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EFFECTS OF CLIMATE CHANGE ON FARMERS' ECONOMIC DECISIONS

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1. RESEARCH BACKGROUND AND OBJECTIVES

The agricultural sector is very vulnerable to climate change, whether the effects are differentiated over time and space, and can cause different kinds of damage. It is not a new finding that negative climate events also contribute to weak economic returns. Globally, the average surface temperature warmed by 0.85-0.89°C between 2006 and 2015; at +1°C above preindustrial levels, 2015 was the warmest year ever recorded. Hungary has also experienced major changes in days with extreme temperatures, which are increasing faster than average temperatures. The number of hot days, and the intensity, length and frequency of the heatwaves have also increased greatly. The precipitation patterns are volatile over time and space. During the period 1981-2016, the number of days with 20 mm precipitation increased and the dry periods also increased considerably. Summer precipitation intensity in the South-Western Transdanubia and North-Eastern regions decreased, and this decrease can also be observed in the spring period.

Climate change projections are based on greenhouse gas and aerosol emission concentrations. The results of model calculations show a more rapid increase in temperature in Hungary in the period 2021-2040 compared to the average of the period 1961-1990. Mean temperatures are expected to increase by 0.8-1.8°C annually. Temperature warming in the Great Plain region is faster than in the Transdanubia region, and the increase in summertime temperature is expected to be greater than in the spring periods. The amount of annual precipitation will remain unchanged, but large differences can be experienced between the seasons.

Most research findings conclude that negative meteorological events contribute to weak economic returns (e.g. Chavas et al., 2009; Trnka et al., 2011; Huang et al., 2013; Melkonyan-Asadoorian, 2013; Spinoni et al., 2015; Hatfield-Prueger, 2015; Mishra et al., 2018; Assefa et al., 2020). While some authors challenge these results, others conclude that the effects are quite positive (Deschenes-Greenstone, 2007).

Understanding the factors affecting technical efficiency is crucial for developing efficient farm operating processes. The results can be substantial at farm or decision maker level: the farms with efficient operating processes and higher income generation are most resistant to the negative effects of market processes and climate change while, based on available information, decision makers are able to draw up strategies to develop sectoral productivity and competitiveness.

We systematically reviewed articles published in peer-reviewed journals which discuss the relationship between climate change and economic efficiency. Based on this review, we assessed the international embeddedness of this topic, as well as its geographic extension, the key findings and the types of data sources used in the studies.

The most commonly investigated topics are crop production and total agriculture, while livestock studies are the rarest. This is not surprising, since crop production is the most vulnerable to the extreme climatic events, followed by animal breeding and forestry (Solís-Letson, 2013).

Based on our research protocol, we made a comparison of studies using Data Envelopment Analysis (DEA). We segregated the results by host country and found that the highest average efficiency farms occur in Western and Northern European regions. This indicates that the farmers can reach higher technical efficiency in regions where highest a0verage income exists.

The aim of the dissertation is to assess the impacts of climate change on technical efficiency in the Hungarian crop sector. The three objectives are:

O1: To explore biophysical factors existing in the natural environment which can affect farmers' efficiency with conventional market-based production factors.

O2: To analyse the mid-term effects of climate change which can affect the Hungarian crop production sector. The results constitute the inputs of the third goal, therefore in this research we did not examine the efficiency results separately.

O3: To investigate the effects of different meteorological indicators in efficiency calculations by specific phenological phases of plant production (seeding, vegetative and generative).

By using a rarely applied novel approach in the agricultural economics literature, the dissertation allows a deeper understanding of climate change effects on Hungarian crop production. The first part of the methodology aims to show the relationship between the production function and short-term weather events (by separating three different development stages of production cycle). The second part of the methodology attempts to show the factors influencing the efficiency of farms.

Based on the literature review, the most frequently examined areas are the USA, Asia, Western Europe and Southern Europe, while the Central and Eastern parts of Europe remain under researched. Since the biggest uncertainty of climate projections is expected in Central and Eastern European regions, there exist a need for further studies. The dissertation aims to partially fill these gaps.

2. DATA AND METHODOLOGY

2.1. Data

We used a newly generated dataset based on existing available data. The Farm Accountancy Data Network (FADN) as a representative information system was established by the European Commission (EC) for the analysis of the incomes and economic activities of agricultural farms. The Hungarian FADN data are collected and managed by NARIC AKI FADN Department and the Hungarian sample covers 1,000 crop producers. In our research we used FADN data for the period 2002-2013 with nearly 12,000 observations.

