

ENERGY PRICE CHANGE IMPACT ON UKRAINIAN AGRICULTURE: CONSIDERING THE IMPACT OF RUSSIAN WAR AGAINST UKRAINE

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Summary, highlights and conclusions

This report investigates the impact of energy price fluctuations – particularly those intensified by the Russian invasion of Ukraine – on Ukrainian agricultural production and markets. Since fossil fuels and energy-dependent inputs like fertilizers account for 30–50% of crop production costs, the sector's sensitivity to energy market shocks is exceptionally high. Following the 2022 invasion, domestic prices for gasoline, diesel, and LPG rose by 65%, 120%, and 50%, respectively, while natural gas prices peaked in mid-2022. Simultaneously, export disruptions drove down farm-gate prices for corn and wheat, intensifying financial strain on producers and threatening national and global food security.

The analysis focuses on **six key crops** – wheat, corn, sunflower, soybeans, barley, and peas – which together represent the majority of Ukraine's sown area and export value. Employing both **short-run and long-run cost function models**, the study estimates price elasticities for major energy inputs (diesel, gasoline, LPG, electricity, natural gas, fertilizers). The modeling framework enables evaluation of **how farmers' input use and production technologies respond to changing energy prices**.

Key Highlights

- **Energy Dependence in Agriculture:** Energy-related costs comprise up to **35% of total production costs** for some crops, making energy one of the most critical inputs after land and labor.
- **War-Induced Price Shock:** The full-scale invasion in February 2022 triggered a dramatic rise in energy and fertilizer costs, combined with blocked exports and logistical constraints, creating dual pressure on Ukrainian farms.
- **Empirical Findings:**
 - Short-run elasticities of energy demand are relatively low (–0.17 to –0.35), confirming that **immediate substitution possibilities are limited**.
 - Long-run elasticities are higher, reflecting that **technological adjustments (e.g., switching fuel sources or optimizing fertilizer use) become feasible over time**.
 - **Fertilizer costs** exert the strongest influence on total production expenses, especially for wheat and corn.
- **Comparative Insights:** **International literature confirms similar trends across countries:** higher energy prices generally decrease agricultural profitability and employment, while encouraging efficiency and diversification.

Conclusions

The study concludes that **Ukrainian agriculture's resilience is limited in the short term** but can improve through targeted adaptation in the medium to long term. The heavy reliance on fossil fuel-based inputs and fertilizer imports exposes the sector to global market volatility and geopolitical risks. To strengthen resilience:

1. **Promote energy efficiency** through adoption of precision agriculture, renewable energy sources, and optimized machinery use.
2. **Diversify input supply chains**, including domestic fertilizer and biofuel production, to reduce dependency on imports.
3. **Encourage crop diversification** and conservation practices to mitigate energy dependency and enhance sustainability.
4. **Integrate agricultural and energy policies**, ensuring coordinated strategies for long-term food and energy security.

In essence, **energy price volatility has become a structural challenge** for Ukrainian agriculture. Strategic investments in efficiency, technology, and policy coherence will be essential to safeguard both domestic production and Ukraine's role in global food markets.

Table of contents

Summary, highlights and conclusions.....	1
1. Introduction.....	6
2. State of art: estimation of impacts of energy price changes.....	8
2.1 Detailed analysis of studies.....	9
3. Review of changes in cost shares of production of agricultural and food commodities in Ukraine before and after the Russian invasion.....	52
3.1 Questionnaires	58
3.2 Surveys statistics	64
4. Energy price change impacts: estimation of production inputs demand (short- and long-run) elasticities.....	67
4.1 Methodology.....	67
4.1.1 Own-price elasticities of demand for inputs and elasticities of substitution.....	67
4.1.2 Short-run implications.....	69
4.1.3 Outline of the empirical model	69
4.1.4 Estimation of impacts on agricultural production quantities and prices	72
4.2 Data	73
4.3 Estimation	76
4.3.1 Preliminary data analysis	76
4.3.2 Model fitting.....	78
4.3.3 Model diagnostics	87
4.4. Estimation results.....	93
4.5. The results summary.....	98
References.....	100
to chapter 2.....	100
to chapter 4.....	103

Figure 4-1: Pregibon's approximation to Cook's statistic for the long-run wheat production costs model	88
Figure 4-2: Pregibon's approximation to Cook's statistic for the long-run corn production costs model	88
Figure 4-3: Pregibon's approximation to Cook's statistic for the long-run sunflower production costs model	89
Figure 4-4: Pregibon's approximation to Cook's statistic for the long-run soybeans production costs model	89
Figure 4-5: Plot of the dependent variable against predicted values of long-run wheat production costs model	91
Figure 4-6: Plot of the dependent variable against predicted values of long-run corn production costs model	91
Figure 4-7: Plot of the dependent variable against predicted values of long-run sunflower production costs model	92
Figure 4-8: Plot of the dependent variable against predicted values of long-run sunflower production costs model	93
Table 2-1: Summary of the studies reviewed	9
Table 3-1: Costs structure of wheat production before and during the war	52
Table 3-2: Costs structure of corn production before and during the war	52
Table 3-3: Costs structure of sunflower seeds production before and during the war	53
Table 3-4: Costs structure of peas production before and during the war	53
Table 3-5: Costs structure of barley production before and during the war	54
Table 3-6: Costs structure of soybeans production before and during the war	54
Table 4-2: Descriptive statistics of core variables in the dataset	74
Table 4-3: Mean values of core variables across different producer specializations	75
Table 4-4: Correlation coefficients	77
Table 4-5: VIF values	77
Table 4-6: Wheat production long-run cost function estimation results	79
Table 4-7: Corn production long-run cost function estimation results	80
Table 4-8: Sunflower production long-run cost function estimation results	81
Table 4-9: Soybeans production long-run cost function estimation results	82

Table 4-10: Wheat production short-run variable cost function estimation results	83
Table 4-11: Corn production short-run variable cost function estimation results.....	84
Table 4-12: Sunflower production short-run variable cost function estimation results	85
Table 4-13: Soybeans production short-run variable cost function estimation results	86
Table 4-14: Values of McElroy- R^2 of the estimated models	90
Table 4-15: Long run own-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans	94
Table 4-16: Long-run cross-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans	95
Table 4-17: Long-run substitution elasticities for production of wheat, corn, sunflower and soybeans ...	96
Table 4-18: Short-run own-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans	97
Table 4-19: Short-run cross-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans	97
Table 4-20: Short-run substitution elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans	98

1. Introduction

Energy, and fossil fuels in particular, play an important role in agricultural production. It is consumed either directly through combustion of fossil fuels or indirectly through the use of fertilizer or crop protection measures, production of which relies heavily on the natural gas. According to the SSSU data¹, shares of costs related to direct use of diesel and gasoline varied from 9% to 15% for production of different crops. The shares of inorganic fertilizer costs varied from 26% to 35%. Therefore, agricultural production could be sensitive to changes in energy prices.

On February 24th, Russia conducted a full-scale military invasion to Ukraine, which led to the increase in prices of gasoline, diesel, liquefied petroleum gas, natural gas and inorganic fertilizers on both local Ukrainian and global markets. According to the A-95 Consulting Group data², in December 2022, as compared to December 2021, prices for gasoline, diesel and LPG have grown by 65%, 120% and 50%, respectively. Natural gas prices have been increasing since the beginning of 2020, and peaked in June 2022. At the same time, export complications led to the significant decrease in corn and wheat farm-gate prices. These two effects combined, depending on their scale, may lead to profit loss for agricultural producers, who may decide on crops substitution, application of different production technologies, exiting the market, etc.

