasing the degree of specialisation by one standard deviation (we use standardised coefficients), increases the variability of income by approximately 20%. Dairy, general cropping and mixed farms that receive more agri-environment payments also have more stable incomes, reducing variability by between 4 and 8%. In contrast, an increase in direct subsidies paid to farmers based on the area farmed is associated with a relatively large decrease in the stability of farm income, ranging from 6-35% across most farm types. Reducing the intensity of inputs is found to be an important factor increasing the stability of income for all farm types; on average reducing the intensity of inputs reduces variability of income by 20%. Practices associated with increasing agricultural diversity and agri-environment schemes have previously been found to lead to a better provision of ecosystem services and resilience to abiotic stresses, reducing the need for expensive chemical inputs. Engagement in environmentally sustainable farming practices including agri-environment schemes, increasing agricultural diversity, and reducing the intensity of inputs, may increase the stability of many farm businesses whilst at the same time reducing negative impacts of farming on the environment.

Keywords

Agri-environment schemes; Diversity; Farm income; Stability; Farm Business Survey; Sustainable farming practices

1 Introduction

Farm incomes are subject to a variety of threats including unpredictable weather, changes in policy or regulation, variation in the price of outputs and rising input costs (OECD, 2009). Levels of farm income are important, but the stability of income is also a key issue for agricultural businesses. Fluctuating incomes can affect farm decisions and the ability of a farm to sustain its operations year to year (Mishra and Sandretto, 2002; Severini et al., 2016). Instability (or variability) in farm income represents a significant challenge for farm management and the design of public policies. Greater stability of farm income, over a range of conditions, could improve the economic viability and sustainability of farms and therefore help maintain continuity in food production for a growing population with increasing demands for food (FAO, 2009). How we balance the need for food, the stability of farm businesses, as well as the protection of biodiversity and the environment also represents a major challenge.

Research has examined drivers of agricultural system dynamics (i.e. changes over time), however, quantitative assessments remain rare, particularly at the farm level (Dardonville et al., 2020). We summarise a range of farming practices and government payments which may support stability of farm income and the gaps identified in previous research.

One important strategy considered to increase the ability of agricultural systems to cope with shocks and variability, is increasing agricultural diversity (Dardonville et al., 2020; Gaudin et al., 2015; Urruty et al., 2016). Practices associated with increasing agricultural diversity involve harnessing ecological functions to increase the resilience and sustainability of landscapes and tend to have a positive impact on the natural environment (Pretty, 2008; Pretty and Bharucha, 2014; Rockström et al., 2017). Diversification of crop and livestock activities is commonly recognised as an effective tool for managing business and climatic risks, by lessening the effects of variable commodity markets and weather, at the farm level (Bradshaw et al., 2004; Castañeda-Vera and Garrido, 2017; Martin et al., 2017). The effect of agricultural diversification on economic stability has previously been examined using different financial variables. Greater diversification of crop and livestock revenue has been associated with an increase in the stability of gross farm revenue and household income across valley, hill and mountain regions of Switzerland (El Benni et al., 2012). In addition, growing a wider range of crops or using a mixed cropping and livestock system has been found to stabilise return on capital, for lowland and small upland farms in Argentina (Pacín and Oesterheld, 2014). Further empirical studies are warranted to validate the relationship between agricultural diversity (degree of specialisation in different crop and livestock activities) and the stability of agricultural systems in different contexts and at different spatial and temporal scales (Dardonville et al., 2020; Urruty et al., 2016), particularly for a range of farm types.

Previous research examining the effect of farming intensity (based on input or output intensity) on the stability of farm income has found mixed results. Nitrogen fertiliser and pesticides have been found to increase yield but, similarly, their effect on the variability of yields is unclear (Dardonville et al., 2020). Intensification commonly relies upon a greater use of expensive agri-chemicals (Geiger et al., 2010). Higher pesticide and fertiliser costs, used as a proxy for physical quantities, have previously been associated with an increase in crop income by boosting production, but also with an increase in the variability (decrease in stability) of crop income (Enjolras et al., 2014). In contrast, Reidsma et al. (2009) found that variability of farm income was higher on less intensive farms across Europe, measured using total output per hectare (€). However, they did not test whether this varied between farm type, for example cereal or grazing farms, which require different levels of intensity. Further analysis would therefore help understand how increasing intensity, via the use of expensive inputs, affects the stability of farm businesses.

The Common Agricultural Policy (CAP) scheme currently supports producer incomes in the European Union (EU), and a central aim is to reduce income variation by reducing domestic price volatility (El Benni et al., 2012; OECD, 2009). The CAP provides payments to farmers across the EU via two main categories: Pillar 1 provides direct payments to farmers and market support, with the majority dedicated to payments based on the area farmed (namely the Single Payment Scheme (SPS) which was replaced by the Basic Payment Scheme (BPS) in 2015). Pillar 2 pays farmers to implement environmentally friendly actions, e.g. installing hedges, through voluntary agri-environment schemes or to support the wider rural economy. Agricultural subsidies have been argued to play a role in stabilising farm incomes (Castañeda-Vera and Garrido, 2017; Enjolras et al., 2014; OECD, 2009) as the variability in subsidies is potentially lower than other agricultural income (Severini et al., 2016). However, empirical studies have also found the opposite effect; Reidsma et al. (2009) found that variability was higher on farms that received more subsidies per hectare, across regions of Europe. Previous analysis in Italy has also linked direct payments to an increase in crop income variability (from production only), suggesting these payments may encourage farmers to engage in riskier production practices (Enjolras et al., 2014). Further quantitative studies are warranted to evaluate the relationship between direct subsidies across a range of farm types and in different European countries (Castañeda-Vera and Garrido, 2017). In addition, the effect of agri-environment scheme payments (Pillar 2), which compensate farmers for implementing measures to benefit the environment or biodiversity, on the stability of farm income has not been examined previously.

Across Europe and a range of farm types, larger farms have been associated with greater stability of farm income (El Benni et al., 2012; European Commission, 2009; Reidsma et al., 2009; Severini et al., 2016). Larger farms may benefit from greater economies of scale, as well as, a wider range of soils and landscapes and therefore may be better able to cope with extreme or adverse weather across the farm (El Benni et al., 2012; Marra and Schurle, 1994). However, further evidence is needed across a range of farm types, to understand the relative importance of farm size compared to a range of farming practices and subsidies, on the stability of farm income.

On-farm diversification is considered an important strategy to reduce reliance on income from agricultural production which is subject to a wide variety of price fluctuations and climate stresses (McNally, 2001; McNamara and Weiss, 2005). On-farm diversification refers to activities which are fully integrated and derive income for the farm business, for example, income from a farm campsite or letting farm buildings. A greater proportion of income from on-farm diversification has previously been found to increase the economic sustainability of farm businesses in Scotland, by providing an hourly return to the farmer of at least the minimum wage (Barnes et al., 2015). The effect of on-farm diversification on the year-to-year stability of farm business income has been less investigated. A large number of studies have examined how reliance on off-farm income (from off-farm employment outside of the farm business) affects the stability of household or farmer income, with mixed results (e.g. El Benni et al., 2012; Jetté-Nantel et al., 2011; Mishra and Sandretto, 2002). A larger share of household income from off-farm employment has been associated with a decrease in the stability of farm revenue, considered a result of a shift in labour and potentially riskier agricultural production with farmers feeling more protected by alternative income sources (El Benni et al., 2012). Whether income from on-farm diversification has a similar effect on instability of farm income, or conversely increases stability by providing a more stable source of income is not well known.

The stability of farm income has previously been measured using a range of different indices, across different temporal scales (e.g. Barry et al., 2001; El Benni et al., 2012; Loughrey and Hennessy, 2016; Pacín and Oesterheld, 2014; Reidsma et al., 2009; Reidsma and Ewert, 2008). Alternative methods for measuring stability of income may provide different results, affecting the interpretation of a stable farm business. Therefore, we use a range of stability measures to provide a robust and more comprehensive analysis. In this study we use four stability measures to investigate the effect of farming practices and agricultural policy on the stability of farm income in England and Wales between 2007 and 2015, using a multilevel mixed effects model.

