Gefördert durch:

Bundesministerium
für Ernährung
und Landwirtschaft

aufgrund eines Beschlusses
des Deutschen Bundestages

Deutsch-Ukrainischer
Agrarpolitischer Dialog

At the Institute for Economic Research and Policy Consulting

Agricultural Policy Report APD/APR/01/2018

Efficiency and Profitability of Ukrainian Crop Production

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Kiew, December 2017

About the Project "German-Ukrainian Agricultural Policy Dialogue" (APD)

The project German-Ukrainian Agricultural Policy Dialogue (APD) started 2006 and is supported up to 2018 by the Federal Ministry of Food and Agriculture of Germany (BMEL). On behalf of BMEL, it is carried out by the mandatary, GFA Consulting Group GmbH, and a working group consisting of IAK AGRAR CONSULTING GmbH (IAK), Leibniz-Institut für Agrarentwicklung in Transformationsökonomien (IAMO) and AFC Consultants International GmbH. Project executing organization is the Institute of Economic Research and Policy Consulting in Kyiv. The APD cooperates with the BVVG Bodenverwertungs- und- verwaltungs GmbH on the implementation of key components related to the development of an effective and transparent land administration system in Ukraine. Beneficiary of the project is the Ministry of Agrarian Policy and Food of Ukraine.

In accordance with the principles of market economy and public regulation, taking into account the potentials, arising from the EU-Ukraine Association Agreement, the project aims at supporting Ukraine in the development of sustainable agriculture, efficient processing industries and enhancing its competitiveness on the world market. With regard to the above purpose, mainly German, but also East German and international, especially EU experience are provided by APD when designing the agricultural policy framework and establishing of relevant institutions in the agriculture sector of Ukraine.

APD German-Ukrainian Agricultural Policy Dialogue

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List of abbreviations

AP – animal production

BP – balanced panel

CP – crop production

CZ – climatic zone

Coef. – coefficient

DEA – data envelopment analysis

Ha- hectares

Mln – million

TE – technical efficiency

TFP – total factor productivity

TP – total production

Tsd – thousands

UAH – Ukrainian hryvnya

UP – unbalanced panel

1. Introduction

1.1. Motivation and statement of the research question

Because of large areas with favorable soil qualities, Ukraine features some of the prime locations for crop production in the world. Agricultural production from Ukrainian farms thus can play an important role to provide food for an increasing world population and, on the other hand, can represent an important income source for Ukrainian rural population. In fact, agriculture accounts for a significant share in gross domestic product and export revenues. For instance, Ukraine is the fourth largest exporter of maize worldwide in 2013 (by holding this rank since 2005) and the tenth largest producer of wheat over the years 2011 to 2014 (FAOSTAT, 2016).

While crop production worldwide increases steadily over the last decades, Ukrainian agriculture (as other former socialist countries) had to sustain a harsh drop in absolute and relative production after the collapse of the Soviet Union. Only recently, the production value of crop production (in constant prices of 2010) recovered and exceeded the level of 1991. For most crop products, for instance wheat and maize, the worldwide trend of increasing production is simultaneously accompanied by a reduction (wheat) or under-proportional expansion (maize) of the harvested area (FAOSTAT, 2016), which highlights a significant increase in productivity, e.g., in terms of yields per hectare (see Figure 1). We also obtain this trend for Ukraine, in the case of maize even more pronounced. Despite the presumed favorable natural conditions, however, Ukrainian average yields only recently exceeded world averages. The question therefore arises whether Ukrainian farms exploit the yield potential of their land or if there is a considerable yield gap that, given appropriate management, can cause significant production growth.

In fact, the discussion of yield gaps has attracted a lot of attention over the past two and a half decades. Per definition, yield gaps are differences between yield potential and the average farmers' yields for a given region and growing season, where the yield potential refers to the yield a crop would reach under optimal conditions, i.e., without water, nutrients, pests, or diseases stress (Lobell et al., 2009). Commonly this yield gap is larger for developing and transition countries than for developed countries (Neumann et al., 2010). The yield gap is smaller if the production system relies on irrigation rather than on (uncertain and uncontrollable) rain-fed water supply (Schierhorn, et al. 2014). These aspects are relevant for Ukraine as well as Central Eurasia - a region that reportedly has the largest yield gaps worldwide (Neumann et al., 2010). The definition of the yield gap, however, focuses on the natural conditions of crop production but often or mostly ignore the question whether the maximum possible is also economically optimal.

Often the argument is made that given the existence of the (seemingly considerable) yield gap, Ukrainian farms might be able to substantially increase total crop production. Whether this claim is justified depends however, e.g., on the economic and political environment of Ukrainian farmers. This paper will shed some light into these issues by investigating the productivity and efficiency of Ukrainian farms and their determinants. Moreover, the question is tackled whether farms have a rational choice to improve productivity given adverse political and economic conditions.

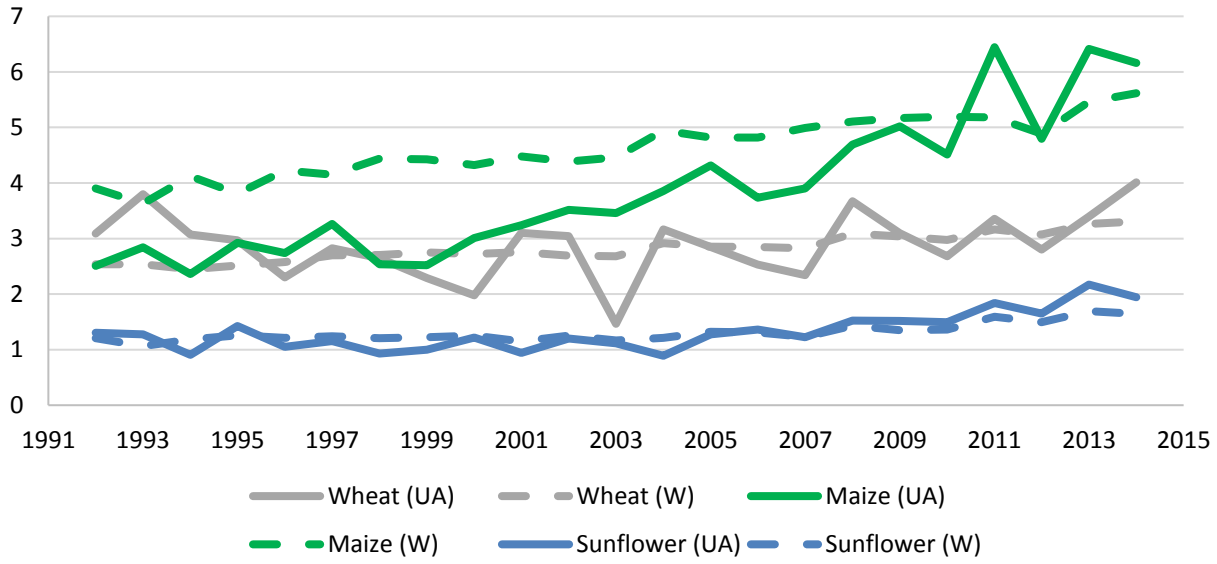


Figure 1. Yield development of major crops in Ukraine (UA) and Worldwide (W), t/ha

Source: Own calculation based on data from FAOSTAT (2016

1.2. Structure and development of crop production in Ukraine

The agricultural sector plays an important role for the Ukrainian economy. In 2013, agriculture accounts for 8.8% of gross domestic product (GDP), 26.9% of export revenues (excluding revenues from services), and employs 8.1% of the working population (SSSU, 2014a; SSSU, 2014b). Besides the ongoing geopolitical frictions, the current situation of the agricultural sector, however, is still affected by the transition from a planned to a free market economy. Following the collapse of the Soviet Union and Ukraine's independence, Ukrainian farms were confronted with new and difficult internal and external conditions including an underdeveloped banking system, the strong reduction of subsidies paid by the government, the disconnection of former supply chains, and the need to integrate into global markets. The farms themselves were mostly collective enterprises with high debts and no or vague ownership of production factors. Under these circumstances, agricultural production value dramatically declined by 64% from 1991 to 1999. Only after new regulations for

agricultural taxation were introduced in 1999, and the improved access to capital and infrastructure together with trade liberalizations and the farms organizational transformation took effect (Osborne and Trueblood, 2002; Matyukha et al., 2015), the negative trend has been reversed. However, the total agricultural production value in 2014 was still lower relative to 1991, which is mainly caused by the low level of production value from animal production (see Figure 2). While crop production exceeds the 1991 level in 2013 and 2014, animal production barely reaches the level of 50% of the base year (1991) in 2014.

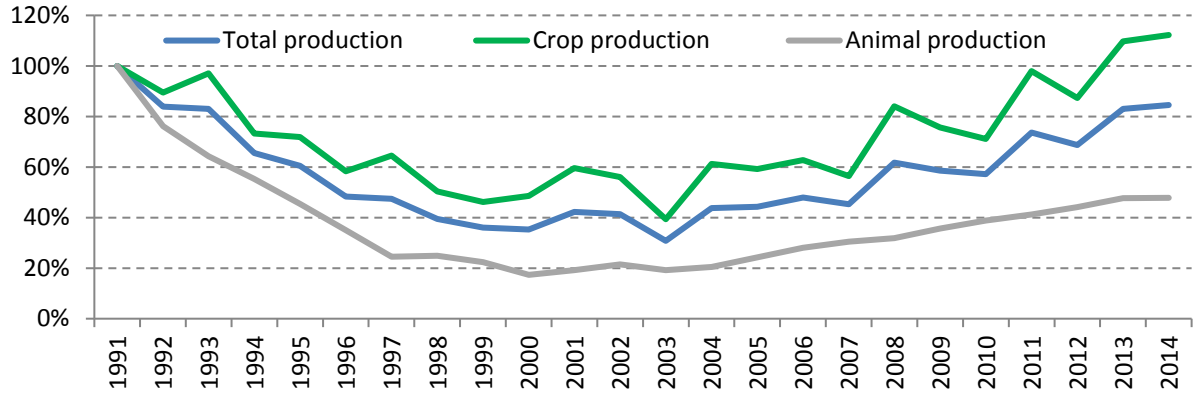


Figure 2. Agricultural production value, 1991 = 100% (calculated based on constant prices of 2010)

Source: SSSU, 2016

The relative better performance of crop production underlines the favorable conditions for this farming orientation and we are going to detail some major factors and developments in the following.

According to official statistics, 41.5 mln hectares or approximately 71% of the total area in Ukraine are agricultural land. Individuals or households use one third of this land while about half of the agricultural land is operated by commercially oriented farms, namely 20.4 mln hectares (SSSU, 2014a). The average farm size was about 2120 ha in 2013. The farm size distribution is shown in Figure 3. The comparison of the two pictured years (2008 and 2013) indicates a slight increase in total land use by small farms with less than 100 ha while all other groups decline in total land use. This decline is caused by the rapid increase of land farmed by agroholdings as illustrated on the right hand side of Figure 3. With 5731 ha per holding subsidiary, these organizations are significantly larger than the average farm.

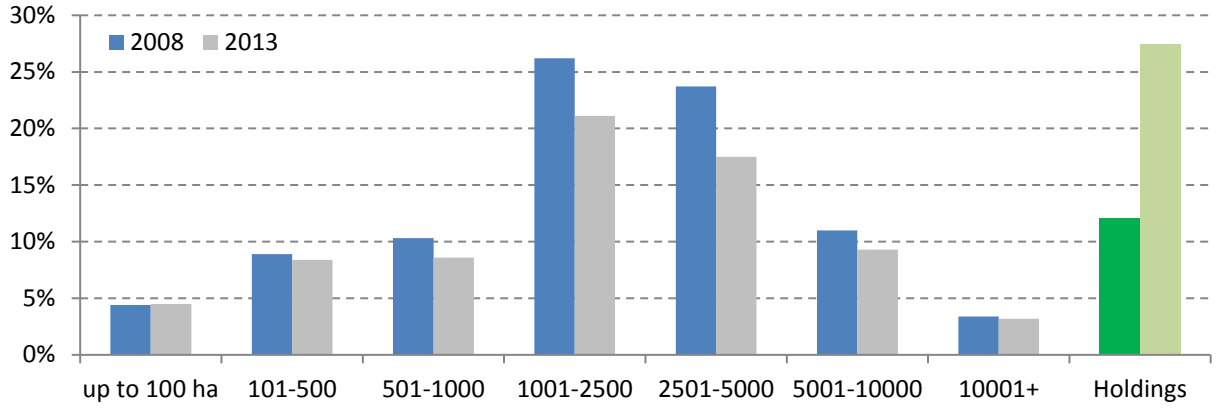


Figure 3. Distribution of farms by the sizes of land area in use

Source: AgriSurvey, 2013

Because the total number of farms in Ukraine is decreasing, the average farm size increases overall. However, the decline in farm numbers differs across farm types (see Figure 4). For instance, the number of private enterprises declined by 8%, peasant farms[1] by 9%, agricultural cooperatives by 51%, and other types of enterprises by 55%, while the number of business partnerships slightly increased (+3%).

