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INVESTMENTS IN AGRICULTURAL MACHINERY AND ITS EFFICIENCY IN UKRAINE

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Abstract. *One of the major conditions of effective agriculture production is sufficient farm mechanization. However, the unstable economic situation in Ukraine, combined with bureaucratic problems, an unstable currency exchange rate, and sharply changed trade routes (which has caused major losses to a number of farms and traders working with the Custom Union) created significant obstacles for investing in machinery in Ukraine. It is especially topical for small and medium farms that usually function in poor economic conditions without any adequate access to the credit market. Consequently, Ukrainian agriculture producers often have an inadequate mechanization rate. As a result, the productivity of Ukrainian farms is significantly lower as compared to other countries that have similar natural conditions in terms of temperatures, precipitation and quality of agricultural lands.*

A no less important problem is the lack of awareness of small and medium farms, which may not realize the effect that investment has in agriculture machinery. Thus, in order to provide specific numbers for potential investors and prove the efficiency of this fund placement, an expected direct economic effect from machinery investment (as an increased profit from higher yield) was estimated. The first step was to define those types of agricultural machinery that have significant impact on the yield and productivity levels for each of the most important crop types: grain, oil crops, vegetables, fruits, etc. Then, an impact of additional investment in various machinery means on crops yield was estimated. Finally, based on fixed prices and a discount rate, an expected additional profit generated by newly purchased machinery on an average farm was estimated. The model proved especially high profitability of investment in such machinery as ploughs, fertilizers spreaders, harvesters, tractors, and machines for irrigation – most of them are paid off (on a land parcel with area around 2000 ha) in three years or less.

Keywords: *agriculture mechanization, MANOVA, stochastic frontier analysis, investment, mechanization rate.*

1. Introduction

Agricultural productivity is closely interrelated with investments in all the aspects of agricultural activity, including selection, irrigation, machinery and others. The United Nations, in its *Least Developed Countries Report*, regard the degree of mechanization as one of the major indicators of agricultural productivity (2015). This group of countries is characterized by a limited use of such inputs as fertilizers, irrigated water and machinery.

A number of obstacles for effective investment exist in Ukraine, which include economic instability, problems with currency exchange rate, closed external trade with one

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of the basic partners – the Russian Federation, a lack of access to credits (especially for small and average farms), an ineffective land market (where only a rental market exists), decreased subsidizing etc. Similar problems are observed in a few countries, including India, as stated by Andrew D. Foster and Mark R. Rosenzweig (2011). They prove in their research that underinvestment in machinery is caused mainly by the presence of credit constraints and past profit shocks. Moreover, currently additional problems have become topical: due to bureaucratic problems caused by the liquidation of the State Agriculture Inspection of Ukraine, farmers cannot even register purchased machinery. According to the Cabinet of Ministers' Order of August 23, 2016, 3M UAH (appr. 1M USD) were allocated to the liquidation of the State Agriculture Inspection of Ukraine (within the framework of reducing the number of state control authorities in all sectors in order to shorten state expenditures and pressure on business). The inspection was responsible for certification of machinery and crop seeds; meanwhile, no service may fully take over these functions. As a result, the registration of machinery is not conducted with a required speed; thus, (i) farmers have to pay for machinery transportation by special transport means to the field and (ii) are under the risk of high fines in case they use their own (not registered) machinery. Based on the information of the Ministry of Agrarian Policy, as of 2015, more than 70% of total machinery in Ukraine is older than 16 years.

Thus, a number of improvements in social, economic and financial issues should be conducted to ensure an increased mechanization rate in Ukraine. This paper is aimed at assessing the expected benefit from investment in machinery for average and large farms to prove its reasonability. To do so, the following steps were undertaken:

1. Firstly, a MANOVA analysis was conducted in order to define the existence of any real impact of agriculture machinery on the major efficiency parameters: yield and profitability.
2. For the crops the production effectiveness of which is significantly impacted by the machinery investment, the production function was estimated using a stochastic frontier analysis. The dependent variable was chosen to be yield due to its stability (profitability may be biased due to the inflation process).
3. Based on the estimated elasticities of yield in the production function, and due to the newly obtained machinery, increased profit was estimated for the next three years per 1 invested UAH.

This way it becomes possible to estimate the economic effect of investment in machinery, which should be the crucial argument for farmers to invest.

2. Literature Review

Mechanization helps not only in increasing productivity, but also in improving the quality of all the farm operations and final products. It also helps to decrease the self-cost of agricultural products. The USDA report emphasizes current trends showing diminishing machinery prices relatively to the labor price (2015).

Another important effect of farm mechanization is an increase of yield. Meanwhile Ukraine, regardless of its high quality soil and favorable conditions, is inefficient in its production, which among other things is caused by a low level of mechanization. Consider the difference between the corn yield in Ukraine, the US, Canada and th European Union, all of which (according to the USDA data) include significant areas of Mollisols (very dark coloured, base-rich, mineral soils of the steppes – USDA (1999)) and Alfisols (soils formed under forest that have a subsurface horizon in which clays have accumulated – USDA (1999)). For instance, according to USDA statistics, the US yields being around 11 MT/HA (metric tonnes/hectare) in 2015 are almost twice as large as the ones in Ukraine (6 MT/HA). Gajendra Singh (2015) conducted a study based on the case of India and observed there a variation of mechanization and agricultural productivity between Indian states, which proved that there is a strong and significant relationship between the farm power (equipment that is used by a farm) and output per ha.