This study examines a range of different farm types, based on type of production, which can exhibit very different farm management and characteristics, for example livestock is considered a lower risk production output than crops (Chavas et al., 2019). Farms are often restricted to a type of production due to a substantial machinery investment or landscape characteristics, therefore, we analyse the effect of farming practices and agricultural policy for each farm type separately to provide targeted recommendations for farmers. Previous evidence, in other territories, has either focused on one production or farm type, or used a single measure of stability.

We examine a range of farming practices and subsidies which, as overviewed above, previous literature has indicated may support the stability of farm businesses in different territories, or with mixed results, using different measures of stability. Understanding which management changes are beneficial to agriculture in the current climate, across different scales and a range of environments is important for understanding the adaptation options available in agriculture (Porter et al., 2014). The main aims of the present study are to provide comprehensive analysis of the effect of farming practices and subsidies on the stability of farm income, and their relative importance. Our results are useful in informing farmers which practices may aid in managing income stability and lead to a more robust farm business in the face of increasingly variable weather or future economic shocks.

2 Materials and methods

2.1 *Data and study area*

The Farm Business Survey (FBS) is a survey conducted in England and Wales, collecting extensive information on the physical and economic performance of approximately 2,500 farm businesses annually (Department for Environment Food and Rural Affairs, 2020). The population of farms covered by the survey is detailed in the supplementary materials. Farms are classified into farm types according to which crop or livestock production accounts for more than two-thirds of standard gross margin (SGM). We analyse FBS data from 2007 to 2015 for the following six farm types: dairy, cereals, general cropping (arable crops including field scale vegetables account for more than two-thirds of SGM), mixed (no other type accounts for more than two-thirds of SGM), Less Favoured Area (LFA) grazing (grazing livestock accounts for more than two-thirds of SGM and 50 per cent or more of the total land area is in LFA) and lowland grazing farms. Horticulture farms were excluded due their complexity (large diversity in production), as well as, pig and poultry farms due to small sample sizes. The data was examined for outliers and inconsistencies and less than 0.2% of observations, considered to be erroneous, were removed.

Farm business income per hectare is used as the measure of income in this study and is calculated as the sum of: total output from agriculture, on-farm diversification and subsidies, less all fixed and variable costs, including paid labour and depreciation, and profit or loss from the sale of fixed assets. Farm business income represents the financial return to all those invested in the business (farmers, partners, shareholders) and is in essence the same as financial net profit. Farm business income enables the analysis of changes in income over time and is also used by policy makers when assessing the impact of new policies on the individual farm business (Department for Environment Food and Rural Affairs et al., 2018), therefore is the preferred measure of income in our study.

2.2 *Measuring the stability of farm income*

Stability of agricultural production or income is often measured by examining its variability; high stability of income is associated with low variability. We summarise the key measures of stability (or variability) used in studies that have previously examined the stability of income, using panel data. Stability has been measured over several time periods, to indicate medium-term stability, or as an annual deviation in income from the prior year or years. Stability has also been measured by examining absolute variability, or as a relative measure (ratio) to allow comparison between farms with different means. In this study we use four different measures for the stability of farm income (Table 1): two annual (or short-term) measures of stability (absolute and relative anomaly) and two medium-term measures of stability using the standard deviation and relative standard deviation of farm income.

2.2.1 Annual measures of stability

To measure stability of a given year or season, we use the absolute anomaly calculated as the deviation in income from the expected income. Determining the expected income requires some consideration. Reidsma et al. (2009) considered using the trend in income per farm type over a 14 year period, however since the trend was often not different from zero, the authors used the mean income per farm type as an indicator of expected income. Measuring the absolute deviation from the mean income per farm type indicates the variation in income, for a particular year, from the average performance of farms considered to have similar characteristics. A compromise of this approach is that calculating absolute deviation from the mean for each farm type can result in large absolute anomaly values for those farms with income consistently above (or below) the farm type mean, even though these farms may show low variability in their own income year to year. In this study we calculate the absolute anomaly using the annual deviation from the individual farm mean, over a five-year rolling period. This provides an indication of the deviation in farm income from the average performance at the individual farm. We use a five-year rolling period[1] to calculate the four stability measures in this study, therefore we consider only farms with a minimum of five consecutive years of data in the Farm Business Survey.

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[1] We calculated stability measures over longer (13 years) and shorter time periods (3 years), these measures were highly correlated both with one another and with the 5-year measures (shown in Table 1). We chose a 5-year period to enable us to capture temporal changes over the dataset but also include sufficient data points to calculate the mean income.

Annual stability in farm income and crop yields have also been examined using the relatively anomaly; the ratio of the absolute anomaly and the expected income (Reidsma et al., 2009). Using a relative measure enables stability of farm income to be directly compared across farms (or farm types) with different means. However, relative measures should only be used with ratio data where there is a true or absolute zero. To examine relative stability on an annual basis we calculate the relative anomaly by dividing the absolute anomaly for the individual farm, by the 5-year rolling mean of each farm type (which is always positive) therefore accounting for temporal changes in the mean farm business income over the period 2007 to 2015. This gives an indication of the relative deviation from the average performance of farms considered to have more similar characteristics (e.g. as per Reidsma et al. (2009)).

2.2.2 Medium-term measures of stability

A common method of measuring absolute stability of income in the medium or long-term is the standard deviation (SD) (Loughrey and Hennessy, 2016; Pacín and Oesterheld, 2014). This indicates, for an individual farm or farm type, the amount of variation or dispersion around the mean over time. Measuring the SD of income at the farm level enables assessment of differences in stability between individual farms, which is not possible when examining SD for each farm type. Similar to the method used in Barry et al. (2001) and El Benni et al. (2012) we calculate the standard deviation by splitting the full data set (2005-2017) into 13 overlapping time periods, each containing 5 consecutive years of farm business data per farm e.g. the standard deviation for 2007 comprises 5 income records for each farm with data for all years between 2005 and 2009 inclusive.

The coefficient of variation (CV; SD divided by the mean) has also been used to analyse temporal variation in farm income (Barry et al., 2001; El Benni et al., 2012). Using a relative measure such as the CV, enables stability of farm income to be compared directly between farms, or farm types, with different means. However, as above, relative measures should only be used with ratio data where there is a true or absolute zero. Farm business income in this study measures the financial return to farmers or shareholders, therefore can be a positive (profit) or negative (loss) figure. As a result, the CV at the farm level (farm SD divided by the mean farm income) can be very large where the mean is close to zero (due to positive and negative income values) and in such instances does not accurately measure stability. We did not want to restrict the analysis to farms which only made a profit since this would not represent the full range of farms in England and Wales. Equally, we did not want to use an alternative measure of financial performance since Farm Business Income is a key measure of financial performance, widely used by policy makers to assess the impact of new policies on the individual farm business. To examine relative stability in the medium term we calculate a relative (or scaled) standard deviation by dividing the standard deviation for the individual farm by the rolling 5-year mean income of each farm type, therefore accounting for temporal changes in the mean income over the period 2007 to 2015. The rolling 5-year farm type mean income is always positive. This relative standard deviation is calculated using the mean income of farms with similar characteristics. Similar methods (scaling using the mean for each farm type) have been used to calculate relative stability in previous studies (e.g. Reidsma et al., 2009; Reidsma and Ewert, 2008). Table 1 outlines the four measures used to examine stability of farm income in our analysis.

Econometric studies have also examined changes in agricultural production and income by measuring the cost or willingness to pay to reduce risk, and exposure to downside risk (low yields or income) (Antle, 1987; Chavas, 2019; Chavas et al., 2019). Our study does not examine upside or downside risk separately, but instead we examine relative or absolute variation in income around the mean, each year and over 5 years. Large changes in income, particularly over a number of years, can be challenging for farm planning and management and therefore our results hope to inform which farming practices and subsidies are associated with less variable income, using these 4 alternative measures of stability.