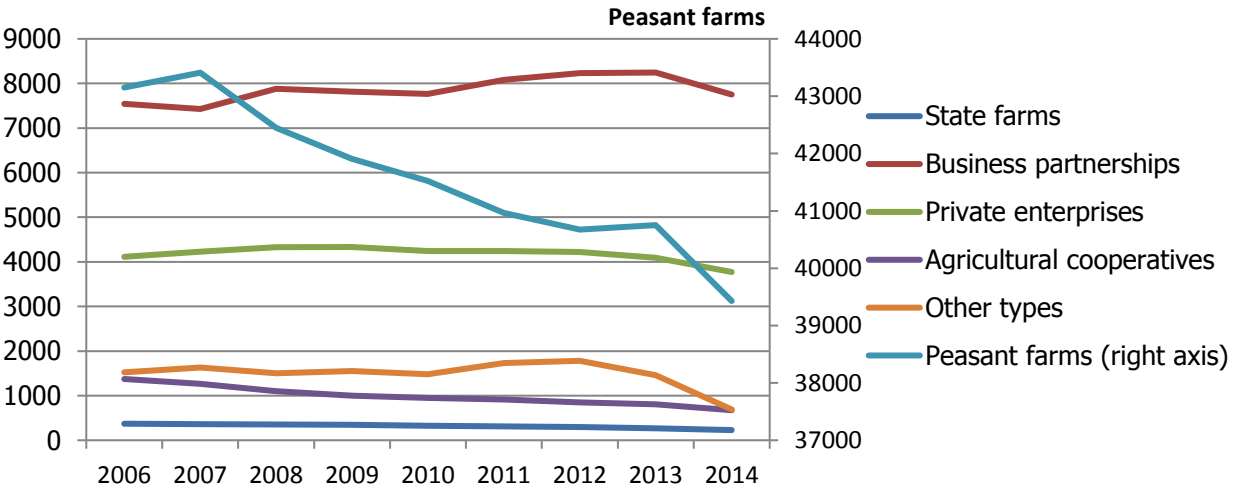


Figure 4. Number of active farms in Ukrainian agriculture

Source: SSSU, multiple years

[1] This farm group mainly represents small market players with an average land area of about 100 ha but there are also large peasant farms that operate more than 20 tsd ha. In general, farms in this group feature a dynamic increase in farm size from 92 ha in 2006 to 119 ha in 2014 (i.e., an increase of almost 30%).

Driven by the export oriented production – more than half of the produced cereals were exported in 2013/14 – the crop mix considerably changed over the last two decades. In 2013, the six major crops (wheat, barley, corn, sunflower, soya, and rapeseed) accounted for 92% of the sowing area and 87% of revenues (see Figure 5 and 6). It is noteworthy that some of these "cash crops" were only marginally important in 1990. For instance, the share of corn increased from 3% to 20% of the total sowing area while sunflower (from 5% to 22%), soya (from 0.3% to 9%), or rapeseed (from 0.3% to 5%) show similar developments (see Figure 5). These crops have substituted fodder and some niche crops, which were intended mainly for the domestic market.

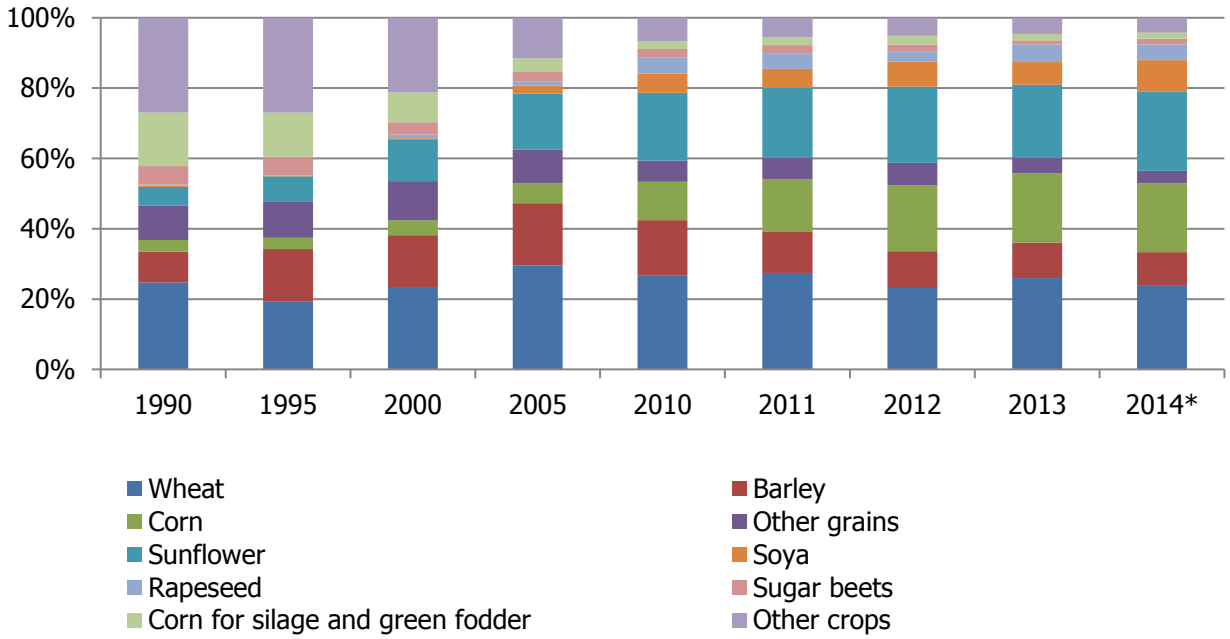


Figure 5. Structure of sowing areas

Source: SSSU, multiple years

* without Crimea and occupied territories of Donetsk and Lugansk regions

Accordingly, the sales structure (see Figure 6) also features an increase in the share of corn (from 12% in 2008 to 28% in 2013), sunflower (from 12% in 2008 to 19% in 2013) and soya (from 3% in 2008 to 7% in 2013).

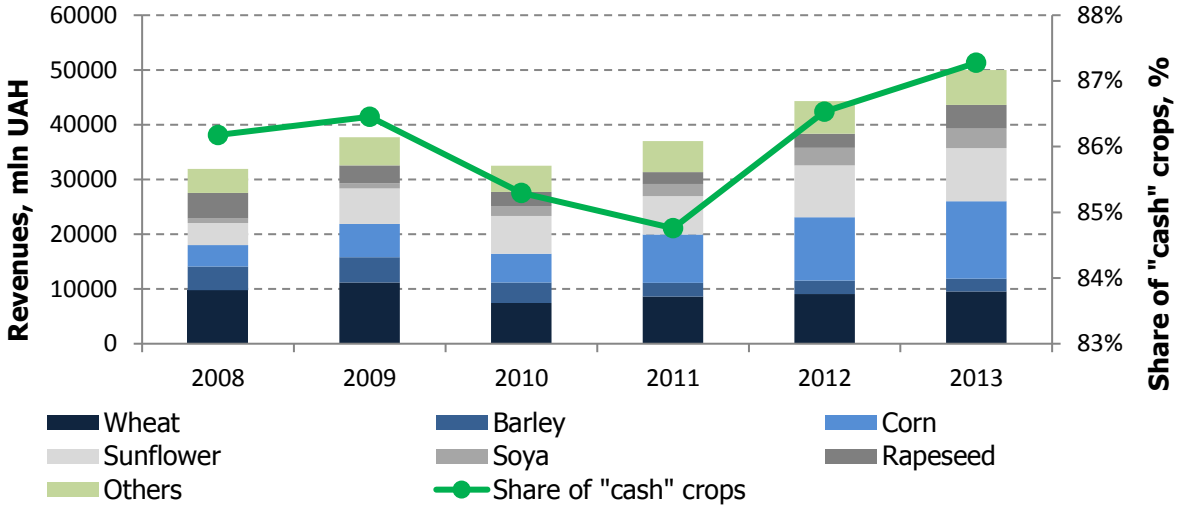


Figure 6. Revenues from the sales of crops by farms of Ukraine, mln UAH (in constant prices of 2008)

Source: own calculations based on SSSU (multiple years)

As initially illustrated, there is an increase in factor productivity of the input land (see Figure 1), but also a considerable rise in labor productivity from 2000 to 2014 (about 8 times) as shown by Figure 7. Structural changes (e.g., the decline in animal production, technological change) caused here a reduction of workforce by 79% (2014) compared to the base year (2000).

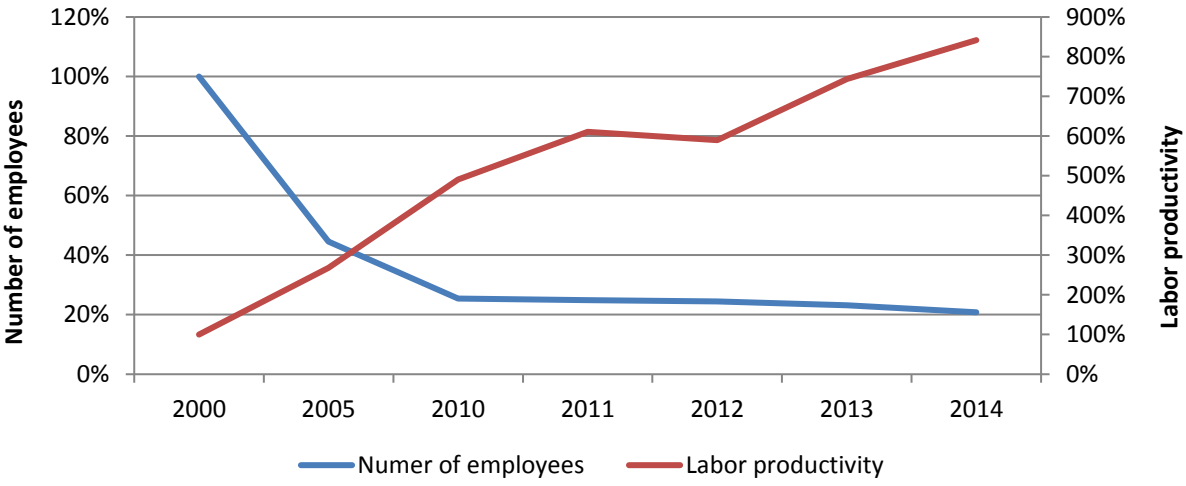


Figure 7. Number of employees and labor productivity, 2000 = 100%

Source: SSSU, multiple years

Relating to the cost level (Figure 8), we see that labor was substituted by capital causing an intensification, which bolstered the yield development. In the period 2008-2011 farms spent about two thousand UAH per hectare and year in average (inflation adjusted), while the costs per hectare rose to 2.6 thousand UAH in 2012-2013. The major components of this intensification were technological improvements (e.g., better machinery and techniques reflected in the doubling of depreciation costs) and some material inputs (see Table 1). The main source for increasing capital input were comparable high profits in the years 2008-2011, but price developments in world markets caused lower profit margins in 2012-2013, which sparks concerns regarding the continuation of this trend.[2] However, Ukrainian farms produced a record 62.2 mln tons of cereals in 2013.

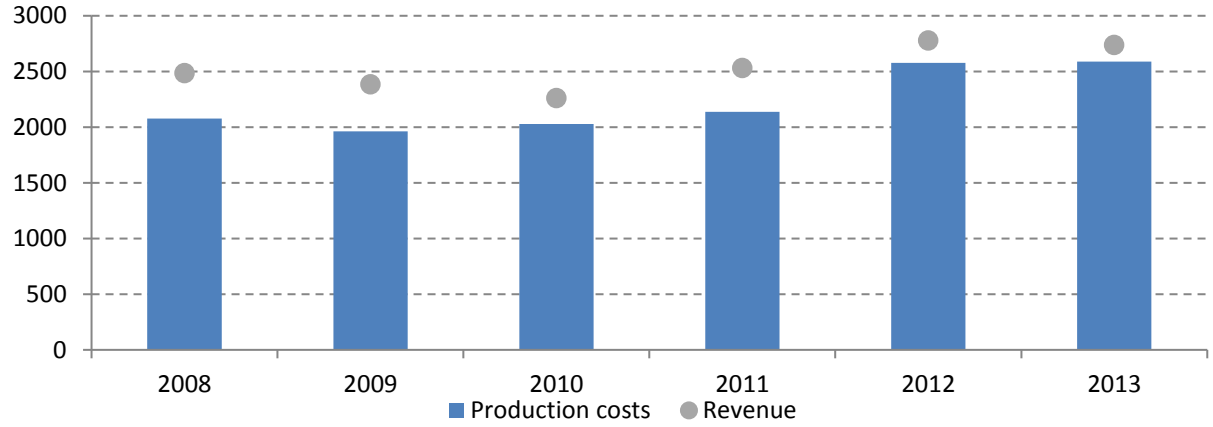


Figure 8. Total costs and revenues per hectare in crop production by farms, (inflation adjusted)

Source: own calculations

Table 1. Production costs in CP (deflated), UAH/ha

		2008	2009	2010	2011	2012	2013
Total costs		**2077**	**1962**	**2027**	**2137**	**2577**	**2590**
Labor		213	192	185	166	157	148
Social costs		51	58	66	54	83	55
Material costs	*total*	*1410*	*1239*	*1278*	*1427*	*1763*	*1823*
	seeds	257	239	216	222	285	310
	other agricultural products	13	13	12	13	31	17
	fertilizers	366	295	296	330	359	393
	oil products	313	237	253	291	409	400
	electricity	21	23	25	24	24	26
	fuels	20	18	16	22	36	38
	spare parts	121	126	139	160	185	175

[2] According to FAO, cereals price index dropped by 4.9 points in 2012 and by 16.8 points in 2013, while for oils by 30.6 and 30.9 points respectively.