However, purchasing new agricultural machinery cannot ensure such results without additional measures. Faleye T, Adebija JA and Farounbi AJ (2012) proved that a number of minimum conditions of mechanization should be met in order to ensure efficient small farm functioning: suitability to small farms, simple design and technology, affordability (for small farmers) and the provision of support services from the government. Meanwhile, most of these issues are rather problematic in Ukraine and can hardly be solved without state intervention. At the same time, Kazakhstan, for example, supports farmers in their mechanization according to a FAO report (2010) in three ways: state-supported leasing, subsidized credit and local machinery service stations. China provides a machinery rental service for small-scale farmers (OECD).

Moreover, investments in farm mechanization were proved to be highly cost-effective under various circumstances. For instance, Muhammad Aurangzeb, Shaheen Nigar and Mir Kalan Shah (2007) have conducted a cost benefit analysis to prove the efficiency of investment in mechanization for corn production and estimated that on average a farmer obtains 0.5 rupee of net income per 1 rupee spent on mechanization.

The level of mechanization in any country greatly depends on the profitability of its farms. If a farm obtains high real income, it has a possibility to invest in more effective technologies. At the same time, when farmers obtain low revenues, they prefer to overuse machinery for a period longer than provided for exploitation or use relatively cheap labor force. Behnam Jalalzadeh, Ali Mohammad Borghei and Morteza Almassi (2016) have developed a dynamic model with a number of inputs and outputs included, which helped them to estimate an optimal level of farm mechanization to ensure the highest yield. This level approaches the value of 2.4 Kw/ha; meanwhile, the highest level of profitability is reached at the mechanization level 2.2 Kw/ha.

Bidyut Kumar Ghosh (2010), based on the logit regression analysis, proved that farm mechanization depends on the variety of factors, including social, agricultural and eco-

nomic ones, among which the major factors include the following: outdated customs, lack of support from for providing knowledge and information of modern agriculture to small and average farmers, and lack of access to credit resources.

Thus, according to the existing literature, investments in agricultural machinery have proved themselves to be effective and highly advantageous for agriculture development and economic development in general.

3. Current Trends in Ukraine

Ukraine, regardless of the low efficiency of agricultural sector and a low level of yield (as compared to the yield produced from other land of equivalent quality), takes an important place in global agriculture production. According to USDA statistics, Ukraine ensures almost a third part of total world sunflower production, takes the 4th place in the world by barley production, 5th place among countries of rye producers and 6th place in corn production (Fig. No. 1).

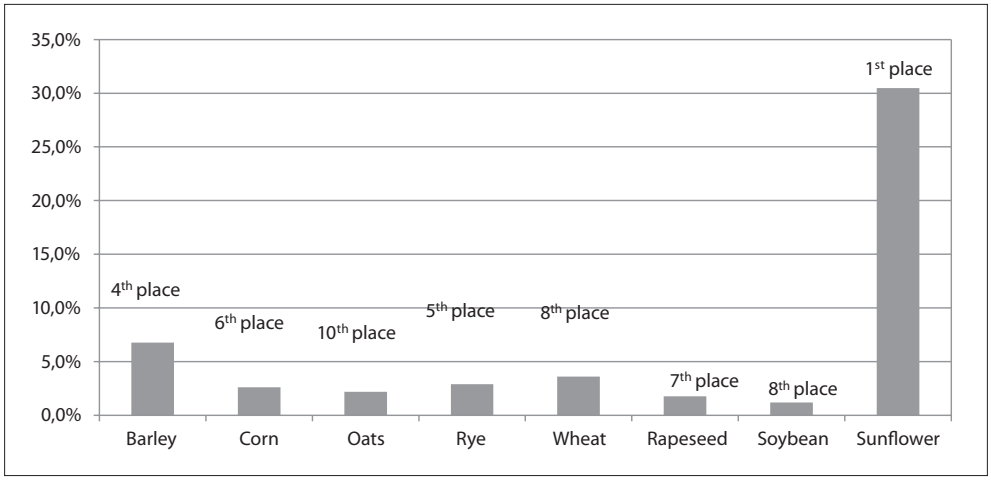

FIG. No. 1. **The share of Ukraine in crop production and its place in the world rating.**

Source: prepared by the authors, based on the data of the USDA.

Moreover, agriculture plays a crucial role in Ukrainian finance, being one of the key sectors of the national economy. Now it produces around 12% of gross value added and provides nearly 40% of export earnings with a significant positive trade balance (over $11 billion in 2015).

However, despite the fact that Ukrainian statistics demonstrate a high level of profitability of agricultural farms, we should understand that it is mainly caused by the specifics of the Ukrainian economic situation and agricultural production process. Thus, due to the high level of inflation taking place in Ukraine during the last few years, combined with

the seasonality of agricultural production, when a significant part of inputs (especially the seeds and fertilizers) is purchased earlier, in the period of late spring to early summer, while the agricultural goods produced from these inputs are sold in autumn. Consequently, their value depreciates and, moreover, this effect increases if a farm sells any products on the internal market and buys seeds on the external one, paying in foreign currency.