Stability measure		**Calculation**	**What measure shows?**
Short-term/annual measures			
1	Absolute anomaly: absolute deviation from the rolling 5-year mean* FBI per ha (of individual farm)	$ABS_{it} = \lvert Y_{it} - \bar{Y}_i \rvert$ where $\bar{Y}_i = \frac{1}{5}(\sum_{t-2}^{t+2} Y_i)$	Absolute deviation in FBI per ha at each farm, from the average performance at the farm $\bar{Y}_i$, in year *t*.
2	Relative anomaly: ratio of absolute anomaly from farm mean *(measure 1)* divided by rolling 5-year mean* FBI per ha (per farm type)	$REL_{it} = \frac{ABS_{it}}{\bar{Y}_{m,i}}$ where $\bar{Y}_{m,i} = \underset{\forall \text{ type } m}{\text{mean}} (\bar{Y}_i)$	Relative deviation in FBI per ha; absolute deviation in FBI per ha from the mean performance at the individual farm, scaled to the 5-year rolling mean FBI per ha of farms of the same type *m*

			(across England and Wales), in year *t*.
Medium term measures			
3	Standard deviation: Rolling 5-year SD of FBI per farm	$\mathrm{SD}_i = \sqrt{\frac{1}{4}\sum_{t-2}^{t+2}(Y_{it} - \bar{Y}_i)^2}$	The amount of variation or dispersion in FBI per ha at the individual farm over a 5-year period.
4	Relative (scaled) standard deviation: Rolling 5-year SD of FBI per farm (*measure 3*) divided by rolling 5-year mean FBI per ha (per farm type)	$\mathrm{REL.SD}_i = \frac{\mathrm{SD}_i}{\bar{Y}_{m,i}}$	The amount of variation or dispersion in FBI per ha at the individual farm, scaled to the 5-year rolling mean FBI per ha of farms of the same type *m* (across England and Wales), in year *t*.

*We also calculated the absolute anomaly and relative anomaly per farm type using the median FBI per ha, these measures were very strongly positively correlated (Pearson’s coefficient >0.98) with the absolute anomaly using the mean income, therefore the mean was used for consistency across all measures.

Table 1 - Measures of stability of Farm Business Income (FBI) used in this analysis

2.3 Factors associated with the stability of farm income

In this study we analyse the factors affecting the stability of farm income for each farm type, based on the type of production (dairy, cereals, general cropping, mixed, LFA grazing and lowland grazing farms). We are not focused on comparing farm types, however, farm characteristics and practices, e.g. size, intensity and diversity often vary significantly between farm types, therefore, we use separate models to quantify how each covariate affects stability for each farm type. The results of a comparative multilevel model including all farm types and farm type interactions are included in the supplementary material.

The definition and calculation of farming practices and EU subsidy payments examined, are shown in Table 2. To examine farming intensity across a range of farm types we use the IRENA indicator 15, which is calculated as the total cost of fertiliser, crop protection and concentrated animal feed per hectare (European Environment Agency, 2005). This IRENA indicator was developed to identify intensive, high input farms in comparison to extensive farms believed to have a lower environmental impact (European Environment Agency, 2005). The Farm Business Survey (FBS) does not provide a complete record of physical input quantities (e.g. fertilisers and pesticides used), and the IRENA indicator has previously been used to examine farming intensity in the FBS data across a range of farm types (crops and livestock) (Gerrard et al., 2012).

Agricultural diversity (or inversely specialisation) of crop and livestock activities has been examined using the Herfindahl index (El Benni et al., 2012; Poon and Weersink, 2011). The Herfindahl index is calculated based on the proportion of gross farming revenue earned from crops (including wheat, barley, oilseed rape and other key crops) and livestock production (including milk and cattle production and other livestock products). The index ranges from 0 to 1 with lower values indicating a higher degree of agricultural diversity. An alternative measure of agricultural diversity is the Shannon Index, which calculates the diversity of crops grown (number of crops and their proportional representation) (Gerrard et al., 2012). However, we found the Herfindahl index more suitable to identify diversity across a range of different farm types.

To examine agri-environment payments we use total rural development payments (pillar 2) per hectare, which comprise primarily agri-environment schemes, as well as, dedicated support for LFA farmers (refer to the supplementary materials for details of the schemes in operation during the study period).

Independent variable	**Calculation**
Farm characteristics	
Farm size (area farmed per hectare)	The utilised agricultural area, plus land let in /minus land rented out
Farming practices	
Intensity of inputs (IRENA indicator 15; European Environment Agency, 2005; Gerrard et al., 2012)	The total cost of fertiliser, crop protection and concentrated animal feed (£), per hectare (area farmed)
Agricultural specialisation (inverse of diversification)	Herfindahl index (S) = $\sum_{i=1}^{n} (p_i)^2$ Where *n* is the total number of farming activities, p_i is the proportion of revenue earned from the *i*-th farming activity (revenue from farming activity divided by the total farming revenue).

	Can also be written as sum of revenue for each farming activity squared, divided by total revenue for agriculture squared: (Wheat^2+ barley^2 + other cereals^2 + oilseed rape^2 + peas and beans^2 + potatoes^2 + sugar beet^2 + horticulture^2 + other crops^2 + by-products and forage^2 + milk^2 + cattle^2 + sheep^2 + pigs^2 + eggs^2 + chickens and other poultry^2 + other livestock^2 + other agriculture^2) /total agricultural gross revenue^2
On-farm diversification (reliance on diversified income: activities integrated into the farm business, in addition to agricultural output)	Gross revenue (output) from on-farm diversification (£) divided by total gross revenue (output) (£)
EU subsidies (Agricultural policy)	
Direct payments per hectare	Total direct payments (£) (Primarily the single payment scheme or basic payment scheme), per hectare (area farmed)
Agri-environment payments per hectare	Total payments under rural development policy (£; pillar 2), per hectare (area farmed)

Table 2 - Definition and calculations of variables (farm characteristics, farming practices and EU subsidy payments) analysed in the study

Summary statistics for the variables used in this study are shown in Table 3. The UK Consumer Price Index is used to deflate all monetary variables, including farm business income, to account for the change in the value of money over time (ONS, 2020).

	All Farms	Dairy	Cereals	Gen. cropping	Mixed	LFA Grazing	Lowland Grazing
Farm Business Income (FBI) per ha (£)	364.95	599.38	387.18	532.18	297.43	200.34	266.83
Dependent variables							
Absolute anomaly of FBI per ha (£)	142.16	209.88	156.99	217.82	131.42	77.73	115.40
Relative anomaly of FBI per ha (£)	0.42	0.36	0.44	0.43	0.43	0.42	0.47
Standard deviation of FBI per ha (£)	195.14	281.13	214.02	291.36	184.12	112.95	160.00
Relative SD of FBI per ha (£)	0.59	0.49	0.61	0.57	0.61	0.61	0.65

Independent variables							
Specialisation (Herfindahl index) (0-1)	0.58	0.71	0.40	0.38	0.49	0.63	0.69
Input intensity per ha (£)	431.07	954.45	330.67	407.19	616.18	173.58	211.11
Direct payments (SPS/BPS) per ha (£)	226.17	227.11	240.58	235.50	221.11	213.40	229.78
Agri-environment payments per ha (£)	53.04	33.30	50.23	40.25	47.56	71.91	58.45
Area farmed (hectares)	188.65	132.03	233.13	277.44	191.88	205.02	120.63
On-farm diversification (reliance) (0-1)	0.04	0.02	0.07	0.04	0.05	0.02	0.06
Number of observations	12,628	2,635	2,367	1,086	1,139	3,687	1,714
Number of farms	2,333*	503	514	268	319	645	390
Number of counties/unitary authorities	78	54	56	39	57	35	53

*Note 283 farms change between farm types during the period, therefore appear in more than one farm type group during the relevant years.

Table 3 - Summary statistics of FBS data (2007-2015); values deflated using UK Consumer Price Index (2015=100; ONS, 2020).

2.4 Multilevel (two-level linear mixed effect) model

The Farm Business survey collects extensive data on farm characteristics of individual farms across England and Wales on an annual basis. Many farms remain in the survey each year, however membership in the survey can change and therefore the data represents an unbalanced panel between 2007 and 2015.