	3rd party services	298	289	322	366	433	466
Depreciations		117	191	194	197	240	224
Other costs	*total*	*286*	*281*	*303*	*293*	*334*	*339*
	land rent	174	175	175	155	152	151
	property rent	3	2	2	2	2	2
	other	110	105	126	137	180	186

Source: own performance

As mentioned earlier, one emerging phenomena over the last two decades in Ukrainian agriculture is the increasing importance of agroholdings, which can be defined as large vertically and/or horizontally integrated farm enterprises. After the turn of the millennium these organizations developed rapidly. Today, agroholdings manage almost 30% of the land in Ukraine (Figure 9) and they account for a large share of agricultural production. In 2014, 20% of all crop products (19% in 2013) were grown or processed by agroholdings. Relative to the average non-holding farm size in Ukraine with 1682 ha, agroholdings are significantly larger in terms of land endowment (5731 ha per farm or holding). Because of this size, these farms might be able to utilize economies of scale and size and be better equipped for investments in modern technologies and infrastructure.

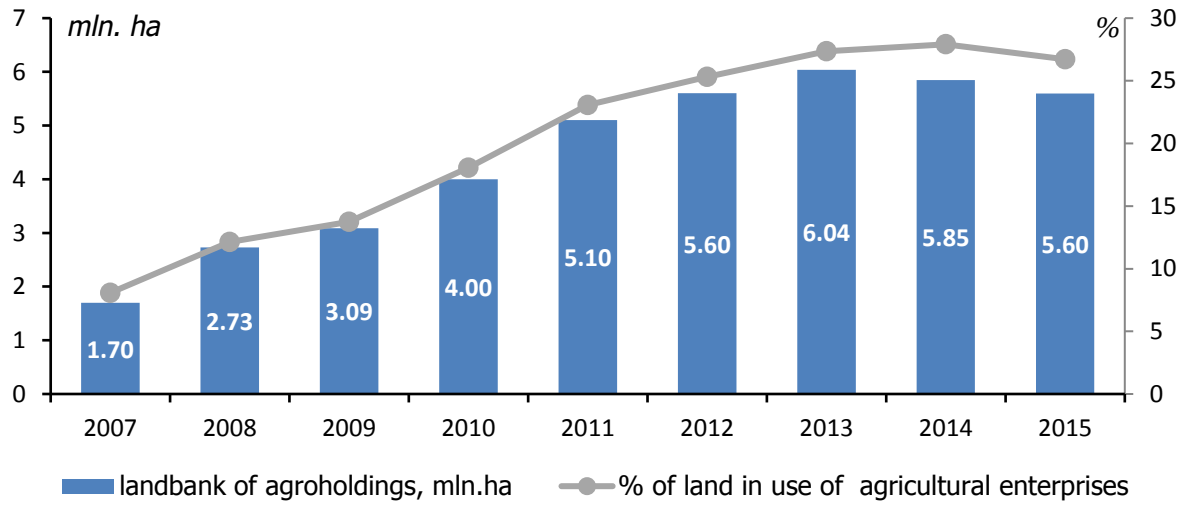


Figure 9. Land bank of agroholdings in Ukraine

Source: The Largest Agroholdings of Ukraine 2015, AgriSurvey

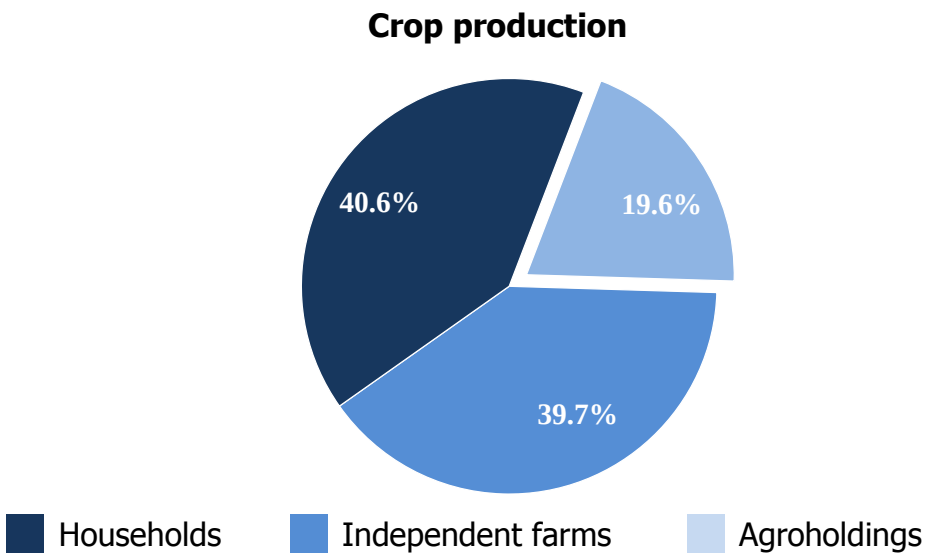


Figure 10. Share of agroholdings in crop production in 2014

Source: AgriSurvey, 2015

2. Data and methods

To investigate whether and to what extent a potential yield gap is rooted in farm-intern economic conditions, we conduct an efficiency analysis and regress upon the determinants of the farms' efficiency or inefficiency. We also approach the question if efficiency is always accompanied with or a precondition for high profitability. The rationale behind this procedure is as follows: if Ukrainian farms are highly efficient, there is less room for inter-farm improvements and the perceived yield gap is the difference between the fictive optimal yield and the actual yield of best practice. If inefficiencies are observed, however, their sources might help to understand what hold farms back from achieving higher productivity. Subsequently, we present the dataset and briefly describe the methods used.

In general, this analysis follows the study by Balmann et al. (2013) but we use an extended dataset, differentiate for production regions (climatic zones), and apply additional methods (e.g., truncated regression and treatment effect analysis as described below). Most of the results by Balmann et al. (2013) are supported by our findings while some new insights and/or more detailed observations are presented in this paper.

2.1. Dataset

Our study is based on farm-level accounting data of Ukrainian farms provided by the State Statistics Service of Ukraine (SSSU). These data cover the time period 2008 to 2013. The original dataset consists of 51 686 observations of Ukrainian farms with crop production and of various legal forms and sizes.

In order to control for the price development effect, the data have been deflated using input and output price indices on disaggregated level. To eliminate inconsistent entries and outliers as well as to prepare the data for the efficiency analysis, a two-stage data cleaning was conducted. In the first stage three standard deviations threshold procedure and histogram analysis were used (see Table 2 for the estimated upper limit of ratio indicators), while the second stage identified and removed observations with super efficiency values above 150%. As a result of the data cleaning, 6 785 observations (13%) were excluded and the obtained dataset contained 44 901 observations for a five-year (2008 to 2013) unbalanced panel and 26 982 observations for a balanced panel (same time period). The share of agroholdings in the total number of farms is 9(8) % in the unbalanced (balanced) panel[3]. Compared to the data of statistical yearbooks, provided by the SSSU website, the unbalanced panel covers between 85 to 91% of arable land, employees, revenue, or costs in crop production

[3] The share of holdings in the original dataset also amounts to 9% of all farms.

through the observation period. This illustrates the representativeness of the dataset for Ukrainian crop farms.

Table 2. Cleaning parameters for ratio indicators

Ratio	2008	2009	2010	2011	2012	2013
(Material costs + depreciation) / CP value[4]	<2.1	<1.8	<1.9	<1.8	<2	<1.9
Arable land / CP value	<3.1	<3	<2.8	<2.1	<2.1	<1.5
Labor in CP / CP value	<0.08	<0.07	<0.07	<0.06	<0.045	<0.03
CP value / (material costs + depreciation)	<5.8	<5.5	<5.5	<5.5	<4.5	<4.5
CP value / arable land	<9	<9	<9	<10	<10	<11
CP value / labor in CP	<830	<900	<900	<1150	<1250	<1400

Note: lower limit is always greater than 0, while upper limit is provided in the table. Monetary values are inflation adjusted.

Source: own performance

To track peculiarities of production technologies caused by natural conditions, we distinguish three climatic zones (production regions), which are composed of six agroclimatic zones in Ukraine (Bulava, 2008), including two mountain regions (Crimea and Carpathian). We merge the Carpathian region with the 1st climatic zone (1st climatic zone: moist, moderately warm); also, two southern agroclimatic zones (2nd climatic zone: representing "dry and very warm" and "very dry and very warm" conditions) are subsumed. The 3rd climatic zone consists of Crimea mountainous region and the South-Eastern regions. Figure 11 shows the location of the three zones as used in this study.

[4] Note that, e.g., the share of material and capital costs in crop production value should be less than 1 for positive profits, to be efficient, and to be productive. However, in our analysis we leave some space for inefficient farms (eliminating only extreme or zero values) in order to obtain a comprehensive picture of Ukrainian agriculture.

1st climatic zone – enough moisture, moderately warm;

2nd climatic zone – not enough moisture, warm;

3rd climatic zone – (very) dry, very warm.

Figure 11. The three Ukraine climatic zones (production regions).
Source: own presentation based on Bulava (2008)

2.2. Data envelopment analysis (DEA)

In order to analyze recent productivity developments of farms, we investigate technical efficiency and total factor productivity based on a standard Data Envelopment Analysis (DEA) framework. This method makes use of linear programming to construct a non-parametric piecewise surface (frontier) over the data which allows deriving efficiency scores relative to this frontier (Coelli et al., 2005). The model is specified as a single output - multiple input problem, and assumes output-oriented optimization with constant returns to scale. The analysis is carried out on the balanced as well as the unbalanced data panel for 2008-2013 with respect to individual frontiers for each year. One disadvantage of the method is its limitation in controlling for data (measurement) errors and effects of differences in production conditions (e.g., land quality). Therefore, the rigorous data cleaning was carried out before the data were processed in the DEA. Additionally, we differentiate between three production zones with different climatic conditions.

The DEA model includes one output and three input variables. Appendix A provides main statistics for the listed DEA variables for the years 2008-2013 and for the group of observations in the balanced and unbalanced data panel with respect to the corresponding climatic zones. Descriptive statistics for individual years are presented in Appendix B. Output is represented by crop production value, which is derived from production sales. This value thus considers real sales prices in aggregating the farms' production volumes. Such a measure has the benefit of reflecting possible differences in product quality along the technical ability to produce. Among the three input variables, two are expressed in natural values (quantities) - land in hectares and labor in

employees in the given year (full-time employee equivalent). The third input variable is the sum of material costs and depreciations as an indicator of capital costs. These two input categories are pooled because a significant share of material cost refers to services provided by third parties. Such services do not entail purely provision of materials, but also their application that reduces the need for own machinery, equipment or other capital.

2.3. Regression analysis

The technical efficiency scores derived from DEA as well as crop yields (wheat, corn and sunflower) are further regressed upon a number of variables that may contribute to the explanation of these variables' variation among the farms. Accordingly, model specifications detailed in Table 3 were used. For the yield regression, we used simple ordinary least squares (OLS) regression and to estimate the technical efficiency scores a truncated regression model was used because the dependent variable is restricted between 0 and 1 here.

The explanatory variables take account of several structural farm characteristics such as size, specialization, input use intensity, etc. The regression analysis considers also control variables (time, holding membership dummies). Technical efficiency scores are measured with respect to the individual years' frontiers and with regard to climatic zones. Additional variables account for size effects in groups of "smaller" and "larger" producers. A farm size dummy [arable land > median (dummy, by CZ)] represents farms larger than median in terms of total arable land while a crop specific harvested area dummy [crop harvested area > median (dummy, by CZ)] relates to farms with larger harvested area of the analyzed crop. Because we assume a positive correlation of knowledge and year-to-year production, we test whether continuous production of a particular crop [experienced crop producer (dummy)] realize higher yields. The last two variables, profit per hectare in crop production [profit in CP (1 year lag)] and VAT reimbursements in crop production [VAT support in CP (1 year lag)], allows to track for the influence of earnings and state support in previous year on efficiency and productivity of the analyzed year. These estimations are based on the balanced panel data for 2008-2013.