Considering this fact, the number of tractors and the amount of any crucial machinery of agriculture has decreased since 2012 (Fig. No. 2) in terms of both parameters: absolute value and the number of tractors per hectare of sown area.

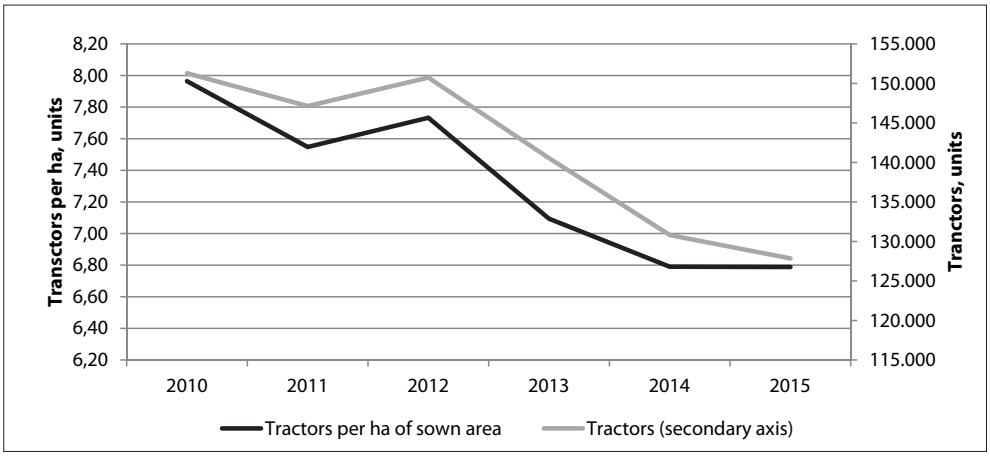

FIG. No. 2. **Number of tractors being used in the Ukrainian agricultural production.**

Source: prepared by the authors, based on the data of the Ukrainian Statistical Service.

Besides, a decline in tractor investments (in USD) was observed in 2014, as presented in Fig. No. 3.

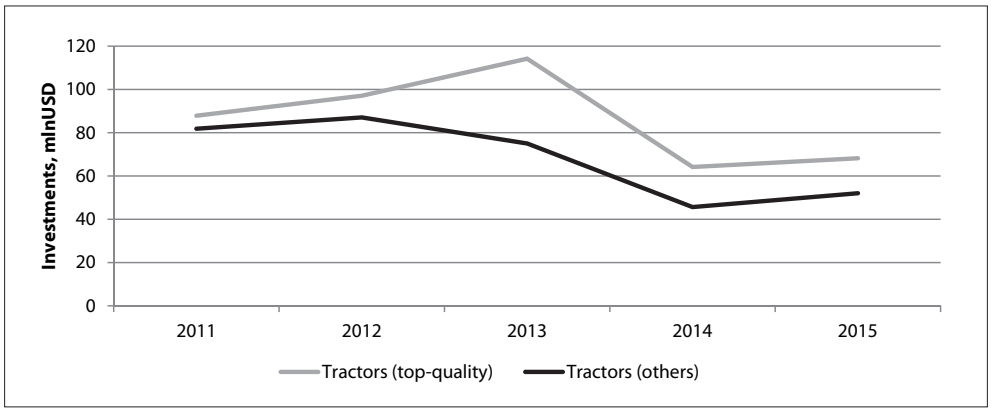

FIG. No. 3. **National investment in tractors in Ukraine, million USD.**

Source: prepared by the authors, based on the data of the Ukrainian Statistical Service.

At the same time, Fig. No. 4 demonstrates that the yield of major Ukrainian crops during this period increases or remains stable.

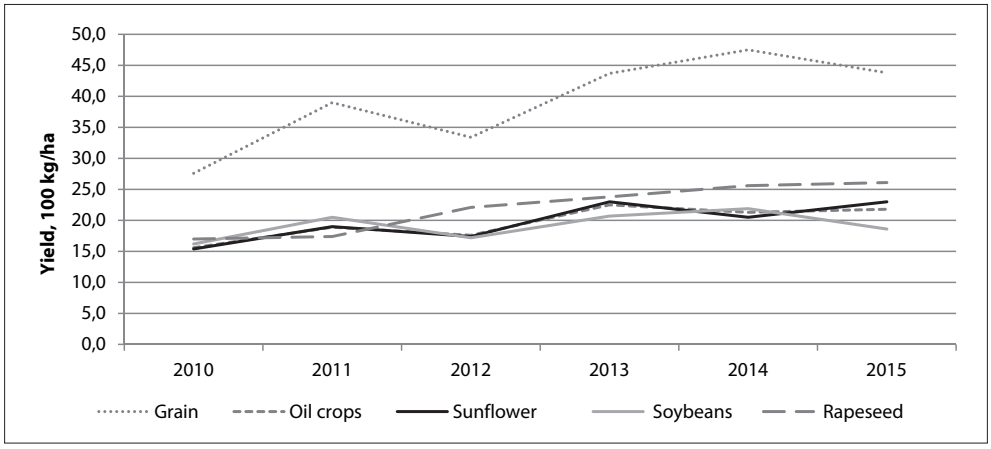

FIG. No. 4. **The yields of major crops in Ukraine, 100kg/HA.**

Source: prepared by the authors, based on the data of the Ukrainian Statistical Service.

