Analysis of the Impact of Subsidies on Farm Performance Using a Mixed Effects Model

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Abstract: Agricultural subsidies are a key element of agriculture and have a major impact on international trade. In the European Union, the policy supporting agricultural incomes is called the Common Agricultural Policy, which is a complex system involving various instruments. The impact of this policy on the economic performance of farms is, therefore, an interesting topic, especially for policymakers. Czech agriculture has undergone major policy changes that have affected its position in the national economy and its importance at the regional level. Differences in natural conditions, as well as economic and social inequalities, continue to affect the level of gross agricultural production. Using a mixed-effects model, this study analyzed data from 10 South Bohemian farms (2012–2021). Results indicate that subsidies have a positive but statistically insignificant effect on economic performance, while assets positively and significantly contribute to profitability. Conversely, liabilities and investments in long-term assets negatively impact economic performance. These findings highlight the importance of asset management and cautious debt strategies for farm sustainability.

Keywords: agriculture, subsidy, mixed effects model
JEL Classification: Q11, Q18

1 Introduction

The aim of this paper is to analyse the impact of the received subsidies on the economic performance of farms. Subsidies play a major role in supporting the agricultural sector, especially in post-communist countries, but their real impact on farm economic performance can be varied. This research will focus on assessing how statistically significant the impact of subsidies is on the financial stability of farms in the Czech Republic. Agricultural subsidies play a key role in supporting farmers, stabilization food prices and ensuring food safety. These financial supports can have various forms, including direct payments, tax breaks and price supports. Their purpose depends on the current agricultural policy.

Subsidies help stabilise farmers' incomes, especially in times of market volatility. They act as a financial cushion, allowing farmers to manage the risks associated with unpredictable weather, fluctuating market prices, and changing consumer demands. Subsidies reduce income variability and make it easier for farmers to plan for the future and invest in their operations. This is particularly important for small and medium-sized farming enterprises that may lack the financial resilience to withstand economic shocks (Jovanović & Zubović, 2019). Subsidies are essential for supporting food safety by ensuring that food remains affordable to the general public. Supporting the production of staple crops keeps food prices low, which is vital for low-income populations (Anderson et al., 2023). Although concerns exist about the environmental impacts of certain subsidies, efforts are being made to structure them in a way that supports sustainable agricultural practices. For example, investment subsidies encourage farmers to accept environmentally friendly techniques. However, there is a contradiction between environmentally friendly techniques and technologies in relation to the volume of agricultural production (Špička et al., 2009).

In many regions, especially in rural areas, agricultural subsidies contribute to the overall economic development of communities. The financial support provided to farmers stimulates local economies, creates job opportunities and improves the quality of life in rural areas. This is particularly important in countries where agriculture is the primary source of employment and economic activity (Goodwin et al., 2011).

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Subsidies also play a role in addressing income inequality in the agricultural sector. The financial support provided to small-scale farmers and marginalised groups levels the individual conditions of each farmer to a national average. However, it is important to design subsidy programmes carefully to avoid disproportionately favouring larger farms at the expense of smaller farms (Kirwan & Roberts, 2016). The productivity of different crops and the efficiency of input use are fundamental components that affect the farm's bottom line. The attitudes and behaviors of farm managers significantly affect profitability. Studies have shown that specific personal characteristics such as business objectives, temperament and growth mindset are associated with higher profitability. For example, a study conducted in the UK found that these factors can predict up to 40% of differences in farm profitability (O'Leary et al., 2018). Access to finance, especially credit, plays a crucial role in increasing farm profits. Research conducted in Sudan showed that farmers with access to microcredit had higher profits compared to those without access, although the overall impact of loans on earnings was limited due to small loan volumes (Ibrahim et al., 2013). This suggests that while loans can improve financial conditions, it must be significant enough to have a significant impact on production outcomes.