Table 3. Description of explanatory variables in regression analyses of technical efficiency, crop yield and crop production value determinants

Variable	Description	Model specifications*	
yield	Yield wheat/corn/sunflower (t/ha)	DV	
te (bp)	Technical efficiency (balanced panel)		DV
harvestedarea	Harvested area of wheat/corn/sunflower (ha)	+	
arableland	Arable land (ha)		+
landrent_ha	Land rent per ha (tsd UAH/ha)	+	+
laborcosts_ha	Labor costs per ha (tsd UAH/ha)	+	+
seeds _ha	Costs of seeds per ha (tsd UAH/ha)	+	+
fertilizers_ ha	Fertilizers costs per ha (tsd UAH/ha)	+	+
3rdparty_othercosts _ha	3rd party services and other material costs per ha (tsd UAH/ha)		+
otheragproducts_ha	Costs of other agricultural products used in production, per ha (tsd UAH/ha)		+
oils_ ha	Costs of oils per ha (tsd UAH/ha)		+
electricity_ ha	Electricity costs per ha (tsd UAH/ha)		+
fuels_ ha	Fuel costs per ha (tsd UAH/ha)		+
spareparts_ ha	Costs of spare parts per ha (tsd UAH/ha)		+
propertyrent _ha	Costs of property rent per ha (tsd UAH/ha)		+
3rdpartyservices_ha	3rd party services per ha (tsd UAH/ha)	+	
other_matcosts_ha	Other material costs per ha (tsd UAH/ha)	+	
other_procosts_ha	Other production costs per ha (tsd UAH/ha)	+	
depreciation_ha	Depreciations per ha (tsd UAH/ha)	+	+
cropshare_arableland	Share of wheat/corn/sunflower area in total arable land	+	
animprod_dv	Animal production dummy, if farm has animal production = 1, otherwise 0	+	+
shareap_totvalue	Share of animal production in total production	+	+
othercpvalue_cpvalue	Share of niche crops in crop production ("cash" crops: wheat, barley, corn, sunflower, soybean, rapeseed; others – niche crops)	+	+
td2009	Time dummy - 2009, year 2009 = 1, otherwise 0	+	+
td2010	Time dummy - 2010, year 2010 = 1, otherwise 0	+	+
td2011	Time dummy - 2011, year 2011 = 1, otherwise 0	+	+
td2012	Time dummy - 2012, year 2012 = 1, otherwise 0	+	+
td2013	Time dummy - 2013, year 2013 = 1, otherwise 0	+	+
holding_dummy	Agroholding farm dummy, agroholding farms =	+	+

Variable	Description	Model specifications*	
	1, independent farms = 0		
arable land > median (dummy, by CZ)	Farm size dummy, for farms > median = 1, otherwise 0. The median values were calculated for each model separately (i.e., it depends on crop and climatic zone)	+	+
crop harvested area > median (dummy, by CZ)	Crop (wheat/corn/sunflower) harvested area dummy, for farms > median = 1, otherwise 0. The median values were calculated for each model separately (i.e., it depends on crop and climatic zone)	+	
experienced crop producer (dummy)	Dummy represents farms that had produced particular crop (wheat/corn/sunflower) during the whole period of analysis: if production > 0 each year during 2008-2013 = 1, otherwise 0.	+	
profit in CP (1 year lag)	Profit per hectare in crop production with 1 year lag (tsd UAH/ha)	+	+
VAT support in CP (1 year lag)	VAT reimbursement in crop production per ha with 1 year lag (tsd UAH/ha)	+	+

* DV – dependent variable, "+" – independent variable,

Note: The yield model specification is crop specific (for wheat, corn, and sunflower). Each specification consists of variables related to the production costs of the respective crop (e.g., wheat yield is explained by wheat production costs), while for crop production value and technical efficiency models, total crop production costs are used.

2.4. Treatment effect analysis

In order to explain the differences between more and less profitable crop producing farms, we employ treatment effect analysis – a matching procedure that allows the comparison of treated and non-treated groups by pairing their structural variables (see works of Rubin, Holland, Robins, Wooldridge for more details). In our sample the treated group is represented by farms with crop production profitability above the median of the base year (2008) while 50 percent of farms with lower profitability belong to non-treated group. Profitability is measured by the relation of profit to total costs.

The advantage of this method is bias elimination related to size and structural differences of farms. As we choose a direct-covariate matching approach, an outcome is calculated by comparing farms ("neighbors") with similar structural characteristics. These "neighbors" are determined with covariates' weighted function, calculated for each individual. The average treatment effect (ATE) is calculated as an average difference of observed and potential outcomes of the nearest neighbors:

$$ATE = E(y_1 - y_0)\ .$$

One requirement for reliable results under the application of this method is a large sample size, which our dataset provides[5].

3. Results

3.1. Development of technical efficiency and total factor productivity

Our results show surprisingly low technical efficiency among Ukrainian farms. This not only indicates highly heterogeneous farm performances but also a significant potential of improvement on the farm level. In the sample, up to 30% of the farms are unprofitable (in each year), which provides one explanation for such low technical efficiency and indicates a high correlation between technical efficiency and profitability. Estimations for both the unbalanced (see Table 4) and balanced panel (see Table 5) show similar trends: an increasing mean of the efficiency scores for the 1st and 2nd climatic zones, while there is no or even a negative change of this indicator in the 3rd region. Overall, efficiency is slightly higher for the balanced panel, which highlights the effects of inefficient farms that leave the sector at some point (in the unbalanced panel) or that new (or merged) farms run through an adjustment period and might require some time to improve their performance. But even for the balanced panel and best year (2012), on average farms in the 1st climatic zone could (theoretically) increase output levels by 43% without changing the level of input.

Table 4. Technical efficiency development (unbalanced panel), 2008-2013

	2008	2009	2010	2011	2012	2013
Climatic zone 1						
Number of observations	1462	1347	1156	1196	1119	1090
Mean	0.367	0.412	0.407	0.393	0.482	0.429
Standard deviation	0.169	0.163	0.168	0.165	0.188	0.173
Climatic zone 2						
Number of observations	2314	2248	2170	2166	2185	2193
Mean	0.417	0.409	0.404	0.419	0.450	0.462
Standard deviation	0.163	0.157	0.163	0.164	0.161	0.148
Climatic zone 3						
Number of observations	3883	3970	4115	4247	4022	4018
Mean	0.380	0.407	0.382	0.376	0.358	0.379
Standard deviation	0.149	0.153	0.153	0.152	0.153	0.143

Note: means are geometric
Source: own calculations

[5] Estimations were done using "teffects nnmatch" command in Stata software (StataCorp., 2015).

Table 5. Technical efficiency development (balanced panel), 2008-2013

	2008	2009	2010	2011	2012	2013
Climatic zone 1						
Number of observations	560	560	560	560	560	560
Mean	0.501	0.451	0.480	0.436	0.566	0.466
Standard deviation	0.176	0.156	0.153	0.164	0.169	0.156
Climatic zone 2						
Number of observations	1325	1325	1325	1325	1325	1325
Mean	0.434	0.431	0.410	0.433	0.467	0.502
Standard deviation	0.152	0.147	0.152	0.152	0.149	0.137
Climatic zone 3						
Number of observations	2612	2612	2612	2612	2612	2612
Mean	0.391	0.440	0.412	0.393	0.368	0.393
Standard deviation	0.141	0.144	0.145	0.136	0.136	0.134

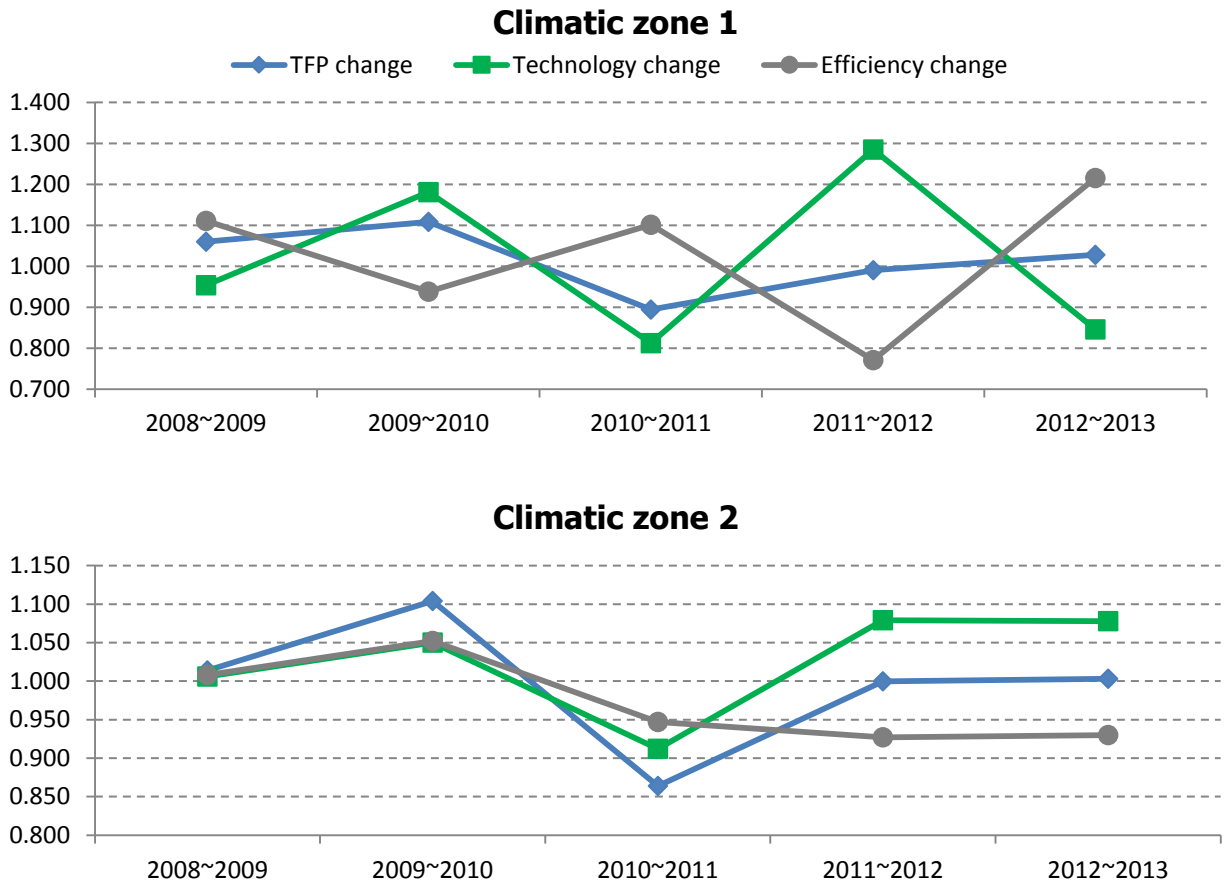
Note: means are geometric

Source: own calculations

The development of total factor productivity (TFP), efficiency and technological change is summarized in Figure 12 (further results including the decomposition of the efficiency change are presented in Appendix C). Low efficiency scores might be due to high technological change. In fact, we observe a positive development in climatic zones 2 and 3, while a negative trend is obtained in region 1. Besides that these dynamics seem insufficient to explain the low technical efficiency, there is also considerable variation over the observed years. Except for climatic zone 1, the annual average efficiency change is below one, suggesting that farms become more heterogeneous in efficiency (i.e., the distance between best and worst farms increases). The combination of both, technological and efficiency change, provides the measure for total factor productivity (TFP). While farms in climatic zones 1 and 3 became more productive, the opposite is true for farms in climatic zone 2 (based on the annual average).

Of course, one of the main drivers behind the observed dynamics relates to weather conditions. For instance, the technical efficiency drop in climatic zone 1 in the years 2010 and 2012 are largely caused by adverse weather conditions (cf. Figure 1, representing crop yields). Other impacts concern the political framework as illustrated by the negative TFP change in climatic zone 2. This region is the major grain producer and therefore it was over-proportionally affected by the introduction of trade restrictions (export quotas in 2010 and export duties in 2011), which let prices increasingly diverge in Ukrainian and foreign markets (Kulyk et al., 2014). Farms in

climatic zone 3 show positive TFP change due to positive technical change while efficiency change was slightly negative. The latter is caused by the decrease of crop yield accompanied by increasing costs in 2009 and increasing heterogeneity across farms (decreasing scale efficiency) over the whole time period. Pure efficiency change is slightly positive over the considered years though. These developments are summarized in Table C of the Appendix and illustrated in Figure 12.



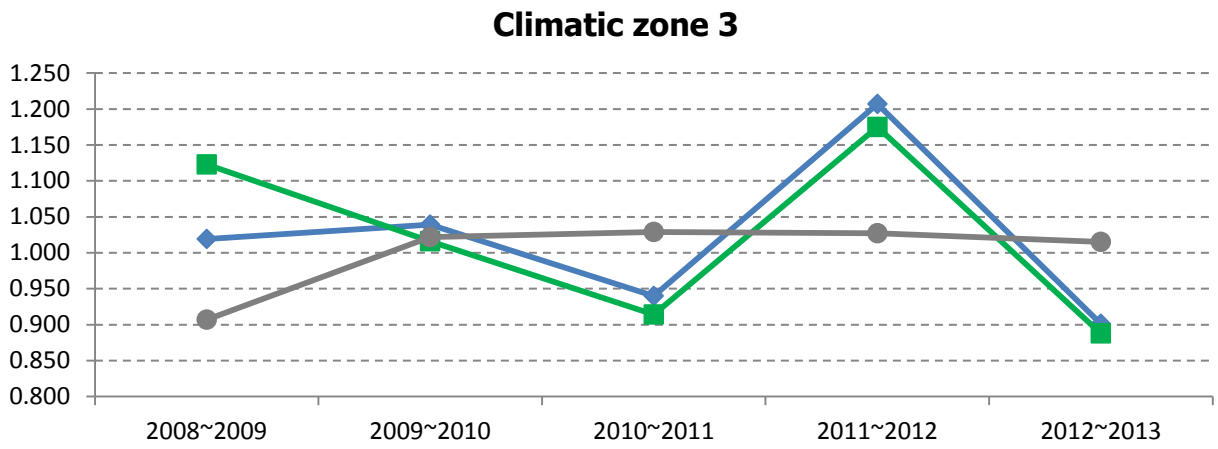


Figure 12. Average annual technical efficiency, technical and total factor productivity changes, balanced panel, 2008-2013

Source: own calculations

3.2. Identification of important determinants of efficiency and productivity

While the previous section shows the efficiency and productivity developments, we now proceed with the determinants behind these measures in greater detail. First, we analyze crop yield determinants (as one of the most important productivity indicators) before we account for efficiency determining factors directly.