This can lead us to the conclusion regarding two potential reasons of such a particular economic situation. First, it could be caused by the increasing quality of newly purchased machinery, while a second possible reason is the growth of investments in machinery repairing.

As it can be seen on the graph, the real investments in repairing (in 2010 year prices), which were calculated by the State Statistic Service since 2013, increase each year, substituting (in some way) the purchases of new machinery (Fig. No. 5).

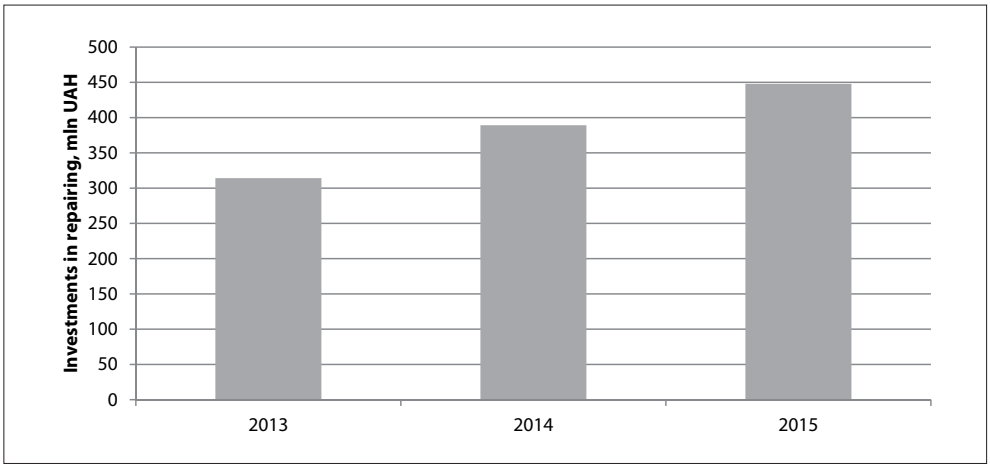

FIG. No. 5. **Investment in machinery repairing in Ukraine, million UAH.**

Source: prepared by the authors, based on the data of the Ukrainian Statistical Service.

During the last years, the most popular brands purchased by Ukrainian farmers are the ones of Ukrainian and Belarus production. These mainly include such brands as Belarus (36% of total sales in terms of number of tractors in 2015) and Minsk Tractor Factory (9% of total number of tractors purchased), which are both relatively cheap. However, in terms of tractors popular among the big farmers, other imported brands see widespread use, among which are included the brands John Deere (10% of total number of tractors) and Case (7%). Apart from the lack of funds in currency for the import of machinery, the current agricultural situation can also be often explained by the need to adapt foreign machinery to Ukrainian agricultural conditions.

However, by taking a look at the structure of purchased machinery (represented by the basic mean – a tractor, which is used for any production of crops), the following situation can be seen. Tractors have been separated by two crucial characteristics: by their engine power[1] and tractor quality. In more detail, Ag Decision Maker of Iowa State University also stated that the engine power of a tractor should be chosen based on such characteristics: crop acreage, labor supply, tillage practices, crop mix, weather, and risk management. They also provide specific advice on the proper choice of the machinery power. The latter characteristic forms two groups: tractors that are commonly mentioned as high quality machinery (including such brands as Claas, John Deere, Case, New Holland, Fendt and Massey Ferguson) and other brands (both Ukrainian and imported).

As it can be noticed from Fig. No. 6, only high-power, top-quality tractors were purchased, which can lead us to the conclusion that only mostly large and partly medium farmers are able to buy tractors of more expensive brands. For any tractor type, a significant drop of tractors purchased is observed in 2014, just after the start of the crisis, with consequences including the closed market of Russia, when its import has stopped, and the devaluation of the UAH rate. In 2015, the drop has stopped and a slight recovery was observed, mainly due to the following facts:

1. The highest share of tractors, especially of "top-quality" ones, is purchased by big grain and oil crops producers, which export a large part of their products; thus, they obtain profits in more stable currencies (usually in USD) as comparing to UAH;
2. In 2015, the currency rate has more or less stabilized and producers got accommodated to new circumstances and market conditions.

Besides, it's worth mentioning that tractors with power higher than 100 KW were the least susceptible to crisis, as such vehicles are purchased by big producers.

In order to improve the issue with machinery procurement, a number of interventions are essential. The FAO report *Mechanization for Rural Development* (2013) names the following measures to stimulate machinery demand, which is the most problematic in Ukraine:

[1] Tractor engine power can be broken down into these categories: up to 40 KW – for small holders, small garden processing; from 40-60 KW – often used for livestock producers in seed-plots; from 60-100 KW and higher than 100 KW – for the field work of average to large scale producers.