Agricultural production is one of the largest sectors in Ukrainian economy, on which the local food security and the well-being of rural communities depends heavily. Besides that, Ukraine is one of the world's major wheat, corn, barley and sunflower exporters, so the disruption of the local agricultural production might affect the global market and welfare of other countries as well. Only crop production is a subject of the analysis because fuel plays much less significant role in the livestock production sector. According to SSSU data³, in 2019 average share of fuel in livestock production costs was only 2.01%. For different sub-sectors it ranges from 0.45% for eggs production up to 4.20 % for milk production. Fuel shares in beef, poultry and pork production costs are 4.02%, 0.90%, and 1.52%, respectively. Thus, livestock sub-sector is not included in the analysis, as it is not expected to be affected significantly by increase in energy prices. There is not enough data available for processing sub-sector, although in some sub-sectors energy makes up a significant share of costs . According to own calculations based on the SSSU 2012-2020 data^{4 5}, average

¹ SSSU. Costs of agricultural production in enterprises in 2019. -

https://www.ukrstat.gov.ua/operativ/operativ2018/sg/vytr_na%20ver_sg_prod/vytr_na%20vyr_sg_prod_2019.xlsx

² Minfin Media. Ціни на бензин, дизпаливо, газ на АЗС України. За інформацією Консалтингової групи А-95. - <https://index.minfin.com.ua/ua/markets/fuel/a95/>

³ SSSU. Costs of agricultural production in enterprises in 2019. -

https://www.ukrstat.gov.ua/operativ/operativ2018/sg/vytr_na%20ver_sg_prod/vytr_na%20vyr_sg_prod_2019.xlsx

⁴ SSSU. Purchases of energy products and payments to subcontractors by type of economic activity in 2012–2020. -

https://www.ukrstat.gov.ua/operativ/operativ2021/fin/pdp/pdp_ue/vvp_ek_2012_2020_ue.xlsx

⁵ SSSU. Costs of agricultural animal production by type in enterprises in 2019. -

https://www.ukrstat.gov.ua/operativ/operativ2021/fin/pdp/pdp_ue/vvp_ek_2012_2020_ue.xlsx

share of energy expenditures (including electricity, natural gas and oil products) in sugar production is 19.49%, in bread production is 8.50%, 5.26% in flour production, 5.10% in dairy and cheese production. Wheat, corn, sunflower, soybeans, barley and peas have the highest sown areas among all the crops produced in Ukraine, according to the SSSU data. Thus, these crops are selected for the analysis.

The topic of the impacts of changing energy prices on agriculture have brought interest of researchers in the past. It was found that the scale of the effects highly differs depending on region and sub-sector. No research devoted to this topic was conducted for Ukrainian agriculture previously. Besides that, in this research we will undertake a first attempt to estimate both short- and long-run demand for energy for different crops production separately instead of aggregated crop production.

In this study, we aim to analyze both the short- and long-term impacts of changes in prices for energy resources on agricultural production technology, output and prices. It is important to understand the relationship between energy costs and agricultural production decisions of the Ukrainian producers of wheat, corn, sunflower, peas, soybean and barley. These six crops were selected for the analysis as those, which have the highest sown areas in Ukraine among the cereal, leguminous and industrial crops, according to the SSSU 2021 data.⁶ To achieve that, short- and long-run cost functions for each crop type is estimated. Its parameters allow to obtain own- and cross-price elasticities of demand for fuel (diesel, gasoline, LPG), natural gas, electricity and fertilizer and the elasticities of substitution. These parameters would allow to assess the total impact on the production technology, costs and their structure and to identify possible adaptation strategies of Ukrainian farmers.

⁶ SSSU. Areas, gross harvest and yields of agricultural crops by their species. - https://www.ukrstat.gov.ua/operativ/operativ2017/sg/pvzu/arch_pvxu_e.htm

2. State of art: estimation of impacts of energy price changes

Considering the fact that energy resources are an important production factor in agriculture, a numerous research devoted to the impact of energy prices on agricultural industry have been conducted. There is an empirical evidence of the negative effect of increase in oil and natural gas prices on agricultural production. Regarding this topic, there are 3 main directions of research.

The first group is the analysis of relationship between energy (mostly oil) prices and agricultural commodities' prices or production technology. Koirala et al. (2015) examines relationship between energy prices and agricultural commodity prices using the Clayton model and daily 2011-2012 US prices. Relationship is found to be high for all three sub-sectors studied – corn, soybean and cattle production. However, there are studies which suggest different results. Tyner (2010) used 1982-2007 crude oil and corn futures prices and observed much weaker relationship between the them (correlation coefficient of about 0.16). A study by Hertel (2011) have found the evidence of significant increase of the abovementioned relationship between 2001 and 2008 (from 0.32 to 0.92). Thus, the impact of oil and natural gas prices depends highly depending on production technology and market conditions, which differ substantially across the time, location and sub-sector.

Another perspective is the relationship between oil and natural gas prices and agricultural production itself. There is an empirical evidence of negative effect of increased oil prices on agricultural employment, meaning energy and labor inputs being complementary in agricultural production (Uri, 1996). Agricultural productivity is less affected by the shocks in energy prices, Binuomote et al. (2013) have found no significant long-term relationship between them, and negative, but weak (-0.04), relationship in the short-term.

Second group of studies is represented by modelling of the impacts of increased energy prices using partial equilibrium models. Most studies focus on the country- or region-level effects. A study by Sands and Westcott (2011) models the impacts on production of 8 most popular crops in the US. The most significant impact was found to be on acreage and farmers' profits. Impact on prices was found to be around 1% per 6.6%, 13.4% and 14.0% increase in the prices of diesel, natural gas and electricity, respectively. Increase in the price of natural gas has the highest negative impact on the production of fertilizer-intensive crops, like cotton. Uri and Boyd (1997) have obtained similar effect on the aggregated price level of agricultural goods using general equilibrium model of the Mexican economy. For 26.2% gasoline price increase no significant change in equilibrium price and 0.22% decrease in equilibrium quantity was found. Earlier study by Tewari et al. (1988), which used the price-endogenous partial equilibrium model have found the effect on prices to be more substantial for crops production sub-sector of agriculture. Under the doubled crude oil and natural gas prices scenario, prices for crops and livestock increase by 20% and 10%, respectively. Besides that, fertilizer consumption was found to be less elastic than fuel, leading to the higher decrease in it's consumption. Adams (1976) have found that in the short-run diesel and natural gas consumption in response to increased energy prices would change very little, with the most significant impact on the net revenues of farmers (16% decrease).

Third category of research is the analysis of demand for agricultural inputs. Studies mostly review aggregated agricultural production of a given country, only differentiating crops and livestock production. Scale of the effects is found to be differ by country and period. Own-price elasticities of demand for energy range from -0.17 (crop production demand for diesel) (Adeleja, 1986) up to fairly high -0.64 (aggregated agriculture demand for energy) (Gopalakrishnan, 1989), with majority of estimates being between -0.3 and -0.4. One of the few studies, in which short-term price elasticities of input demand were estimated along with the long-term ones, is Lambert (2010). Author uses dynamic translog cost function to differentiate between long- and short-run adjustments to energy price changes. Both short- and long-term elasticities are found to be similar, with short-run being only slightly lower than the long-run ones, such that own-price elasticity of demand for energy is -0.176 in the short run and -0.181 in the long run. All papers of this group study United States' agriculture, with the only exception being Turkekul (2011), which studies Turkey. It's results differ highly from the estimates obtained by Lambert (2010) for US agriculture. Demand for diesel is found to be more elastic in the short-run than in the long-run, with own-price elasticities being -0.79 and -0.38, respectively. Demand for electricity is much less elastic in the short-run than in the long-run (own-price elasticities of -0.19 and -0.72, respectively). There are only a few studies, which estimate price elasticities of demand for different kinds of energy inputs simultaneously and none of them differentiates by crops at the same time. Besides that, considering different scale of impacts in different regions and the fact that no such research of Ukrainian agriculture exist, conducting it would be a valuable contribution to the already extensive set of studies.

2.1 Detailed analysis of studies

Studies which are reviewed chronologically cover the period of 1976-2022. Geographically they cover a wide variety of countries, including United States, Canada, China, India, Turkey, Nigeria and United Kingdom. Only a few studies study impacts on the farm-level (Jones, 1989; Li, 2016; Raulston 2015), while other analyze aggregated agricultural production of a country or a region. Analyses mostly focus on the impact of oil price change or aggregated energy input. In terms of specific sub-sectors studied, most studies use aggregated agricultural or crop production. There are studies which differentiate by crops, mostly corn, wheat, soybean and rice. The studies reviewed are briefly summarized in the following table.