Another critical factor affecting farm profitability is the introduction of new technologies. Participation in discussion groups has been shown to facilitate farmers' adoption of technologies, leading to increased profits. In Ireland, farms that participated in these groups showed higher levels of profit, while reconciling other aspects such as farm size and location (Hennessy & Heanue, 2012). Similar practices of conservation agriculture have shown in Bangladesh that adoption of techniques such as crop rotation and residue retention can reduce operating costs and increase yields, thereby increasing profits (Miah et al., 2020). Economic viability is often related to structural characteristics of farms such as size and capital intensity. Larger farms tend to be more viable, especially in regions where EU support is available to support income levels. A study in Italy revealed that farms with higher capital intensity and larger size are more likely to be economically viable (Coppola et al., 2020).

2 Methods

A mixed effects model was used to analyse the impact of subsidies on farm performance. This model is suitable for this analysis for several reasons. Each farm has specific conditions, such as different sizes, technological levels, geographical location, climatic conditions or management skills, which can affect its economic performance. Mixed effects capture these variabilities through random effects. Specifically, in this model, a random effect (ui) is included for each farm, which allows estimation of the differences between farms without having to model each farm separately. This ensures that the model better describes the different characteristics of each farm. The data are panel (longitudinal), meaning that the data contain multiple observations for each farm over time (2012-2021). Individual farm results in different years are not independent, as results from one year may be affected by results from previous years. The mixed model accounts for this time dependence, for example through the autoregressive correlation structure (AR(1)), which is used by the model in this analysis. In doing so, the model correctly takes into account that the economic performance of a farm in one year can be affected by its performance in previous years.

Farms can vary in their approach to how they respond to subsidies and other economic factors. A mixed model allows us to analyze fixed effects, (West et al., 2014) such as the effect of subsidies or assets on the bottom line, while accounting for the fact that each farm can have different basic performance or different specific conditions that are not quite explained by fixed effects. If a classical linear model was used, it would ignore the structure of the data (i.e., the dependencies between repeated measurements for the same farm (Hebák, 2013). This could lead to incorrect or biased estimates of fixed effects such as the effect of subsidies. The mixed model accounts for this data structure, leading to more accurate estimates of the effect of subsidies and other variables.

The data were retrieved by field survey during 2023 in the territory of the South Bohemia Region. All data were strictly anonymized and summarized in an Excel file. The paper contains information on the performance of 10 farms for the years 2012-2021 (10 years) and includes various factors that may influence the economic result (variable influencing farm performance). Different variables such as subsidies received (subsidy), assets (assets), land and buildings (lb), stand-alone movable assets (prop), current assets (ca), liabilities (li), sales (sales) and financial performance (fr) were analyzed using a linear mixed model, specifically their impact on farm performance and how these impacts may vary between farms or over time. These are panel data (longitudinal data) that contain information on several farms at different points in time. All variables are numeric except for the letter designation of individual farms to maintain anonymization.

For the sake of clarity, the mathematical notation of the linear mixed model is given here, which will be adapted later for the purposes of RStudio using the "lme" function.

$$pro_{it} = \beta_0 + \beta_1 \cdot subsidy_{it} + \beta_2 \cdot assets_{it} + \beta_3 \cdot lb_{it} + \beta_4 \cdot prop_{it} + \beta_5 \cdot ca_{it} + \beta_6 \cdot li_{it} + \beta_7 \cdot sales_{it} + \beta_8 \cdot or_{it} + \beta_9 \cdot fr_{it} + u_i + \epsilon_{it} \quad (1)$$

The following are descriptions of each variable with explanations. The model includes both fixed effects (coefficients β1 to β9) and random effects (ui) and the correlation structure of the residuals.