- Remove policies and regulations that restrict the choice of farm machinery by the purchaser, which, in the case of Ukraine, should primarily be the introduction of legal and effectively functioning machinery registration;
- State-supported leasing or credit programs should allow farmers to purchase or lease imported machinery as well as domestically produced machines, which is deemed especially topical for Ukraine by taking into account the high credit interest rates and low affordability of agriculture machinery for small and medium farms in Ukraine. The first steps for that are made in Ukraine, to support both agriculture producers and machinery producers. For instance, a new legislative act states that 15% of agricultural machinery value may be compensated by the state;
- Consumer protection legislation should be introduced particularly for contracts and credit and to protect consumers against being sold faulty or inappropriate machines. The law on consumer protection during the purchase of agriculture machinery and its further handling exists in Ukraine; however, there is no such separate law on the rights of agriculture machinery leasing for consumers;
- Government programs should concentrate on providing information for farmers and farm businesses to enable better choices to be made that consider both technical and business issues. Meanwhile, in Ukraine, this role is mostly occupied by industry associations, international organizations and big private companies that organize various "awareness raising" projects and workshops to spread information among small and medium farmers.

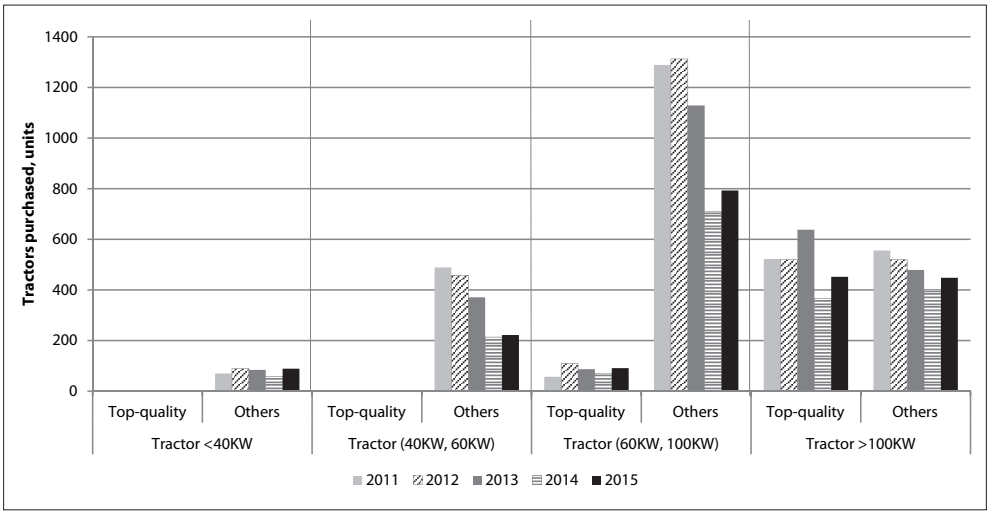

FIG. No. 6. **The number of tractors purchased in Ukraine, by quality and size.**

Source: prepared by the authors, based on the data of the Ukrainian Statistical Service.

All the previously mentioned facts prove the importance of investment in agriculture machinery in Ukraine. A further analysis and results description are aimed at proving this statement based on the estimates in money terms to motivate decision makers to initiate the development of this area.

4. Data and Methods

Based on the farm level dataset containing information on agriculture production and various farm economic indicators, we have estimated the direct economic effect from machinery investment. To do so, a stochastic frontier analysis was used to assess the increased yield due to newly purchased machinery. This method allows including deviations from an efficient frontier, which is required due to technological deficiencies of various farms and non-optimal allocations of resources. It is especially important to include the effect of newly purchased machinery, taking into account all inefficient production due to the low mechanization rate.

Based on the obtained estimates, the average values of land parcel, agriculture products prices, machinery prices and economic effect from each 1 UAH invested during the first three years were estimated. This was done in order to prove the efficiency of machinery investment; in turn, it may motivate farmers to ensure sufficient farm power, which is not achieved by most Ukrainian producers.

4.1. Data Description

The data used for our study is the dataset for all big and average farms (more than 50 ha, 200 heads of pigs/cattle etc.), containing variables on production, inputs structure, expenses, land and other variables for the period of 2012-2015. However, the data on investment was included only for 2013-2015.

Table No. 1 presents the descriptive statistics of major indicators thatare necessary for this research: farm profit obtained from planting, farm cost spent for crops production and investments in machinery used for crops production. Major types of machinery include: tractors, ploughs, cultivators, disk harrows, sowing machines, manure and fertilizer spreaders, machines for irrigation, water pumps and pumping stations, mowing machines, various types of harvesters, threshers, sorting machines and others.

TABLE No. 1. **Descriptive statistics for major indicators**

Year	Number of farms	Mean (profit), K USD	Standard deviation (profit)	Mean (cost), K USD	Standard deviation (cost)	Mean (investment), USD	Standard deviation (investment)
2012	9,160	1278.290	4336.597	1094.255	3960.332	NA	NA
2013	9,112	1229.761	4211.027	1155.309	3715.196	59188.700	225001.8
2014	8,619	1275.582	4636.330	1038.288	3702.839	38382.790	124314.2
2015	8,518	1281.168	5112.774	886.719	3192.283	39686.200	115621.5

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

The Spearman correlation, calculated separately for each year, has given the results presented in Table No. 2. The Spearman correlation coefficient was chosen as it prohibits any assumptions on the linear dependence and frequency distribution of the variables.