Table 2-1: Summary of the studies reviewed

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Moss (2010), Gopalakrishnan (1989)	price elasticity of demand for inputs	(1) Differential demand system, (2) translog cost function	(1) ML, (2) 3SLS	All agricultural producers	(1) Oil products, (2) all energy inputs	(1) KLEM (Jorgenson, 2010) – data on capital, labor, energy, machinery use in 1960-2006. (2) American agriculture cross-section	(1) The increase in energy prices has the biggest effect on agricultural production and it has a significant effect on producers' labor demand.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
						data for 1982 - input expenditure, input prices, aggregate output and input share of total expenditures.	However, expanding the specification in an attempt to estimate the effect of energy prices on the supply of agricultural inputs is limited due to the concavity concerns. (2) Main finding is that cross-price elasticity between capital and energy input is found to be the largest (0.43), suggesting the possibility of between them. Other input pairs suggest possibilities for substitution as well, except for land-capital and labor-capital.
Koirala (2015)	Relationship between energy and agricultural commodity prices	Copula model (single equation Clayton copula and Clayton-Gumbel mixture)	OLS	Corn, soybean	Crude oil	495 daily observations of future prices (oil, gasoline, diesel, biodiesel, corn, soybean, kettle) for March 2011 – September 2012	The correlation between corn future prices and all other forms of energy prices are high according to the Clayton portion of the mixture model. Same trend is observed for soybean, with higher correlation for biodiesel. For kettle prices, the highest correlation is observed with gasoline and diesel prices, while biodiesel, natural gas and crude oil prices

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							correlation is similar to corn and soybean.
Dunn (1981)	Effect of increased energy price on competitive position of a region	basic model for interregional competition for a single commodity as developed by Samuelson (1952)	OLS	No specific crop, aggregated region output	Oil products	Input-Output table	It is found that likelihood of substantive changes in Northeast agriculture sector competitive position due to real energy price increase is very low.
Dodder (2015)	Modelling the effect of increased oil and natural gas prices on energy and agricultural markets	integrated framework with MARKAL (energy) and CARD (agriculture) models	Algebraic models	Corn, soybean	Crude oil, natural gas	The EPA's U.S. nine-region database (EPAUS9r_12, version 1.0)	Scenario comparisons show biofuel markets affected more by crude oil prices than natural gas prices. Higher natural gas prices shift the biofuel production mix away from corn-grain based to more cellulosic ethanol. Alternatively, the scenario with no cellulosic feedstock lowers total ethanol production and raises ethanol and corn prices.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
USDA (2011), Marshall (2015)	Impact of increased energy prices on agriculture and food prices	(1, 2)FAPSIM (dynamic econometric model of the U.S. agricultural sector), (1)Farm-Level Partial Budget Model	OLS (FAPSIM)	(1, 2) corn, sorghum, barley, oats, wheat, rice, upland cotton, and soybeans and	(1) Petroleum products (Industrial distillate fuel oil, Transportation diesel fuel), natural gas, electricity; (2) crude oil and natural gas	(1) FAPSIM dataset - yearly agricultural production, costs, prices. Farm-Level Partial Budget Model - individual farm data from USDA's Agricultural Resource Management Survey, (2) FAPSIM dataset, oil and gas price assumptions from USDA Agricultural projections to 2024 (2015)	(1) energy-related costs vary highly for different crops, with the highest for corn and rice and lowest for soybeans. Total acreage for the eight studies decreases on average for 0.2 (low price change scenario) and 0.4 (higher price scenario) percent over 2012-2018. Planted area decreases for all the crops, except for soybeans. Besides that, producers of fertilizer-intensive crops like cotton suffer higher cash income decline. In terms of effect on farm county economies and populations, no substantial impact is found. (2) The fertilizer sector is hit by the energy price increase the hardest because of its greater than 20-percent direct energy cost share. Among the other sectors, crops output falls the most, crops being the sector that employs the most energy, both directly and indirectly (through fertilizer and pesticide

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							use). The reduction in crops production is greatest in the other OECD region, where output falls 2.2 percent. Higher energy prices affect the livestock sector indirectly by causing an increase in feed prices. Production levels of the livestock sectors in the United States and other OECD regions decline only slightly (0.6 percent and 0.4 percent)
Chan (1983)	Analysis of factors contributing to change in agricultural productivity	None	Calculations based on empirical data	No specific crop	Oil products	1952 to 1979 yearly data on input, output prices and amounts in Canada	It is found that rising energy prices did make notable contributions in reducing average labor productivity
Tewari (1988); Ma (2022)	Modelling the effect of increased oil and natural gas prices on energy and agricultural markets	Price-endogenous partial equilibrium model. Comparative statics approach	Algebraic model. Tewari (1988): MINOS software. Ma (2022): GAMS	Wheat, oats, barley, flaxseed, rapeseed (1); wheat, rice, corn, soybean, peanut, rapeseed, potato (2)	Oil and natural gas (1); Crude oil (2)	Tewari(1988): 1979-1983 averages of input use, total cultivated areas, output quantities and prices from various sources. Price elasticities estimates for export and domestic demand are taken from various studies. Ma (2022): Agricultural production, acreages and	(1) energy prices increase affects quantity of outputs, low-value crops are hit more severely than the high value crops; under the doubled energy prices scenario, prices for crops and livestock increase by about 20% and 10% respectively; rising energy prices induce producers to curtail energy use; fertilizer consumption

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
						outputs of seven main crops (rice, wheat, corn, soybean, rapeseed, potato and peanut) in China; Demands and prices of agricultural products. Total demand is divided into food ration demand, seed demand, industrial demand and depletion. These parts of demand are calculated individually and then summed together, using data from "China Statistical Yearbook 2019" and "BRIC Agricultural Database". Demand elasticities are referenced from existing studies, prices of outputs, Quantities and prices of energy inputs, including diesel, electricity, fertilizer, pesticide and agricultural film are given by	would decline by an amount greater than that estimated for fuel (due to inelastic demand); despite reduced energy consumption, energy expenditures are still expected to rise significantly. (2) It is found that the impacts on agricultural production are relatively limited. However, a higher energy price pushes up agricultural production costs, resulting in the loss of social welfare in the agricultural sector, by around 0.6% to 1.4% for different scenarios; Rapeseed and wheat are the most and least sensitive crops to energy price fluctuations.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
						"Compilation of cost-benefit data of national agricultural products 2019"	
Turkekul (2011)	Co-integration analysis of the price and income elasticities of energy demand in agriculture	Error correction model	ML	No specific crop	Diesel, electricity	Annual data from 1970 to 2008 for diesel and electricity consumptions, prices, agricultural GDP and rural population	The long-run income and price elasticities of demand for diesel are 1.47 and 0.38, respectively. For the electricity, income and price elasticities were found to be 0.19 and 0.72, respectively.
Uri (1997)	Modelling the impact of an increase in the prices of gasoline and electricity in Mexico	General equilibrium model for 13 producing sectors and 14 consuming sectors	Solved as an algebraic model	None	Gasoline, electricity	Data for 1988 baseline: capital income and labour income were obtained from the INEGI. Land income was estimated using factor shares obtained from the INEGI and applied to the capital income component. Data on expenditures on each of the 14 goods and services consumed by each of the 4 household categories were obtained from INEGI.	For 26.2% gasoline price increase, no significant change for equilibrium price and -0.22% decrease of equilibrium quantity was found.
Jones (1986)	Impact of increased energy prices on the viability of	mixed-integer linear programming model of a typical farm	parametric programming	No specific crops. Organic and conventi	Crude oil	"farm management data" from the Ministry of Agriculture, Fisheries and	A doubling of energy prices in the model led to only a small improvement in the competitive