We estimate a multilevel (two-level linear mixed effect) model to examine the effect of a range of farm characteristics, farming practices and EU subsidies on the stability of farm income. This type of model can easily accommodate unbalanced data (Laird and Ware, 1982; Snijders and Bosker, 1999) and has been used previously to examine the influence of management on farm income (Reidsma et al., 2009, 2007). A multilevel model accounts for dependency within the data; observations are likely to be correlated in two ways, firstly because they are from the same farm (level 1), and secondly because farms belong to the same county or unitary authority (level 2) and are therefore likely to have a more similar climate or soil conditions than farms in different locations. A map of county and unitary authority boundaries (hereafter referred to as counties) is included in the supplementary materials (Supplementary Figure 1). We estimate the following two-level mixed model with farms nested within counties, based on restricted maximum likelihood (REML) using each of the four dependent variables measuring the stability of income[2]:

$$\log(Y_{tjk}) = \beta_0 + \beta_1 specialisation_{jk} + \beta_2 intensity_{jk} + \beta_3 direct\ payments_{jk} + \beta_4 direct\ payments_{jk} \cdot year_{jk} + \beta_5 agri\text{-}environment\ payments_{jk} + \beta_6 year_{jk} + \beta_7 area\ farmed_{jk} + \beta_8 on\text{-}farm\ diversification_{jk} + u_k + r_{jk} + e_{tjk} \quad (1)$$

where Y is the variability of income (instability), for each farm observed at level j=1, …, J, (level 1) nested into k=1, …, K counties (level 2), with also t = 1, ..., T_j periods for each, j, farm, β_0 is the mean intercept across all groups, the regression coefficients $\beta_{1,\ldots,}\beta_{p,}$ are common to all groups, u_k is the random intercept for level 2 (counties), r_{jk} is the random intercept for level 1 (farms) and e_{tjk} is the level 1 residual (error term).

Multilevel models account for this dependency or nesting structure (farm and county) by splitting the residual into two uncorrelated components (Rabe-Hesketh and Skrondal, 2012); firstly a permanent component, known as the *random intercept* or *random effect* which is specific to the farm (or county) and represents variation between farms (or counties). The random intercept is uncorrelated across farms (or counties) and represents characteristics of variables not included in the model. Secondly there is an idiosyncratic component or within-farm (level 1) residual which is uncorrelated across time and farm. The multilevel model was also run with a further level, region (n=9), nested above county however this resulted in very little change to the model results. In each of the models, independent variables (listed in Table 2 and Table 3) were used as fixed effects and have been standardised (centred around zero, with a SD of 1) to account for the differences in scale between variables and in order to analyse the comparative effect size of each covariate. For models examining stability of income in the medium-term (standard deviation and relative standard deviation of farm business income per ha), the independent variables are averaged over the same five-year time

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[2] A multilevel model performed significantly better (p value <0.05) than a linear (OLS) model when examining the null hypothesis that the level 1 and 2 groupings are equal to zero.

period used to derive the dependent variables (Table 1). Year, *t*, is also included as a continuous fixed effect to examine the trend in income stability over time, as well as, any interaction between time and the value of direct payments per hectare. Model residuals were checked for normality and heteroskedasticity and all measures of income stability were log transformed to account for the non-normal distribution of the income data, to reduce the impact of outliers, and improve model fit based on the Akaike Information Criteria (AIC). To assess the explanatory power of the models, marginal R^2 was calculated following Nakagawa and Schielzeth (2013) using the r2glmm package in R (Jaeger, 2017; R Core Team, 2019). For models examining stability of income in the medium-term we account for temporal autocorrelation in the farm specific error term using the corCAR1 function of the *nlme* R package (Pinheiro et al., 2019) by fitting a continuous first order autoregressive process. Before fitting the models, we checked for outliers and collinearity using pairwise scatterplots, in addition, correlation coefficients between independent variables were all <0.3 (therefore less than the recommended threshold of 0.7; Dormann et al. (2013).

3 Results

3.1 The effects of farming practices and subsidies on the variability of income

Tables 4-7 show the results of the four multilevel (two-level linear mixed effect) models, using four measures of variability (inverse of stability) and include coefficients indicating the relative strength of factors affecting the variability of income by farm type. Models use the log of the dependent variable, therefore the exponent of the coefficient, minus 1 multiplied by 100, provides the percentage change in the variability of income (instability) for every increase in the independent variable by one standard deviation, holding all other predictors constant.

Farming practices and subsidies explained a greater part of the variance when examining the stability of income in the medium term, using the standard deviation and relative standard deviation (marginal R^2 between 0.12 and 0.39). The variance explained by fixed factors examining the effect on annual variability of income was often small (marginal R^2 between 0.02 and 0.15). The Farm Business Survey provides summarised farm data which we use to examine the effect of farming practices and subsidies, however, the stability of income could also be affected more by specific farm management, as well as changing environmental conditions (e.g. climate variability). When comparing results across all measures of variability, we found regression results show the same relationships between farming practices and EU subsidies across all the four measures, however, the significance levels vary in a few instances. In addition, correlations between the measures of variability (Supplementary Table 1) show short-term variability is correlated with medium-term variability indicating farms with larger annual variability are more likely to also show larger variability of income over several years.

3.1.1 Annual variability of farm income

Table 4 and Table 5 show the results of the multilevel model explaining the factors affecting the variability (inverse of stability) of income on an annual basis, using the log of the absolute and relative anomaly respectively.

Greater specialisation (or less diversity in crops and livestock activities) increases variability of absolute and relative income, between 8 and 21% with a significant relationship for dairy, general cropping and mixed farms. For general cropping farms, specialisation of agricultural activities has the largest relative effect on the variability of income in comparison to other covariates; increasing the Herfindahl index by 1 standard deviation increases the variability of income by approximately 20%. Increasing intensity (spending more on fertiliser, pesticide, or concentrated animal feed) is associated with an increase in variability of farm income between 20 and 30% for both absolute and relative income for all farm types, with exception of cereal farms where the effect is smaller (<10%).

An increase in direct payments per hectare of 1 standard deviation increases the variability of income in absolute and relative terms for dairy and LFA grazing farms by 25 and 35% respectively, in addition, greater direct payments increase the variability of relative income for lowland grazing farms (16%). Over time the effect of direct payments decreases (approximately 3% per year), as the value of direct payments per hectare has generally fallen over the period (Supplementary Figure 2). The effect of agri-environment payments is smaller than direct payments and differs between farm types: for dairy, general cropping and mixed farms an increase in agri-environment payments per hectare decreases the variability in absolute and relative income between 5 and 7%, whereas for LFA grazing farms agri-environment payments increase the variability in annual farm business income by 6%.

When considering temporal changes in the mean farm business income per ha, variability in income, using the relative anomaly, increases for dairy, mixed and LFA grazing farms, indicating income for these farm types is becoming increasingly unstable. Increasing farm area is associated with a decrease in the variability in income in both absolute and relative terms. An increase in utilised agricultural area by 1 standard deviation is associated with a decrease in variability between 5 and 20% for all farm types, with exception of general cropping where there is no significant relationship. Increasing reliance on revenue from on-farm diversification (activities integrated into the farm business, in addition to agricultural output) increases the variability of farm business income for dairy and grazing farms, however, the effect (4-8% increase) is smaller than other farming practices examined. Whereas greater reliance on income from on-farm diversification does not significantly affect the variability of income for general cropping, cereal and mixed farms.