TABLE No. 2. **Correlation between investments in machinery and farms' characteristics**

Year	Total land area	LOG (Profit)	LOG (Profitability)	LOG (Income)
2013	0.2238*	0.1942*	0.0685*	0.1996*
2014	0.1621*	0.0587*	0.0394*	0.2179*
2015	0.1426*	0.0038	0.0033	-0.0031

* – significant at α=0.05
Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

On the one hand, since 2014, when the Ukrainian crisis had started, investments should have been more dependent on the revenue (as only highly profitable farms would be able to invest in machinery). Despite the low level of correlation, the test has demonstrated statistically significant interdependence. Thus, the level of revenue is not the defining factor for investment; however, it impacts its level. As it can be seen, the correlation between investments and various lagged indicators on farm profit (including profits from planting, farm profitability and total income from crop realization) decreases each year, while dependence with farm size (represented by total land area) remains relatively stable.

Separating grain and technical crops from the others (in Table No. 3), we may conclude that the possibility to invest is formed mainly by revenues from grain and technical crops, due to the fact that the major currency flow is created by these crops, which are widely exported from Ukraine. However, as it can be observed, this relation becomes insignificant in 2015.

TABLE No. 3. **Correlation between investments in machinery and farms' characteristics**

	Total land area	L.Profit	L.Profit (grain and technical)	L.Profit (other crops)	L.Income	L.Income (grain and technical)	L.Income (other crops)
2013	0.2238*	0.1942*	0.2007*	0.0024	0.1996*	0.1998*	0.0214
2014	0.1621*	0.0587*	0.1240*	-0.0042	0.2179*	0.2208*	0.0448*
2015	0.1426*	0.0038	-0.0130	0.0171	-0.0031	-0.0146	0.0162

* – significant at α=0.05
Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

After basic data analysis, the next step would be defining the crops the yield of depends on the sufficient availability of machinery.

4.2. Primary Testing on Mean Equality and the Variance of Farm Profitability and Yield Based on the Level of Investment in Machinery

The first step in assessing the impact of machinery on the productivity of farms and thus profitability in the current Ukrainian conditions was to prove a statistically significant difference in average profitability and yield of specific crops for four groups of investments: (i) no investment, (ii) low investment, (iii) medium investment and (iv) high investment.

Using a MANOVA analysis (multivariate analysis-of-variance), we tested the hypothesis that yield and profits for various crops vary for different levels of machinery investments. This method allows for testing the equality of the means of a few response variables for various groups. It is based on the following assumptions:

- Observations should be statistically independent;
- There is a normal distribution of the dependent variable;
- Linear relationships can be seen between all dependent variables and covariates;
- The variance is equal for all the groups of predictors;
- Intercorrelation between dependent variables is homogenous.

Thus, difference of yield and profits for different levels of machinery investment was tested using Pillai's statistics, which is often considered to be the most reliable one for conducting a MANOVA analysis:

$$Pillai's = trace\left\{(E + H)^{-1} H\right\}$$

These statistics test the null hypothesis $H_0 : \mu_1 = \mu_2 = \mu_3 = ... = \mu_n$, where μ_i is the mean value of a respective group. It is rejected in the case of E (error variance) being small enough as compared to H (variance explained by treatments). Consequently, the hypothesis is rejected under high values of the statistics.

4.3. Stochastic Frontier Analysis

The next step of our research is a stochastic frontier analysis for those crops the yield was of which was proved to be dependent on machinery expanding.

Here we take the yield of separate types of crops as output, including such major inputs as labor, fertilizers and appropriate machinery purchased in simultaneous and previous periods.

$$y_{it} = \beta_0 + \sum_{j=1}^{k} \beta_j x_{jit} + v_{it} - u_{it}\text{, where}$$

u_{it} is the stochastic deviation of each farm from the potential output;
y_{it} is the natural logarithm of yield (100 kg/ha). Here, we didn't use any currency terms in order to exclude any economic impact of prices (due to instable exchange rate, market

prices fluctuation etc.). Besides, a separating analysis for separate crops allows us to compare them in physical units:

x_{jit} – natural logarithm of appropriate inputs;
v_{it} – idiosyncratic error;
j – number of a dependent variable;
i – number of an enterprise;
t – time period.

This method was chosen due to the possibility to include the specific efficiency of each particular farm (represented by u_{it}), which allows to include specifics of each separate farm that do not let it use their capacities to full extent. We based this on the assumption of technical efficiency; in doing so, we follow truncated normal distribution since the database includes average and big farms, which are usually closer to effective functioning.

The assumptions used to estimate the model included the following:

- Elasticities are equal for all farms;
- An inefficiency term follows truncated normal distribution;
- An inefficiency tern is time-invariant;
- An idiosyncratic error has symmetric distribution.

5. Results and discussion

We calculated the total investment in machinery for each crop, which is commonly used for this particular crop and separated it into four groups. For instance, the following machinery may potentially be used for producing sugar beet: tractors, ploughs, cultivators, harrows, seeders, manure and fertilizer spreaders, machines for irrigation and water pumps. Thus, for the farms that grow sugar beet, we estimated total investments in all the means of machinery used for its production and, based on its distribution, separated all the observations in three groups by the amount of investments, and we reserved the 4^{th} group to include farms with zero investments.

