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The Determinants of Farm Income Variability: Evidence From Estonia

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Abstract: Farm income is a policy-relevant proxy for farm households' viability. Volatile income levels reduce the well-being of farmers and decrease their incentives to produce, invest, and innovate. This article provides a comprehensive analysis of the associations between agricultural subsidies, farm characteristics, and the stability of farm income, along with their relative importance, by applying a linear fixed-effects model to the Estonian Farm Accountancy Data Network (FADN) sample. Building on previous analyses, we show that a significant portion of agricultural subsidies in gross farm income is positively associated with income instability. Our estimates suggest that financial immobility is positively correlated with income stability. This indicates that farm-specific grants can provide opportunities to invest while also alleviating budget constraints for indebted farms. After controlling for various farm characteristics, we find that income becomes more stable as farmers age, while income volatility associated with agricultural production is positively linked to rising land prices.

Keywords: Agriculture, Agricultural Subsidies, Farm Income Instability, Within Instrumental Variables Estimator, Estonia

1 Introduction

Average income levels are frequently used to assess the general well-being of farms and the farming sector. Sufficiently high and stable incomes are an essential for farms' capacity to provide agricultural produce and public goods (Finger, El Benni, 2021). Income instability affects farmers' well-being and ability to expand operations, repay debt and in turn, it may have indirect long-term effects on agribusiness firms and creditors (Bojnec, Fertő, 2018; Kata, Wosiek, 2020).

There is a growing literature on farm income stability investigation. However, the results in scientific literature remain ambiguous. Farm income variation, instability and inequality may refer to variations of income between regions, farm types and size, but also to variation of income of an individual farm over time (Finger and El Benni, 2021). Several studies (e.g., Castañeda-Vera, Garrido, 2017; Severini et al., 2019; Harkness et al., 2021; Nitta et al., 2022) explained the association between variability of farm income and economic and structural characteristics of farms. By examining a range of different farm types, Harkness et al. (2021) concluded that the stability of farm income is positively associated with greater agricultural diversity. Harkness et al. (2021) and El Benni et al. (2012) showed that the greater agricultural diversity reduces the variability of farm income, while Bojnec, Fertő (2018) suggest the specialisation more likely increases that. Financial structure also has a role. A high share of fixed assets increases financial immobility and associated costs, and may thereby increase farm income variability (Bojnec, Fertő, 2018). Low share of owned land, one of the main fixed assets, enables farms to use current assets more flexibly but on the other hand, it hinders the borrowing capacity of farms (Biagini et al., 2020). It has been suggested that income variability management instruments (e.g., income insurance schemes, mutual funds), non-farm income sources, and policy interventions to facilitate their uptake may decrease income inequalities between farms (Finger, El Benni, 2014; Severini et al., 2019) and may stabilize agricultural income (Castañeda-Vera, Garrido, 2017).

Studies have found that agricultural subsidies implemented under the Common Agricultural Policy (CAP) of the European Union (EU) stabilise farm income and reduce its volatility (Enjolras et al., 2014; Castañeda-Vera, Garrido, 2017; Aleksandrova et al., 2022), and that direct payments in specific help to stabilize farm income (El Benni et al., 2012; Severini et al., 2016). However, receiving government payments may lead farmers to take on more risks by reducing self-insurance and therefore, such farmers may face a higher income variability in turn (Koundouri et al., 2009; Poon, Weersink, 2011; Bozzola, Finger, 2021). Fertő, Stalgienė (2016) encouraged this by finding that the agricultural subsidies had a positive correlation with the income variability in Lithuanian dairy farms.

Analyses of income variation are affected also by the data granularity. Hill, Bradley (2015) and Dabkienė (2020) showed that income instability measured by aggregate data understates the degree of instability experienced at the individual farm level. Therefore, analysing income changes of individual farms over three- or five-year periods is a preferred approach (Bojnec, Fertő, 2018). The mixed results on earnings volatility may also arise from the fact that different studies consider different sets of variables. We address this gap by analysing simultaneously three major sets of variables that influence farm income stability.

The aim of the paper is to comprehensively analyse the effects and the relative importance of farm characteristics, farm financial structure and agricultural subsidies on the stability of farm income in Estonia based on Estonian Farm Accountancy Data Network (FADN) sample. Besides analysing these relationships in the sample of all farm types over long time (2006-2019), the study scrutinizes farm income variability and its relationships with these variables in crop, livestock and mixed farms. To the best of our knowledge, there is no analysis of income variability in the literature that simultaneously includes these three variables sets.

Econometric approach is based on a linear fixed-effects model. We employ instrumental variables approach to account for a potential endogenous explanatory variable (Wooldridge, 2009). We assume potential endogeneity in our data: possible reverse effects could make farm income variability, agricultural subsidies and cost of farm debt endogenous variables (de Mey et al., 2016). The farm may face higher debt costs due to the perceived risk of unstable income. Income variability may lead to increased government subsidies. At the same time, these subsidies might reduce income variability, creating a feedback loop where income variability influences the subsidy amount. Agricultural subsidies account for a large share of farm income (Aleksandrova et al., 2022) and could possibly be correlated with unobserved local conditions.

Accordingly, the main contribution of this paper is threefold. First, according to our knowledge, it is the first study that provides evidence on farm income variability in a Northern European country. Second, most existing studies have explored the association between direct payments and farm income variability, whereas our analysis examines the factors contributing to gross farm income variability considering all agricultural subsidies and their share in gross farm income. Third, the association of farm financial structure and farm income volatility is considered.

The remaining of the paper is structured as follows. Chapter 2 provides an overview of Estonian agriculture and its main characteristics that are relevant for the farm income variability analysis. Also, this chapter explains how farm income variability is measured in this paper, gives an overview of the data that is used, presents the hypotheses of the study. Chapter 3 presents the empirical model. Chapter 4 presents the results of the analysis and Chapter 5 discusses the implications of the findings. The paper ends with the concluding chapter.

2 Material and Methods

2.1 Study Area

Estonia is located in Northern Europe, on the eastern shores of the Baltic Sea, between 57.5 and 59.51 latitude, and covers an area of 45,215 km^2 (Figure 1). Estonia is placed in a maritime and continental climate transition zone. The average temperature varies from -6 °C in February to 16 °C in July. The average annual rainfall is 630 mm. With a population of 1.3 million people and utilised agricultural area (UAA) of 1 million ha, Estonia is a relatively rich in agricultural area per capita, and therefore has an export potential in certain agricultural products (OECD, 2018). Estonia has traditionally been a net-exporter of dairy products (Viira et al., 2015). After the EU accession in 2004, cereals production increased, and the country has become a net-exporter of cereals. At the same time, Estonia is a net importer of meat, eggs, fruits and vegetables (OECD, 2018). Estonia is a smallest country among Baltic countries, and one of the most developed among post-communist countries (Viira et al., 2009). Estonian farm structure is dualistic and livestock farms are the most prevalent farm type. A significant share of land area is farmed under extensive and biodiversity-friendly agricultural practices, compared with more intensive systems (below 10%) that concern mainly livestock farming (OECD, 2018).

Estonian agriculture is significantly supported by the EU funds: OECD producer support estimate (PSE) in the EU has stabilised at around 19% of gross farm receipts since 2010 (OECD, 2019). Total subsidies (excluding on investments) in the period 2006-2019 increased by 96% and their variation was comparable with the variation of total intermediate consumption (Aleksandrova et al., 2022).

Figure 1. Estonia and its location in the EU

Source: authors' elaboration

In 2004, accession to the EU improved agricultural policy and market conditions for Estonian farmers and started a period of agricultural growth (Viira et al., 2009; Šapolaitė et al., 2019). Value of the output of agricultural industry (in current prices) increased by 85% from 2006–2019. Growth in crop output (139%) outpaced the growth in animal output (41%) (Figure 2). At the same time, value of animal output showed larger variation than the value of crop output. Fixed capital consumption increased by 155%, total intermediate consumption increased by 114%, and compensation for employees increased by 87%. According to Looga et al. (2018), during the observed period, all these cost items showed markedly smaller variation than output. Paid interests increased by 57% and paid rents increased by 304%. While Aleksandrova et al. (2022) showed that the variation of paid interests was comparable to the variation in animal output, the variation of paid rents was significantly larger than other cost and revenue categories, indicating potential uncertainties related to land prices. Entrepreneurial income decreased by 16% and its variation exceeded variation in output and most of the cost categories.

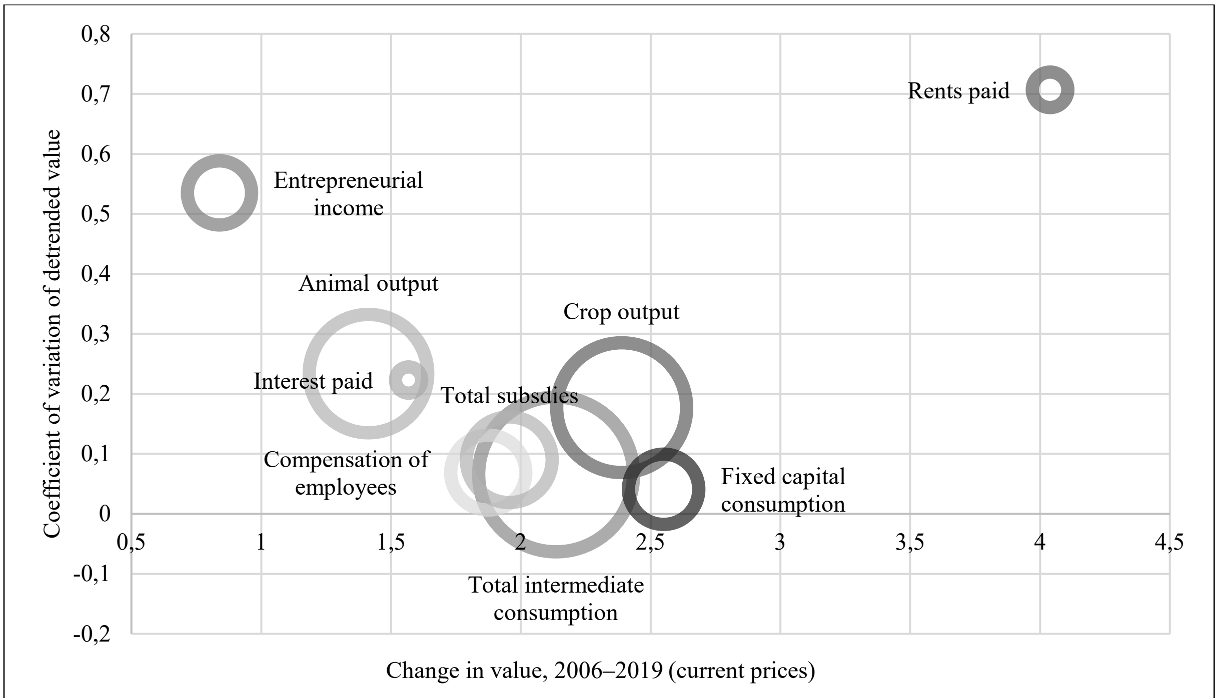

Figure 2. Change in value of output, costs and subsidies (in current prices) of Estonian agriculture, and associated variation (detrended) (2006-2019)

Note: size of the circle indicates value in Euros in 2019
Source: authors' calculation based on Statistics Estonia (2021)

Variation in the value of crop output is mainly due to variation in yield and crop prices. Animal production has generally been more stable, but its output value was significantly impacted by several events: the financial crisis in 2009, the import ban imposed by the Russian Federation in 2015-2016, and the outbreak of African Swine Fever from 2015 onward. These factors affected prices, dairy and pig herds, and consequently, overall animal output (OECD, 2018).