As the Hungarian FADN does not contain environmental or geophysical data, we extended the farm level data with meteorological and geophysical data. The meteorological variables focused on average daily temperature and daily precipitation variables based on the AGRI4CAST MARS Crop Yield Forecasting System of the European Union Joint Research Centre (EU-JRC). The panel dataset adopted the soil variables based on the EUSOILS dataset of the ESDA EU-JRC, the dataset consists variable describing limitation to agricultural use of soils, water capacity of subsoil and topsoil and organic content.

2.2. Method

In the literature, two main approaches compete for efficiency and productivity change calculations: non-parametric techniques based on DEA (Coelli et al., 1998) and parametric techniques based on stochastic frontier analysis (Bakucs et al., 2010; Baráth-Fertő, 2013).

In non-parametric approach the DEA is the most appropriate method, which defines minimum quantity of two or more inputs for generating one output (Coelli, 1998). The construction of efficient frontier is based on the distance functions: farms located on the frontier are fully efficient; in contrast, farms under the frontier are inefficient, and the increasing distance from frontier provides less efficient farms.

We employed a two-step approach for assessing the influence of climatic and soil characteristics on technical efficiency. In the first step, we calculated the technical efficiency of farms using the DEA output-oriented model (Farrell, 1957; Thiele and Brodersen, 1999). In the second step of the analysis, we focused on the impact of climate and soil factors on the technical efficiency scores. In regression, the dependent variable represents the efficiency of selected arable farms, while independent variables represent the climatic and soil variables.

Using a parametric method, we calculated technical efficiency scores. Since the pioneering work of Knox-Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), efficiency measurement using stochastic frontier models has become a standard approach of applied economists. However, traditional efficiency models assume that all firms face a common frontier and the only differences result from the intensity of input use.

Greene (2005) proposed two stochastic frontier models called the 'true' fixed-effects (TFE) and 'true' random-effects (TRE) models. We used five model specifications:

- Model 1 (M1): Pooled frontier without climatic variables;
- Model 2 (M2): Pooled frontier with climatic variables;
- Model 3 (M3): True fixed effect model with climatic variables (TFE);

- Model 4 (M4): True random effect model with climatic variables (TRE);
- Model 5 (M5): True random effect model with Mundlak specifications.

3. RESULTS

The dependent variable represents the efficiency of selected arable farms, while independent variables represent the climatic and soil variables. In this context, the temperature and the precipitation increases had a statistically significant positive effect on efficiency of farms in the seeding and vegetative periods in both the CRS and VRS models. By contrast, the temperature increase during the generative phase of crop production had a negative effect on production efficiency: the direction of the effects is consistent with our a priori expectations. Soil dummies were found to have significant coefficients (Table 1).

The results of stochastic frontier analysis underpin our expectations regarding the changing phenology phases influences the Hungarian crop sector. (Table 2). Higher temperatures measured during the seeding period have a positive effect on efficiency. The result is not surprising, as we assume that sowing can be made in April in the continental climate belt, during which time higher temperatures are essential for the germination of spring-sown plants. The effect of changes in precipitation patterns over the same period is not clear. While for M2 and M3 specifications the increase in precipitation has a positive effect, for M4 and M5 it has reduced efficiency. The results are explained by the fact that rainfall distribution is a key issue in outdoor crop production, the mere increase in rainfall does not improve yields, and the temporal and spatial distribution of falling precipitation images is difficult to predict.