Estimation of crop yield determinants

As crop yields are an important productivity indicator, it is crucial to define the pivotal factors affecting yield and if they differ among the regions (climatic zones) and crops. In this section, we analyze three major crops: wheat, corn, and sunflower. Figure 13 shows the shares of these crops in sowing areas across the three zones (in 2013). We note the dominant role of wheat and sunflower for climatic zone 1, while corn is the major crop in the central and northern parts of Ukraine (climatic zones 1 and 2). More specifically, 24% of the area is covered by wheat and 25% by corn in climatic zone 1 while climatic zone 2 features 33% corn, 32% wheat and 28% sunflower, respectively. The yields of these crops naturally vary across climatic zones. The highest yield level is achieved in climatic zone 2 due to favorable temperatures, humidity, and soil qualities. In the case of corn, however, high yields are observed in climatic zone 1 as well. Comparing the costs and revenues in this figure, we can observe some degree of correlation. However, due to price decreases on key commodities both on the world and the domestic markets, in average only for climatic zone 2 revenues exceed costs in case of grains in 2013. Average profitability figures[6] on the country-level, published by State Statistic Service of Ukraine (2014c), also indicate low financial results of grain production (2.4% for wheat and 1.5% for corn) and better results for sunflower (28.5%).

[6] As a ratio of profit to costs

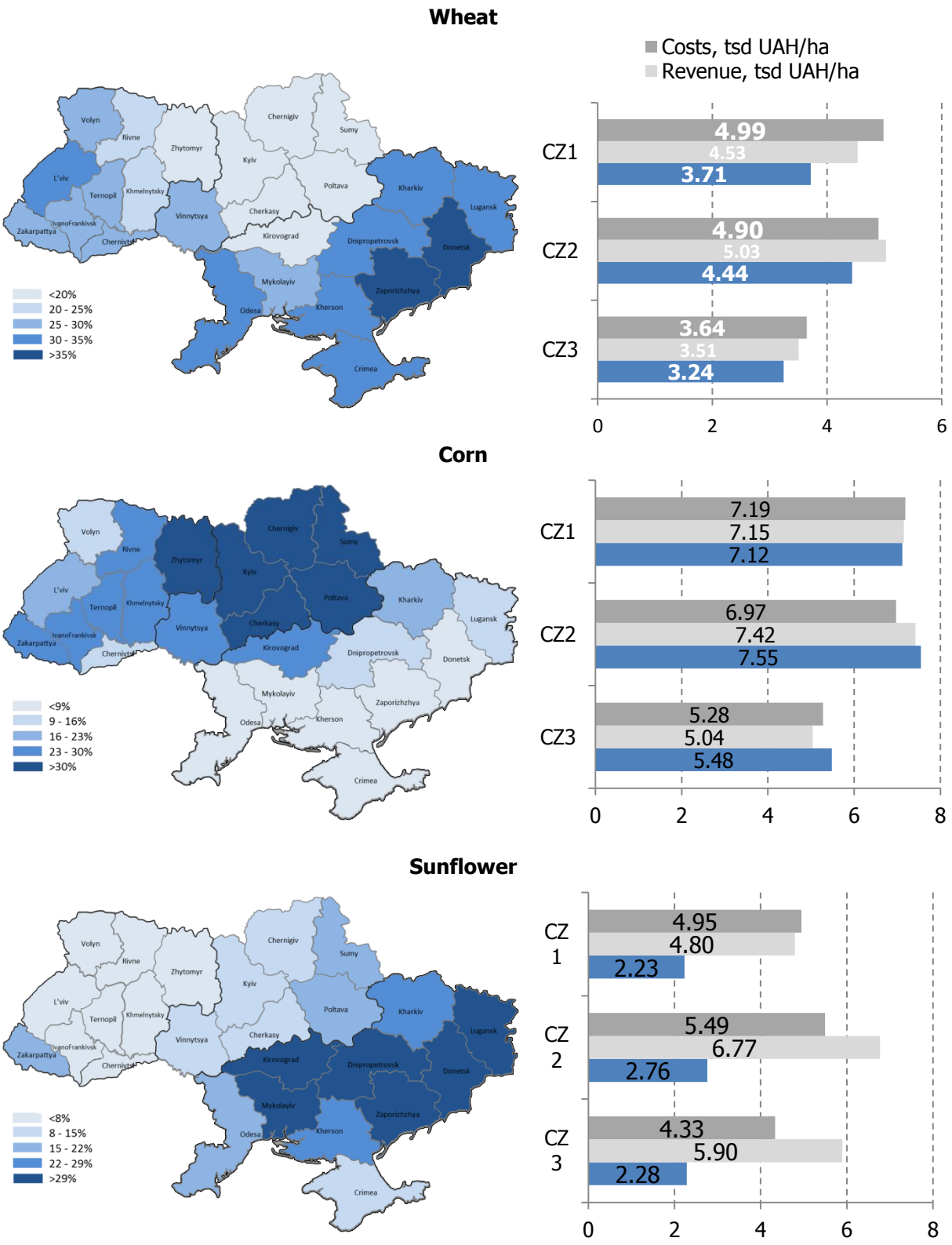


Figure 13. Distribution of sowing areas, production costs, revenues and yields in Ukraine in 2013

Source: SSSU (2013), own representation.

Note: The maps represent the shares of sowing areas covered by the specific crop in each region. The climatic zones are highlighted with a black border. The charts represent mean values of costs, revenues and yields.

Wheat yield determinants. As Table 7 shows, fertilizer [fertilizers] is the most limiting production factor for wheat yield. According to our model, the additional application of fertilizer (in terms of higher input costs) of 1 thousand UAH per hectare would cause an increase in yield by about 1 to 1.2 tons per hectare. Contrarily, seed costs [seeds] have no significant influence on wheat yield except of climatic zone 2. However, even in this region the effect is comparatively small. This might highlight that most farms use seed from the last season's harvest. Services of third-party organizations [3rd party services] and other material costs [other material costs] also have a significant positive impact on wheat yield. Unfortunately, we cannot decompose these groups further, but we should note that both may include crop protection costs (either as a service of application or as a purchase of crop protection products), while machinery leasing and direct production and harvesting services could be also included in third party services.

Other groups of production costs such as land rent payments [land rent per ha], labor [labor costs in wheat production], depreciation [depreciation], and other production costs [other production costs], have statistically significant, positive influence on wheat yield. Concerning the labor costs in crop production, we might note that there can be a bias as farm managers may not track for the actual time allocated to a single crop. Thus, they – to avoid additional transaction costs – may distribute the labor costs of a farm arbitrarily among crops. As long as this distribution is consistent over time, the bias might be small but, nonetheless, we cannot differentiate heterogeneous labor costs developments among the different crops. In the case of land rent payments, our results indicate that yield is sensitive regarding land quality, where we observe higher dependence of yield on land quality (approximated by rental payments) in regions with less favorable soils conditions (climatic zone 1) as well as with low precipitation and high temperatures (climatic zone 3).

The share of wheat in total sowing areas of a farm [share of wheat in sowing area] in climatic zones 1 and 3 show statistically significant negative effect on yield. This may suggest that the dominant role of these crops within the crop rotation is sufficiently high to depress yields, e.g. by soil depletion or the occurrence of crop-specific weeds, insects, and fungus. However, this effect can also relate to intra-regional differences in soil quality and/or climatic conditions for which we cannot control. In particular, this seems to be plausible for climatic zone 1 where a broader crop rotation (that also includes niche crops [share of niche crops in CP]), provides a negative yield effect; something we also observe in region 2. A positive yield effect is obtained for farms with

animal production [animal production (dummy)] in climatic zones 2 and 3. This is in line with the previous finding such that farms can, e.g., use the manure to improve the fertilizer application practices in wheat production. However, the effect of the share of animal production [share of AP in TP] has no statistically significant influence on yields.

We further obtain some evidence of scale effects. In terms of arable land, larger farms [arable land > median (dummy, by CZ)] achieve higher wheat yields in climatic zone 2. The harvested area of wheat, included into the model as a continuous variable, shows a statistically significant positive effect on a low level in climatic zone 1. However, larger wheat producers – in terms of harvested area separated by median level [wheat harvested area > median (dummy, by CZ)] – achieve higher yields across all climatic zones. The holding affiliation [holding dummy] provides a positive influence only in climatic zone 3, a region with the smallest share of land harvested by holdings (approximately 17% compared to 28% in climatic zone 1 and 37% in climatic zone 2).

Moreover, experienced wheat producers [experienced wheat producer (dummy)], who harvest wheat in all considered years (i.e., from 2008 to 2013) also achieve higher yields in climatic zones 1 and 2. This might indicate learning effects, while the negative effect in climatic zone 3 may suggest that experienced farmers apply cost minimizing production practices to manage climate risks. The data provide some support for this account: In wheat production and compared to climatic zone 1, farmers in climatic zone 3 had 17% lower production costs per hectare, whereas the yield difference was only 5% (see Figure 13).

Our results also suggest that higher profit per hectare received in the previous year [profit in CP (1 year lag)] influences wheat yields positively. These effects are consistent across all climatic zones. We also observe the positive effect of VAT reimbursement [VAT support in CP (1 year lag)] on wheat yield in climatic zones 1 and 2, while in climatic zone 3 it is negative.

Table 6. Parameter estimates of regression model of wheat yield determinants, balanced panel, 2008-2013

	Climatic zone 1		**Climatic zone 2**		**Climatic zone 3**	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
harvested area (wheat)	0.000	0.021	0.000	0.806	0.000	0.877
land rent per ha	0.340	0.000	0.161	0.007	0.392	0.000
labor costs in wheat production	1.224	0.000	0.866	0.000	1.069	0.000
seeds	0.092	0.391	0.184	0.011	-0.060	0.301
fertilizers	1.192	0.000	1.070	0.000	1.020	0.000
3rd party services	0.755	0.000	0.613	0.000	0.880	0.000

	Climatic zone 1		Climatic zone 2		Climatic zone 3	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
other material costs	0.679	0.000	0.591	0.000	0.797	0.000
depreciation	0.656	0.000	0.571	0.000	0.570	0.000
other production costs	0.255	0.000	0.490	0.000	0.493	0.000
share of wheat in sowing area	-0.802	0.000	0.053	0.683	-0.251	0.001
animal production (dummy)	0.054	0.198	0.199	0.000	0.167	0.000
share of AP in TP	-0.062	0.461	-0.104	0.148	-0.051	0.416
share of niche crops in CP	-0.400	0.000	-0.640	0.000	0.052	0.408
holding dummy	0.001	0.986	-0.036	0.373	0.183	0.000
arable land > median (dummy, by CZ)	0.065	0.160	0.162	0.000	0.026	0.219
wheat harvested area > median (dummy, by CZ)	0.200	0.000	0.088	0.013	0.145	0.000
experienced wheat producer (dummy)	0.194	0.005	0.136	0.002	-0.097	0.000
profit in CP (1 year lag)	0.246	0.000	0.255	0.000	0.224	0.000
VAT support in CP (1 year lag)	0.267	0.041	0.222	0.000	-0.221	0.000
Constant	0.840	0.000	1.435	0.000	1.565	0.000
Nr. of observations	2628		6026		12212	
Prob > F	0.000		0.000		0.000	
R-squared	0.654		0.547		0.498	
Adjusted R-squared	0.651		0.545		0.497	

Source: own calculations

Note: To keep the table at reasonable length, the time dummies considered in the model are not reported. Arable land median: CZ1 – 1193 ha, CZ2 – 1623 ha, CZ3 – 1891 ha. Wheat harvested area median: CZ1 – 348.5 ha, CZ2 – 358 ha, CZ3 – 493 ha. All the monetary valued are deflated and calculated per hectare of harvested area.

Corn. In general, most of the findings obtained for wheat production hold true for corn as well. For instance, farms seem to operate on low input levels making intensification an option to considerably increase corn yield. This is implied by positive yield effects of fertilizers [fertilizers], third party services [3rd party services], other material costs [other material costs], as well as other production costs like labor [labor costs in corn production] or depreciation [depreciation]. Furthermore, we also found evidence of economies of size, i.e., larger farms [arable land > median (dummy, by CZ)] achieve higher corn yields in climatic zones 1 and 2. However, positive scale effects with regard to corn area ([harvested area (corn)] and [corn harvested area > median (dummy, by CZ)]) are observed only in climatic zone 3. Thus, the expansion of corn production (in

terms of sowing area) in this region may contribute positively to corn yield, which implies potential gains from specialization. This is not the case for the major production region (climatic zone 2), which – together with a negative yield effect of an increasing corn share of the crop area – potentially indicates that corn area is at its upper limit in crop rotations in this region.