2.2 Data and Sampling Procedure

For the empirical estimation, this paper uses the Estonian FADN individual farm data from the period 2006–2019. In the Estonian FADN dataset, the sampling methodology relies on non-random sampling techniques (Heckelei et al., 2023), specifically stratified and quota sampling, to ensure the representativeness of farms. The data was provided by the Centre of Estonian Rural Research and Knowledge (METK), which is a liaison agency for the FADN data collection in Estonia and follows this structured approach to ensure that the collected data is both representative and useful for policy analysis and economic research. The FADN dataset is a rotating, unbalanced panel that includes representative farms in order to assess the economic development of the whole farming sector (Aleksandrova et al., 2023). In addition to the mandatory data transmitted to the EC, several other indicators are collected in Estonia, which are necessary for a more comprehensive analysis of the economic results of the agricultural sector at the domestic level and for evaluating the effectiveness of support measures implemented for the development of rural life (FADN FARM RETURN, 2020). Estonian FADN dataset for the period 2006-2019 is an unbalanced panel containing 8,591 observations.

During this period a total of 1,256 farms were surveyed with 646 farms (51%) having at least six consecutive years of entries. To address the issue of missing data, but to still be able to measure possible income variability shifts over time, we followed the approach that has been developed by El Benni et al. (2012), Bojnec, Fertő (2018), Harkness et al. (2021). The whole period was split into 10 partially overlapping periods, each comprising five consecutive years. The first time period comprised five income records for each farm that had entries for all years between 2006 and 2010. Consequently, the second period comprised five income records for each farm that had entries for all years between 2007 and 2011, etc. (El Benni et al., 2012; Bojnec, Fertő, 2018).

In the empirical models we use the following variables:

1. Gross farm income (FADN variable is coded SE410) is used as the measure of income and is calculated as the sum of revenues and grants and tax balance minus cost of external factors of the *i*-th farm in period *t*;
2. Subsidies is calculated as the ratio of total subsidies (excluding on investments) (FADN variable is coded SE605) to gross farm income (FADN variable is coded SE410) of the *i*-th farm in period *t*;
3. Profitability is calculated as the ratio of gross farm income (FADN variable is coded SE410) to total assets (FADN variable is coded SE436) of the *i*-th farm in period *t*-1;
4. Age is defined as farm owner's or farm manager's (if owner was not a manager) age of the *i*-th farm in period *t*;
5. Farm size is defined as farms with a standard output (SO) 4000–8000 euros belong to size class 3, farms with SO above 3 000 000 euros belong to size class 14 of the *i*-th farm in period *t*;
6. HHI is calculated as Herfindahl-Hirschman Index (HHI) of sales revenue of crops, share of livestock products, and share of non-agricultural activities in total sales revenue of the *i*-th farm in period *t*;
7. Land is the share of owned land (considered as a difference of total utilized agricultural area (FADN variable is coded SE025) and leased agricultural land (FADN variable is coded SE030) of the *i*-th farm in period *t* divided by the total utilized agricultural area (FADN variable is coded SE025) of the *i*-th farm in period *t*;
8. Cost of farm debt is represented by the ratio of interest paid (FADN variable is coded SE380) over total outstanding farm debt (FADN variable is coded SE485) of the *i*-th farm in period *t*;
9. Financial immobility is represented by the ratio of fixed assets (FADN variable coded SE441) to total assets (FADN variable is coded SE436) of the *i*-th farm in period *t*;
10. Land price is represented by the ratio of value of land, permanent crops and quotas (FADN variable is coded SE446) to owned land (difference between total UAA (FADN variable is coded SE025) and leased agricultural area (FADN variable is coded SE030) of the *i*-th farm in period *t*. In the empirical estimation, natural logarithm of land price was used.

Table 1 provides descriptive statistics of independent variables used in the empirical estimation.

Table 1. The independent variables and their descriptive statistics

Variable	Mean	SD
Subsidies	0.17	15.45
Profitability	0.21	0.08
Age	52.66	10.46
Farm size	7.70	2.28
HHI	0.78	0.17
Land	0.48	0.26
Cost of farm debt	0.08	0.30
Financial immobility	0.75	0.11
Ln (Land price)	6.52	0.88

Source: authors' calculations based on FADN data for Estonia

The dataset was compiled from the full dataset by selecting observations for those farms that: (i) did not have missing values for the variables needed for estimation, (ii) were present in the dataset for at least six consecutive years, and (iii) did not present zero values in the denominator of used variables. These observations were considered outliers and were removed from the initial dataset. After removing the outliers, our final unbalanced dataset contained 2,584 observations (455 farms).

The sample selection procedure might be potential source of bias compared to initial dataset. Figure 3 shows the share of farms in the whole and restricted samples (after removing outliers and constructing of final dataset). With regard to the considered data set, the percentage of farms in general are similar in the restricted and the full data set. Livestock farms are slightly overrepresented in the restricted panel for 2015 and 2016, comprising 45% of the total in 2015 and 50% in the final dataset, while in 2016, they account for 40% of the total and 45% in the final dataset. Conversely, crop farms are slightly underrepresented in 2016, making up 44% of the total sample compared to 37% in the final dataset. However, the differences in the restricted panel and whole data sample are not large. Thus, removing the outliers and constructing of final datasets did not cause a bias compared to initial sample selection.

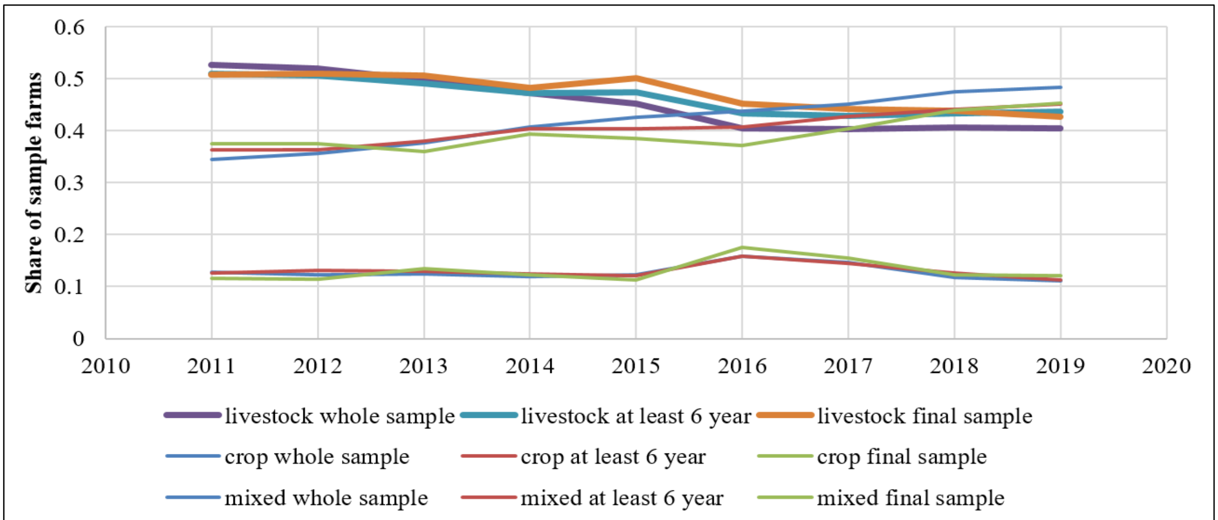

Figure 3. Share of livestock, crop and mixed farms in total and restricted samples

Note: Type of farming (livestock; crop production and mixed) was determined according to the EU classification of types of farming (EC, 2015); "whole sample" refers to the share of livestock, crop and mixed farms in the total sample. "At least 6 year" refers to the share of livestock, crop and mixed farms among those farms with at least six consecutive years of entries; "final sample" refers to the share of livestock, crop and mixed farms in the final dataset.
Source: author's calculations based on FADN data for Estonia

Despite applying outlier rules (i)-(iii), there were still outliers in the subsidy, cost of farm debt, and income variability variables in the final dataset. Therefore, to mitigate effect of outliers during model fitting, the Winsorization technique[1] was used (Yuliyani et al. 2017). We utilized this technique to avoid even greater data loss due to simple deletion of data containing outliers.

Farm production type also affects income variability due to differences in the seasonality of production, exposure to changing weather conditions, frequency of sales and market transactions, inherent price instabilities, influences of government programs, differences in production variabilities, and other factors (Severini et al., 2016). Farms were divided into following production types (EC, 2015): (1) crop farms (specialist cereals, oilseeds and protein crops, specialist other field crops, and mixed crops); (2) livestock farms (specialist milk, specialist cattle, specialist sheep and goats, specialist granivores, and mixed livestock); and (3) mixed farms (mixed crops and livestock).

2.3 Measuring the Stability of Farm Income

In this study we use three different measures for the stability of farm income (Table 2): CV and two annual measures of stability (absolute and relative anomaly) of farm income (Harkness et al., 2021).