- pro_{it} : The value of the dependent variable "economic result" (pro) on farm *i* in time *t*.
- β_0 : Intercept (constant term) of the model.
- β_1 , β_2 , . . . , β_9 : Fixed effects coefficients for each variable (subsidy, assets, lb, ...).
- $subsidy_{it}$, $assets_{it}$, lb_{it}, $prop_{it}$, ca_{it}, li_{it}, $sales_{it}$, fr_{it}: Values of the explanatory variables for farm *i* at time *t*..
- u_i : Random effect for farm iii, capturing inter-farm variability.
- e_{it} : The residual (residual) component that represents the random noise or error for farm *i* in time *t*.

Fixed effects: subsidies received, year. Random effects: Individual farms (each farm may have its own specific conditions and factors affecting economic performance).

The Excel file with the data was imported into RStudio, where the following code was used:

res = lme((pro) ~ subsidy + assets + lb + prop + ca + li + sales + fr, random = ~1 | Farm, correlation = corAR1(form = ~ year | Farm), data = Semi)

summary(res)

This code defines and runs (let down) a linear mixed model using the lme() function and then displays a summary of the results using the summary() function. The focus of this research is to analyze the impact of the subsidies received on the economic performance of farms. Subsidies are often considered as a key instrument to support the agricultural sector to improve the economic stability and performance of farms. However, the question remains to what extent these funds actually contribute to better economic performance.

For the purpose of the research, two main hypotheses were formulated:

H0: Subsidies have a positive effect on the economic performance of farms.

H1: Subsidies have a negative effect on the economic performance of farms

3 Research results

Based on the outputs from the RStudio of the linear mixed-effects model, it is possible to interpret the influence of various factors on the economic performance of farms (pro) in the South Bohemian Region between 2012 and 2021.

The model takes into account random effects at the farm level, which captures the variability between farms. The standard deviation of the random effect (2257.858) indicates that there are differences in the underlying economic outcomes between farms that are not explained by fixed variables, and this variability is quite large. The variance of the residual component (4287.9) is also substantial, indicating that the model captures some but not all of the factors affecting economic performance. The AR(1) correlation structure used suggests that the economic results for each year are not completely independent. The correlation parameter, Phi (-0.05286333), is very close to zero, indicating that the dependence of results between years is weak.

The fixed effects analysis shows the effect of each variable on the economic performance of farms. Subsidies (subsidy) have a positive effect on economic performance (β = 0.1719), indicating that an increase in subsidies could lead to an improvement in farm economic performance. However, this effect is not statistically significant at 5% significance level (p-value = 0.0861), suggesting that the relationship between subsidies and performance is not unequivocal. Assets show a positive and statistically significant effect on farm economic performance (β = 0.1371, p-value = 0.0003). This confirms that farms with higher levels of assets tend to have better economic performance. Land and buildings (lb) have a negative and statistically significant effect (β = -0.1183, p-value = 0.0009). This result may indicate that heavy investments in long-term assets such as estates and buildings may burden farms in the short run and reduce their economic performance. Liabilities (li) also have a negative and highly significant effect (β = -0.1636, p-value < 0.0001), suggesting that higher farm indebtedness leads to lower economic performance. This is consistent with the expectation that higher liabilities

increase the financial burden on farms. Revenue (sales) and financial result (fr) are not significant factors affecting farm economic result, as evidenced from their statistically insignificant p-values (p-value > 0.05). This result may be surprising as one would expect higher sales and financial result to have a positive impact. It is possible that in this case these variables do not fully reflect the farm's complex economic situation.