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
	organic farms in UK			on-farm		Food Farm Management Survey (MAFF, 1982).	position of the organic system.
Lambert (2010)	Long- and short-run price elasticities of demand for inputs	SUR	ML	No specific crops.	All energy inputs	1948-2002 data from USDA ERS, includes an aggregate measure of crop and livestock output quantities and both price and quantity indices for five inputs: labor, capital, land, energy, and intermediate inputs other than energy	Factor demands in U.S. agriculture are price inelastic. As prices of labor, capital, land, energy, or materials increase, total expenditures in the affected factors increase. Elasticities of substitution indicate all factors are Morishima substitutes, so substitution of other factors does occur in response to increases in the price of one factor. Substitution elasticities are low, however, reflecting fixity in input use due possibly to short run commitments to an output mix, predetermined factor usage due to established farming practices, and lumpy investments in farm equipment.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Adams (1976)	Modelling short-run impact of increased energy prices on agriculture	Partial equilibrium model	Linear programming	Cotton, grain, sorghum, wheat, corn, soybeans	diesel, herbicide, natural gas, nitrogen fertilizer, water	Crop enterprise budgets by Texas Agricultural Extension Service -	Diesel and natural gas consumption would change very little in the short run. Rising inputs prices would cause acreage shifts from irrigated land to dryland, with the first crops to shift being sorghum and corn, and cotton being the least affected crop. The most significant impact is on the net revenue of the farmers, doubling of diesel price would cause 16% net revenue decrease
Mapp (1976)	Modelling impact of increased natural gas prices in 10 period	Recursive partial equilibrium model	Linear programming	No specific crop	Natural gas	1976 target crop prices, 1976 input prices, per-acre resource requirements, costs, returns based on data compiled by Schwartz	The natural gas price increase causes pumping costs to grow and reduces net revenue. Under constant gas prices scenario, pumping costs rise from 0.99\$ to 3.24\$ per acre and net revenues decline by 45%, while under rising gas prices scenario, pumping costs grow up to 10.75% and net revenues decrease by 63%. Pumping costs increase leads to gradual shift from irrigated to dryland production under both scenarios,

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							with increasing gas price making this shift more rapid.
Zafeiriou (2018)	Co-integration analysis of crude oil-corn and crude oil-soybean futures prices	ARDL	OLS	Corn, soybean	Crude oil	monthly futures prices of crude oil (CME NYMEX WTI Crude Oil Futures in US dollars per ton), corn, and soybeans (CME CBOT grain futures)	The results derived indicate the existence of interactions among agricultural commodities and crude oil prices, as expected.
Musser (2006)	Factors determining energy use in agriculture	Bivariate censored regression	ML	Corn	Oil and oil products, natural gas	2001 USDA Resource and Management Survey	It is found higher acreage decreases fuel use, as well as reduced tillage; soil tests decrease nitrogen use; higher education of operators decreases nitrogen use; irrigation increases use of both inputs, on-farm drying increases fuel use; yield goal increases fertilizer use; manure use decreases fertilizer use. If energy prices remain high, one would expect that some of these practices that reduce energy use will become more widely used.
Taghizadeh-Hesary (2019)	Linkages between agricultural food prices	Panel VAR	ML	Agricultural output in general	Crude Oil	2000-2016 panel data for 8 asian countries	It is found that food price has a positive response to any impulse from global oil

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
	and oil prices						price and biofuel price and negative response to impulse from interest rate. Other variables show no significant impact on food price.
Lundberg (2021)	Oil price pass-through to agricultural commodities	Multiple-horizon regression	OLS	Corn, wheat, soy, and livestock (broilers, hogs, cattle)	Crude oil	Time series of daily corn, soy, wheat, broilers, hogs, cattle and oil prices, from 21 August 1971 to 29 November 2019.	First, there is significant heterogeneity across horizons for both grain and livestock regardless of the contracting intensity or biofuel technology regime. Second, there is contracting in both commodities reduces the long-run relationships between oil and agricultural commodities. Third, the introduction of biofuel technology exhibits heterogeneous effects by horizon, crop type, and contracting intensity. Both the short- and long-run relationships between oil and corn increase substantially after the introduction of biofuel technology. With high levels of corn contracting,

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							however, the long-run relationship post-biofuel increases only slightly.
Li (2016)	Energy costs impact on potato-producing households	Linear regression	OLS	Potato	All energy inputs	2007-2012 rural household survey data from 2 Chinese regions, includes income, costs, amount of inputs used, demographic characteristics, 1000 observations	The average cost of energy used for producing potatoes has a significant and negative association with family income for all the farmers surveyed. Given rising energy prices, increasing efficiency at the farm level appears to be a significant factor in farmers' ability to increase their income. The negative relationship between energy cost and family income is much more significant for poorer families than for wealthier families. Energy costs appear to have a more significant association with family income for potato farmers who have a certain size of potato-sown area. Families with potato-sown areas that are either too large or too small are less likely to benefit from reduced energy costs

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Raulston (2015)	Modelling farm-level effect of increasing energy prices	FLIPSIM (monte Carlo simulation model)	Recursive programming	Feedgrain, wheat, cotton, rice, livestock (dairy and beef producers)	All direct fuel use related expenses and Nitrogen fertilizer	"primary representative farm data" from 10 western US states, 30 representative farms	It is found that, farms with less energy consumption and farms that share a portion of the energy costs with landowners are less vulnerable to the rising costs, but no one is completely insulated from this trend. The results suggest that farmers will likely face increasing cashflow pressures that may accelerate their adoption of energy conserving crop rotation patterns and production systems.
Hanson (1993)	Modelling the economy-wide effects of oil price shock	USDA/ERS Competitive general equilibrium model	Algebraic model	Cotton, food grains, feed crops, oilseed crops, sugar, other crops + dairy and livestock	Crude oil	1986 CGE model database	Major crop sectors where exports are important (cotton, food grains, feed crops, and oilseed crops) all had an increase in value added after the oil price shock, but in all but oilseed crops the associated decline in government deficiency payments led to a decline in sector income.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Uri (1996)	Relationship between crude oil price and agricultural employment using Granger causality	ARIMA	ML	None (agricultural employment is studied)	Crude oil	1947-1995 yearly data of crude oil price and agricultural employment	The results of this study suggest that at least part of the trend in agricultural employment can be explained by the changes in the crude oil price. Results suggest that the increase in the real price of crude oil on average has accounted for an annual decrease in the agricultural employment of approx. 0.21%
Uri (1998)	Relationship between energy price and the use of conservation tillage using Granger causality	Autoregressive model, logistic regression	ML (both)	None (use of conservation tillage is studied)	Crude oil as a proxy for gasoline, diesel and LPG	1967-1997 yearly data of crude oil price and conservation tillage use	The results are significant, but small: a 10% increase in the real price of crude oil leads to 0.4% increase in the total planted acres devoted to conservation tillage.
Adelaja (1986)	A multi-product cost function model is used to analyze energy demand in various agricultural subsectors.	SUR	ML	grain, seed, hay, forage, silage, tobacco, fruit, nut, berry, vegetable, melon, nursery, and greenhouse products	gasoline, diesel, LP gas, fuel oil, electricity, kerosene, and natural gas as a single energy input category	Pooled cross-section data of West Virginia agriculture (prices, input cost shares, revenue shares, and output), n=300, 55 counties - years 1959, 1964, 1969, 1974, 1978, and 1982	higher energy prices result not only in increased production costs but also in slowdowns in the rate of increase in mechanization. However, compared to livestock costs, crop production costs are more sensitive to changes in energy prices (own-price elasticity of demand for energy is 0.4 for livestock sector and 0.17 for

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							crops production).
Anand (2014), Parsons (1978)	Input-Output analysis	Input-Output model	Quantitative model	(1) Paddy, wheat, jowar, bajra, maize, gram, pulses, sugarcane, groundnut, coconut, other oilseeds, jute, cotton, tobacco, other agriculture. (2) Spring/winter wheat, barley, oats; sugar beet; maincrop potatoes; field beans; carrots; livestock; dairy	(1) natural gas, oil, coal. (2) Oil	(1) 1990-2012 input-output tables of Indian economy. (2) Input-Output Tables for the U.K., 1971, HMSO	(1) An increase of 10% in fossil fuel prices increases direct input cost of farming, on an average by 0.56%, could impact total farming costs by about 3.75%. (2) The obtained results suggest that agriculture as a whole is not really any more strongly affected by the oil-price increase than the economy as a whole. The percentage cost/price changes for comparison being (in sub-cases 1, 3, 4 and 5) 3.72 vs. 3.18, 9.43 vs. 8.45, 6.42 vs. 6.00 and 34.72 vs. 32.60