1. table: Simar-Wilson results

Independent variables	CRS	Lower bound	Upper bound	VRS	Lower bound	Upper bound
$T_{seeding}$	0.231***	0.1872	0.2741	0.223***	0.1683	0.2771
$T_{seeding2}$	-0.009***	-0.0105	-0.0070	-0.009***	-0.0107	-0.0064
$T_{vegetative}$	0.372***	0.2928	0.4478	0.340***	0.2477	0.4313
$T_{vegetative2}$	-0.010***	-0.0116	-0.0074	-0.009***	-0.0112	-0.0063
$T_{generative}$	-0.225***	-0.3688	-0.0886	-0.309***	-0.4877	-0.1375
$T_{generative2}$	0.005***	0.0014	0.0078	0.007***	0.0028	0.0107
$P_{seeding}$	0.003***	0.0027	0.0036	0.002***	0.0013	0.0024
$P_{seeding2}$	-0.000***	0.0000	0.0000	-0.000***	0.0000	0.0000
$P_{vegetative}$	0.000	-0.0002	0.0003	0.000	-0.0003	0.0003
$P_{vegetative2}$	-0.000**	0.0000	0.0000	-0.000**	0.0000	0.0000
$P_{generative}$	-0.000**	-0.0004	0.0000	-0.000	-0.0003	0.0002
$P_{generative2}$	0.000	0.0000	0.0000	-0.000	0.0000	0.0000
AGRICUL	0.019*	-0.0012	0.0385	0.036***	0.0124	0.0612
HWC_SUB	0.024***	0.0176	0.0311	0.018***	0.0105	0.0262
HWC_TOP	0.014*	-0.0007	0.0299	0.010	-0.0088	0.0278
LOC	-0.013***	-0.0193	-0.0066	-0.017***	-0.0249	-0.0093
cons	-2.001***	-3.3292	-0.6037	-0.701	-2.3527	1.0128
sigma	0.168***	0.1655	0.1704	0.197**	0.1936	0.2000
Wald chi2	754.831	-	-	388.337	-	-
N	11785	-	-	11785	-	-

*p<0.1; **p<0.05; *** p<0.01

Source: own calculations

2. table: Stochastic frontier analysis results

Változók (Határ)	**M1**	**M2**	**M3**	**M4**	**M5**
lnLand	0.00	0.01	0.01	0.02	0.01
lnLabor	0.08***	0.09***	0.09***	0.08***	0.09***
lnCap	0.09***	0.09***	0.09***	0.08***	0.09***
lnMat	0.83***	0.82***	0.82***	0.82***	0.82***
lnLand_lnLabour	-0.05**	-0.06***	-0.06***	-0.06***	-0.06***
lnLand_lnCap	0.03	0.03**	0.03**	0.04**	0.04**
lnLand_lnMat	0.03	0.03	0.03	0.03	0.03
lnLabor_lnCap	-0.04***	-0.04***	-0.04***	-0.04***	-0.04***
lnLabor_lnMat	-0.05**	-0.04*	-0.04*	-0.04*	-0.04*
lnCap_lnMat	-0.03*	-0.04***	-0.04***	-0.04***	-0.04***
lnLand2	0.00	0.01	0.01	0.01	0.01
lnLabor2	0.06***	0.06***	0.06***	0.06***	0.06***
lnCap2	0.03***	0.03***	0.03***	0.03***	0.03***
lnMat2	0.01	0.01	0.01	0.01	0.01
Trend	0.01***	-0.04***	-0.03***	-0.04***	-0.03***
Trend2	-0.00***	0.00***	0.00***	0.00***	0.00***
lnTSeeding		0.29***	0.29***	0.51***	0.30***
lnTVegetative		-0.15	-0.10	0.04	-0.17*
lnTGenerative		-1.46***	-1.21***	-1.10***	-1.45***
lnPSeeding		0.00	0.00	-0.01	-0.00
lnPVegetative		0.05***	0.04***	0.07***	0.05***
lnPGenerative		-0.03***	-0.03***	-0.01	-0.03***
lnTSeeding_2		1.05**	0.94*	1.50***	1.09**
lnTVegetative2		-9.14***	-8.40***	-8.05***	-9.23***
lnTGenerative2		3.54	4.14*	4.33*	3.95*
lnPSeeding2		-0.01***	-0.01***	-0.01***	-0.01***
lnPVegetative2		-0.03*	-0.03**	-0.02	-0.03*
lnPGenerative2		-0.06***	-0.06***	-0.04***	-0.06***

Source: own calculations

There is a change of sign in the vegetative (Tvegetative) and generative (Tgenerative) periods. The phenologically important plant growth or vegetation period occurs in May-June, during which time the vegetative parts of the plants, for example the stems and leaves, are formed. The higher temperature in most cases significantly and negatively affected the change in efficiency in most model specifications. The results show that higher precipitation measured during the growth period improved the efficiency of the surveyed plants.

4. CONCLUSIONS AND RECOMMENDATIONS

The main conclusions and recommendations based on the dissertations follows the list of objectives.

The first objective of the dissertation is to explore biophysical factors existing in the natural environment which can affect the farmers' efficiency with conventional market-based production factors. Based on the literature, at the beginning of analysed twenty-year time period the articles in this topic are rarely published, while 60 percent of the articles were published in the last five years, which confirms the embeddedness of international research on the topic. In a systemic review technique rarely applied in agricultural economics, we identified the most important agricultural effects. These conditions affecting the agricultural farm operations are extreme climatic events, changes of plant development stages, effects of human resources, transformations of environmental conditions and the farm level factors.