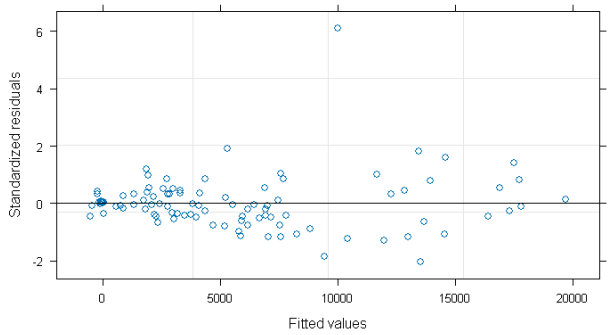
The results of the analysis suggest that assets and subsidies have a positive effect on farm profitability, although the effect of subsidies is not statistically significant. Conversely, liabilities and investments in land and buildings have a negative impact on economic performance. Inter-farm variability plays an important role, which is captured by the random effects of the model. The model provides useful insights into the factors affecting farm economic performance, with assets and indebtedness, being the main determinants, while other variables are found to be less significant. Below is a summary of the model results.

```
Linear mixed-effects model fit by REML
  Data: semi
       AIC      BIC    logLik
  2009.341 2039.471 -992.6705

Random effects:
 Formula: ~1 | Farm
        (Intercept) Residual
StdDev:    2257.858   4287.9

Correlation Structure: AR(1)
 Formula: ~year | Farm
 Parameter estimate(s):
        Phi
-0.05286333
Fixed effects:  (pro) ~ subsidy + assets + lb + prop + ca + li + sales + fr
                Value Std.Error DF   t-value p-value
(Intercept) -758.4811 1491.5843 82 -0.508507  0.6125
subsidy        0.1719    0.0990 82  1.737136  0.0861
assets         0.1371    0.0365 82  3.761338  0.0003
lb            -0.1183    0.0344 82 -3.442897  0.0009
prop           0.1075    0.0804 82  1.336532  0.1851
ca             0.0212    0.0559 82  0.379465  0.7053
li            -0.1636    0.0351 82 -4.657343  0.0000
sales         -0.0147    0.0173 82 -0.852093  0.3966
fr            -0.3712    0.5526 82 -0.671723  0.5036
 Correlation:
        (Intr) subsdy assets lb     prop   ca     li     sales
subsidy -0.535
assets   0.015  0.019
lb      -0.006 -0.176 -0.930
prop    -0.173 -0.011 -0.467  0.349
ca      -0.268 -0.152 -0.383  0.345  0.175
li       0.189  0.045 -0.715  0.669 -0.061 -0.065
sales    0.106  0.200 -0.081  0.082  0.320 -0.757  0.090
fr      -0.014  0.094 -0.397  0.324  0.593 -0.043  0.282  0.308

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-2.05229509 -0.44905118 -0.04031984  0.33793281  6.12138304

Number of Observations: 100
Number of Groups: 10
```

3.1 Robustness checks and post-estimation diagnostics

Graphs for residual tests, normality tests, autocorrelation tests and Durbin-Watson (DW) test are an essential part of the diagnostics for mixed effects models (and other statistical models). These tests and plots help to verify that the model correctly describes the relationships in the data and that it meets the basic assumptions for the reliability of the estimates, especially when analysing the impact of subsidies.

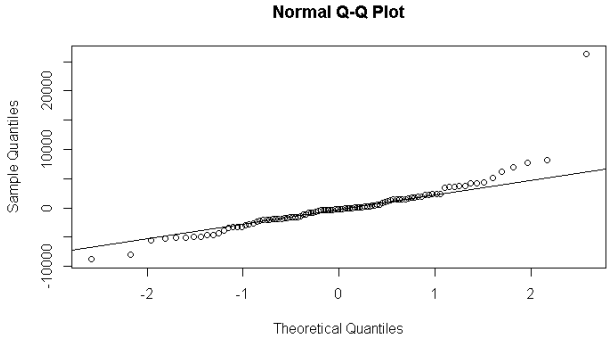
Graph 3 Residual Tests



The residuals plot shows whether the residuals (prediction errors) of the model are randomly distributed. In tests of residuals from the analysis, it can be seen that the dispersion of the residuals is not completely uniform. There are some variations, which may indicate that the model is not predicting certain aspects of farm performance accurately.