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Corong (2020)	Modelling the impacts of changing energy costs using the GTAP-E-RD model to project the global economy to 2030	GTAP-E-RD (recursive, dynamic)	Algebraic model	Rice, fruits and vegetables, sugar, other crops, livestock (raw milk, dairy, cattle, sheep, wool, beef, sheepmeat, other meats), fisheries	Oil, natural gas	GTAP version 10 database, with a base year of 2014	For key New Zealand agricultural sectors, including beef, sheep meat and dairy products, it is found that exports and output decline with increases in global carbon emission prices. Change in NZ carbon emission price much less substantive effect on NZ agriculture, most sub-sectors being have little to no effect, with exception being wool industry (8-12% increase in real output) and dairy / raw milk sectors (3-5% decrease in real output).
Nkang (2018)	Modelling the impact of a 50% oil price decrease on nigerian agriculture and households' welfare	General equilibrium model (extended representative household approach)	non-linear programming - GAMS	No specific crop	Oil	2006 Social Accounting Matrix for Nigeria (by IFPRI)	GDP recorded a significant increase, while aggregate government income, households' income and total savings all recorded a decline. Sectoral results show that gross domestic output and supply of composites in the food and other agriculture sectors increased substantially forcing prices in the two agriculture sectors to

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							decline. Moreover, while there was an increase in capital demand in the agricultural sector following the shock, there was however a fall in labor demand in the food sector although same went up in the other agriculture sector
Binuomote (2013), Ikram (2014)	Analysis of the relationship between crude oil prices and agricultural productivity using co-integration / EC model	Error correction model	ML	No specific crop	Crude oil	(1) time series data at the macro level spanning from 1981 to 2010: agricultural gross domestic product, exchange rate, crude oil price, capital, labour, land and fertilizer quantities (Nigeria); (2) 1980-2013 annual data on Pakistani agricultural GDP, crude oil prices, water availability, croppet area and fertilizer use	(1) while the direct effect of the oil price shocks in the long run is not significant, in the short run it has a negative (-0.04, significant at 10% level) impact on agricultural production (agricultural GDP). (2) All variables are found to be integrated at level one in ADF and PP unit root tests. In EC model the negative linkage of oil price and agricultural GDP is found.
Mondi (2011)	Analysis of relationship between rice and oil markets	VAR	ML	Rice	Crude oil	monthly data from October 1980 to December 2009, variables: world petroleum production, real oil price, world rice supply, and	Model shows that an oil price shock causes rice supply to move in the same direction, increasing unexpectedly despite higher production costs. With regard to the price of rice, strong linkage

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
						the Thai export price of rice	with oil price shocks starts to be evident only from the late nineties. Two months after an oil shock the price of rice rises by 2.5%, and six months after the shock it stabilizes at a level 5% higher than the original one.
Gopalakrishnan (1985)	Modelling impact of increased energy prices on net revenues of farms	Simple linear programming model (net revenues function)	algebraic model	Sugar, coffee, macadamia nut	Combined energy input	total acreage devoted to each of the crop on a farm, average yield, output price, unit costs per ha for each input, amount of inputs, processing costs	Higher energy costs do not greatly impact the net revenues of small growers, although they have differential impacts depending on the resource endowments of each crop grower. A generally observed phenomenon is that the lower the output price, the greater the impacts on the net revenue from crop growing under given energy cost scenarios. In any case, net revenues appear to be relatively inelastic to the changes in energy costs.
Tewari (1989)	Modelling impact of increased energy prices for cases of different trade-	Quadratic programming sector model of Saskatchewan agriculture	algebraic model	Wheat, oats, barley, flaxseed, barley, livestock	Oil and natural gas	1979-1983 averages of inputs quantities and prices, total cultivated areas, output quantities and prices	

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
	demand elasticities						
Miranowski (1979)	Modelling effect of increased energy price on a representative farm	linear programming model of a representative model	algebraic model	Corn, soybeans, oats, alfalfa hay	diesel fuel, gasoline, liquified petroleum gas, electricity, and nitrogen fertilizer (25% of the direct energy price increase)	representative farm data - input/output quantities, prices, acreages, yields	Fivefold energy price increase changes mix of optimum activities and implies 46% net returns decrease. Tenfold energy price increase also changes the mix of optimum activities towards more acreage devoted to soybean and decreases net returns by 83%, as compared to the baseline solution.
Du (2012)	Analysis of relationship between gasoline, ethanol and corn prices	GARCH, Structural VAR	ML	Corn	Ethanol, gasoline	daily March 2005 - March 2011 gasoline, ethanol and corn prices	In the more recent period, ethanol, gasoline, and corn prices are found to be more closely linked with a strengthened corn-ethanol relation. Variance decomposition shows that for each market a significant and relatively large share of the price variation could be explained by the price changes in the other two market.

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
Fei (2020)	Analysis of substitution effect and rebound effect of China's energy consumption in agricultural sector	SUR	ML	No specific crops	All energy as a single input	China's provincial agriculture data from 2000 to 2017. It includes data on agricultural GDP of each province and quantities of energy, labor and capital inputs as well as their prices.	Results suggest that the price elasticity of agriculture demand for energy, labor and capital are all quite small, which may be caused by the price control due to governmental regulation.
Gohin (2010)	Analysis of the relationship between energy and agricultural commodities prices using computable general equilibrium model	GTAP - static CGE model	GAMS	Wheat, beef, dairy	Crude Oil	version 6 GTAP database	A positive relationship due to the cost push effect has been identified, but it is found that the introduction of the real income effect may indeed imply a negative relationship between world food and energy prices.
Wang (2014)	Impacts of Energy Shocks on US Agricultural Productivity Growth and Commodity Price	VAR	ML	No specific crop	Gasoline	annual data of real U.S. gasoline prices, agricultural total factor productivity (TFP), real GDP, real agricultural exports, and real agricultural commodity price from 1948 to 2011	The results indicate that an energy price shock has a negative impact on productivity growth in the short run (1 year). An energy price shock and an agricultural productivity shock each account for about 10 percent of U.S. agricultural commodity price volatility with the productivity shock's contribution slightly higher. However, the impact from

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							energy prices outweighs the contribution of agricultural productivity in the medium term (3 years). With more persistent impacts, energy shocks contribute to most (about 15%) of commodity price's variation in the long run.
Tokgoz (2008)	Modelling the impact of increased oil price using partial equilibrium models	Partial equilibrium models system ("large set of multicountry, multicommodity models")	algebraic model	corn, wheat, soybean	crude oil	2006 historical data of agriculture production (inputs/outputs quantity and price, yields, acreage), crude oil and ethanol prices	The increased oil price is found out to have positive impact on corn production: 11% increase in acreage and production, 20% increase in farm gate price, 30% export reduction and 12% reduction of corn feed use. On the other hand, impact on wheat and soybeans is quite the opposite: 6% reduction of planted area, 8.5% and 6.6% (wheat and soybean, respectively) reduction in production, but still 9% farm gate price increase.
Kulshreshtha (1983)	Impact of increased energy costs on agricultural production	quadratic programming model, input-output model	MINOS software	wheat, barley, oats, flaxseed, rapeseed	fuel, fertilizer	not specified	With a 50% increase in energy cost, grain and livestock activities were not altered to any large extent. In most cases, the changes were

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							within 2 or 3 percent of the benchmark solution. With 300% increase in energy price, the largest decrease was noticed in the production of barley and oats, and their export levels. The prices for barley and livestock products increased in each scenario, whereas for wheat and rapeseed a positive change in price was observed only for the largest increase in energy costs. The share of fertilizer and fuel in total expenditures increased from 12.9% in the benchmark run to 28.8% in the 300% energy increase scenario.
LeBlanc (1985)	Analysis of demand for inputs	SUR	ML	Agricultural sector	natural gas	Time series data for the years 1947 through 1980 on input and output prices and quantities	Increases in fertilizer prices have a small negative effect on energy and feed-seed, but a relatively large positive effect on the demand for labor. Furthermore, the alternative fertilizer price paths generate large differences in profits. Profits, however, vary more between