In contrast to wheat production, corn seeds [seeds] are crucial in providing a (considerable) positive yield effect. This suggests that the appropriate selection of adopted high-quality corn varieties (hybrids) substantially increase the yield level (e.g. Troyer, 1996). Land quality (approximated by land rent [land rent per ha]) only has a significant positive effect in climatic zone 1, while an increase of niche crops (e.g., indicating diversification) positively affects corn yield in climatic zone 3 (where the crop rotation is especially narrow). Also animal production ([animal production (dummy)] and [share AP in TP]), which might provide organic fertilizer, can contribute a positive effect. The affiliation with a holding has no statistically significant influence on corn productivity.

For all climatic zones, higher profitability in the previous year [profit in CP per ha (1 year lag)], and, for climatic zone 1 and 3, the permanent engagement in corn production [experienced corn producer (dummy)] have positive influences on corn yield. In case of VAT reimbursements [VAT support in CP per ha (1 year lag)], we observe a positive (negative) effect in climatic zone 2 (3).

Table 7. Parameter estimates of regression model of corn yield determinants, balanced panel, 2008-2013

	Climatic zone 1		**Climatic zone 2**		**Climatic zone 3**	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
harvested area (corn)	0.000	0.823	0.000	0.304	0.000	0.046
land rent per ha	0.493	0.072	0.051	0.675	-0.008	0.947
labor costs in corn production	0.838	0.000	0.501	0.000	1.130	0.000
seeds	1.233	0.000	1.016	0.000	1.337	0.000
fertilizers	1.115	0.000	1.007	0.000	1.199	0.000
3rd party services	0.805	0.000	1.014	0.000	1.250	0.000
other material costs	0.786	0.000	0.707	0.000	0.797	0.000
depreciation	0.371	0.007	0.654	0.000	0.759	0.000
other production costs	0.685	0.000	0.603	0.000	0.663	0.000
share of corn in sowing area	0.749	0.087	-1.181	0.000	1.108	0.000
animal production (dummy)	-0.198	0.136	0.099	0.205	0.256	0.000
share of AP in TP	0.917	0.001	0.436	0.010	0.206	0.180

	Climatic zone 1		Climatic zone 2		Climatic zone 3	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
share of niche crops in CP	-0.414	0.121	-0.717	0.000	0.366	0.053
holding dummy	0.096	0.564	-0.197	0.028	0.014	0.864
arable land > median (dummy, by CZ)	0.445	0.000	0.162	0.022	-0.143	0.002
corn harvested area > median (dummy, by CZ)	-0.304	0.019	0.075	0.347	0.321	0.000
experienced corn producer (dummy)	0.323	0.002	0.082	0.251	0.119	0.005
profit in CP (1 year lag)	0.504	0.000	0.393	0.000	0.284	0.000
VAT support in CP (1 year lag)	0.271	0.329	0.496	0.000	-0.305	0.013
Constant	1.786	0.000	3.165	0.000	1.046	0.000
Nr. of observations	1593		4687		6752	
Prob > F	0.000		0.000		0.000	
R-squared	0.520		0.448		0.573	
Adjusted R-squared	0.513		0.446		0.572	

Source: own calculations

Note: To keep the table at reasonable length, the time dummies considered in the model are not reported. Arable land median: CZ1 – 1541.5 ha, CZ2 – 1822 ha, CZ3 – 2182 ha. Corn harvested area median: CZ1 – 168 ha, CZ2 – 271 ha, CZ3 – 172 ha. All the monetary values are deflated and calculated per hectare of harvested area.

Sunflower. Compared to the previous two crops, there are no significant differences regarding sunflower yield determinants. The major production region is climatic zone 3 and the results show that additional specialization towards sunflower [share of sunflower in sowing area] has a negative effect in this production region as well as in climatic zone 2. However, the yield level is positively affected almost by any intensification measure (including fertilizer [fertilizers], labor [labor costs in sunflower production], 3rd party services [3rd party services] or other material costs [other material costs]). Similar to corn (but not wheat), seeds [seeds] have a positive effect. Sunflower yield shows higher sensitivity to land quality [land rent per ha] in climatic zone 3. Also larger farms [arable land > median (dummy, by CZ)] have higher yields in climatic zone 3, but farms that harvest more area under sunflower [sunflower harvested area > median (dummy, by CZ)] realize higher yields in climatic zone 2. Again we obtain the positive relation between profitability and yield level [profit in CP per ha (1 year lag)] and the learning effect [experienced sunflower producer (dummy)] that positively influences yield across all climatic zones. As in the case of corn, we observe a positive effect of VAT reimbursement [VAT support in CP per ha (1 year lag)] only in climatic zone 2.

Table 8. Parameter estimates of regression model of sunflower yield determinants, balanced panel, 2008-2013

	Climatic zone 1		Climatic zone 2		Climatic zone 3	
	Coef.	P>|t|	Coef.	P>|t|	Coef.	P>|t|
harvested area (sunflower)	0.000	0.526	0.000	0.800	0.000	0.014
land rent per ha	0.175	0.237	0.109	0.008	0.276	0.000
labor costs in sunflower production	0.205	0.301	0.278	0.000	0.370	0.000
seeds	0.727	0.000	0.671	0.000	0.930	0.000
fertilizers	0.274	0.001	0.465	0.000	0.508	0.000
3rd party services	0.351	0.000	0.284	0.000	0.336	0.000
other material costs	0.461	0.000	0.285	0.000	0.394	0.000
depreciation	0.182	0.045	0.292	0.000	0.304	0.000
other production costs	0.270	0.000	0.270	0.000	0.314	0.000
share of sunflower in sowing area	0.459	0.179	-0.469	0.000	-0.160	0.000
animal production (dummy)	-0.104	0.107	-0.004	0.877	0.082	0.000
share of AP in TP	0.542	0.001	0.230	0.000	0.031	0.502
share of niche crops in CP	-0.078	0.623	-0.380	0.000	-0.152	0.002
holding dummy	-0.065	0.371	-0.045	0.161	0.035	0.157
arable land > median (dummy, by CZ)	0.061	0.333	0.033	0.163	0.035	0.015
sunflower harvested area > median (dummy, by CZ)	0.024	0.706	0.061	0.011	-0.017	0.207
experienced sunflower producer (dummy)	0.181	0.001	0.115	0.000	0.093	0.000
profit in CP (1 year lag)	0.237	0.000	0.148	0.000	0.189	0.000
VAT support in CP (1 year lag)	0.224	0.254	0.081	0.084	-0.051	0.142
Constant	0.795	0.000	1.245	0.000	0.627	0.000
Nr. of observations	688		4946		12185	
Prob > F	0.000		0.000		0.000	
R-squared	0.565		0.512		0.535	
Adjusted R-squared	0.550		0.510		0.534	

Source: own calculations

Note: To keep the table at reasonable length, the time dummies considered in the model are not reported. Arable land median: CZ1 – 1931 ha, CZ2 – 1702 ha, CZ3 – 1888.5 ha. Sunflower harvested area median: CZ1 – 120 ha, CZ2 – 220 ha, CZ3 – 450 ha. All the monetary values are deflated and calculated per hectare of harvested area.

Estimation of technical efficiency in crop production

The importance of determinants influencing technical efficiency of Ukrainian crop production differs across climatic zones. For instance, in climatic zone 1, labor [labor costs in CP], land quality [land rent], and fertilizers [fertilizers] are among the most important drivers while in region 2 labor [labor costs in CP], seeds [seeds], and fertilizers [fertilizers] contribute the most. For climatic zone 3, we identify land quality [land rent], other agricultural production used as inputs [other agricultural products], electricity [electricity], fuels [fuels], and property rent [property rent] as most important. The crucial role of labor costs on technical efficiency can be explained from different perspectives. For instance, this effect might be caused by the competition for and higher costs of skilled labor (e.g., operators of new machinery) or higher salaries may indicate a wage system that appreciates productive employees.

Diversification of production, assessed by the dummy variable "animal production (dummy)", shows a positive effect on technical efficiency of crop production in climatic zones 2 and 3. However, the share of animal production in total production [share of AP in TP] negatively influences efficiency of crop production in climatic zones 1 and 2. One possible explanation is the use of otherwise idle capacities (e.g., buildings) for animal production to cover some of the fixed costs. Increasing shares of animal production, however, might cause conflicts in the use of farm resources for crop production.

Furthermore, the share of niche crops in the production structure [share of niche crops in CP] has no statistically significant influence on technical efficiency. Regarding the size of the farm or its integration into an agroholding, results are mostly ambiguous. Larger farms [arable land > 1131 ha (median, dummy)] tend to have slightly higher TE in climatic zones 1 and 3, while an agroholding-membership [holding dummy] impacts TE negatively in the same regions.

Farms with higher profit per hectare [profit in CP per ha (1 year lag)] have usually also higher technical efficiency and this effect is comparably high across all regions. VAT reimbursement [VAT support in CP per ha (1 year lag)] does not show a statistically significant effect on TE in climatic zones 1 and 2 but there is a negative effect in climatic zone 3.

Table 9. Parameter estimates of regression model of technical efficiency determinants, balanced panel, 2008-2013

	Climatic zone 1		Climatic zone 2		Climatic zone 3	
	Coef.	P>|z|	Coef.	P>|z|	Coef.	P>|z|
arable land	0.000	0.007	0.000	0.000	0.000	0.161
land rent	0.097	0.000	0.061	0.000	0.108	0.000
labor costs in CP	0.114	0.000	0.071	0.000	0.027	0.012
seeds	0.034	0.033	0.065	0.000	0.044	0.000
other agricultural products	0.012	0.724	0.064	0.003	0.105	0.018
fertilizers	0.086	0.000	0.072	0.000	0.058	0.000
oils	-0.087	0.000	-0.034	0.001	-0.046	0.000
electricity	0.000	0.995	-0.008	0.887	0.071	0.036
fuels	0.077	0.134	0.026	0.346	0.073	0.000
spare parts	0.016	0.305	0.027	0.001	0.014	0.086
services in CP and other material costs	0.038	0.000	0.045	0.000	0.052	0.000
property rent	-0.249	0.076	-0.137	0.052	0.191	0.055
depreciation in CP	0.013	0.275	-0.001	0.865	-0.028	0.000
animal production (dummy)	0.006	0.440	0.010	0.027	0.009	0.001
share of AP in TP	-0.034	0.038	-0.042	0.000	0.010	0.312
share of niche crops in CP	0.010	0.445	-0.007	0.373	0.015	0.141
holding dummy	-0.033	0.001	-0.004	0.462	-0.010	0.057
arable land > 1131 ha (median, dummy)	0.014	0.028	0.005	0.222	0.010	0.000
profit in CP (1 year lag)	0.045	0.000	0.039	0.000	0.044	0.000
VAT support in CP (1 year lag)	0.024	0.221	-0.008	0.341	-0.015	0.051
Constant	0.317	0.000	0.336	0.000	0.275	0.000
Nr. of observations	2693		6329		12590	
Log likelihood	1530.537		3928.590		8066.616	
Wald chi2 (24)	1110.540		2044.360		2660.960	
Prob > chi2	0.000		0.000		0.000	

Source: own calculations

3.3. Comparing differences among farms of different profitability levels with similar structural characteristics

In this section we provide results of the treatment effect analysis (TEA) where we compare developments of TFP, TE, growth indicators, and the input structure of farms based on their profitability in the base year (2008). Farms with a profitability level above 13.9% (the median of all farms) are coded as "1" and belong to the treated set, while farms with lower profitability are in the non-treated group (coded as "0").

The treated group shows on average higher TFP change than less profitable farms with similar structural characteristics, but their TE change is significantly lower (see Table 10). We also observed no significant differences in TFP and TE changes comparing farms with different land endowments (based on median of 2008).

Besides the base year (2008), we conducted this analysis also for the final year of the dataset (2013) to investigate the dynamics of the results. It showed, that farms with higher profitability in 2008 featured higher TE scores (on average by 0.133) but due to moderate growth rates the difference significantly decreased until 2013.

Table 10. Treatment effect analysis of TFP and TE changes in farms with high and low profitability levels in base year, 2008-2013

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
TFP change*	All farms	4497	0.286	0.000
TE in 2008*	All farms	4497	0.133	0.000
TE change*	All farms	4497	-0.330	0.000
TE in 2013*	All farms	4497	0.021	0.000

Source: Own calculations

** without exact matches on regions*

Figure 14 also illustrates the relations between base-year TE scores and TE change over the period of investigation. Thus, more profitable farms, which feature higher technical efficiency, show less TE change due to decreasing marginal returns.