Table 2. Measures of Farm Income (FI) stability used in our analysis

Stability measure	Calculation	What does the measure show?
Coefficient of variation from the rolling 5-year: ratio of standard deviation from farm mean divided by rolling 5-year mean	$CV = \frac{\sigma}{\bar{Y}}$, where $\bar{Y} = \frac{1}{5}\sum_{t}^{t+4} Y_i$	Coefficient of variation of FI at the individual farm.
Absolute deviation from the rolling 5-year means of individual farm (MAD: mean absolute deviation)	$ABS_{it} = \lvert Y_{it} - \bar{Y} \rvert$	Absolute deviation in FI at each farm from the average efficiency at the farm $\bar{Y}$ in year t.
Relative MAD: ratio of absolute deviation from farm mean divided by rolling 5-year mean	$REL_{it} = \frac{ABS_{it}}{\bar{Y}}$	Relative deviation in FI; absolute deviation from the mean efficiency at the individual farm, scaled to the 5-year rolling mean FI of farms

Source: author's calculations based on FADN data for Estonia

Figure 4 shows that the coefficient of variation of gross farm income decreased from 2011 to 2013 and from 2016 to 2019, but increased from 2013 to 2016. Period 2013-2016 was connected with difficult periods for Estonian agriculture: import ban imposed by the Russian Federation in 2014, abolition of dairy quota in 2015, and spread of African Swine Fever in production farms in 2015-2017.

1 To winsorize data means to set extreme outliers equal to a specified percentile of the data. We winsorized the dependent variable (variability of farm income), subsidies and cost of farm debt at the 95th percentile: the upper 5% of the data is replaced by the value of the data at the 95th percentile and the value of the under 5% of the data is replaced by the value of the data at the 5th percentile.

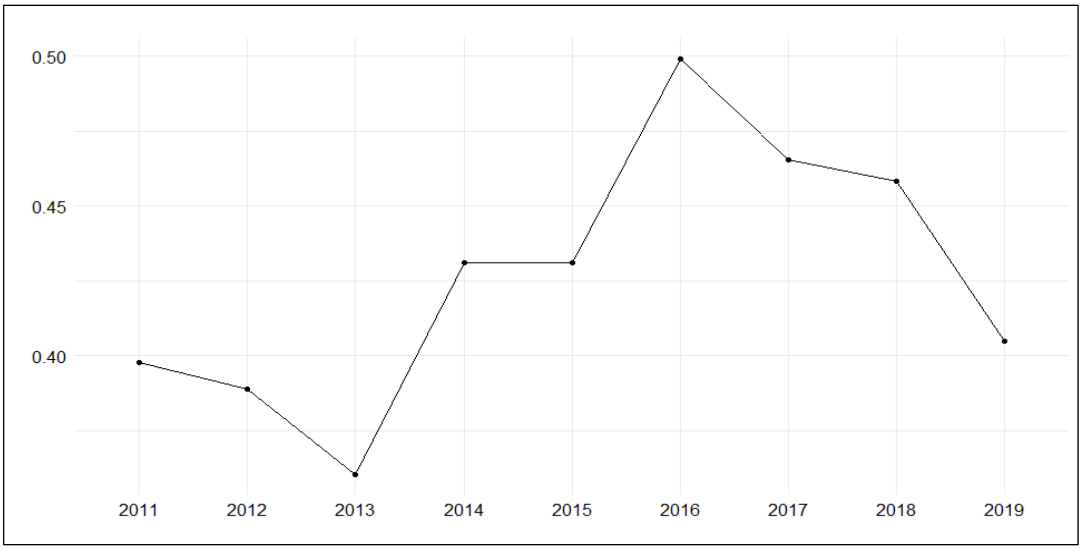

Figure 4. Coefficient of variation of gross farm income over time (on average, across all farms)

Note: Coefficient of variation is calculated from the rolling 5-year as shown in Table 2
Source: authors' calculation based on FADN data for Estonia

2.4 Hypotheses

The hypotheses and the respective explanatory variables are divided to three groups: (i) farm income; (ii) farm characteristics; and (iii) financial structure and assets (Figure 5). Share of owned land is considered to characterise both farm and its financial structure and assets.

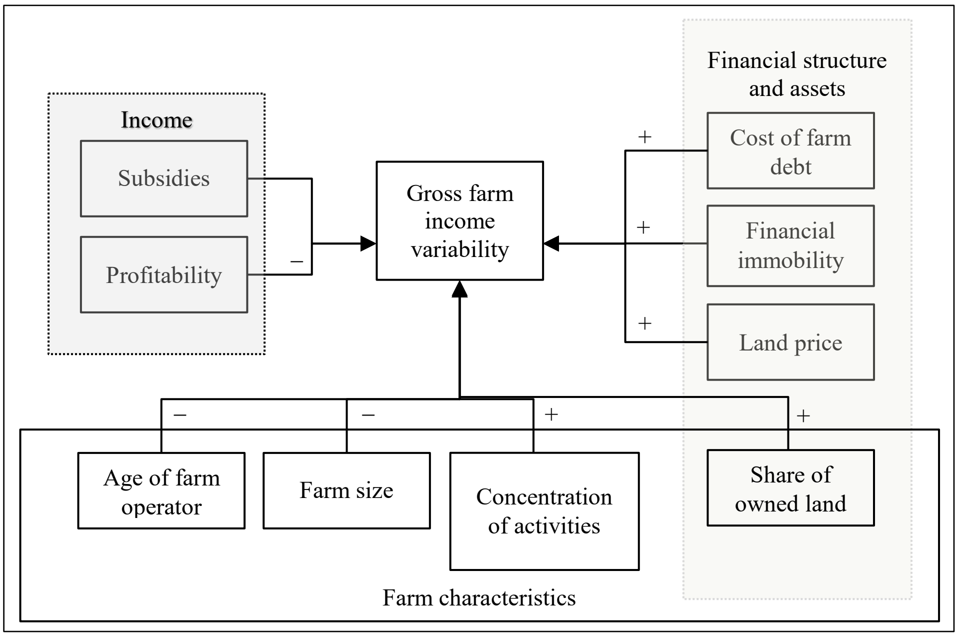

Figure 5. Factors that affect gross farm income variability and their hypothesized associations

Note: "plus" and "minus" signs point to hypothetical associations between dependent and independent variables.
Source: authors' elaboration

Following Bojnec, Fertő (2018), we consider that share of agricultural subsidies (excluding subsidies on investments) in farm gross farm income is negatively associated with farm income variability.

- H_1: The share of subsidies in gross farm income is negatively associated with farm income variability.

In our farm income variability equations, we expect to find a negative association with past levels of profitability. Farm profitability is measured by the ratio of gross farm income and assets (de Mey et al., 2016).

- H_2: There is a negative association between past levels of profitability and farm income variability.

Older farmers are assumed more risk averse than younger farmers (Fertő, Stalgienė, 2016; El Benni, Finger, 2013), and follow more conservative technology yielding lower income variability.

- H_3: There is a negative association between farmers' age and FI variability.

Larger farms may be able to better manage extreme events and benefit more from economies of scale and production efficiencies (Bojnec, Fertő, 2018). In the FADN database, the type and economic size of farm households is determined based on the value of the standard output (SO). In the empirical estimation, economic size classes (that range from 3 to14) are used as an indicator of farm size.

- H_4: There is a negative association between farm size and FI variability.

Diversification of activities is the usual income stabilisation management tool, while specialization is a source of economic efficiency via economies of scale (El Benni, Finger, 2013). In the empirical model, the concentration of activities is measured by the Herfindahl-Hirschman Index (HHI), which is calculated based on the shares of sales revenues from crop, livestock and non-agricultural production in total revenues. The index ranges between 0 and 1, and the closer the value to 0, the higher the degree of specialization.

- H_{5a}: Concentration of farmer's activity is positively associated with farm income variability.
- H_{5b}: There is a non-linear negatively association between concentration of farmer's activity and farm income variability.

Farm households that own a larger percentage of their land have higher levels of equity, which positively affects their borrowing capacity and liquidity (Biagini et al., 2020). Thus, share of owned land characterises both, the farm and the structure of its assets. Low proportion of owned land may increase uncertainty of the agricultural land use, and thus increase the variability on farm income.

- H_{6a}: Share of owned agricultural land is positively associated with farm income variability.
- H_{6b}: There is a non-linear negative association between share of owned of agricultural land and farm income variability.

Financial structure may substantially influence the variability of returns to equity and stability of farm equity. In particular, increases in the debt to assets ratio or the interest paid to assets ratio will increase the variability of farm income (Biagini et al., 2020). The cost of farm debt is represented by the interest paid over total outstanding farm debt (de Mey et al., 2016).

- H_7: Farm income variability is positively associated with cost of farm debt.

Fixed assets potentially represent higher sunk costs, therefore, the higher the share of fixed assets in total assets, the less financially immobile farms are, the lower the farm liquidity, and thus the higher the farm income variability (Bojnec and Fertő, 2018). Higher liquidity may allow a farmer to deal with more risks and therefore it is expected to reduce income variability (Fertő, Stalgienė, 2016).

- H_8: Farm income variability is positively related with farm financial immobility.

As credit adjusts to new equity values, land value influences credit availability positively, thereby increasing liquidity and allowing financial variability also to increase (Biagini et al. 2020). In the empirical model, value of agricultural land is used as a proxy of price of agricultural land, and natural logarithm is used to reduce the range of values for the variable.

- H_9: There is a positive association between price of land and farm income variability.

To test the hypotheses, we rely on statistical null hypothesis testing based on the estimated coefficients from Equation (1) using the Within Instrumental Variables Estimator (w2sls) (Croissant, Millo, 2019) under the assumption of random sampling. We use estimated confidence intervals to interpret the compatibility of the model with our data (Amrhein, Greenland, 2022).