The MANOVA results proved, as demonstrated in Table No. 4, statistically significant positive results of investments in machinery for grain, sunflower, sugar beet, vegetables and fruits. In terms of potato yield, investments may have a positive impact of yield and profit with a lower significance level of 0.1. That can be due to the fact that in Ukraine the bigger share of potato produce is occurs in households, thus any relations gathered from big farms data may not be that reliable as for grain or oil crops.

However, investments in machinery have no significant effect on grape or berries yield and profit due to commonly applied manual labor for the producing of these crops. Moreover, it should be mentioned that for such crops as grain and sunflower, investments have a significant positive effect even if starting from a small sum – this is represented

by the first group. At the same time, small investments (lower than 300 K UAH) do not impose any significant impact either on the profits or yields of sugar beet produce.

Concerning vegetables and fruits, investments have a positive effect solely on their yield.

TABLE No. 4. **Statistics values for different crops**

	Grains	Sunflowers	Sugar beets	Potatoes	Vegetables	Fruits	Grapes	Berries
Pillai's lambda	0,036***	0,047***	0,033***	0,012*	0,012**	0,050***	0,009	0,020

*** – H0 rejected with significance level α = 0.01
** – H0 rejected with significance level α = 0.05
* – H0 rejected with significance level α = 0.1

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

For the estimation of the impact that investments may have on the crop yields by using a stochastic frontier analysis, we included such major factors of crop production as labor, fertilizers used and investments in respective machinery (the one that is potentially used for production of the crop). Apart from the previously mentioned variables, the one to represent the climate was added for most crops. We separated three climate zones:

1. Northwest Ukraine (*Polissia*), which includes regions with a climate characterized by high humidity, lower temperature, where mostly small holders operate. Consequently, they are usually characterized by a high level of production of such crops as rye, oat, potato, various vegetables, livestock etc.
2. The territory united by the second climate includes most of the regions situated in the central part of Ukraine (Forest-steppe). The climate is mild here; however, in the last years, droughts have been observed in this part of Ukraine. It's characterized by average and big farms that are mainly specialized in livestock, wheat, sugar beet, potato, corn, oil crops and forage crops.
3. Finally, the last climate includes all the southern regions (S*teppe*), where wheat, barley, vegetables and most oil crops are produced.

We didn't include the climate variable for grain yield analysis as various grain crops are more or less evenly distributed along the territory of Ukraine. A negative sign for the effect of labor involved in the production shows that replacing machinery with human labor decreases the yield as compared to the potentially achievable yield. Separate means of machinery that have statistically significant impact on grain yields include ploughs, fertilizers spreaders and harvesters. For the first year of purchase, the effect is significantly lower, due to the inability to use certain machinery at full power; it also depends on the period when the machine was purchased. During the next periods, effect increases and stabilizes.

As for the yield of sunflowers, we can observe a situation similar to the one regarding grains. The most effective investment for sunflower production would be tractors, fertilizer spreaders and ploughs. However, in contrast to other machine means, the effect from the plough appears to be significant only starting from the next period. As the best period for sunflower cropping in Ukraine is in the first part of May (then the soil temperatures reach 10 C and stabilize), newly purchased ploughs are unlikely to be massively used that year.

As for sugar beet, machine investments were proved to be less influential. Only seeders, fertilizer spreaders and cultivators were proved to have positive impact with some lag (in 1-2 years). The model may be unreliable for sugar beet as we observe an extremely high deviance of both v_{it} and u_{it}, an insignificant mean of inefficiency coefficients.

Taking into account the frontier analysis for the yield of vegetables, only machines for irrigation were proved to have significant impact on it. The results are presented in Appendix A.

Based on the obtained estimates of elasticity (as coefficients of the estimated log-log specification regressions), we have assessed the expected effect of one purchased machinery mean using the current average prices and an average farm with around 1950 ha of arable land (the expected investment per ha of arable land was calculated). We also assume that only a single crop is produced for the period of 3 years.

TABLE No. 5. **The estimated economic effect from 1 UAH invested in machinery for grain production**

Grain					
Plough		**Fertilizers spreaders**		**Harvesters**	
Number of items purchased at once	Additional income per 1 UAH invested during the first 3 years, UAH	Number of items purchased at once	Additional income per 1 UAH invested during the first 3 years, UAH	Number of items purchased at once	Additional income per 1UAH invested during the first 3 years, UAH
1	2,883	1	7,816	1	1,532
2	1,442	2	3,908	2	0,766
3	0,961	3	2,605	3	0,511
4	0,721	4	1,954	4	0,383
5	0,577	5	1,563	5	0,306

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

Regarding machinery investments applied in grain production, we can see that all the purchased machines will pay off during the first three years (Table No. 5). The effect of machinery investment for sunflowers is lower as demonstrated in Table No. 6, especially for ploughs and tractors; however, it should be taken into account that sunflower is not recommended to be sown for a few years, instead planting other crops. Consequently, as all the machinery may be used for various crops, its paying off would depend on how other crops are produced.