	Dairy	Cereals	Gen. cropping	Mixed	LFA Grazing	Lowland Grazing
Random effects						
County SD	0.000	0.000	0.110	0.205	0.126	0.065
Farm SD	0.272	0.210	0.364	0.315	0.248	0.346
Level-1 residual	1.100	1.187	1.072	1.117	1.094	1.115
Fixed effects (Standard Error)						
Intercept	4.591 ***	4.983 ***	5.137 ***	4.336 ***	3.705 ***	4.386 ***
	(0.077)	(0.083)	(0.117)	(0.123)	(0.066)	(0.088)
Specialisation (agricultural)	0.111 ***	0.018	0.192 ***	0.076 *	0.028	0.008
	(0.026)	(0.026)	(0.043)	(0.043)	(0.021)	(0.033)
Input intensity	0.186 ***	0.089 ***	0.186 ***	0.258 ***	0.200 ***	0.201 ***
	(0.028)	(0.028)	(0.041)	(0.042)	(0.023)	(0.034)
Direct payments per ha	0.217 ***	0.064	-0.150	-0.040	0.301 ***	0.108
	(0.065)	(0.072)	(0.110)	(0.118)	(0.057)	(0.074)
Year x direct payments per ha	-0.029 ***	0.011	0.022	0.015	-0.019 **	-0.012
	(0.010)	(0.010)	(0.016)	(0.016)	(0.008)	(0.013)
Agri-environment payments per ha	-0.050 **	-0.037	-0.072 *	-0.078 **	0.054 **	0.030
	(0.025)	(0.029)	(0.041)	(0.040)	(0.022)	(0.033)
Year	0.033 ***	-0.058 ***	-0.038 **	0.004	0.016 **	-0.023 *
	(0.010)	(0.011)	(0.016)	(0.016)	(0.008)	(0.012)
Area farmed	-0.123 ***	-0.054 **	0.016	-0.138 ***	-0.224 ***	-0.190 ***
	(0.026)	(0.027)	(0.045)	(0.043)	(0.024)	(0.035)
On-farm diversification	0.041 *	0.041	0.045	0.060	0.077 ***	0.075 **
	(0.025)	(0.027)	(0.041)	(0.041)	(0.020)	(0.032)
Observations (n)	2,635	2,367	1,086	1,139	3,687	1,714
County (n)	54	56	39	57	35	53
Farm (n)	503	514	268	319	645	390
AIC	8,184	7,666	3,396	3,640	11,375	5,434
BIC	8,254	7,735	3,455	3,700	11,450	5,499
logLik	-4,080	-3,821	-1,686	-1,808	-5,676	-2,705
R^2	0.083	0.043	0.065	0.088	0.138	0.065

Table 4 - Multilevel model results using (log) absolute anomaly of farm business income per hectare as dependent variable. Showing the effect of farming practices and subsidies on the variability of farm income. Significant at: *10, **5 and ***1 percent levels.

	Dairy	Cereals	Gen. cropping	Mixed	LFA Grazing	Lowland Grazing
Random effects						
County SD	0.000	0.000	0.105	0.196	0.119	0.036
Farm SD	0.270	0.210	0.363	0.322	0.251	0.354
Level-1 residual	1.101	1.189	1.072	1.119	1.095	1.120
Fixed effects (Standard Error)						
Intercept	-1.883 ***	-1.285 ***	-1.232 ***	-1.794 ***	-1.832 ***	-1.320 ***
	(0.077)	(0.083)	(0.117)	(0.123)	(0.065)	(0.088)
Specialisation (agricultural)	0.118 ***	0.028	0.186 ***	0.077 *	0.025	0.008
	(0.026)	(0.027)	(0.043)	(0.043)	(0.021)	(0.033)
Input intensity	0.185 ***	0.066 **	0.179 ***	0.258 ***	0.207 ***	0.201 ***
	(0.028)	(0.028)	(0.041)	(0.043)	(0.023)	(0.034)
Direct payments per ha	0.231 ***	0.108	-0.132	-0.007	0.302 ***	0.151 **
	(0.066)	(0.072)	(0.110)	(0.119)	(0.057)	(0.074)
Year x direct payments per ha	-0.033 ***	-0.001	0.015	0.007	-0.023 ***	-0.023 *
	(0.010)	(0.010)	(0.016)	(0.016)	(0.008)	(0.013)
Agri-environment payments per ha	-0.050 **	-0.033	-0.072 *	-0.076 *	0.059 ***	0.029
	(0.025)	(0.029)	(0.041)	(0.040)	(0.022)	(0.033)
Year	0.048 ***	-0.004	-0.020	0.059 ***	0.059 ***	0.004
	(0.010)	(0.011)	(0.016)	(0.016)	(0.008)	(0.012)
Area farmed	-0.124 ***	-0.062 **	0.009	-0.141 ***	-0.232 ***	-0.195 ***
	(0.026)	(0.027)	(0.044)	(0.044)	(0.024)	(0.035)
On-farm diversification	0.042 *	0.043	0.049	0.061	0.082 ***	0.081 **
	(0.025)	(0.027)	(0.041)	(0.041)	(0.020)	(0.032)
Observations (n)	2,635	2,367	1,086	1,139	3,687	1,714
County (n)	54	56	39	57	35	53
Farm (n)	503	514	268	319	645	390
AIC	8,187	7,671	3,395	3,644	11,384	5,452
BIC	8,258	7,740	3,455	3,704	11,459	5,517
logLik	-4,082	-3,823	-1,685	-1,810	-5,680	-2,714
R^2	0.092	0.015	0.061	0.101	0.145	0.062

Table 5 - Multilevel model results using (log) relative anomaly of farm business income per hectare as dependent variable. Showing the effect of farming practices and subsidies on the variability of farm income. Significant at: *10, **5 and ***1 percent levels.

3.2 Medium-term variability of farm income

Table 6 and Table 7 show the results of the multilevel model, explaining the factors affecting the variability of income in the medium-term, using the log of the standard deviation of income and relative standard deviation respectively.

Greater specialisation, or less diversity in crop and livestock activities, also increases variability of absolute and relative income in the medium term with a significant relationship for dairy (12%), cereal (5%) and general cropping farms. As observed using annual measures of stability, specialisation has the largest partial effect on variability of income for general cropping farms of all covariates examined, with results showing a 24% increase in variability is associate with an increase in the Herfindahl index of 1 standard deviation (Figure 1). Input intensity also increases medium-term variability in income for all farm types (by 10 to 28% for an increase in input intensity of 1 standard deviation). Figure 1 shows the partial effect of input intensity on the stability of income for general cropping farms, using the standard deviation of income.

Consistent with the effect on annual variability, an increase in direct payments per hectare is relatively large and increases the medium-term variability of income in absolute and relative terms for dairy and LFA grazing farms (Figure 2) by approximately 20%. In addition, an increase in direct payments is associated with an increase in the variability of relative income in the medium-term, for cereals and lowland grazing farms, however the effect size is smaller (12 and 6% respectively). Over time the effect of direct payments per hectare on the medium-term variability in income decreases for dairy farms, however, it increases for cereals, mixed and lowland grazing farms. The effect of agri-environment payments on medium term variability is smaller than direct payments and differs between farm types: for dairy, general cropping (Figure 1) and mixed farms an increase in agri-environment payments per hectare decreases the variability in absolute and relative income between 5 and 9%. Whereas an increase in agri-environment payments by 1 standard deviation for LFA grazing farms is associated with an increase in variability by 7% (Figure 2).

Variability in relative standard deviation of farm income, which accounts for changes in farm income over time, increases for dairy, cereals, mixed and LFA grazing farms, indicating income for these farm types is becoming increasingly unstable. Consistent with the effect on annual stability measures increasing farm size is associated with a decrease in medium-term variability in income, in both absolute and relative terms. An increase in utilised agricultural area by 1 standard deviation is associated with a decrease in variability between 4 and 19% across all farm types, except for general cropping farms where there is no significant relationship. For most farm types, farm income shows greater variability in the medium-term with an increasing share of revenue coming from on-farm diversification, however, the size of the effect is smaller than most other farming practices (5-8%).

Results of a sensitivity analysis using alternative measures of intensity and on-farm diversification and the impact of changes in farm type are available in the supplementary material.