3 Empirical Model

One key concern in this analysis is the issue of reverse causality, which can pose significant challenges when interpreting the relationships between variables. Reverse causality occurs when it is unclear whether the independent variable influences the dependent variable or vice versa. We expect the causality to be a problem in our study due to data design and model specification. The gross farm income variable is used for design of dependent variable and two independent variables such as subsidies and profitability. Agricultural subsidies may not only affect farm income but also be influenced by it: if a farm experiences low income due to poor yields or market conditions, it might become eligible for more subsidies. Farms with higher debt levels may engage in riskier activities to generate higher returns, potentially increasing income variability (Severini et al., 2017). Higher farm income variability leads farm households to diversify their assets as a risk management strategy, indicating that income variability influences debt decisions (Serra et al., 2004). Increased debt can negatively impact farm profitability. For instance, in the dairy sector, a higher debt-to-asset ratio is associated with lower productivity and profitability (Ma et al., 2020).

To avoid reverse causality problem between farm income variability, farm profitability and cost of farm debt at the same time, in the Equation (1) we have included a past level of profitability. Using lagged values helps mitigate the reverse causality problem because they reflect historical financial performance that may affect current decisions or conditions, such as investment choices or risk management strategies.

The estimation of income variability in partially overlapping periods leads to a high level of autocorrelation, i.e., all values are correlated with others from previous and next periods (El Benni et al., 2012). In order to obtain the robust results, this autocorrelation has to be taken into account. Furthermore, Breusch-Godfrey test (Breusch, 1978) for autocorrelation in panel data was conducted and the null hypothesis of no first order autocorrelation was rejected at the critical 5 percent significance level (Wooldridge, 2009). The Breusch-Godfrey test based on the idea of Lagrange multiplier testing yielded a related Lagrange multiplier (LM) statistics equal 757.9 for Equation (1). Thereby the H_0 of no first-order autocorrelation at the 5 percent statistically significance level can be rejected under the assumption of random sampling. Since the variance inflation factors (VIF) of all regressors (without squared) are between 1 and 1.5, there is no indication of multicollinearity problems in the data.

Therefore, we estimate a linear fixed-effects model of the following form:

$$y_{it} = \beta_1 Subsidies_{it} + \beta_2 Profitability_{it-1} + \beta_3 Age_{it} + \beta_4 Farm\ size_{it} + \beta_5 HHI_{it} + \\ +\beta_6 HHI_{it}^2 + +\beta_7 Land_{it} + \beta_8 Land_{it}^2 + \beta_9 Cost\ of\ farm\ debt_{it} + \\ +\beta_{10} Financial\ immobility_{it} + +\beta_{11} ln(Land\ price)_{it} + u_t + e_{it}. \quad (1)$$

where
y_{it} is the variability of income for each farm operation, *i*, and five-year time period, *t*;
β_i represents the parameters of the explanatory variables;
u_t is the time specific effects;
e_{it} is the idiosyncratic error term.

To account for unobserved heterogeneity due to the panel structure of the FADN data set, the model is estimated as a fixed-effects (FE) regression where time effects accounting for unobserved heterogeneity that evolves over time but is constant across farms due to highly unbalanced panel per year (only 35% of all farms do exist over the whole period). This regression model refers to the inclusion of time-period-specific effects in panel data models to control for unobservable factors that vary over time but are constant across individuals (Wooldridge, 2010). To test the presence of time-fixed effects in panel data, we estimated the pooled model, the FE model with time effects and the two-way FE model. Comparing of RSS (residual sum of squares) and the adjusted R-squared values of the models indicates that the model with time-fixed effects provides a better fit (Appendix, Table A1). In addition, the vcovSCC[2] function used to compute a robust covariance matrix of parameters for a panel model according to the Driscoll, Kraay (1998) method, which is consistent with cross–sectional and serial correlation in a T-asymptotic setting and irrespective of the N dimension.

The instrumental variable (IV) approach deals with endogeneity using a two-stage approach (Wooldridge, 2009). The set of instruments are lagged values of subsidy variable, lagged values expenditures (in euros) of fertilizers and pesticides[3] and lagged values of cost of farm debt. The variables lagged expenditures (previous periods' spending) of fertilizers and pesticides constitute suitable instrumental variables because lagged expenditures of inputs can influence subsidy decisions, reflecting cost compensation measures by the government (compensating farmers who incur high input costs to encourage continued production). However, these expenditures are not affected by current income variability, ensuring they are exogenous to the main regression equation. To deal with endogeneity, we apply the Within Instrumental Variables Estimator (w2sls), which is consistent, even if the individual effects are correlated with the covariates (Croissant, Millo, 2019). The instrumental variables estimator is computed using the plm function (package "plm") (Croissant, Millo, 2019). Estimator w2sls with time effects is removed time effects, is instrumented the endogenous variables with the specified instruments, and is estimated the coefficients based on the adjusted values of the endogenous variables.

To robustness check of our results, we have used the same approach with 3 and 4-years rolling data. Results of these estimations can be found into Appendix (Coefficients plots estimates Figures A1-A6).

2 The R program uses a non-parametric technique but do not automatically select the maximum lag to be considered in the autocorrelation structure. We selected the maximum lag equal to 5 since our variables are calculated using moving averages of five years.

3 These variables FADN are coded SE295 and SE300, respectively.

4 Results

Tables[4] 3-5 show the results of the three models, using three different measures of farm income variability (the inverse of stability), as described in Table 2. The tables include coefficients indicating the relative strength of factors associated with income variability by farm type. The 95% confidence intervals based on Driscoll and Kraay robust standard errors are reported in parentheses. Coefficient plots (Figures 6-8) visualize the 95% confidence intervals and their corresponding regression estimates. We follow Amrhein, Greenland (2022), who proposed renaming confidence intervals as compatibility intervals, to interpret these results.

Hypothesis H_1 (the share of subsidies in gross farm income is negatively associated with farm income variability) is rejected: the share of subsidies in gross farm income is positively associated with farm income variability. The range of values for the subsidy variable's coefficient shows a significant difference between different samples. The size of this coefficient is more compatible with our data when income variability is measured as CV or relative MAD, compared to when it is measured as absolute MAD (Figures 6-8).

Hypothesis H_2 (there is a negative association between past levels of profitability and farm income variability) is not rejected when farm income (FI) variability is measured as CV (Table 3) or relative MAD (Table 4), but it is rejected when FI variability is measured as absolute MAD (Table 5) for crop farms and the whole sample. The size of the past-level profitability coefficients is compatible with our data sample (the midpoints of all confidence intervals are close to each other) (Tables 3-4; Figures 6-7). However, when absolute MAD is used as the dependent variable, the results differ. Thus, the value of this coefficient is sensitive to how FI variability is measured (Figures 6-8).

Hypothesis H_3 (there is a negative association between farmers' age and FI variability) is not rejected. The ranges of the confidence intervals for the age coefficients indicate that their impact may not appear in the next time period. This suggests that the difference in FI variability for a farmer aged 25 versus 26 years old is not big. However, for the same farmer at ages 25 and 50, the difference in FI variability might become larger.

Hypothesis H_4 (there is a negative association between farm size and FI variability) is not rejected when FI variability is measured as CV (Table 3) or relative MAD (Table 4) (excluding mixed farms), but it is rejected when FI variability is measured as absolute MAD (Table 5). The size of the corresponding coefficients (in absolute value) is larger in Table 5.

Hypothesis H_{5a} (concentration of farmer's activity is positively associated with farm income variability) is not rejected when the dependent variable in Equation (1) is CV, except for mixed farms (Table 3); it is not rejected when the dependent variable is relative MAD (Table 4); and it is not rejected for farm types when the dependent variable is absolute MAD (Table 5). The size of these coefficients varies and depends on the measure of FI variability.

Hypothesis H_{5b} (there is a non-linear negative association between concentration of farmer's activity and farm income variability) is not rejected when the dependent variable in Equation (1) is CV (Table 3), except for mixed farms; it is not rejected when the dependent variable in Equation (1) is relative MAD (Table 4), except for mixed farms; and it is not rejected for farm types when the dependent variable in Equation (1) is absolute MAD (Table 5). The size of these coefficients varies and depends on the measure of FI variability.

Hypothesis H_{6a} (share of owned agricultural land is positively associated with farm income variability) is not rejected when the dependent variable in Equation (1) is CV, except for mixed farms (Table 3); or when the dependent variable in Equation (1) is absolute MAD (Table 5), except for livestock and mixed farms. However, this hypothesis is rejected when the dependent variable in Equation (1) is relative MAD (Table 4), excluding the livestock sample.

[4] We used package stargazer (Hlavac, 2022) in R to format the tables.

Hypothesis H_{6b} (there is a non-linear negative association between share of owned of agricultural land and farm income variability) is not rejected when the dependent variable in Equation (1) is absolute MAD for crop farms and the whole sample (Table 5); however, this hypothesis is rejected when the dependent variable in Equation (1) is relative MAD (Table 4), excluding the livestock sample, or when the dependent variable is CV (Table 3).

Hypothesis H_7 (farm income variability is positively associated with cost of farm debt) is not rejected: the coefficients for farm costs fall within overlapping compatibility intervals and are similar in value, excluding crop farms. Therefore, we can conclude that farm costs are compatible with our data set.

Hypothesis H_8 (farm income variability is positively related with farm financial immobility) is rejected: coefficients for farm immobility are within overlapping compatibility intervals (Tables 3-5, Figures 6-8) and are clearly compatible with our data sample.

Hypothesis H_9 (there is a positive association between price of land and farm income variability) is not rejected: coefficients for the natural logarithm of land price are small and positive, and their confidence intervals are compatible with each other (Figures 6-8). As previously mentioned, the narrow confidence intervals for the coefficients may indicate that rising land prices increase FI variability in the long term, not necessarily in the next time period (year).

