The central aim of the project is to analyse the TFP development in the EU agriculture using different methods and databases.

Recent developments in panel data econometrics highlight that the technological heterogeneity is important issue in TFP analysis and the failure to account for technology heterogeneity leads to misspecified empirical models, with serious implications for any TFP estimates obtained.

In this project, we focused on the estimation of different models, which accounts for heterogeneity.

First, according to recent advancements in the literature in the case of macro panels, Common Correlated Effects (CCE) type models perform well and are able to account for technology heterogeneity, time series properties (cross section-dependence and non-stationary) of the data and endogeneity. We used these type of models to examine differences in TFP growth in global agricultural regions (namely, in industrialized, transition and developing countries), as well as in the EU and its Old Member States (OMS) and New Member States (NMS). We used the USDA- ERS Database and estimated different parametric pooled and heterogeneous models. Based on diagnostic tests we found that the recently introduced Augmented Mean Group model suits well for the analysed Database. Our empirical results showed that TFP growth has accelerated in *world agriculture* over the last two decades. The estimates suggest that the acceleration of global TFP growth in recent decades has been due to better performance in developing and the transition countries. Our findings show that TFP growth *in the EU* has increased over time, although at a slightly slower rate in recent years than in the past decade. Differences between the OMS and NMS are remarkable. In the OMS, the growth rate has significantly decreased, whereas in the NMS there was a remarkable increase in TFP growth in the last decade. These results are also in line with USDA estimates, but are at odds with EAA-based estimates. This confirms our earlier finding that FAO-data-based analyses likely overestimate productivity growth in the EU. Although TFP growth has accelerated in world agriculture, it has slowed down in industrialized countries. Policy implication of our findings are as follows. The most important factor determining productivity growth in the long term is innovation, which is driven by research investment. Most studies find a significant positive effect for the productivity of investment in innovative technologies (EC, 2016). Therefore, for stopping or reversing the slowdown in TFP growth in industrialized countries, sufficient spending on agricultural R&D is essential. Additionally, political instruments can increase or decrease TFP growth. However, the link between single political instruments and productivity is not clear; the results of related studies are mixed, especially in the case of agricultural

subsidies. Further research, which increases understanding of the channels through which agricultural policy instruments affect productivity is also important for improving productivity growth. These results will be published in the journal: *Agris on-line Papers in Economics and Infomatics (The paper is accepted, it is in press).*

Moreover, accounting for heterogeneity using micro panels ('moderate/small-T and large N' panels) the above methods are not adequate. One of the most advanced methods to analyse these types of panels are random parameter models (RPM). Using RPM we examined (1) the importance of theoretical consistency in production models (2) the effect of different subsidies on the components of TFP, (2) the effect of insurance on TFP and (4) differences in farm performance between less favoured area (LFA) and non-LFA farms. In the next paragraphs, we report the results of these research questions.

Effective agricultural policymaking requires the accurate estimation of the production technology and efficiency of farms. However, several methodological issues should be considered when modelling production and estimating technical efficiency. In this research, we focus on two of these—technological heterogeneity and theoretical consistency—as implied in microeconomic theory. Heterogeneity in the efficiency literature is often evaluated using a variable intercept model. However, in farm production, it is likely that heterogeneity also affects the marginal productivity of production factors. Some earlier papers investigated the effect of unobserved heterogeneity on technical efficiency using latent class models, but the application of random parameter models is limited. One of our main contributions in this project is that we apply a modified version of a random parameter model to investigate the effect of unobserved heterogeneity on production factors and efficiency using Hungarian FADN Data. In addition, we imposes regularity conditions into the model through introducing linear and non-linear constraints and thereby investigate their significance. We also examined the relationship between unobserved heterogeneity and the natural and economic conditions of farms. Our findings showed that heterogeneity has a greater effect on variation in output than technical efficiency; furthermore, the violation of theoretical consistency significantly influences the results. These findings also reveal that the explanatory power of regional natural and economic conditions is significant but not sufficient on the variance of estimated unobserved heterogeneity. These results were published in the journal: *Sustainability*.

The effect of subsidies on the performance of farms has received a great deal of attention in the literature. However, much of the related literature examines the effect of subsidies only on one component of TFP, namely on technical efficiency (TE). We examined the effect of different types of subsidies on the different components of TFP. In order to examine this question we used Slovenian FADN data over the period 2006–2013. We estimated a Random Parameter Stochastic production frontier model. Then, based on the estimates of this model, we calculated and decomposed the TFP index into TE, scale efficiency and technological change. In the second step of this analysis, we applied combined difference-in-difference and a matching estimator to examine the effect of investment, less favoured area (LFA) and agri-environmental (AE) subsidies on the different components of TFP. In our case, these subsidies are found to have no significant effect on either TFP or on its components. These results were published in the journal: *Journal of Agricultural Economics*.

Using Hungarian FADN Data, we examined the effect of insurance on farms' economic performance. We hypothesised the existence of reciprocal causation between crop insurance use and the economic performance of farms. The results confirm the reciprocal causation hypothesis. Economic performance is found to positively influence farms' demand for insurance, confirming the significance of budget constraints. Moreover, insurance is found to have a negative effect on Hungarian farms' economic performance, implying that the crop insurance system is inefficient. These results were published in the journal: *Eastern European Economics*.