	Dairy	Cereals	Gen. cropping	Mixed	LFA Grazing	Lowland Grazing
Random effects						
County SD	0.060	0.024	0.154	0.101	0.113	0.113
Farm SD	0.000	0.000	0.000	0.000	0.148	0.137
Level-1 residual	0.480	0.496	0.564	0.518	0.505	0.509
Fixed effects (Standard error)						
Intercept	5.272 ***	5.311 ***	5.509 ***	4.908 ***	4.471 ***	5.043 ***
	(0.044)	(0.044)	(0.073)	(0.068)	(0.043)	(0.052)
Specialisation (agricultural)	0.115 ***	0.051 ***	0.214 ***	0.028	0.022	-0.003
	(0.017)	(0.017)	(0.033)	(0.026)	(0.016)	(0.022)
Input intensity	0.185 ***	0.122 ***	0.141 ***	0.247 ***	0.203 ***	0.191 ***
	(0.019)	(0.017)	(0.028)	(0.026)	(0.017)	(0.021)
Direct payments per ha	0.152 ***	-0.026	-0.041	-0.068	0.179 ***	0.008
	(0.034)	(0.036)	(0.056)	(0.054)	(0.033)	(0.035)
Year x direct payments per ha	-0.017 ***	0.016	0.008	0.028 ***	0.001	0.012 *
	(0.005)	(0.005)	(0.008)	(0.007)	(0.004)	(0.006)
Agri-environment payments per ha	-0.050 ***	0.003	-0.066 **	-0.051 **	0.063 ***	0.027
	(0.016)	(0.018)	(0.028)	(0.022)	(0.016)	(0.022)
Year	0.032 ***	-0.014 ***	-0.011	0.024 ***	0.007 *	-0.015 **
	(0.006)	(0.005)	(0.008)	(0.008)	(0.005)	(0.006)
Area farmed	-0.121 ***	-0.045 ***	-0.016	-0.120 ***	-0.193 ***	-0.157 ***
	(0.017)	(0.017)	(0.035)	(0.026)	(0.019)	(0.025)
On-farm diversification	0.045 ***	0.062 ***	0.019	0.020	0.054 ***	0.077 ***
	(0.016)	(0.017)	(0.029)	(0.024)	(0.014)	(0.021)
Observations (n)	2,635	2,367	1,086	1,139	3,687	1,714
County (n)	54	56	39	57	35	53
Farm (n)	503	514	268	319	645	390
AIC	2,012	1,919	909	1,231	3,066	1,541
BIC	2,088	1,994	974	1,296	3,147	1,612
logLik	-993	-947	-442	-602	-1,520	-758
R^2	0.333	0.121	0.191	0.298	0.403	0.227

Table 6 - Multilevel model results using (log) standard deviation of farm business income per hectare as dependent variable. Showing the effect of farming practices and subsidies on the variability of farm income. Significant at: *10, **5 and ***1 percent levels.

	Dairy	**Cereals**	**Gen. cropping**	**Mixed**	**LFA Grazing**	**Lowland Grazing**
Random effects						
County SD	0.061	0.031	0.145	0.094	0.104	0.110
Farm SD	0.000	0.000	0.000	0.000	0.150	0.000
Level-1 residual	0.487	0.493	0.570	0.523	0.512	0.535
Fixed effects (Standard error)						
Intercept	-1.148 ***	-0.893 ***	-0.793 ***	-1.169 ***	-0.978 ***	-0.600 ***
	(0.044)	(0.044)	(0.073)	(0.068)	(0.043)	(0.053)
Specialisation (agricultural)	0.111 ***	0.049 ***	0.201 ***	0.027	0.017	-0.002
	(0.017)	(0.017)	(0.033)	(0.027)	(0.016)	(0.022)
Input intensity	0.186 ***	0.091 ***	0.122 ***	0.247 ***	0.208 ***	0.183 ***
	(0.019)	(0.017)	(0.028)	(0.026)	(0.017)	(0.022)
Direct payments per ha	0.176 ***	0.115 ***	0.002	0.026	0.193 ***	0.061 *
	(0.034)	(0.036)	(0.057)	(0.054)	(0.033)	(0.036)
Year x direct payments per ha	-0.023 ***	-0.008	-0.006	0.011	-0.007	-0.002
	(0.005)	(0.005)	(0.008)	(0.008)	(0.005)	(0.007)
Agri-environment payments per ha	-0.053 ***	-0.016	-0.093 ***	-0.051 **	0.064 ***	0.017
	(0.016)	(0.018)	(0.028)	(0.022)	(0.016)	(0.022)
Year	0.039 ***	0.035 ***	-0.001	0.071 ***	0.040 ***	0.006
	(0.006)	(0.005)	(0.008)	(0.008)	(0.005)	(0.006)
Area farmed	-0.127 ***	-0.056 ***	-0.024	-0.125 ***	-0.206 ***	-0.160 ***
	(0.017)	(0.017)	(0.036)	(0.026)	(0.019)	(0.025)
On-farm diversification	0.050 ***	0.083 ***	0.026	0.022	0.060 ***	0.081 ***
	(0.016)	(0.017)	(0.029)	(0.024)	(0.014)	(0.021)
Observations (n)	2,635	2,367	1,086	1,139	3,687	1,714
County (n)	54	56	39	57	35	53
Farm (n)	503	514	268	319	645	390
AIC	2,154	1,931	934	1,251	3,191	1,585
BIC	2,230	2,006	999	1,316	3,272	1,656
logLik	-1,064	-952	-454	-613	-1,583	-780
R^2	0.335	0.119	0.200	0.322	0.390	0.201

Table 7 - Multilevel model results using (log) relative standard deviation of farm business income per hectare as dependent variable. Showing the effect of farming practices and subsidies on the variability of farm income. Significant at: *10, **5 and ***1 percent levels.

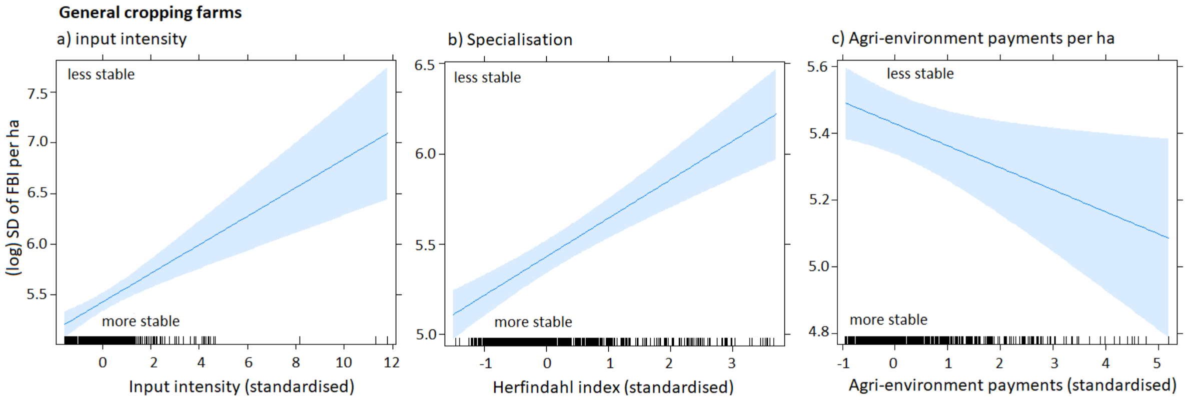

Figure 1 –Effects of input intensity, specialisation of farming activities and agri-environment payments on the standard deviation (SD) of farm business income (FBI) per ha, for general cropping farms. Plots show the partial effects of a) input intensity, b) specialisation and c) agri-environment payments from the multilevel mixed model. The tick marks on the x-axis are the observed data points. The y-axis represents the partial effect of each variable on the (log) standard deviation of farm business income per hectare. The shaded areas indicate the 95 percent confidence intervals.

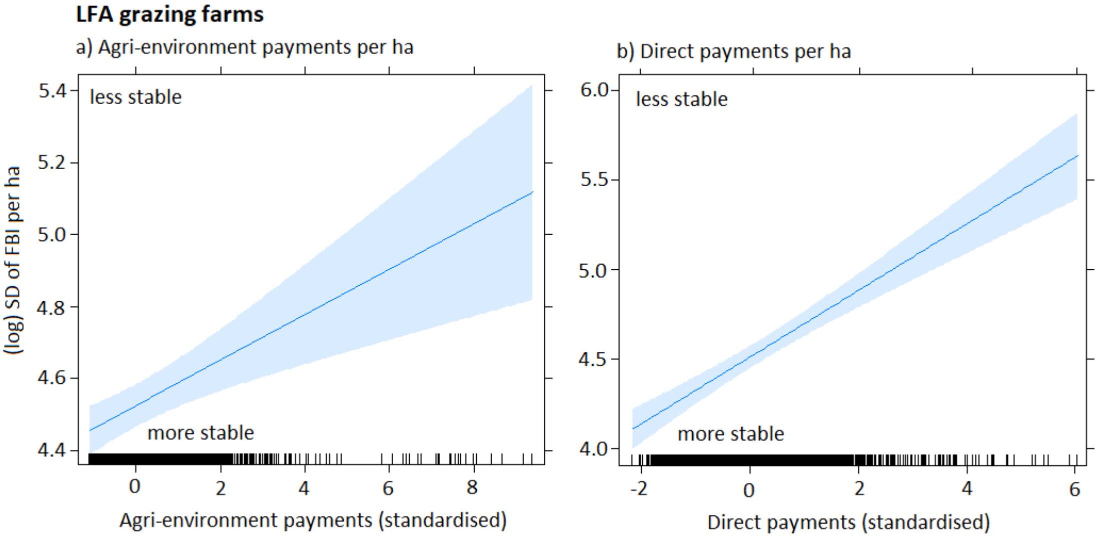

Figure 2 – Effects of agri-environment payments and direct payments on the standard deviation (SD) of farm business income (FBI) per ha, for LFA grazing farms. Plots show the partial effects of a) agri-environment payments and b) Direct payments (t=7) from the multilevel mixed model. The tick marks on the x-axis are the observed data points. The y-axis represents the partial effect of each variable on the (log) standard deviation of farm business income per hectare. The shaded areas indicate the 95 percent confidence intervals.