Table 3. Regression results for determinants of farm income variability: dependent variable is CV(FI), Within Instrumental Variables Estimator (w2sls)

	Whole sample	**Livestock**	**Crop**	**Mixed**
Subsidies	0.08 (0.05, 0.11)	0.07 (0.003, 0.14)	0.07 (-0.12, 0.26)	0.13 (0.09, 0.18)
Profitability	-0.63 (-0.78, -0.49)	-0.80 (-1.09, -0.50)	-0.55 (-0.66, -0.44)	-0.46 (-0.84, -0.07)
Age	-0.0004 (-0.001, 0.0004)	0.0004 (-0.0003, 0.001)	-0.001 (-0.001, -0.0004)	-0.002 (-0.004, 0.0002)
Farm size	-0.01 (-0.02, -0.003)	-0.01 (-0.02, 0.01)	-0.02 (-0.04, -0.004)	0.01 (0.003, 0.01)
HHI	0.89 (0.63, 1.16)	0.91 (0.37, 1.45)	0.58 (-1.10, 2.26)	-0.08 (-1.41, 1.25)
HHI^2	-0.58 (-0.76, -0.40)	-0.59 (-0.88, -0.31)	-0.39 (-1.39, 0.60)	0.19 (-0.87, 1.25)
Land	0.01 (-0.03, 0.05)	0.04 (-0.06, 0.13)	0.01 (-0.12, 0.14)	-0.04 (-0.34, 0.26)
$Land^2$	0.05 (0.02, 0.08)	0.03 (-0.03, 0.09)	0.08 (-0.12, 0.27)	0.07 (-0.14, 0.28)
Cost of farm debt	0.63 (0.09, 1.17)	0.83 (-0.25, 1.91)	0.13 (-0.35, 0.61)	0.04 (-1.38, 1.47)
Financial immobility	-0.29 (-0.32, -0.25)	-0.29 (-0.50, -0.09)	-0.25 (-0.29, -0.20)	-0.37 (-0.51, -0.23)
Ln(Land price)	0.03 (0.02, 0.04)	0.03 (0.01, 0.05)	0.01 (-0.01, 0.03)	0.06 (0.03, 0.09)
Observations	2,544	1,209	999	336
R^2	0.21	0.27	0.16	0.22
Adjusted R^2	0.20	0.26	0.15	0.17
F Statistic	660.76	451.31	170.59	105.28

Note: variables are taken with 5-year rolling; 95% confidence intervals based on Driscoll and Kraay robust standard errors are reported in parentheses.
Source: author's calculations based on FADN data for Estonia

Table 4. Regression results for determinants of farm income variability: dependent variable is relative MAD, Within Instrumental Variables Estimator (w2sls)

	Whole sample	**Livestock**	**Crop**	**Mixed**
Subsidies	0.05 (0.03, 0.07)	0.05 (0.02, 0.07)	0.02 (-0.11, 0.15)	0.17 (0.06, 0.27)
Profitability	-0.53 (-0.63, -0.42)	-0.68 (-0.94, -0.42)	-0.45 (-0.56, -0.34)	-0.40 (-0.83, 0.03)
Age	-0.0004 (-0.001, 0.0003)	0.001 (-0.0003, 0.002)	-0.001 (-0.001, -0.0003)	-0.003 (-0.005, -0.001)
Farm size	-0.01 (-0.02, -0.004)	-0.01 (-0.02, -0.003)	-0.02 (-0.03, -0.004)	0.003 (-0.001, 0.01)
HHI	0.79 (0.56, 1.02)	0.73 (0.59, 0.87)	1.21 (-0.07, 2.49)	0.04 (-1.28, 1.36)
HHI^2	-0.51 (-0.67, -0.35)	-0.48 (-0.56, -0.41)	-0.78 (-1.53, -0.04)	0.02 (-1.00, 1.04)
Land	-0.003 (-0.04, 0.03)	0.05 (-0.02, 0.12)	-0.004 (-0.18, 0.17)	-0.03 (-0.26, 0.20)
$Land^2$	0.05 (0.02, 0.07)	-0.002 (-0.05, 0.05)	0.07 (-0.14, 0.29)	0.03 (-0.09, 0.15)
Cost of farm debt	0.45 (0.002, 0.91)	1.00 (0.44, 1.57)	-0.05 (-0.35, 0.24)	0.41 (-0.49, 1.31)
Financial immobility	-0.23 (-0.25, -0.20)	-0.26 (-0.38, -0.14)	-0.16 (-0.22, -0.10)	-0.40 (-0.68, -0.11)
Ln(Land price)	0.02 (0.01, 0.03)	0.02 (0.01, 0.04)	0.001 (-0.01, 0.02)	0.06 (0.04, 0.09)
Observations	2,548	1,232	925	391
R^2	0.21	0.24	0.13	0.20
Adjusted R^2	0.20	0.22	0.11	0.16
F Statistic	620.37	408.52	127.14	131.57

Note: variables are taken with 5-year rolling; 95% confidence intervals based on Driscoll and Kraay robust standard errors are reported in parentheses.
Source: author's calculations based on FADN data for Estonia

Table 5. Regression results for determinants of farm income variability: dependent variable is natural logarithm of MAD, Within Instrumental Variables Estimator (w2sls)

	Whole sample	**Livestock**	**Crop**	**Mixed**
Subsidies	0.38 (0.29, 0.47)	0.13 (-0.26, 0.52)	1.05 (0.72, 1.39)	-0.32 (-0.57, -0.08)
Profitability	0.54 (0.15, 0.92)	-0.51 (-0.82, -0.19)	1.30 (0.51, 2.10)	-0.09 (-0.85, 0.68)
Age	-0.01 (-0.01, -0.005)	-0.01 (-0.01, -0.004)	-0.005 (-0.01, -0.002)	-0.01 (-0.01, -0.003)
Farm size	0.56 (0.54, 0.57)	0.54 (0.48, 0.60)	0.60 (0.59, 0.61)	0.53 (0.50, 0.55)
HHI	2.65 (1.62, 3.67)	1.53 (0.77, 2.29)	1.86 (-1.36, 5.08)	2.73 (-1.06, 6.53)
HHI^2	-1.76 (-2.54, -0.99)	-1.32 (-1.94, -0.71)	-1.28 (-3.13, 0.58)	-2.15 (-5.12, 0.82)
Land	0.18 (0.04, 0.32)	-0.42 (-0.63, -0.20)	0.75 (0.13, 1.37)	-0.78 (-1.58, 0.03)
$Land^2$	-0.13 (-0.33, 0.08)	0.49 (0.14, 0.85)	-0.42 (-1.00, 0.17)	0.31 (-0.21, 0.83)
Cost of farm debt	3.56 (2.09, 5.02)	1.35 (0.40, 2.30)	0.64 (0.15, 1.13)	0.82 (-1.39, 3.03)
Financial immobility	-0.58 (-0.82, -0.35)	0.21 (-0.50, 0.92)	-0.86 (-1.39, -0.34)	-0.30 (-0.84, 0.24)
Ln(Land price)	0.25 (0.21, 0.30)	0.14 (0.07, 0.20)	0.30 (0.22, 0.37)	0.21 (0.08, 0.34)
Observations	2,548	1,209	1,003	336
R^2	0.77	0.86	0.61	0.86
Adjusted R^2	0.77	0.86	0.60	0.86
F Statistic	8,531.22	7,272.27	1,744.26	1,997.84

Note: variables are taken with 5-year rolling; 95% confidence intervals based on Driscoll and Kraay robust standard errors are reported in parentheses.
Source: author's calculations based on FADN data for Estonia

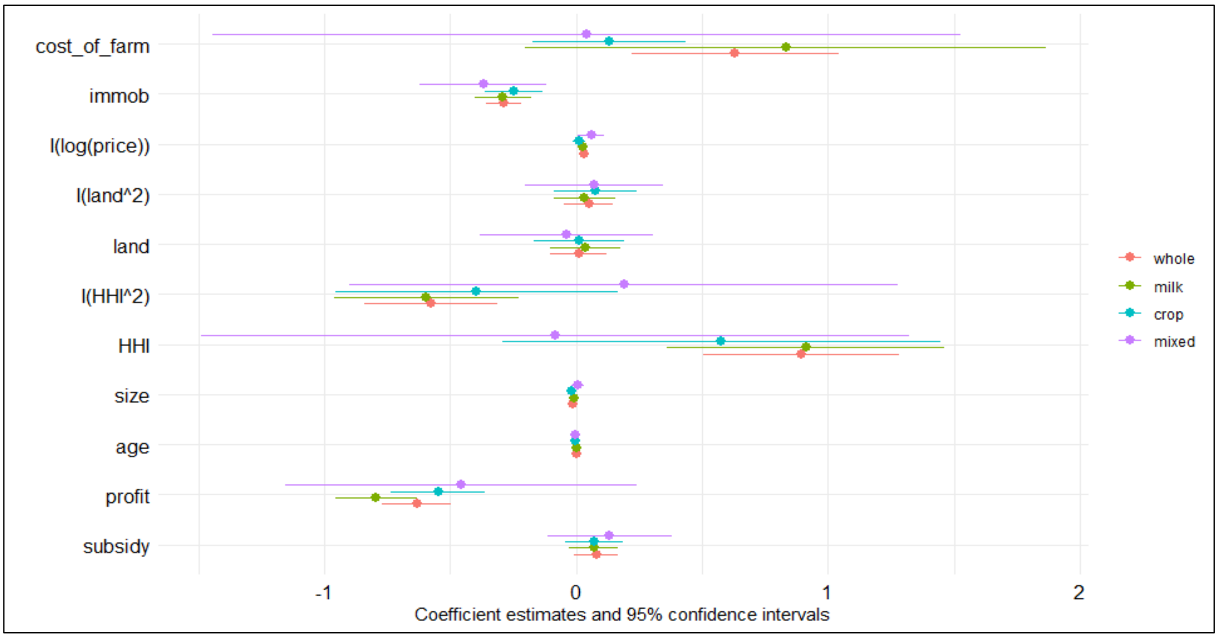

Figure 6. Coefficients plots for model results using coefficient of variation of gross farm income as dependent variable for whole, livestock, crop and mixed farms: Within Instrumental Variables Estimator (w2sls)