Source: Own processing from RStudio

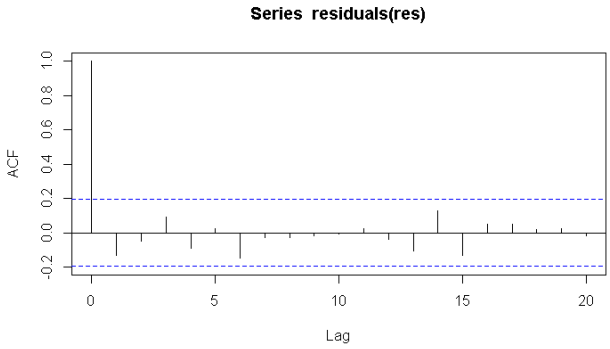
Graph 4 Normality Tests



Based on the displayed Q-Q plot, it can be concluded that the residuals partially deviate from the normal distribution, especially at the extremes. This suggests that the distribution of residuals may not be completely normal, which could affect the results of significance tests. Although small deviations may not be a problem, larger deviations could lead to biased results.

Source: Own processing from RStudio

Graph 5 Autocorrelation Tests (AFC)



Autocorrelation plots (ACF) show whether residuals are correlated over time, which is especially important for panel data where results in different years may be dependent on each other. If the residuals show autocorrelation, it would mean that the model has not correctly accounted for the temporal structure of the data.

Source: Own processing from RStudio

The ACF plot shows a mild negative autocorrelation at lower lags, which means that results from one year may be mildly affected by results from previous years. This weak dependence has been partially accounted for by using an AR(1) structure in the model, which suggests that the model is relatively well-specified, but there is still a slight time dependence.

DW

- `lag Autocorrelation D-W Statistic p-value`
- `1 -0.2217271 2.442986 0.01`
- `Alternative hypothesis: rho != 0`

The Durbin-Watson test is a specific test for autocorrelation in the residuals. A D-W statistic value of 2.44 indicates that no significant autocorrelation is present (a value close to 2 is optimal). Based on this statistic, it can be assumed that the model successfully accounts for temporal dependencies between observations.

4 Conclusions

The conclusion of this paper confirms that the economic performance of farms in the South Bohemian Region during the period 2012-2021 is influenced by several factors, but the effect of subsidies on the economic result is not statistically significant.

The hypothesis that subsidies have a positive effect on the economic result of farms (H0) was not confirmed by the model results. Although the coefficient for subsidies was positive, suggesting that an increase in subsidies may lead to an improvement in farm profitability, this effect was not statistically significant (p-value = 0.0861). This suggests that within the analyzed period and data sample, it is not possible to say with certainty that subsidies significantly affect farm economic performance. This result may be due to the fact that subsidies are not the main factor influencing the long-term economic stability of farms, or that their effect is only manifested in combination with other variables.

The hypothesis that the other variables have an effect on the economic performance of farms (H1) was partially confirmed. In particular, assets (assets) emerged as a key factor with a positive and statistically significant effect on economic performance ($\beta = 0.1371$, p-value = 0.0003). This means that farms with more assets tend to have better economic outcomes, which is logical given that assets can provide farms with stability and the ability to respond better to market and weather conditions.

Other variables such as estates and buildings, (lb) and liabilities (li) show a negative effect on the economic performance of farms. This negative effect is statistically significant, which suggests that high investment in fixed assets such as real estate may reduce economic performance in the short run, probably due to the higher costs and debt burden associated with these investments.

An important aspect of the analysis was also the random effect between farms, which showed that there is significant inter-farm variability that is not explained by fixed variables. This means that, in addition to the analysed factors, there are other farm-specific conditions that affect their economic performance. These factors may include, for example, managerial skills, technological level, or geographical and climatic conditions, which have not been taken into account in this model.

Overall, this paper provides important insights into the factors affecting farm economic performance. While subsidies are not a major determinant of economic performance, assets and indebtedness appear to be key factors. These results suggest that support aimed at improving farms' access to assets and reducing their debt burden could have a greater impact on their long-term economic stability.

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