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							output price assumptions than between fertilizer price assumptions because of the large effects that output price has on output supply and revenue.
Dobbs (1991)	Modelling impacts of energy price increase on conventional and sustainable farming systems	Set of models from previously conducted case-studies. (Details not specified)	-	Corn, soybean, wheat	Fuel, fertilizer, pesticides	Data and models are taken from a set of case-studies, details not specified.	Scenario with only fuel price increase suggests only a little difference between effects on conventional and organic farms. Adding 50% fertilizer increase leads to \$2-6 per acre costs increase for organic farms and \$1-9 for conventional, depending on a region.
Ivanovic (2012)	Impact of increased energy prices on profit of family farms	"A model of family farm" - no details	-	No specific crop	Diesel, fertilizers (NPK, UREA, KAN)	Interviews with 15 family farms holders - qualitative data and costs/production data	The 20% increase in diesel D-2 prices leads to the decrease in family farms profit by 35.56%, what makes this input distinguished for its importance for profitable operations of the observed farms. In the second place, the highest impact on the profit is created by the prices of different NPK fertilizers, whereas prices of KAN and UREA fertilizers do not have so powerful impact on the profit of the

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							farms specialized in field crop production.
OECD, FAO (2008)	Agricultural outlook	A jointly developed modelling system, based on the OECD's Aglink and FAO's Cosimo models	algebraic models	Wheat, maize, vegetable oil	biofuel, oil	Aglink and Cosimo databases	The constant oil prices scenario shows that wheat, coarse grains and vegetable oil price projections are all shown to be highly sensitive to petroleum-price assumptions. Many countries tend to have better economic growth if the oil price is low, but others benefit from a high oil price. Under the constant oil price assumption, the prices of maize and vegetable oil are about 10% lower and the wheat price falls 7% in 2017 when compared with the baseline projection.
Pal (2019)	Correlation between crude oil and agricultural commodities prices	GARCH (DCC, ADCC, GO-GARCH)	ML	Corn, soybeans, oats, wheat	Crude oil	Daily spot closing prices of crude oil (West Texas Intermediate) and four major field crops cultivated in the U.S., namely, corn, soybeans, oats and wheat	
Vincent (1979)	Short-run impacts of increased oil price on agriculture	ORANI 78 model of the Australian economy	Algebraic model	Sheep, cereal grains, meat cattle,	Oil	ABS 1968/69 Input-Output (I/O) tables (ABS 1977) which	For 40% post-refinery oil price increase, model results suggest the following

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
		(general equilibrium)		milk cattle and pigs, poultry and other farming		distinguish 109 industry sector	impacts on agriculture: a contraction in aggregate employment of 0.8% and in employment of rural workers of 2.8%; contractions in the outputs of export oriented agricultural industries of about 0.9% to 1.8%; contractions in the incomes of export oriented farm industries of 6-8% in real terms.
McDonald (1991)	Modelling long-run impacts of increased energy prices on agriculture	CGE model	Algebraic model	Crops and livestock sectors	Crude oil	1987 data of inputs/outputs for 5 economy sectors: crops, livestock, fertilizer, manufacturing and other services	
Christensen (1983)	Impact of increased fuel prices on agriculture input sector	CARD-NAES model,	economic model, estimation method not specified	Feed grains, wheat, soybeans, cotton, tobacco, beef, pork, lamb, mutton, chicken, turkey	Diesel	NAES-CARD database	It is found that the growth in fertilizer, pesticide, and machinery purchases will slow down due to the relative expense of these inputs. Irrigation is also an energy intensive practice that will decrease under higher energy prices. The negative growth of farm and hired labor, on the other hand, and as predicted in the model, may slow down in order to

Study	Approach	Model	Estimation method	Sectors	Energy resource	Data	Impact
							counteract the effects of other input usage decreases

Source: own elaboration

1. Adams et al. (1976)

Authors develop a partial equilibrium model of agriculture in Texas Plains to estimate the impact of increased energy prices. Studied energy inputs are diesel, herbicide, natural gas, nitrogen fertilizer, water (since Texas agriculture relies heavily on energy-intensive irrigation). Main findings are that diesel and natural gas consumption would change very little in the short run. Rising inputs prices would cause acreage shifts from irrigated land to dryland, with the first crops to shift being sorghum and corn, and cotton being the least affected crop. However, these shifts occur only after certain level of inputs price increase. Besides that, the most significant impact is on the net revenue of the farmers, doubling of diesel price would cause 16% net revenue decrease.

2. Adelaja and Hoque (1986)

Multi-product cost function model was used to analyze energy demand in subsectors of West Virginia agriculture. Model is estimated as seemingly unrelated regressions. Data used includes input prices, input shares, revenue shares, and output. Inputs are divided into six categories: fertilizer, energy (gasoline, diesel, LPG, fuel oil, electricity, kerosene, natural gas), machinery, capital (including land), and other. Output of a subsectors was also divided into two categories: livestock (poultry, dairy, sheep, cattle, hog, lamb) and crop products (grain, seed, hay, forage, silage, tobacco, fruit, nut, berry, vegetable, melon, nursery, and greenhouse products). Total costs for each sector are estimated in a translog form as a function of vector of outputs and vector of input prices. Then cost shares, obtained using Sheppard's lemma, are used to estimate the elasticity of substitution between inputs, from which, price elasticities of demand for them are estimated. Tests for separability (with null hypothesis $k=0$ and another null hypothesis that $k_{ri}b_s = k_{si}b_r$, for all i and r) and technological non-jointness (null hypothesis $d_{rs} = -b_r b_s$). Null hypotheses are rejected in all 3 tests. It is concluded from the study that higher energy prices result not only in increased production costs but also in slowdowns in the rate of increase in mechanization. However, compared to livestock costs, crop production costs are more sensitive to changes in energy prices (own-price elasticity of demand for energy is 0.4 for livestock sector and 0.17 for crops production). Marginal increase in livestock production requires more energy than the marginal increase in production of crops.

3. Anand (2014)

The paper focusses on the interaction between fossil fuels and farming in India, to capture total intensity of fossils in farming and offer some evidence on inflationary impact of fossil fuel price increase in India.

Authors use 3 sector (agriculture, fossil fuels, rest of the economy) Input-Output model. Coefficients for balanced 3-sector (commodity*commodity) transactions coefficients (direct effect) and Leontief inverse (total effect) are derived for 1998 and 2007. Then, agriculture group is re-expanded into 15 sectors and coefficients for Direct and Total Effects of Price Change of Fossil Fuels are estimated.

An increase of 10% in fossil fuel prices increases direct input cost of farming, on an average by 0.56%, could impact total farming costs by about 3.75%.

4. Binuomote and Odeniyi (2013)

Data used in this study are time series data at the macro level spanning from 1981 to 2010, it includes agricultural gross domestic product, exchange rate, crude oil price, capital, labor, land and fertilizer.

First, the agricultural GDP is specified as a function of exchange rate, crude oil price, invested capital, labor quantity, size of land, and fertilizer amount:

$LAGDP = \beta_0 + \beta_1 LEX + \beta_2 LP_o + \beta_3 LK + \beta_4 LLb + \beta_5 LLd + \beta_6 LF + T + \mu$, where variable coefficients (beta) represent long-run elasticities. Then, error correction model is estimated, with variable coefficients (gamma) representing short-run elasticities:

$$\Delta LAGDP = \gamma_0 + \sum_{i=1}^p \gamma_1 \Delta LEX_{t-p} + \sum_{i=1}^j \gamma_2 \Delta LP_{o_{t-j}} + \sum_{i=1}^k \gamma_3 \Delta LK_{t-k} + \sum_{i=1}^m \gamma_4 \Delta LLb_{t-m} + \sum_{i=1}^y \gamma_5 \Delta LLd_{t-y} + \sum_{i=1}^z \gamma_6 \Delta LF_{t-z} + \mu_t ECM \quad (2)$$

Optimal amount of lags is determined based on AIC.