Source: author's calculations based on FADN data for Estonia

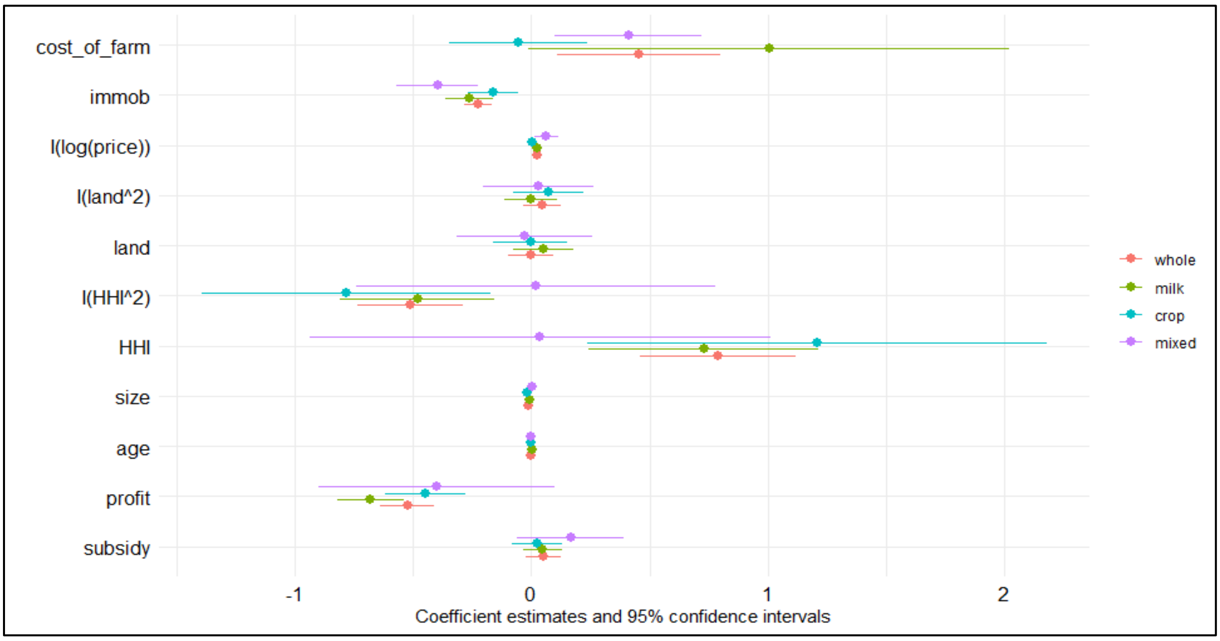

Figure 7. Coefficients plots for model results using relative MAD as dependent variable for whole, livestock, crop and mixed farms: Within Instrumental Variables Estimator (w2sls)

Source: author's calculations based on FADN data for Estonia

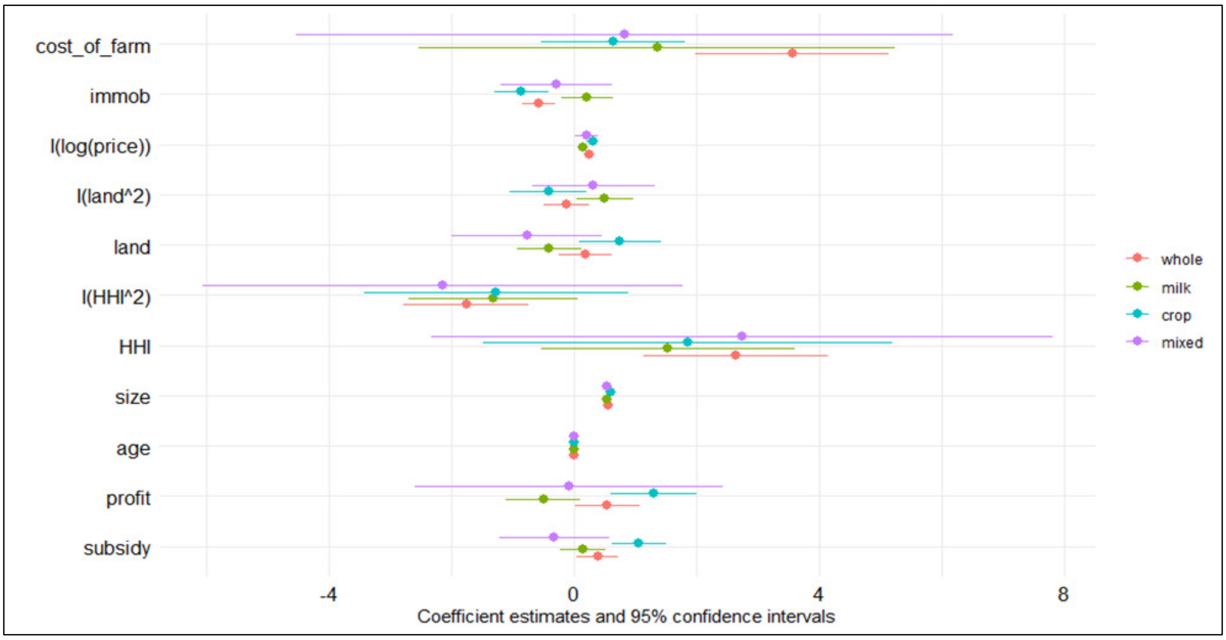

Figure 8. Coefficients plots for model results using natural logarithm of MAD as dependent variable for whole, livestock, crop and mixed farms: Within Instrumental Variables Estimator (w2sls)

Source: author's calculations based on FADN data for Estonia

5 Discussion

5.1 Farm Income (Subsidies and Profitability)

Our results show that higher share of subsidies in gross farm income is associated with higher variability of gross farm income. This result could be interpreted in two ways. As suggested by Poon, Weersink (2011) and Koundouri et al. (2009), farm subsidies might lead farmers to more risky behaviour. On the other hand, these results may also indicate that in Estonia, from 2006-2019 farm payments were correlated with market income. In the period 2006-2019, the correlation between output of agricultural industry and farm subsidies was 0.84. From Figure 9 it appears that in 2009, and from 2014-2016, subsidies were smaller than in the preceding year. If the share of subsidies in gross farm income is high, any decrease or increase in subsidies will result in a larger change in gross farm income compared to a scenario where the share of subsidies is smaller.

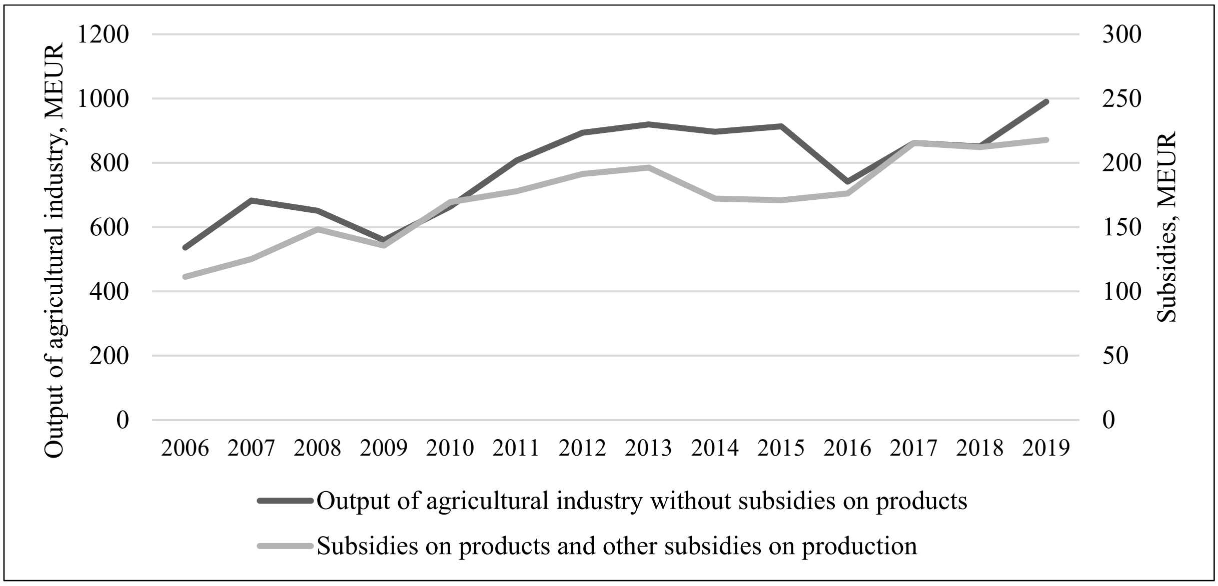

Figure 9. Output of agricultural industry and farm subsidies in Estonia (2006-2019)

Source: Statistics Estonia

In contrast to our findings for other types of farms, most previous research indicates that agricultural subsidies stabilize farm income and associate with reduce income volatility (El Benni et al., 2012; Enjolras et al., 2014; Castañeda-Vera, Garrido, 2017). This suggests that subsidies are linked to increased use of variable inputs, improved agricultural performance, and higher income among farming households. In other words, how subsidies are allocated, the price of global inputs, and stakeholder targeting all have significant consequences for the expected outcomes.

We have ambiguous results for profitability, depending on how FI variability was measured. In cases of CV and relative MAD our results indicate that past profitability levels are negatively associated with farm income variability across all farm types. This finding aligns with the work of Slijper et al. (2022) that profitability is positively associated with robustness (related to stability) of Swedish farms. However, our results contrast with other findings from Slijper et al. (2022), where they report that profitability is negatively associated with robustness for farms in Southern, Eastern, and Western Europe.

5.2 Farm Characteristics (Age of Farm Operator, Farm Size, Concentration of Activities)

As farmer age their income becomes more stable if farmer has not gone out of farm business for all the years of the farm's existence. The results in this point are consistent with findings of other researchers. E.g., Fertő, Stalgienė (2016) found this for Lithuanian farms, El Benni, Finger (2013) for Swiss farms, Trestini et al. (2017) for Italian farms. Their results point out that older farmers are more risk averse than younger ones. This may be related to the fact that farm business often exhibits life cycle pattern that parallels the life cycle of the farm operator (de Mey et al., 2014); according to the life cycle approach, farmers prefer to pay off their debts as they become older.

There are mixed results for different measures of farm income variability and its relationship with farm size. For absolute MAD of income there is positive association whereas for relative MAD and CV the association is negative (except for mixed farms). Larger farms are more stable, coping with price fluctuations due to diversified sources of income. Our findings in this point are consistent with those of El Benni et al. (2012) about Swiss, Trestini et al. (2017) about

Italian farms. They found that farm size has a negative association with the gross farm income instability.

It can be concluded that concentration of farm activities is positively associated with a gross farm income volatility. Here our result is consistent with the results for Slovenian farms (Bojnec, Fertő, 2018), but inconsistent with El Benni et al. (2012), Harkness et al. (2021) who found the greater diversity of agricultural activities associates with increasing of income variability in Swiss agriculture and in England and Wales respectively.

Results indicate the share of owned land is positively associated with FI variability in long term. A lower share of owned land is generally associated with higher rates of return and business growth (Liu et al., 2018).