The second objective of the dissertation is to analyse mid-term effects of climate change which can affect the Hungarian crop production sector. The dissertation demonstrates the changes in climatic and non-climatic conditions in the Hungarian crop sector. For this purpose, we used a representative set of panel data of crop producers. The dataset contains farm level data and high resolution meteorological and soil data.

In the literature, two main approaches compete for efficiency and productivity change calculations. We used parametric techniques based on stochastic frontier analysis and non-parametric techniques based on Data Envelopment Analysis. Previously, the mentioned method was used to determine milk producer's efficiency most commonly in Western Europe and USA. Results of non-parametric analysis suggest that, in the 2002-2013 time period, high heterogeneity of production performance results in a low level of efficiency of Hungarian crop producers. During this period, the constant return to scale (CRS) reached the efficient frontier for only two percent of farms, and for variable return to scale (VRS) the figure was 4-6 percent.

In the research period, the efficiency of farms is characterised by high levels of fluctuation. By introducing meteorological factors, we found the following results: The temperature increase during the generative phase of crop production had a negative effect on production efficiency: the direction of the effects is consistent with our a priori expectations. Soil dummies were found to have significant coefficients. The biophysical results suggest that the high water holding capacity of the top- and subsoil had a positive effect on efficiency. The same negative relationship was identified for low organic content of soil as we expected: the low organic content of soil lowers the efficiency on both the constant and variable returns to scale models.

By using the parametric stochastic frontier analysis approach, we analysed the relationship between the technical efficiency of farms and meteorological and soil variables considering five model specifications. In all specifications we confirmed that the higher temperatures measured during the seeding period have a positive effect on efficiency. The result is not surprising, as we assume that in the continental climate belt sowing can be made in April, during which time higher temperatures are essential for the germination of spring-sown plants. The phenologically important plant growth or vegetation period occurs in May-June, during which time the vegetative parts of the plants, for example the stems and leaves, are formed. The higher temperature in most cases significantly and negatively affected the change in efficiency in most model specifications. The results show that higher precipitation measured during the growth period improved the efficiency of the surveyed plants. Increased precipitation in this phenology phase also suggests a negative effect. The results are based on the effects of yields on harvest quality, as the sudden rise in temperature and falling precipitation degrade the marketability and quality characteristics of most crops.

Our results confirm that the negative climate effects in the generative phase greatly and significantly impaired the efficiency. By these results we agree with Hatfield-Prueger (2015); Qi et al. (2015), Arshad (2016) and Rahman-Anik (2020), who concluded that the major impact of warmer temperatures was during the generative stage of development and in all cases grain yield was significantly reduced. In case of precipitation change, in seeding and vegetative periods the effects are positive. Our results are also in line with other researchers (Jiang-Koo, 2013; Arshad et al., 2016). The negative effects in the generative phase are shown by Ochuondho et al. (2014), while spring-winter precipitation effects are also recognised by Qi et al. (2015) and Auci-Vignani (2020).

This dissertation shows the effects of changing extreme climatic variables such as number of hot and frosty days, the deviations from average temperature and precipitations from long run average and deviations from extreme observations. The frequently observed cold and hot stress caused by climate change is deteriorating the molecular, biochemical and physiological processes. These are the key factors influencing the decreasing yield. The cold stress inhibits nutrient uptake, nutrient utilisation, development of vegetative parts, photosynthesis, the intensity of respiration, and the quantity and quality of plant yield. Low temperature is a crucial factor determining the natural occurrence and geographical distribution of plants. In case of agricultural production, temperature is the factor which most likely limits cultivation. This standpoint is shown by the international literature (Daalgard et al., 2015; Mishra et al., 2015; Bouttes et al., 2018).

The traditional farm level factors are also influencing the mitigation of climate change effects. The farms owning large areas of land cannot reduce the negative effects of climate by increasing the workforce. In contrast, the farms owning large areas of land combined with high level of capital significantly and positively affects the production output, resulting in crop producer farms with large territory and capital, and having technically developed inputs can generate more output taking into account the negative circumstances of climate. The results are shown in the scientific literature (OECD, 2004 and Kovács et al., 2009), who argued that agricultural producers have risk-averse attitude and the degree of risk-aversion differs from producer to producer and from country to country. Barnes (2006) claims that farms with many livestock are operating more efficiently than farms with smaller livestock herds. Some studies (e.g. Pourzand-Bakhshoodeh, 2014; Yaqubi et al., 2016) say that farms maintaining sustainability criteria by improving the input use reached higher levels of efficiency.