Results suggest that, while the direct effect of the oil price shocks in the long run is not significant, in the short run it has a negative (-0.04, significant at 10% level) impact on agricultural production (agricultural GDP)

5. Chan (1983)

Authors use profit specification of production function for the agricultural sector instead of the conventional value-added production formulation, this paper explains changes to regional productivity in Canada in terms of changes in output prices, material prices, energy prices. capital deepening and technical progress. Authors estimate annual change of labor productivity in agriculture, factors contributing to it and their shares in the labor productivity change. It is found that rising energy prices did make notable contributions in reducing average labor productivity.

6. Christensen and Earl (1983)

The national agricultural econometric simulator (NAES-CARD) is used to estimate the effect of increased petroleum price on the other inputs use in American agriculture. ARD). There are 11 sectors in the CARD-NAES model including five major crop commodity sectors - feed grains, wheat, soybeans, cotton, and tobacco; and five livestock commodity sectors - beef, pork, lamb and mutton, chicken, and turkey. The final sector aggregates components from each of the aforementioned sectors and sums those results to the exogenously determined variables for the rest of the U.S. agricultural economy. Baseline scenario assumes that diesel prices remain constant in real terms at the 1980 level of 1\$ in 1980-2000. 4 alternative scenarios are tested: (1) 50% diesel price increase in 1980-1990 and smaller price increase in 1990-2000 (alternative energy sources development assumption); (2) 50% diesel price increase in 1980-2000; (3) 100% diesel price increase in 1980-1990 and smaller increase in 1990-2000; (4) 100% diesel price increase in 1980-2000.

It is found that the growth in fertilizer, pesticide, and machinery purchases will slow due to the relative expense of these inputs. Irrigation is also an energy intensive practice that will decrease under higher energy prices. The negative growth of farm and hired labor, on the other hand, and as predicted in the model, may slow down in order to counteract the effects of other input usage decreases.

7. Corong and Strutt (2020)

Authors model global economy (up to 2030) using GTAP-E-RD model, a recursive dynamic extension of GTAP model. Baseline year is 2014, aggregated to 16 regions and 34 sectors. Baseline scenario assumes conservative increases in New Zealand carbon emission prices and moderate changes in world oil & gas prices. There are 5 alternative scenarios: (1) New Zealand carbon emission prices rising to a moderate level in 2030; (2) New Zealand carbon emission prices rising to a relatively high level in 2030; (3) Global carbon emission prices rising to a moderate level in 2030; (4) Oil and gas prices rising by a lower than baseline amount; (5) Oil and gas prices rising by a higher than baseline amount.

For key New Zealand agricultural sectors, including beef, sheep meat and dairy products, it is found that exports and output decline with increases in global carbon emission prices. Change in NZ carbon emission price much less substantive effect on NZ agriculture, most sub-sectors being have little to no effect, with exception being wool industry (8-12% increase in real output) and dairy / raw milk sectors (3-5% decrease in real output).

8. De Gorter and Just (2009)

Paper assesses whether the conditional correlation of crude oil with energy crops (corn and soybeans) is different from that of food crops (oats and wheat). Correlation is explored using three different GARCH models (DCC, ADCC, GO-GARCH). All 3 models are estimated with AR(1) term. In order to reduce risk associated with crude oil price fluctuations, this study also examined hedging possibilities against crude oil by investment in agricultural commodities. Although hedging effectiveness is low with all underlying agricultural commodities, soybeans provide relatively better hedging possibilities compared to other agricultural crops.

The results indicate that the dynamic conditional correlations between crude oil and corn across the GARCH models were positive. The average correlation value was around 0.20. In a similar vein, the dynamic

conditional correlations between crude oil and soybeans have also evolved to be positive for all 3 models with the average correlation value being around 0.25. The correlations between crude oil and oats oscillated between negative and positive values. The correlations between crude oil and wheat were mostly positive for each of the GARCH models.

It was found that the average hedge ratio between crude oil and corn was 0.3656 under the GO-GARCH model, signifying that hedging of a U.S.\$1 long position in crude oil is possible for 36 cents short position in the corn market. Similarly, a U.S.\$1 long position in crude oil can be hedged for a 47 cents short position in soybeans. The corresponding hedge ratios of crude oil with oats and wheat are relatively low at 0.1154 and 0.1661, respectively. Among the three GARCH models employed in this study, DCC-GARCH specification was found to be most effective for constructing hedge ratios.

9. Dobbs and Cole (1991)

Report focuses on the impact of rising energy prices on the attractiveness of sustainable farming systems compared to conventional farming. Analysis was based on a set of case studies of conventional and sustainable farms in five different agro-climatic areas of South Dakota. Baseline whole-farm analysis models (details not specified) represent 1988 costs and returns the farms mentioned above.

Analyses were conducted to determine the effects on costs and net income for three alternative scenarios: (1) a 50% increase in fuel prices and 25% increase in crop drying costs; (2) a 50% in fuel and fertilizer prices, and a 25% increase in crop drying costs; (3) a 50% increase in fuel, fertilized and herbicide prices, and a 25% increase in crop drying costs.

First scenario suggests that sustainable farming systems have slightly less adverse effect of energy price increase, than the conventional ones. The increases in direct costs range are \$1.80 on average for sustainable farms and \$2.80 for conventional farms. Fertilizer 50% price increase leads direct costs to increase by \$2-\$6 per acre (depending on a region). A 50% increase in pesticide costs adds \$1-\$9 to direct costs of conventional farms, while almost not affecting the costs of sustainable farms.

10. Dodder et al. (2015).

The study examines impact of energy prices and cellulosic biomass supply on biofuel crops production using integrated modeling approach. Authors use integrated framework that includes MARKAL model to model energy resources (oil and its products, natural gas, bio fuels) markets and partial-equilibrium CARD model for US agriculture market. Projections are made for 3 scenarios: (1) a permanent only crude oil 25% price increase; (2) a permanent crude oil and natural gas 25% price increase and (3) unavailability of cellulosic biomass feedstock for ethanol production on the biofuels. Scenario comparisons show biofuel markets affected more by crude oil prices than natural gas prices. Higher natural gas prices shift the biofuel production mix away from corn-grain based to more cellulosic ethanol. Alternatively, the scenario with no cellulosic feedstock lowers total ethanol production and raises ethanol and corn prices.

11. Dunn (1981).

Study examines the effect of increased energy prices on the competitive position of the region using inter-regional competition model for one commodity. It is found that likelihood of substantive changes in Northeast agriculture due to real energy price increase is very low.

12. Fei (2020)

Authors examine substitution effect and rebound effect of China's energy consumption in agricultural sector. From the translog cost function, cost shares for each input (capital, labor, energy) are derived. System of equations of cost shares is estimated as seemingly unrelated regressions. With the obtained coefficients, own-price elasticities of demand for inputs are calculated.

This study uses the sample of China's provincial agriculture data from 2000 to 2017. It includes data on agricultural GDP of each province and quantities of energy, labor and capital inputs as well as their prices.

Results suggest that the price elasticity of demand for agricultural energy labor and capital are all quite small, which may be caused by the price control due to governmental regulation.

13. Gohin and Chantret (2010)

A world Computable General Equilibrium model with detailed representations of food and energy markets is used to investigate food and energy products price long-run relationship. Particular attention is paid to specifying macro-economic linkages which have often been overlooked in recent analysis and debate. The analyzed crops and sub-sectors are wheat, beef and dairy. Energy source studied is crude oil.

Authors make simulations in three different frameworks: (1) no budget constraint; (2) fixed income and (3) full CGE model. The simulated crude oil price increases in these frameworks are +116%, +122% and +129% as compared to the 2001's baseline 25\$ per barrel. After model calibration, a sensitivity analysis is applied.

A positive relationship due to the cost push effect has been identified, but it is found that the introduction of the real income effect may indeed imply a negative relationship between world food and energy prices.