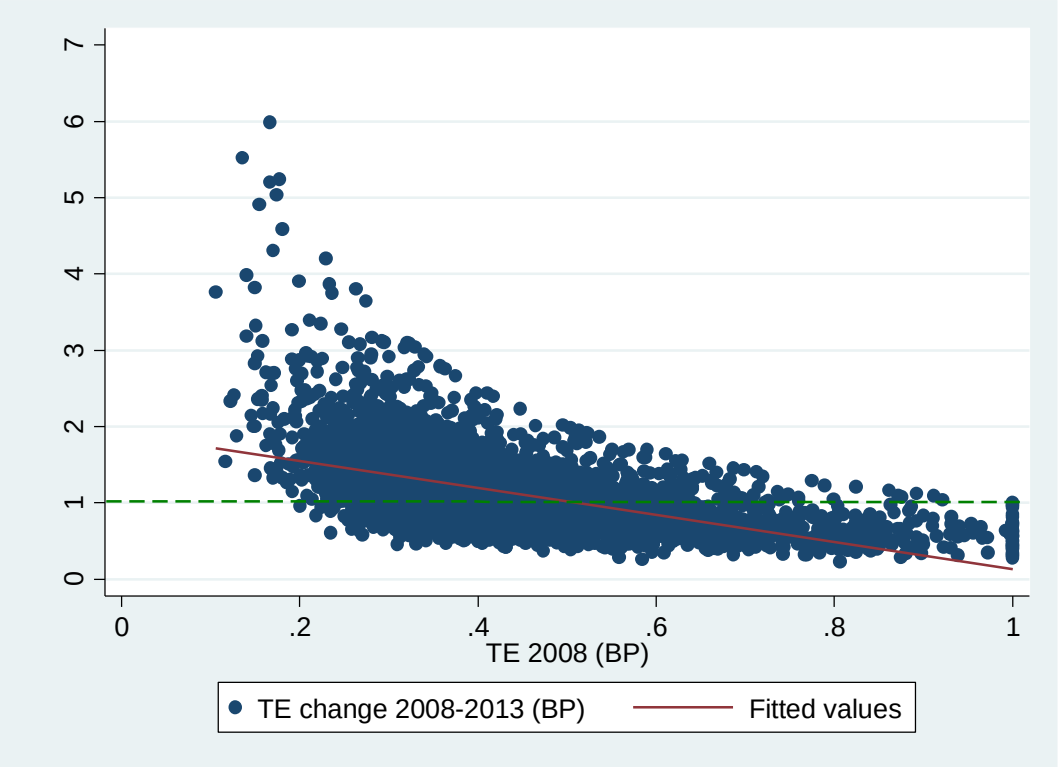


Figure 14. Correlation of TE in base year and TE change
Source: own calculation

The application of TEA to growth indicators shows that farms with above median profitability (in 2008) have lower growth of crop production but the significantly higher production level (on average by 1537.3 tsd UAH[7]) compared to farms with below median profitability. Between the two groups, there are no significant differences in arable land and labor, while the treated group outperforms the control group in terms of profit per hectare and crop yield. Again, growth rates for farms of the treated group are lower but the levels of profit and yield per ha are still higher in 2013 compared to the non-treated group.

Table 11. Treatment effect analysis of growth indicators in farms with high and low profitability levels in base year, 2008-2013

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
CP value in 2008*	All farms	4497	1537.538	0.000
CP value – absolute growth*	All farms	4497	-1398.799	0.000
CP value – relative growth*	All farms	4497	-0.495	0.000

[7] Median CP volume in 2008 – 3901.6 tsd UAH

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
CP value in 2013*	All farms	4497	138.739	0.659
Arable land in 2008*	All farms	4497	87.119	0.146
Arable land – absolute growth*	All farms	4497	-55.371	0.335
Arable land – relative growth*	All farms	4497	-0.021	0.715
Arable land in 2013*	All farms	4497	31.747	0.643
Labor in CP in 2008*	All farms	4497	1.089	0.491
Labor in CP – absolute growth*	All farms	4497	-0.494	0.698
Labor in CP – relative growth*	All farms	4497	0.002	0.938
Labor in CP in 2013*	All farms	4497	0.594	0.665

Source: Own calculations

** without exact matches on regions*

Table 12. Treatment effect analysis of performance indicators in farms with high and low profitability levels in base year, 2008-2013

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
Profit per ha in CP in 2008*	All farms	4497	0.513	0.000
Profit per ha in CP – absolute growth*	All farms	4497	-0.217	0.000
Profit per ha in CP – relative growth*	All farms	4491	-1.315	0.621
Profit per ha in CP in 2013*	All farms	4497	0.296	0.000
Crop yield in 2008*	All farms	4497	0.415	0.000
Crop yield – absolute growth*	All farms	4497	-0.230	0.001
Crop yield – relative growth*	All farms	4497	-0.354	0.000
Crop yield in 2013*	All farms	4497	0.185	0.006

Source: Own calculations

** without exact matches on regions*

On the input side, we see that higher profitability is correlated with lower costs. In 2008, more profitable farms had paid less for rented land, on average 23UAH/ha (approximately 13% below the median) compared to less profitable farms. Differentiation with respect to the investigated regions shows that there were no significant differences in the first climatic zone, while the rental price for farms in the

treated group was 30(21) UAH/ha lower relative to the non-treated group in climatic zone 2(3). Because of a less dynamic price development in the treated group, this gap increases over the years, i.e., farms with higher profitability pay less land rent and the price increase is smaller relative to the non-treated group. Accordingly, the price difference in 2013 increased to 43 UAH/ha (ca. 7% of the median, see Table 13).

Material costs of the treated group were lower on average by 34 UAH (ca. 3% of the median) per hectare in 2008 but in 2013 the difference between both groups was not different from zero.

Farms with higher profitability seem to use superior (modern) technology (indicated by higher capital assets), while less profitable farms rather rely on third-party services and have a tendency to increase their use. Additionally, the treated group has higher labor productivity (lower labor costs per hectare in CP) both in the base and the final year. The observable increase in labor costs is higher for more profitable farms but mostly reflects an increase of salaries. These results indicate that substitution of labor by capital (i.e., mechanization and modernization) plays a major role in the treated relative to the untreated group of farms.

Table 13. Treatment effect analysis of inputs in farms with high and low profitability levels in base year, 2008-2013

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
Land rent per ha in 2008*	All farms	4301	-0.023	0.000
Land rent per ha – absolute growth*	All farms	4236	-0.019	0.039
Land rent per ha – relative growth*	All farms	4236	-0.411	0.162
Land rent per ha in 2013*	All farms	4336	-0.043	0.000
Material costs in CP per ha in 2008*	All farms	4497	-0.034	0.000
Material costs in CP per ha – absolute growth*	All farms	4497	0.043	0.277
Material costs in CP per ha – relative growth*	All farms	4496	0.030	0.551
Material costs in CP per ha in 2013*	All farms	4497	0.010	0.812
Material costs in CP per ha – absolute growth	Farms of the climatic zone №1	560	0.326	0.016
Material costs in CP per ha – absolute growth	Farms of the climatic zone №2	1325	-0.188	0.037

Dependent variable	Target population	Number of observations	Coefficient	P>|z|
Material costs in CP per ha – absolute growth	Farms of the climatic zone №3	2612	0.077	0.068
Depreciation in CP per ha in 2008*	All farms	4163	0.011	0.009
Depreciation in CP per ha – absolute growth*	All farms	4085	0.040	0.000
Depreciation in CP per ha – relative growth*	All farms	4085	0.702	0.423
Depreciation in CP per ha in 2013*	All farms	4288	0.055	0.000
Third-party services in CP per ha in 2008*	All farms	4497	-0.022	0.000
Third-party services in CP per ha – absolute growth*	All farms	4337	-0.034	0.069
Third-party services in CP per ha – relative growth*	All farms	3895	0.081	0.974
Third-party services in CP per ha in 2013*	All farms	4337	-0.047	0.005
Labor costs in CP per ha in 2008*	All farms	4497	-0.033	0.000
Labor costs in CP per ha – absolute growth*	All farms	4497	0.012	0.097
Labor costs in CP per ha – relative growth*	All farms	4492	0.092	0.469
Labor costs in CP per ha in 2013*	All farms	4497	-0.021	0.009

Source: Own calculations

** without exact matches on regions*

3.4. Summary and discussion of the results

On average, Ukrainian farms feature low technical efficiency, which highlights considerable farm heterogeneity in terms of production performance. Based on our differentiation of production regions, we find that water restricted regions (as climatic zone 2 and 3) are especially prone to inefficiencies. This highlights the importance of water in particular and weather conditions in general regarding the efficiency of farms. While adverse weather events (as drought or very cold/long winter) might have negative effects for all farms, local conditions and/or managerial potential play an important role by dealing with such circumstances (Deininger et al., 2015).

Despite the observed high fluctuations in its development, there is a positive trend in farm productivity, especially manifested in the gradually increasing yield levels (of major crops). However, not all (or even not the majority of) farms can benefit from such development which also means that a relatively small share of farms is mainly responsible for efficiency gains. As shown by Balmann et al. (2013) or Deininger et al. (2015), one group of farms contributing to this trend are agroholdings – seemingly answering the call by Zynich and Odening, (2009) to vertically and horizontally integrate to better manage credit risk. However, we could not identify a similar restriction to one farm organization. But more broadly, other - or the majority of – farms is lagging behind the more productive ones, which gives rise to increasing inequality in farm performances. The relevance of this finding is underlined by the positive correlation of efficiency and farm profitability but also by the fact that there are 15 to 30 percent of farms annually featuring negative profits. In this respect, it is not surprising that the developments on the world market for agricultural products have major impacts on productivity because Ukrainian farms depend highly on cash crops that are mostly intended for export.

Our main focus is on crop yield levels and the analysis shows that there is considerable potential to increase crop yield by intensification. Particular importance can be attributed to inputs as fertilizer or seed – production components that can have a considerable impact on (cost) efficiency and therefore require appropriate technology and managerial knowledge. Despite the already large farm structure in our sample, we identified positive size effects while no significant effect could be found regarding the organization of farms, i.e., whether a farm belongs to a holding or not.

Land quality has a significant effect on the productivity of farms. Given the overall low efficiency, this might indicate that (some) production systems are poorly adopted to the local production conditions and instead aim to maximize short term benefits by the engagement in cash crops such as wheat, corn, and sunflower. This is also supported by the observation that in some regions the diversification of the crop rotation positively affects efficiency, which hints the presence of phytosanitary problems in narrow production systems.

The major finding of the presented analysis is that almost any indicator reacts positive towards intensification. On the one hand, farms operating on low input levels aim to minimize costs. On the other hand, if there are positive marginal profits by intensification, there must be reasons to not extend input use. In fact, one might argue that most of these reasons are exogenous to farms. For instance, one source of inefficient production is limited access to required capital, i.e., financial means for short or long term investments. This conclusion is also supported by empirical evidence of imperfect capital markets (Zynich and Odening, 2009).

A second source for (persistent) production inefficiency on the input side of the farm might relate to land market imperfections. Not only can the scattered landownership and large scale-farm structure give rise for local market power and restrict the access to the major production factor (Vranken and Swinnen, 2006), but the unresolved issue to open and liberalize the land market is a prime source for inefficient resource allocation (Deininger et al., 2015; Lioubimtseva et al., 2013). Land is one of the most important production factors of agriculture and if its free transfer, e.g., from inefficient to efficient farms is restricted, inefficiencies are conserved. Our results show (at least for some regions) positive effects of farm growth on efficiency and productivity, which requires a sufficiently dynamic structural change.

From a farm output perspective, further reasons for inefficiencies are the presence and increasing exposure of agriculture to different types of risk. In general, if farms are risk averse they will reduce input levels in the face of increasing uncertainty (Chavas, 2006). For instance, Skakun et al. (2015) show that drought risk is non-uniformly distributed in geographical space, can be substantial, and requires for an appropriate insurance system, which is often not available (Shynkarenko, 2007). As a consequence, farms at different locations in a region face and are affected by risk differently without adequate measures to manage it. Zynich and Odening (2009) also highlight the need to reduce credit risk by appropriate risk management instruments, while farms also have to deal with considerable and increasing market risk in terms of price volatility (Bellemare et al., 2015). Those and similar sources of risk may cause low input levels and inefficiency in production by Ukrainian farms.

Furthermore, the dependence to export agricultural raw products to be processed abroad might relate to capacity constraints of domestic processing. On the one hand, processing itself has to consider domestic demand for processed agricultural products and if this demand is weak, the processing sector has little or no incentive to invest. Accordingly, excess production of agricultural raw products (i.e., beyond the level of domestic processing in downstream markets) will need to go abroad. This, however, will transfers value added out of Ukraine. On the other hand, production for the international market often suffers from high regulation and risk exposure for Ukraine processors. In fact, only the sunflower processing is well developed in the sense that more than 90% of sunflower seed are processed into sunflower oil and almost all of it is exported each year. The contrary is the case for soya and rapeseed. In fact, there are initiatives concerning this issue but, e g., the attempt to implement a biofuel sector based on rapeseed to participate in this dynamic market, were unsuccessful (Schaffartzik, 2014).