The environment and economic performance of farms working on Least Favoured areas is an important issue. In contrast, little is known in the literature about these farms performance. In order to contribute to the examination of this question, we examined the differences between less favoured area (LFA) and non-LFA farms using the Slovenian Farm Accountancy Data Network sample of farms in the period 2007–2013. We modelled production technology with a random parameter model that allows us to examine both the direct effect of heterogeneity on production and the indirect effect through the interaction of unobserved heterogeneity with time and input variables. Additionally, we consider intersectoral heterogeneity among types of farming. Results confirm the importance of all these sources of heterogeneity. Secondly, in addition to using conventional statistical methods, we examined the differences between less favoured area (LFA) and non-LFA farms using matching techniques. Results indicate that there

is only a minor and statistically nonsignificant difference in TE between these groups. However, the difference is highly significant in terms of heterogeneity and technology. In other words, results show that farms in LFAs are not more inefficient but rather use different, production–environment-specific technologies. These findings call attention to the fact that omitting the effect of heterogeneity on production technology leads to biased TE estimates and, in turn, leads to potentially imperfect policy choices. These Results were published in the journal: *Agricultural Economics*.

Another main point of the project was the examination of the effect of climatic variable and the effect of financial crises of 2007-2008 on TFP in Hungarian agriculture using FADN Data.
In order to examine the effect of climatic variable and financial crisis in Hungarian agriculture we included environmental variables (precipitation, temperature) into a stochastic random parameter production frontier. The parameter estimates of this model permitted the application of a very recently introduced TFP estimation and decomposition framework (O'Donnel, 2018). The main virtue of this decomposition that it permits the estimation of the effect of environmental change on TFP. In other words, it is possible to decompose the TFP index in addition to the traditional components – technological change, technical efficiency change, scale efficiency change – into an environmental change component. Results showed that TFP fluctuated over the analysed period; technological change was the main driver of TFP growth; the effect of environmental change on TFP is high, it varies between 4-15% from year to year. Furthermore, we examined the effect of financial crisis on the development of TFP using structural brake tests. Results showed that the financial crisis didn't have significant effect on TFP of Hungarian agriculture.

Moreover, we examined convergence among European countries and the effect of financial crisis of 2007-2008 on EU countries using USDA-ERS Data. First, we used nonparametric technique to estimate environmentally corrected TFP index. In order to examine TFP convergence among EU countries we applied the concept of stochastic convergence. In the case of stochastic convergence: group of countries converge if the null hypothesis – H_0: the difference between each country's examined variable and the cross-sectional mean of this variable has a unit root – can be rejected in favour of the alternative hypothesis that each difference is stationary. Earlier studies of convergence usually evaluated convergence by means of ß convergence and σ convergence. However, later the econometric validity of these approaches has been questioned and time-series methods has been suggested. The extension of

the time series approaches to the panel framework has significantly influenced the literature on how to measure convergence. Both time series and panel investigation of the convergence hypothesis usually relies on unit root tests. Over the previous decade, a number of panel unit root tests have been developed. However, recent advances in panel-data econometrics indicate that first generation panel unit root tests, which do not account for cross-sectional dependence (CD), tend to over-reject the presence of unit roots. This issue led to the development of second generation panel unit root tests. We applied one of the most popular second generation panel unit root test, namely the Im–Pesaran–Shin (CIPS) test. This test didn't reject the null hypothesis of a unit-root process of TFP development, i.e. it suggest that there is no convergence among the examined countries using the USDA-ERS Database. Additionally, structural brake tests didn't show any significant differences in the aggregated TFP index of EU countries before and after the 2007/2008 financial crises.

Last but not least, we examined the effect of risk and uncertainty on production. According to the literature, one of the best ways to think about all problems in the economics of uncertainty is the state-contingent approach. The theory of state-contingent modelling is well developed, however the number of empirical applications is limited. In addition, to the best of our knowledge, most studies so far modelled stochastic production technology considering only one source of uncertainty, namely production risk. However, price volatility is another important source of uncertainty in agriculture and plays an important role in agricultural decision-making. In addition, due to a negative correlation between prices and yields which is common for agricultural markets, output price variation can – to a certain extent – offset adverse impacts of production risk on farm output and, therefore, may influence farm production and input use decisions too. Hence, neglecting price uncertainty may influence outcomes of the test of the output-cubical technology hypothesis assuming the absence of substitution across states of nature. An important part of the empirical implementation of the approach is a consistent mapping of stochastic output to particular uncertain events in the context of a multi-output production technology. Using consistent mapping rules is particularly critical in the context of panel data analyses when the effect of uncertainty may be confounded by firm heterogeneity. An important result of this project that, we developed an empirical strategy to formulating states of nature using reduced form fixed effects models of crop yields. Specifically, we propose to formulate states of nature by identifying weather-related yield losses in Hungarian cereals production using statistical inferences about yield responses to interannual weather variation.

We sent these results to the Journal: European Journal of Agricultural Economics (the paper is under Review).