5.3 Financial Structure and Assets (Cost of Farm Debt, Financial Immobility and Land Price)

Cost of farm debt, measured by the interest paid over total outstanding farm debt, is positively associated with farm gross income variability. It should be noted that the cost of borrowing has been relatively low during the period considered.

The financial immobility has negative association with farm income variability. This may indicate that farms with a smaller share of fixed assets and greater share of current assets may use variable inputs more intensively; this way they take larger risks by larger cost investment and have a potential for higher outputs, but also more volatile gross farm income. However, our finding here is not consistent with El Benni et al. (2012), who found the financial immobility was not associated with changes in farmers' incomes in Swiss agriculture.

The price of land is positively associated with the instability gross farm income in Estonia. According to our knowledge, this is the first result obtained for its association with farm income variability.

This study, like many other studies, has some limitations: (i) due to the lack of such data, the analysis disregards off-farm income that has been found to reduce the variability of the overall income of farm households (e.g., Mishra, Sandretto, 2002); (ii) due to lack of the respective panel data in this study did not consider the farm income variability dependencies on weather/climate that impact agricultural production; (iii) the limited causal interpretability between variables used.

6 Conclusions

Our study provides new insights into the associations between agricultural subsidies, farm characteristics, and the stability of farm income. The novelty and contribution of this paper lie in its analysis of the determinants of farm income variability across the three main farm types in Estonia. The analysis was conducted using the Winsorization technique, fixed-effects (FE) models, and an instrumental variable (IV) approach (w2sls) applied to the FE models.

The results show that a higher proportion of fixed assets relative to total assets is associated with decreased income variability. This finding supports the inclusion of investment subsidies in rural development policies, as farm-specific funding can create opportunities for investment while also alleviating budget constraints for indebted farms. Additionally, increasing the diversity of agricultural activities is positively associated with the stability of gross farm income. Conversely, a higher share of agricultural subsidies in gross farm income is positively associated with increased income volatility. This can be explained by the heterogeneity of farms in terms of income volatility over time and the use of production-specific environmental technologies. In further analyses, practices including agri-environment payments that may lead to sustainable incomes should consider this farm heterogeneity more extensively when informing policy decisions.

Based on these results, several policy implications can be drawn. First, providing farmers with income variability management tools, such as crop insurance, can help mitigate the impacts of plant or livestock diseases and other risks on their income. Factors such as the farm's asset liquidity, degree of specialization, farmer's age, and profitability should also be considered in potential revenue insurance contracts. Second, improving access to credit and financial services can enable farmers to better manage their finances and invest in their operations, thereby reducing their vulnerability to income variability. Third, encouraging farmers to diversify their income sources can help reduce their dependence on a single agricultural activity and lower their exposure to income fluctuations.

Analysing farm income variability is crucial for developing effective farm income insurance instruments; therefore, our empirical assessments are important for advising farmers, policymakers, and other stakeholders on strategies to reduce income variability.

Future research could incorporate additional explanatory factors to distinguish between market and weather/climate dependencies affecting farm income volatility, as well as include other farm and household characteristics as control variables. While the results of our study are specific to Estonia, applying this approach in other EU countries could provide valuable comparative insights.

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Appendix

Table A1. Statistical results for the pooled model, the FE with time effects and the two-way FE model: Equation (1) estimates for different dependent variables

Dependent variable		Pooled model	FE with time effects	Two-way FE model
CV	RSS	73.51	72.80	30.02
	R2 adj.	0.22	0.22	-0.115
	F-statistic	66.80	64.11	18.80
Ln(MAD)	RSS	1.7246e+12	1.6893e+12	4.6691e+11
	R2 adj.	0.73	0.73	-0.19
	F-statistic	624.95	625.22	6.08
Relative MAD	RSS	53.62	53.16	22.54
	R2 adj.	0.21	0.20	-0.13
	F-statistic	62.45	59.78	16.41

Note: RSS is the residual sum squares
Source: author’s calculations based on FADN data for Estonia

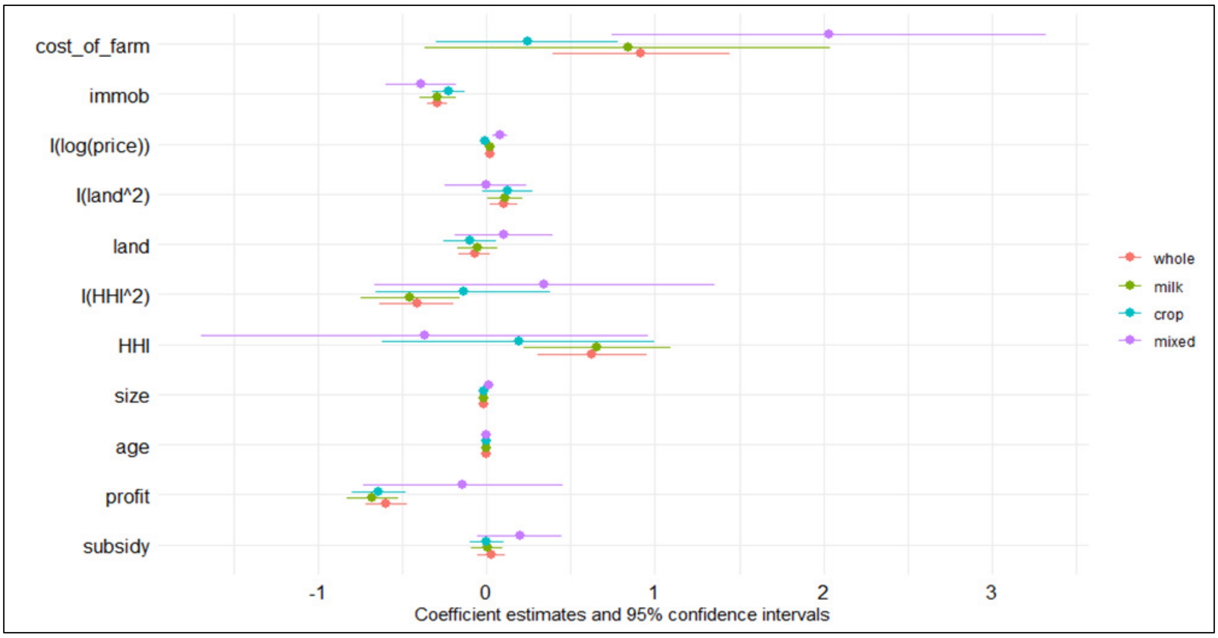

Figure A1. Coefficients plots for model results using coefficient of variation of gross farm income as dependent variable for whole, livestock, crop and mixed farms

Note: CV is a coefficient of variation from the rolling 3-year
Source: author's calculations based on FADN data for Estonia

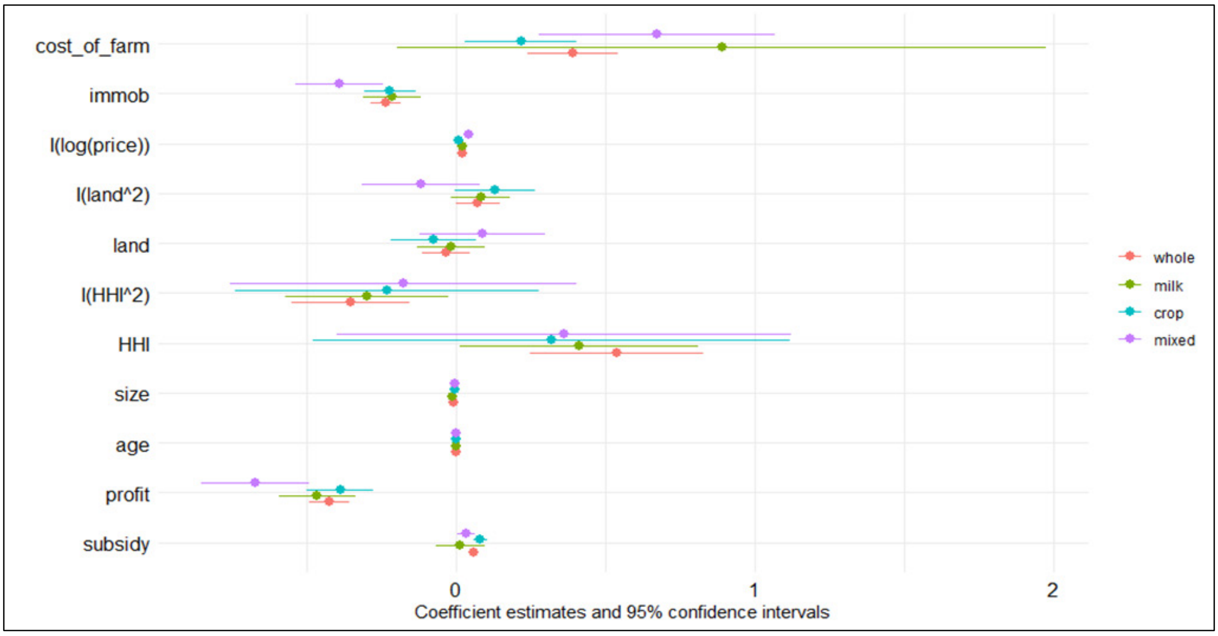

Figure A2. Coefficients plots for model results using relative MAD as dependent variable for whole, livestock, crop and mixed farms

Note: Relative MAD is the ratio of absolute deviation from farm mean divided by rolling 3-year mean have been calculated as shown in the Table 2.
Source: author's calculations based on FADN data for Estonia