4 Discussion

4.1 *Agricultural diversity, a lower intensity of inputs and agri-environment payments are, for most farm types, associated with greater stability of income*

Our study demonstrates that increasing the diversity of agricultural activities and reducing the intensity of inputs, as well as, receiving higher payments from agri-environment schemes are associated with an increase in the stability of farm income. Our results highlight the potential of these farming practices and agri-environment schemes to improve the economic stability of farm businesses, which at the same time may benefit the environment. Greater agricultural diversification (i.e. lower degree of specialisation in different crop and livestock activities) increases the stability of farm income, in dairy, general cropping, cereal and mixed farms, and is a particularly important factor for general cropping farms. Reducing the intensity of inputs is found to be a particularly important factor to increase stability for most farm types, with a large effect size in comparison to other farming practices examined. Agri-environment payments are associated with greater stability at dairy, general cropping and mixed farms, however, the effect size is small in comparison.

4.2 *Agricultural diversity associated with greater stability*

Prior research has found greater diversity of agricultural activities or crops improves stability of revenue and household income, as well as, return on capital (El Benni et al., 2012; Lawes and Kingwell, 2012; Pacín and Oesterheld, 2014). There was, however, a need to validate the relationship between the diversity of agricultural activities and the stability of farm business income, across a range of different farm types and in other territories. Our analysis shows that greater diversity of agricultural activities also increases the stability of farm business income, in all farm types except for grazing farms. The effect of agricultural diversity is particularly important for general cropping farms who are, on average, the most diverse (Table 3) and may have the opportunity, and structure, to grow a wider range of crops. Increasing agricultural diversity could make farm businesses more resilient to economic shocks with access to a range of markets, therefore, reducing risks from potential price downturns (Bradshaw et al., 2004; Pacín and Oesterheld, 2014). Increased crop diversity has been found to lead to a better provision of ecosystem services, including higher yield, improved soil services and pest regulation (Degani et al., 2019), as well as, a reduction in the risk of crop failure (Gaudin et al., 2015). More diverse farms may be in a better position to adapt to changing environmental conditions, including drought (Degani et al., 2019; Lawes and Kingwell, 2012) or hot and dry years (Gaudin et al., 2015) due to improved soil moisture retention. Whereas, highly specialised farms could be more vulnerable to a given pest or disease and weather events affecting a larger proportion of production and be less able to recoup losses via other crops or livestock activities. Increasing resilience to abiotic and economic stresses by increasing agricultural diversity, may therefore also aid the stability of income. Increasing cropping system diversity has also been found to suppress weeds and improve soil fertility, lessening the need for expensive chemical inputs and reducing input costs, helping to maintain profitability whilst also reducing negative impacts on the environment (Davis et al., 2012).

Whilst we examine agricultural diversity at the farm level, we do not examine the "composition effect" i.e. whether the presence of certain species may influence stability. The presence of productive and drought resistance species in grasslands, and legumes as a cover crop in diverse crop rotations, have been found to improve yield stability and therefore may also effect the stability of farm income (Dardonville et al., 2020). We also consider that farmers may seek to diversify agricultural activities to reduce exposure to the variance in agricultural income (as suggested in Lin et al., 1974), therefore, this relationship may also be reflective of the risk averse attitude of some farmers. However, our finding that increasing agricultural diversity is associated with an increase in economic stability is consistently supported by a number of other studies, which examine a wide range of other farm characteristics, farming practices, insurance and economic variables, in different regions and contexts (e.g. Barry et al. (2001), Dardonville et al. (2020), El Benni et al. (2012), Enjolras et al. (2014), Loughrey and Hennessy (2016))

4.3 Lower input intensity associated with greater stability

Previous research has found mixed results regarding the effect of farming intensity, using different measures, on the stability of farm income (Enjolras et al., 2014; Reidsma et al., 2009). Modelling each farm type separately, we found a decrease in input intensity (lower cost of fertiliser, pesticides and concentrates per hectare) is associated with an increase in the stability of income across all farm types. With rising input prices, a concern of farmers is to control the use of expensive inputs and thereby increase profitability (Firbank et al., 2013). Farms with higher input costs are more likely to have higher gross revenues, however, this does not always translate to a higher farm business income (net profit); input intensity is weakly positively correlated ($r<0.3$) with farm business income per hectare (Supplementary Table 2). In crops, when designing fertiliser management practices there is a trade-off between yield, nutrient use efficiency and the environment; as you increase nutrient input, yields typically increase (but at a decreasing rate) and nutrient use efficiency declines (Roberts, 2008). Increasing fertiliser rates has also been previously linked to a decrease in yield stability (Just and Pope, 1979). For livestock farms, intensive grain-fed livestock incurs higher costs for animal feed, as well as, increased water use (Godfray et al., 2010). Farms using more inputs may be taking greater risks; they have the potential for higher outputs, but their larger cost investment could lead to larger financial losses in the event of extreme weather events and production failures. The impact of input intensity on the stability of income during different weather events, for instance wet years where pests or diseases may be prevalent, would be an important interaction to examine further. Our results indicate that reducing the intensity of inputs is an important factor increasing the stability of income, with a large effect on stability, relative to the other farming practices examined. The input intensity indicator used in this study is based on the cost of inputs per hectare and therefore can only provide an approximation for physical quantities, however, reducing synthetic inputs could also improve environmental health by reducing surface runoff and eutrophication (Raun and Johnson, 1999).

4.4 Receiving larger direct payments associated with a decrease in stability

Direct payments provide flat-rate income support to farmers based on the area of land farmed. Direct payments, along with intensity of inputs, are found to be highly influential with models showing large effects on the stability of farm income. An increase in direct payments per hectare is associated with a decrease in the stability of farm income across most farm types. This may seem counterintuitive as one of the goals of the CAP is to support and stabilise farm incomes, however, previous studies have also found similar results. Flat-rate subsidy payments potentially represent a moral hazard to farmers. Farms receiving larger direct payments may be more inclined to engage in riskier production or be less focused on production outputs, with the knowledge they will receive a guaranteed level of income support from the government (Enjolras et al., 2014; Poon and Weersink, 2011; Reidsma et al., 2009).