TABLE No. 6. **The estimated economic effect from 1 UAH invested in machinery for sunflower production**

Sunflower					
Plough		**Fertilizers spreaders**		**Tractors**	
Number of items purchased at once	Additional income per 1 UAH invested during the first 3 years, UAH	Number of items purchased at once	Additional income per 1 UAH invested during the first 3 years, UAH	Number of items purchased at once	Additional income per 1 UAH invested during the first 3 years, UAH
1	0,796	1	3,439	1	0,875
2	0,398	2	1,720	2	0,437
3	0,265	3	1,146	3	0,292
4	0,199	4	0,860	4	0,219
5	0,159	5	0,688	5	0,175

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

As for vegetables (Table No. 7), only irrigation machines may have a significant positive impact on yields, as vegetables are often produced in the south of Ukraine, where droughts are becoming a more and more common problem and where irrigation is essential for high yields. As it can be seen, the return from investment is rather high, even for a higher number of irrigation machines purchased at once.

Obtained estimates prove the reasonability of investment in agricultural machinery, particularly for average and big farms. However, these results present a situation possible only under the perfect effectiveness of machinery use. Corrections according with the specifics of farms and their capacities should be conducted.

TABLE No. 7. **The estimated economic effect from 1 UAH invested in machinery for vegetables production**

Vegetables	
Machines for irrigation	
Number of items purchased at once	Additional income per UAH invested during the first 3 years
1	8,360
2	4,180
3	2,787
4	2,090
5	1,672

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.

6. Conclusions

The problem of insufficient mechanization is common for the least developed and developing countries. It may be caused by constraints in either demand or supply. In Ukraine, major problems can be observed with the demand of small and average farmers, who have a lack of access to credit sources and are not usually informed about the importance of investment in agricultural machinery or about any possibilities on the market. Among other problems, an absence of official registration may be emphasized, due to which farms, even granted the conditions of fund availability and the desire to invest, still have difficulties with transporting machinery to their fields.

A direct benefit from investments in machinery (as additional income due to increased yield) was estimated. The conducted assessment proved a high efficiency and return from investments. Funds invested in ploughs, fertilizer spreaders, harvesters and machines for irrigation pay off in 3 years with high return.

The results have demonstrated the highest level of profitability from the investment in irrigation machinery, which is expected to generate around 8 UAH of additional income per each 1 UAH invested during the first 3 years in case it is used on a land parcel of an average area, being equal to 1950 Ha. Compared to this, an additional income that is expected to be created by a newly purchased plough varies from 0.8 UAH to 2.9 UAH depending on the crop that is planted. At the same time, by taking a look at tractors – the basic piece machinery in agriculture production – it is forecasted at the level of 0.9 UAH per each 1 UAH invested only for the first three years of tractor usage.

A high level of farm mechanization, apart from being highly advantageous for a separate farmer, has indirect positive effects, which manifest themselves through improved quality, reduced self-cost, general development of agricultural sector, caused by technological development and development of machinery production sector. That way, it's not only the agricultural producers that would benefit from investing in the machinery, but also the society in general. Moreover, it is expected to have a positive impact on Ukrainian currency. Increased production, taking into account the saturated Ukrainian market of agriculture products, the obtained surplus (or its processed products) is likely to be exported, which is going to strengthen the Ukrainian Hryvnia. This proves the fact that the government is also responsible for the right development of machinery in Ukraine, and that it must commit to enforce any improvements in food quality and increase the competitiveness of Ukraine within the world market.

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Annex A

Estimated coefficients of stochastic frontier by crops

	ln(Grain yield)	ln(Sunflower yield)	ln(Sugar beet yield)	ln(Vegetables yield)
Climate zone 1		0.096***	110.116***	
Climate zone 2		0.331***	106.079***	-0.437***
ln (labor expenses/ha)	-0.017***	-0.055***		
ln (fertilizers expenses/ha)	0.169***	0.111***	33.882***	0.081***
L1. ln (ploughs)	0.046***	0.011***		
L1. ln (fertilizers spreaders)	0.043***	0.016***	9.225***	
L1. ln (harvesters)	0.025***			
L1. Ln (tractors)		0.021***		
L1. Ln (machines for irrigation)				0.048**
L2. Ln (ploughs)	0.048***			
L2. Ln (fertilizers spreaders)	0.047***			
L2. Ln (harvesters)	0.027***			
L2. ln (cultivator)			7.350***	
L2. ln (seeders)			10.549***	
ln (ploughs)	0.024***	0.011***		
ln (fertilizers spreaders)	0.019***			
ln (harvesters)	0.012***	0.007**		
ln (tractors)				
Constant	3.774***	2.580***	674.074	5.681***
/mu	1.436***	-6.419	619.997	0.711**
/lnsigma2	-1.272***	1.022**	10.016***	0.995***
/ilgtgamma	0.043	2.967***	-0.189	1.848***
sigma2	0.280, (0.273; 2.641)	1.012, (2.777; 7.621)	20740.090, (22375.620; 24140.120)	1.976, (2.706; 3.705)
gamma	0.511, (0.495; 0.136)	0.871, (0.951; 0.982)	0.396, (.453; 0.510)	0.814, (0.864; 0.902)
sigma_u2	0.143, (0.136;)	-0.162, (2.641; 5.444)	8359.785, (10129.740; 11899.690)	1.491, (2.338; 3.185)
sigma_v2	0.137, (0.134; 0.139)	0.132, (0.136; 0.139)	11049.160, (12245.880; 13442.590)	0.328, (0.368; 0.408)

Source: estimated by the authors, based on the data of the Ukrainian Statistical Service.