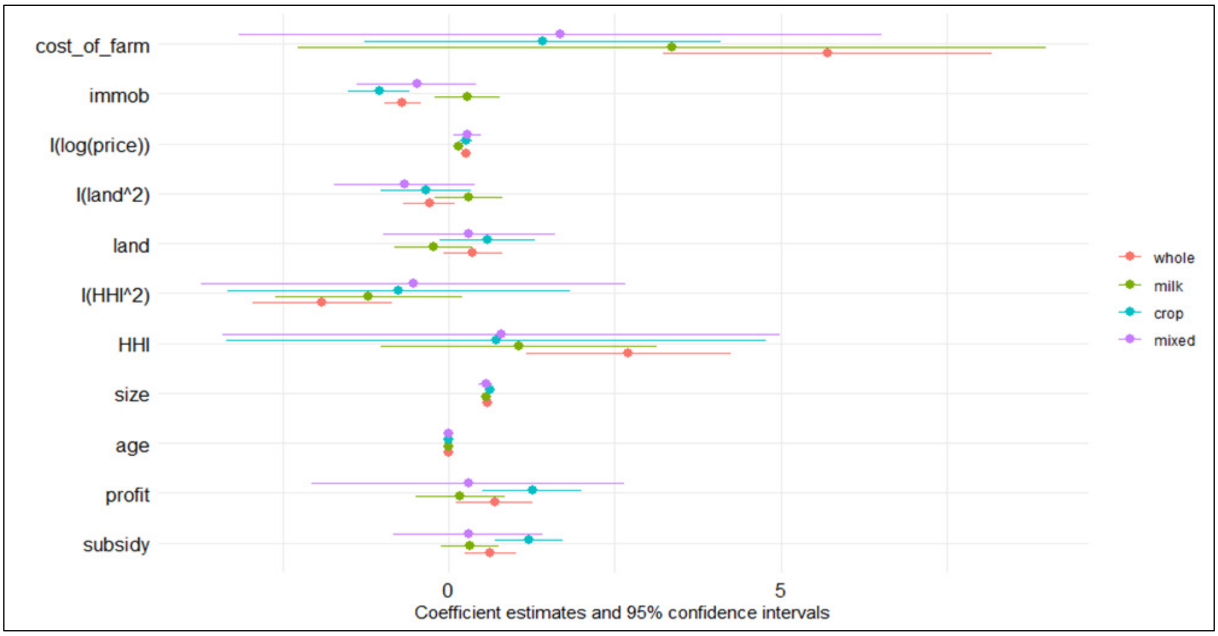

Figure A3. Coefficients plots for model results using natural logarithm of absolute MAD as dependent variable for whole, livestock, crop and mixed farms

Note: absolute MAD is the absolute deviation from the rolling 3-year mean of individual farm have been calculated as shown in the Table 2.
Source: author's calculations based on FADN data for Estonia

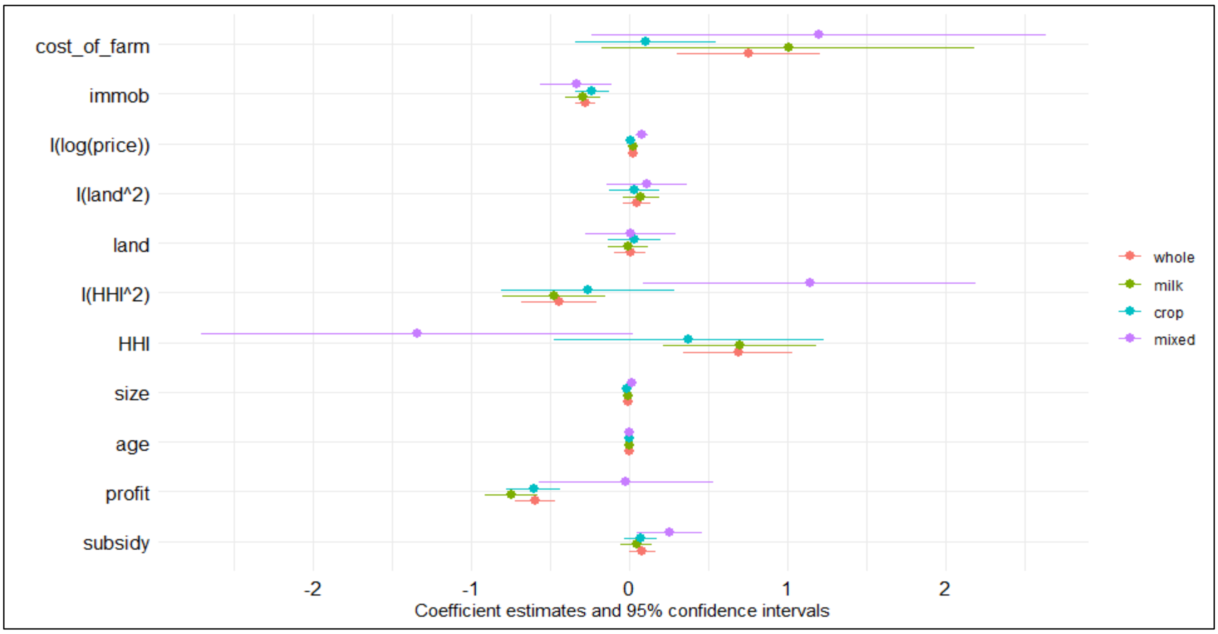

Figure A4. Coefficients plots for model results using coefficient of variation of gross farm income as dependent variable for whole, livestock, crop and mixed farms

Note: CV is a coefficient of variation from the rolling 4-year.
Source: author's calculations based on FADN data for Estonia

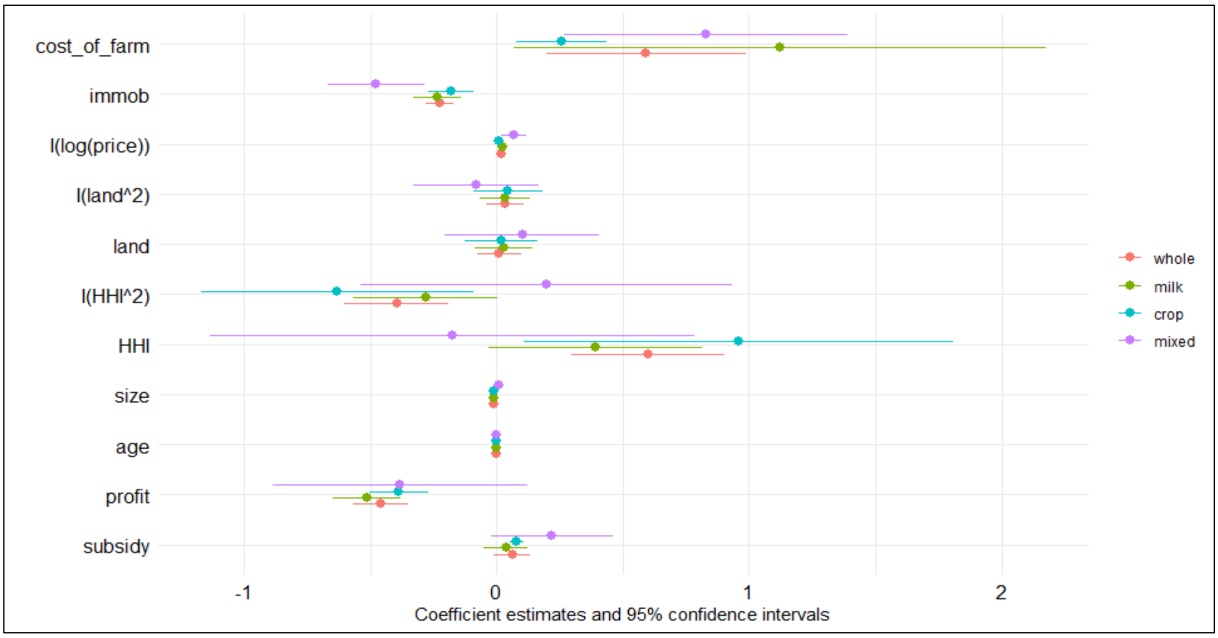

Figure A5. Coefficients plots for model results using relative MAD as dependent variable for whole, livestock, crop and mixed farms

Note: relative MAD is the ratio of absolute deviation from farm mean divided by rolling 4-year mean have been calculated as shown in the Table 2.
Source: author's calculations based on FADN data for Estonia

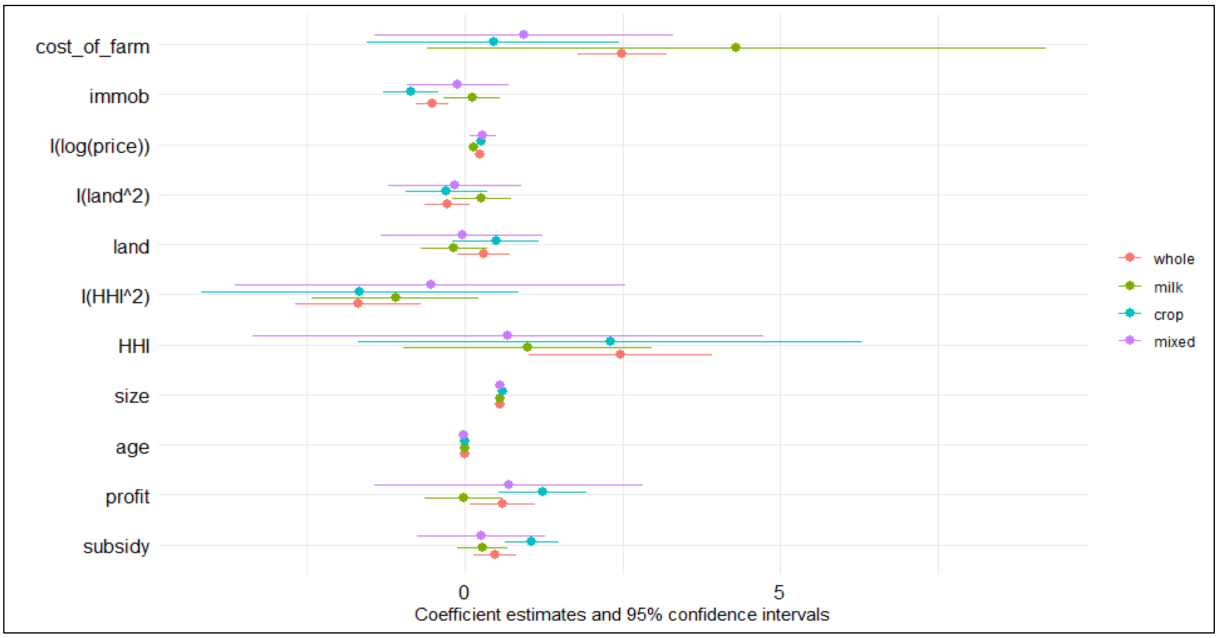

Figure A6. Coefficients plots for model results using natural logarithm of absolute MAD as dependent variable for whole, livestock, crop and mixed farms

Note: absolute MAD is the absolute deviation from the rolling 4-year mean of individual farm have been calculated as shown in the Table 2.
Source: author's calculations based on FADN data for Estonia