Governmental instruments as subsidies can have a positive effect on farm productivity (Zhu and Lansink, 2010). A recent study by Curtiss et al. (2017) shows that these

effects vary across different farm types depending on farm size or organization, and the time period (subsidy level). In fact, subsidies might have the potential to decrease (increase) average farm efficiency if already efficient (inefficient) farms benefit over-proportional from those transfers. Given the low level of government payments after 2008, such subsidy effects are rather low if not negligible. The regression in our analysis accounts for a specific type of subsidy – VAT reimbursement. In contrast to direct subsidies, this support mechanism became a major source of agricultural production subsidization. Despite the absent (climatic zones 1 and 2) or negative (climatic zone 3) effect on technical efficiency, we found a positive influence of these payments on yields, In this case though, the impact is heterogeneous across different climatic zones and crops. Furthermore, we need to note that most support mechanism themselves usually induce distortions by incentivizing or preserving inefficient market allocations of resources. The implementation of any policy instruments therefore need to focus on the mitigation of the aforementioned market imperfections on capital and land markets and the development of the insurance system. Appropriate measures can help to enable or support farms to benefit from risk reducing options as insurance or irrigation systems, which offers the potential to increase farm productivity, e.g., crop yields.

4. Concluding remarks

In aiming to answer the question whether Ukrainian farms are able to considerably increase total crop production, we identify substantial inefficiencies. While this might provide indeed the potential for significant productivity improvements, some of the necessary conditions to access this potential are exogenous to Ukrainian farms. Whether the supposedly large yield gap can be reduced, will therefore hinge on numerous external factors in the realm of the institutional, economical, and social framework in Ukraine as well as the natural conditions. As always, simple or general solutions are not available but some basic conclusions can be made. For instance, imperfections on input and output markets restrict farm development towards more efficient production outcomes. While there are certainly considerable sources of inefficiencies within the farm sector, (better) functioning markets for land and capital as well as on the farm output side may provide major incentives to reallocate resources and boost farm efficiency and productivity. On the other hand, there might be adverse conditions as climate change that will affect the future prospect of crop production and even might decrease yield levels (Mueller et al. 2016).

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Appendix A. Summary statistics of variables for DEA model, 2008-2013

Variables	Obs	Mean	Std. Dev.	Min	Max
DEA model variables - unbalanced panel					
Climatic zone 1					
CP value (tsd UAH)	7370	5443	13867	14	295482
Labor units in CP (persons)	7370	32	56	1	1309
Total land (ha)	7370	1636	2895	6	90621
Material costs and depreciations in CP (tsd UAH)	7370	3957	11575	4	424671
From that – depreciation	7370	400	1257	0	30322
- material cost (without services)	7370	3557	10768	2	418044
- services	7370	947	4551	0	233980
Climatic zone 2					
CP value (tsd UAH)	13276	8343	25110	17	824351
Labor units in CP (persons)	13276	50	128	1	4161
Total land (ha)	13276	2365	5601	4	178083
Material costs and depreciations in CP (tsd UAH)	13276	5231	15603	8	450777
From that – depreciation	13276	547	1721	0	76789
- material cost (without services)	13276	4684	14432	8	447163
- services	13276	1143	4299	0	127464
Climatic zone 3					
CP value (tsd UAH)	24255	5314	10434	19	370905
Labor units in CP (persons)	24255	38	80	1	4213
Total land (ha)	24255	2210	3630	8	136400
Material costs and depreciations in CP (tsd UAH)	24255	3228	6253	6	222737
From that – depreciation	24255	451	1039	0	54395
- material cost (without services)	24255	2777	5427	4	216445
- services	24255	574	1558	0	64274
DEA model variables - balanced panel					
Climatic zone 1					
CP value (tsd UAH)	3360	7056	14303	59	237306
Labor units in CP (persons)	3360	42	59	1	1217
Total land (ha)	3360	2023	2847	40	40503
Material costs and depreciations in CP (tsd UAH)	3360	4915	11283	30	268813
From that – depreciation	3360	528	1270	0	21812
- material cost (without services)	3360	4387	10436	27	266681
- services	3360	1099	4313	0	119675
Climatic zone 2					
CP value (tsd UAH)	7949	9188	24593	99	603044
Labor units in CP (persons)	7949	56	129	1	3265
Total land (ha)	7949	2558	5625	81	178083
Material costs and depreciations in CP (tsd UAH)	7949	5654	14954	57	325126
From that – depreciation	7949	619	1890	0	76789

Variables	Obs	Mean	Std. Dev.	Min	Max
- material cost (without services)	7949	5035	13623	40	319700
- services	7949	1139	3614	0	126824
Climatic zone 3					
CP value (tsd UAH)	15673	6320	11776	76	370905
Labor units in CP (persons)	15673	45	92	1	4213
Total land (ha)	15673	2578	4177	60	136400
Material costs and depreciations in CP (tsd UAH)	15673	3781	6993	21	222737
From that – depreciation	15673	547	1162	0	54395
- material cost (without services)	15673	3235	6066	21	216445
- services	15673	629	1680	0	64274

Note: Monetary values are expressed in nominal values.

Source: Own calculations

Appendix B. Summary statistics of variables for DEA model for individual years, 2008-2013

	2008			2009			2010			2011			2012			2013		
Variables	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
DEA model variables - unbalanced panel																		
Climatic zone 1																		
CP value (tsd UAH)	1462	3858	7705	1347	3919	9057	1156	4335	9984	1196	5845	16067	1119	7440	17266	1090	8140	20150
Labor units in CP (persons)	1462	33	43	1347	30	42	1156	33	53	1196	31	55	1119	33	63	1090	35	79
Total land (ha)	1462	1314	1797	1347	1417	2078	1156	1641	2510	1196	1678	3078	1119	1865	3213	1090	2053	4351
Material costs and depreciations in CP (tsd UAH)	1462	2447	5070	1347	2450	6243	1156	3152	8018	1196	4216	11442	1119	5671	14816	1090	6655	19230
From that - depreciation	1462	172	728	1347	299	791	1156	416	1179	1196	422	1044	1119	562	1599	1090	626	1937
- material cost (without services)	1462	2275	4640	1347	2152	5694	1156	2736	7231	1196	3794	10818	1119	5109	13725	1090	6029	18010
- services	1462	442	1477	1347	514	2391	1156	710	2919	1196	1071	4676	1119	1425	4975	1090	1787	8376
Climatic zone 2																		
CP value (tsd UAH)	2314	6928	18335	2248	7208	22603	2170	6949	21787	2166	8866	27424	2185	9718	26675	2193	10493	31726
Labor units in CP (persons)	2314	53	135	2248	48	103	2170	51	132	2166	49	129	2185	51	148	2193	49	119
Total land (ha)	2314	2199	5198	2248	2258	4922	2170	2427	6169	2166	2365	5597	2185	2458	5740	2193	2496	5928
Material costs and depreciations in CP (tsd UAH)	2314	4152	12152	2248	3965	11119	2170	4368	13647	2166	5287	15680	2185	6440	18119	2193	7264	20696
From that - depreciation	2314	259	723	2248	496	2039	2170	503	1265	2166	595	1639	2185	700	1952	2193	749	2221
- material cost (without services)	2314	3892	11605	2248	3468	9687	2170	3865	12757	2166	4692	14461	2185	5741	16688	2193	6515	19254

	2008			2009			2010			2011			2012			2013		
Variables	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
- services	2314	867	3747	2248	811	2894	2170	979	4079	2166	1222	4846	2185	1415	4398	2193	1587	5392
Climatic zone 3																		
CP value (tsd UAH)	3883	5419	10123	3970	4881	9252	4115	4587	8598	4247	5563	10907	4022	5236	11116	4018	6201	12124
Labor units in CP (persons)	3883	44	99	3970	40	89	4115	37	82	4247	36	77	4022	35	63	4018	33	64
Total land (ha)	3883	2314	3692	3970	2279	3708	4115	2199	3602	4247	2140	3631	4022	2170	3573	4018	2166	3575
Material costs and depreciations in CP (tsd UAH)	3883	2965	5896	3970	2683	5636	4115	2650	5204	4247	3198	5955	4022	3677	7101	4018	4195	7318
From that - depreciation	3883	255	612	3970	431	974	4115	427	965	4247	477	1004	4022	544	1279	4018	562	1226
- material cost (without services)	3883	2709	5372	3970	2252	4811	4115	2222	4388	4247	2721	5141	4022	3132	6174	4018	3633	6309
- services	3883	504	1418	3970	462	1389	4115	491	1327	4247	577	1306	4022	622	1925	4018	789	1847
DEA model variables - balanced panel																		
Climatic zone 1																		
CP value (tsd UAH)	560	6165	9766	560	6030	10819	560	5407	9198	560	7652	15885	560	8476	17410	560	8605	19169
Labor units in CP (persons)	560	45	50	560	42	50	560	41	54	560	42	63	560	42	71	560	40	64
Total land (ha)	560	1842	2105	560	1950	2418	560	2005	2626	560	2097	3117	560	2110	3204	560	2135	3391
Material costs and depreciations in CP (tsd UAH)	560	3756	6339	560	3708	7733	560	3920	8406	560	5309	12449	560	6333	15797	560	6465	13468
From that - depreciation	560	275	560	560	477	980	560	537	1195	560	580	1219	560	648	1545	560	651	1736
- material cost (without services)	560	3481	5892	560	3231	7137	560	3383	7730	560	4729	11699	560	5686	14845	560	5814	12029
- services	560	694	2086	560	825	3551	560	844	3274	560	1317	5843	560	1549	6086	560	1365	3504

	2008			2009			2010			2011			2012			2013		
Variables	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Climatic zone 2																		
CP value (tsd UAH)	1325	7996	19880	1325	8191	23900	1325	7402	19049	1325	9998	27851	1325	10524	26523	1325	11016	28486
Labor units in CP (persons)	1325	60	156	1325	54	118	1325	55	118	1325	56	127	1325	57	128	1325	56	122
Total land (ha)	1325	2446	6029	1325	2496	5513	1325	2555	5764	1325	2609	5546	1325	2617	5387	1325	2622	5496
Material costs and depreciations in CP (tsd UAH)	1325	4551	11197	1325	4506	12175	1325	4528	11175	1325	5832	15287	1325	6890	17843	1325	7620	19569
From that - depreciation	1325	308	769	1325	592	2473	1325	537	1121	1325	668	1739	1325	763	1962	1325	847	2536
- material cost (without services)	1325	4242	10586	1325	3913	10410	1325	3991	10513	1325	5165	13932	1325	6126	16391	1325	6773	17701
- services	1325	892	3111	1325	868	2951	1325	954	2987	1325	1280	4575	1325	1312	3481	1325	1530	4204
Climatic zone 3																		
CP value (tsd UAH)	2612	6256	11216	2612	5722	10418	2612	5599	9819	2612	6942	12347	2612	6181	12496	2612	7220	13812
Labor units in CP (persons)	2612	49	111	2612	46	101	2612	45	96	2612	45	92	2612	42	71	2612	41	75
Total land (ha)	2612	2587	4229	2612	2605	4274	2612	2608	4207	2612	2591	4157	2612	2560	4118	2612	2517	4075
Material costs and depreciations in CP (tsd UAH)	2612	3349	6610	2612	3100	6401	2612	3197	5986	2612	3923	6680	2612	4310	7974	2612	4809	7902
From that -depreciation	2612	296	694	2612	509	1079	2612	529	1089	2612	612	1116	2612	659	1450	2612	675	1350
- material cost (without services)	2612	3052	6005	2612	2591	5482	2612	2668	5063	2612	3311	5761	2612	3651	6958	2612	4134	6763
- services	2612	548	1597	2612	502	1577	2612	566	1526	2612	652	1388	2612	683	2121	2612	822	1756

Note: Monetary values are expressed in nominal values.

Source: Own calculations

Appendix C. Total factor productivity change, 2008-2013

Variable	2008~2009	2009~2010	2010~2011	2011~2012	2012~2013	Cumulative
Climatic zone 1						
TFP change	1.060	1.108	0.894	0.990	1.028	**1.069**
Technical change	0.954	1.181	0.812	1.285	0.846	**0.995**
Efficiency change	1.111	0.938	1.101	0.771	1.215	**1.075**
Pure efficiency change	1.078	0.911	1.082	0.835	1.219	**1.082**
Scale efficiency change	1.031	1.030	1.018	0.923	0.997	**0.995**
Climatic zone 2						
TFP change	1.014	1.104	0.864	1.000	1.003	**0.970**
Technical change	1.006	1.050	0.912	1.079	1.078	**1.121**
Efficiency change	1.008	1.052	0.947	0.927	0.930	**0.866**
Pure efficiency change	0.999	1.066	0.925	0.922	0.964	**0.876**
Scale efficiency change	1.009	0.986	1.024	1.005	0.965	**0.988**
Climatic zone 3						
TFP change	1.019	1.039	0.940	1.207	0.901	**1.082**
Technical change	1.123	1.016	0.914	1.175	0.888	**1.088**
Efficiency change	0.907	1.022	1.029	1.027	1.015	**0.994**
Pure efficiency change	0.943	1.015	1.037	1.029	1.021	**1.043**
Scale efficiency change	0.962	1.007	0.992	0.999	0.994	**0.954**

Note: The values are geometric means of individual farm values.

Number of observations: CZ1 - 560, CZ2 - 1324, CZ3 - 2612 (numbers are equal for the same climatic zone across years).