Treatment of effects assumes exploring the vulnerability of farms, setting up mitigation actions and formulating adaptation measures. Farmers' options for managing risks include sowing temperature resistant species or short duration less vulnerable crops and irrigation, which can be beneficial in the short term against the traditional rainfed systems. Irrigation as an important adaptation measure is highlighted in the literature in the USA (Schlenker et al., 2005) and in Latin-America (Mendelsohn-Seo, 2007).

Therefore, the decision makers should support investments and restructuring strategies which are consistent with existing production regions, available natural resources and landscape structures by adapting the size of farms, production structures and cultivation of species. Meanwhile, the efforts of increasing efficiency should be prioritised, especially in small farms, by endorsement of appropriate technologies and multidimensional market relations.

The degree of effects is highly dependent on the adaptation strategy of agricultural producers and markets to climate change. If production due to the new climatic conditions shifts to the northern latitudes, as a result, the consumers' welfare does not change, while the producers' welfare decreases because of the decreasing yields. Adaptation can mitigate price increases by increasing the productivity through the adoption of irrigation technologies, crop portfolio adjustments or cropland expansion. Therefore, there is a need to adopt sustainable adaptation strategies, and at the same time to raise the farmer's consciousness towards taking part in adaptation strategies by, for example, mass media, training and experiential education tools (Arshad et al., 2016).

The third objective of the dissertation is to investigate the effects of different meteorological indicators in efficiency calculations by specific phenology phases of plant production (seeding, vegetative and generative).

While some results are not statistically significant, this dissertation enhances our knowledge regarding the economic evaluation and climate change by using domestic (Hungarian) data. The construction of a production function besides the traditional economic variables contain extreme climatic variables, long-run climatic factors and soil characteristics. Uniquely, in a parametric approach we used five model specifications, focusing true fixed and true random effect models. We conclude that an estimation of the potential evolution of these processes based on agricultural productivity would be valuable when designing adaptation strategies.

New research programmes and options are required, because there is a need to understand climate challenges and efficient farm operation methods, taking into account the evaluation of the specific objectives of the Common Agricultural Policy 2020+ national energy use efficiency and climate strategies.

We recognise new research opportunity regarding the relationship between the farm level greenhouse gas emissions and farm level technical efficiency. Unfortunately, the FADN data used in this research served this need only to a limited extent (in 2015 a pilot data collection was conducted regarding 100 swine breeders).

5. NEW SCIENTIFIC RESULTS

1. Using a novel approach, we presented the climate change induced biophysical effects which with the traditional production factors can influence the efficiency of farms. Through systematic literature review we demonstrated that the international scientific literature explicitly shows that climate change alters the synergies between the traditional production factors and the biophysical components of crop production sector.

2. Based on the literature, we identified the meteorological factors most commonly influencing crop yields, namely the average temperature, sum of precipitation and deviations from long run observation of average temperature, number of heat stress and cold stress, by separating the region specific development stages of crop production.

3. In the Hungarian FADN the meteorological and soil variables, which can be used for farm's impact analysis of climatic change, are not available at farm level. For analysis purposes we generated a new database which combined data from the Hungarian FADN with JRC AGRI4CAST and JRC EUSOILS data. By this step, we were able to evaluate questions regarding weather change effects on agricultural farms efficiency level.

4. Our estimations showed that the increasing daily average temperature and increasing daily sum precipitation level in the seeding period of plant production (April) had a positive and significant effect on technical efficiency in crop production. The higher temperature and higher precipitation in most generative phase negatively affected the change in efficiency in most model specifications.

5. The results show that between 2002 and 2013 the number of heat stress days (days with temperature above 30ºC) significantly explains the lack of efficiency in the generative period. Inefficient functioning also increases during the vegetative (growth) period in case of temperature and precipitation variables deviations from long run observations.

6. We demonstrated in all model specifications that by improving the high water holding capacity of subsoil and topsoil and the high organic content of soil can be beneficial for crop producers.

6. PUBLICATIONS FROM THE TOPIC OF THE DISSERTATION

Book

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Bakó, B., Berezvai, Z., Isztin, P., **Vigh, E.**Z. (2020) Does Uber affect bicycle-sharing usage? Evidence from a natural experiment in Budapest. Transportation Research Part A: Policy and Practice, 133: 290-302. https://doi.org/10.1016/j.tra.2020.01.010

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