4.5 The effect of agri-environment payments depends on the farm type

4.5.1 Agri-environment payments improve stability for dairy, general cropping and mixed farms.

In contrast with direct payments, agri-environment payments, for dairy, general cropping and mixed farms, increase stability in income. The contrast between the effect of agri-environment payments and direct payments is particularly interesting and has not been examined previously. The contrast between payments based on land area and payments for environmental activities suggest it could be the impacts of the environmental practices undertaken by the farmer which are associated with the stability of income (rather than just the receipt of money). Voluntary agri-environment schemes compensate farmers for implementing measures to benefit the environment or biodiversity. The CAP focuses on ‘input based systems’ paying farmers and land managers for the ‘cost of inputs’ or ‘income foregone’. The increased stability we see may be due to increase provision of ecosystem services. Maintaining habitats for wildlife, such as wildflower strips, increased flower planting and field diversity through agri-environment schemes may improve the farmed environment for pollinators and natural enemies, supporting crop pollination and natural pest control (Blaauw and Isaacs, 2014; Kennedy et al., 2013; Menalled et al., 2003; Ottoy et al., 2018). This ‘ecological intensification’ (Bommarco et al., 2013; Kleijn et al., 2019; Pywell et al., 2015) may also increase yield and income stability. Insect pollination may increase production stability, for instance by reducing yield losses following heat stress in faba bean (Bishop et al., 2016). Soil management practices under agri-environment schemes, including planting of winter cover crops and minimal cultivation practices, can improve soil fertility and structure and help reduce soil erosion, which could otherwise represent a risk during heavy rainfall events (Büchi et al., 2018; Degani et al., 2019; Natural England, 2013). Increasing soil organic matter has also been found to increase cereal productivity and yield stability (Pan et al., 2009). Agri-environment practices included in agri-environment schemes have been found to help maintain and stabilise yields, increase resilience to pests or disease, as well as reduce the effects of environmental hazards for instance climate shocks. Therefore, it is possible these agri-environment practices could be associated with a greater stability of farm income. The effect of agri-environment payments on stability is smaller than the effect of direct payments, however this remains a new and important finding. Further research to identify which environmental measures may be associated with greater stability of income, across different farm types and landscapes, could be of interest to farmers and policy makers particularly given the UK’s transition to a new agricultural policy focusing on environmental land management and productivity measures. We also consider that the type of farmer choosing to participate in agri-environment schemes may be more progressive or adaptable, with prior research suggesting highly educated farmers who are open to innovation may be more willing to engage in agri-environment schemes (Barreiro-Hurlé et al., 2010; Peerlings and Polman, 2009). However, factors and characteristics which influence participation have been found to be varied and wide ranging, including farmer characteristics and attitudes (e.g. previous experience with agri-environment schemes), farm structure, social capital (e.g. influence of neighbouring farms), and economic factors (Lastra-Bravo et al., 2015), which were not considered as part of this study.

4.5.2 Agri-environment payments decrease stability for Less Favoured Area grazing farms

Agri-environment payments have the opposite effect for Less Favoured Area (LFA) grazing farms, reducing the stability of income. LFA grazing farms receive more money from agri-environment schemes per hectare, on average, than any other farm type (Table 3). LFA farmers received additional area-based payments to support the income of farms in challenging environments (refer to the supplementary materials for scheme details). However, the landscapes of LFA farms may not be well-suited for environmental enhancement, in comparison to other farm types, and therefore less able to deliver the ecosystem service benefits associated with a greater stability of production. LFA grazing farms have significantly fewer entry level and higher level options per agri-environment scheme agreement than other farm types in England (Department for Environment Food and Rural Affairs, 2006). In Wales, agri-environment schemes are considered more effective in providing income to support the viability of upland farming lifestyles, rather than providing ecosystem services (Arnott et al., 2019). Government support for LFA farms, via agri-environment schemes, therefore appears to have a similar effect as direct payments and does not support the stability of income.

4.6 Larger farms have a greater stability of income

Farm size is associated with an increase in the stability of farm income, in line with prior research and is a moderately important factor in stabilising income. Larger farms may be more adept at coping with income and price variation; larger farms are associated with economies of scale, greater wealth, stability of land control and a larger asset base therefore may have a better capacity to adapt to changing economic conditions or prices (El Benni et al., 2012; Velandia et al., 2009). In addition, a larger area of land may benefit from a wider range of topography and soil conditions and therefore yield responses across the farm. As a result larger farms may be better able to adapt to changing or extreme weather conditions (Marra and Schurle, 1994) which could aid in increasing the stability of income.

4.7 Greater reliance on on-farm diversification decreases stability of income

On-farm diversification into other activities (in addition to agricultural output) is often considered advantageous by providing an additional income source (McNally, 2001) and a viable financial return to farmers (Barnes et al., 2015). However, our results show that greater reliance on on-farm diversification decreases the stability of income, although the effect is relatively small. The effect of reliance on income from on-farm diversification has been less investigated in the literature, however, previous research found reliance on income from off-farm employment had a similar effect, reducing the stability of household income (El Benni et al., 2012). Farms may be branching into other activities they are not specialised in. Importantly income from on-farm diversification is also, on average, not a consistent or stable source of income for farmers in England and Wales; farms may dip in and out of diversified activities with revenue from on-farm diversification showing high variability (mean CV of revenue from on-farm diversification is 0.82 across all farm types, over a five-year rolling period), and therefore does not support income stability. Our results provide an initial indication of the relationship between on-farm diversification and the stability of income, however, farms can seek to diversify farm income in a variety of ways. Further analysis on the effect of reliance on on-farm diversification from different activities would help to provide a greater understanding of the relationship with the stability of farm income.

4.8 Stability measures and moving beyond stability

We use four stability measures to provide a robust analysis of overall income stability. The alternative measures of stability are correlated and provide similar results in our study, however, this may not be replicated in other regions, or when examining the effects of other farming practices or covariates. The choice of stability measure should depend upon the specific research question, and how stability is to be interpreted.

Our study focuses on the stability of farm income, which is a key issue for agricultural businesses. However, total levels of farm income are also important to ensure viable businesses for farmers. With a growing population more food will also need to be produced from existing agricultural land, by increasing output intensity using sustainable practices. Prior research identifies practices which strengthen sustainability to produce more food with less environmental impact (Campbell et al., 2014; Charles et al., 2014; Rockström et al., 2017). Examples of sustainable production systems include using conservation techniques such as no-till farming and sophisticated crop rotations, requiring less chemical inputs, which aim to preserve ecosystem services and harness ecological functions to increase productivity, as well as, improve livelihoods (Pretty, 2008; Pretty and Bharucha, 2014; Rockström et al., 2017). Our results show greater agricultural diversity and participation in agri-environment schemes may also reduce the variability of farm income. Therefore, whilst not the focus of our study, there appears to be some compatibility with these results and farming practices advocated to increase agricultural output and total farm income in a sustainable manner.

5 Conclusions

Our study provides knowledge on the effect of agricultural diversity on the stability of farm income in a new territory and across a range of different farm types. Results show that increasing the diversity of agricultural activities is associated with an increase in the stability of farm income, for dairy, general cropping, cereal and mixed farms. Agricultural diversity is an important farming practice associated with stability, particularly for general cropping farms. Prior research indicates farms with greater agricultural diversity may be in a better position to cope with climate and economic shocks, with crops and livestock exhibiting different responses to environmental conditions and by providing access to a wider range of markets. In addition, increasing crop diversity can also improve soil services and pest regulation reducing the need for expensive chemical inputs.

Our results also show that reducing the intensity of inputs is associated with greater stability of income across all farm types. Reducing the intensity of inputs is found to be an important factor increasing the stability of income, with a large effect on stability, relative to the other farming practices examined. Current farming techniques tend to rely upon increasing the intensity of inputs to obtain higher outputs, however, farms using more increasingly expensive inputs may also be exposed to greater variability of income, in the event of extreme weather events and production failures. We did not consider how intensity of farming may increase total income or total production, which is also important to ensure viable businesses for farmers and to feed a growing population. However, increasing the production of food should be done in a sustainable manner, with greater stability, whilst contributing to the health of ecosystems.

Direct subsidies paid to farmers based on the area farmed are associated with a relatively large decrease in the stability of farm income, across most farm types. In contrast, we show that higher agri-environment payments increase the stability of farm income, for dairy, general cropping and mixed farms. Agri-environment schemes may help to reduce the effects of environmental hazards for instance climate shocks, as well as provide a higher and more stable provision of natural pest control, by adopting practices to benefit the environment or biodiversity. LFA grazing farms receive additional dedicated area payments via agri-environment schemes to support farms in challenging environments. This flat rate income support for LFA farms appears to have a similar effect as direct payments and does not support income stability. The effect of agri-environment payments on stability is smaller than the effect of direct payments, however this remains a new and important finding. Further analysis to identify which environmental practices, undertaken through agri-environment schemes, may lead to greater stability of income is an area of research which could be of interest to farmers and policy makers, particularly given the current transition from direct payments to a new agricultural policy in the UK focusing on environmental land management and productivity measures.

Our results suggest that engagement in environmentally sustainable farming practices, including increasing agricultural diversity, engagement in agri-environment schemes and reducing the intensity of inputs, can increase the stability of many farm businesses whilst also reducing negative impacts of farming on the environment.

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