14. Gopalakrishnan et al. (1989)

The paper attempts to investigate the characteristics of US agriculture by analyzing the possibilities of substitution between energy and non-energy inputs (capital, land, labor) by estimating own- and cross-price elasticities for inputs. Input share functions are derived from translog cost function and are estimated using 3SLS method. Main finding is that cross-price elasticity between capital and energy input is found to be the largest (0.43), suggesting the possibility of between them. Other input pairs suggest possibilities for substitution as well, except for land-capital and labor-capital.

15. Gopalakrishnan et al. (1985)

The impact of energy price increase on the production of three main crops produced on Hawaii (sugar, macadamia nut, and coffee) is examined using linear programming model.

Each crop production is disaggregated into different farm sizes, each considered a separate way to grow and sell the crop (5 farm size groups). Consequently, for each production activity, selling activity is modelled as well. Objective function of the model, which is being maximized, is sum of net revenues of every farm. Net revenues are maximized s. t. resource availability, production, marketing and non-negativity constraints.

Dataset includes total acreage devoted to each of the crop on a farm, average yield, output price, unit costs per ha for each input, amount of inputs, processing costs for the farms producing coffee, macadamia nut and sugar in Hawaii.

9 scenarios are estimated – 3 options of output price change (-40%, 0, +40%) and 3 options of energy price change (0%, +50%, +100%). The analysis shows that coffee production is more energy-intensive than macadamia nut and sugar production. Specifically, energy costs constitute about 18% of the total cost in the case of coffee, 10% in case of sugar, 16% in case of macadamia nut. Coffee (the highest priced crop among those studied) is found to be the least affected by energy price increase, with net revenues change being -2.8% under low output price scenario and doubled energy prices. The most affected crop is sugar (most low-priced of the three crops studied), which becomes unprofitable under low output prices scenario with both 50% and 100% energy price increases.

The overall findings are that higher energy costs do not greatly impact the net revenues of small growers, although they have differential impacts depending on the resource endowments of each crop grower. A generally observed phenomenon is that the lower the output price, the greater the impacts on the net revenue from crop growing under given energy cost scenarios. In any case, net revenues appear to be relatively inelastic to the changes in energy costs.

16. Hanson et al. (1993)

Study examines sectoral effects of oil price shock and economywide linkages to agricultural sector. Competitive general equilibrium model of the US economy, developed by USDA and ERS, is used. Agricultural sector in this model is represented by the following sectors: dairy, livestock, cotton, food grains, feed crops, oilseed crops, sugar, other crops.

3 oil price scenarios (+55.4%, +107.2%, +159.1%) are combined with 3 macro-policy scenarios: (1) fixed exchange rate, flexible trade balance; (2) flexible exchange rate, fixed trade balance; (3) flexible exchange rate, reduction in foreign borrowing.

“Major crop sectors where exports are important (cotton, food grains, feed crops, and oilseed crops) all had an increase in value added after the shock, but in all but oilseed crops the associated decline in government deficiency payments led to a decline in sector income. Given the design of the deficiency payment program, the federal government outlays fall because of higher prices of program commodities. When market prices rise, regardless of cost considerations, deficiency payments are reduced. Thus, while the oil price shock causes market sales of food grains, feed grain, and cotton producers to increase, the increase is not enough to offset the reduced program payments, and sector income falls.”

It is found that the government's response to the outflow of dollars to pay for higher priced oil imports matters to farmers.

17. Ikram and Waqas (2014)

Study is similar to Binuomote (2013), authors estimate agricultural GDP as a function of crude oil prices, exchange rate, fertilizer intake, cropped area and water availability. Data used is annual 1980-2013 time series.

All variables are found to be integrated at level one in ADF and PP unit root tests. Then, EC model is estimated, and the negative linkage of oil price and agricultural GDP is found.

18. Ivanovic et al. (2012)

Paper studies the impact of increased energy prices on profit of family farms. The interviews with 15 family farms holders from AP Vojvodina were conducted about natural, organizational and economic conditions in which the farms operate, available resources which are at their disposal and production results. Based on the interviews a “model of family farm specialized in field crop production” (no further details) was made. As a basis for the research, calculations of fixed costs at the level of the whole farm were used, as well as variable costs per enterprises and total variable costs for the whole farm. Based on these elements, the indicators of economic effects of field crop operations were determined – gross margin and profit. Besides that, the sensitivity analysis was conducted to determine change in mentioned indicator variables in response to the increase of fuel (diesel D-2) and fertilizers (NPK, UREA, KAN) prices. Sensitivity analysis was made with the assumption that the price of fuel and fertilizers decreases/increases by 20% and 10%.

Results suggest that the 20% increase in diesel D-2 prices leads to the decrease in family farms profit by 35.56%, what makes this input distinguished for its importance for profitable operations of the observed farms. In the second place, the highest impact on the profit is created by the prices of different NPK fertilizers, whereas prices of KAN and UREA fertilizers do not have so powerful impact on the profit of the farms specialized in field crop production.

19. Jones (1986)

Authors estimate effect of increased energy prices on viability of organic farm in UK using mixed-integer linear programming model. It was found that, although input costs were generally lower with the organic system, the net farm revenue was reduced due to decreased income from crop sales. The organic system, therefore, did not enter the optimal solution. Energy costs per ha with the organic system were 259'0 lower than with a conventional cropping system, although energy costs per £ of output were 25% higher. A doubling of energy prices in the model led to only a small improvement in the competitive position of the organic system.

20. Koirala et al. (2015)

Study examines relationship between energy prices and agricultural commodity prices. Authors assume increased oil prices may lead to higher demand for corn and soybean, as a main input for ethanol and biodiesel production. So the livestock producers might face problems with feedstock availability and its costs.

Authors use a copula model (single equation Clayton copula and Clayton – Gumbel mixture) to investigate the relationship of prices for crude oil, natural gas, gasoline, diesel and biodiesel with corn, soybean and kettle future prices. They use data that includes 495 observations of daily prices for March 2011 – September 2012.

It is found that the correlation between corn future prices and all other forms of energy prices are high according to the Clayton portion of the mixture model. Same trend is observed for soybean, with higher

correlation for biodiesel. For ketchup prices, the highest correlation is observed with gasoline and diesel prices, while biodiesel, natural gas and crude oil prices correlation is similar to corn and soybean.

21. Kulshreshtha et al. (1983)

Quadratic programming model is used to determine the optimum mix of agricultural production under a set of demand relationships. The objective function of a model is a measure of consumers' plus producers' surplus. It is assumed that the energy cost rise causes adjustments in (1) volume of crop produced, (2) crops grown on summerfallow versus stubble, (3) level of fertilizer, and (4) mixture of crops grown.

Then, results are put into an input-output model, with the agricultural sector exogenous. 3 alternative scenarios are developed: 50%, 100%, and 300% increase in energy price.

The results of this study suggest that, in the short run, increases in energy based input prices in the agricultural and other (especially transport) sectors will have a substantial influence upon application of energy based inputs, their share of total production expenditures, and upon producers' surplus.

With a moderate (50 percent) increase in energy cost, grain and livestock activities were not altered to any large extent. In most cases, the changes were within 2 or 3 percent of the benchmark solution. With 300% increase in energy price, changes in production levels were more significant. The largest decrease was noticed in the production of barley and oats, and their export levels. The prices for barley and livestock products increased in each scenario, whereas for wheat and rapeseed a positive change in price was observed only for the largest increase in energy costs. These results can perhaps best be explained in terms of differences in demand elasticities and responsiveness to nitrogen fertilizer. The share of fertilizer and fuel in total expenditures increased from 12.9% in the benchmark run to 28.8% in the 300% energy increase scenario.

22. Lambert and Gong (2010)

Authors use dynamic cost function model to derive short and long run adjustments to change in energy prices within U.S. agriculture. The objective was to estimate both the degree of the farms responsiveness and its' change over time. Authors expect short run adjustments to be limited, with greater adjustments over time. So, to account for lags between changes in economic environment and inputs adjustment, they choose dynamic model, as static models either with or without short-run restrictions assume instantaneous adjustment of inputs.

23. LeBlanc (1985)

Impact of natural gas decontrol, which leads to increase in its price, agriculture is studied. It affects agriculture directly through increased irrigation and crop drying costs, and indirectly, through fertilizer prices increase, as it represents 60-70% of fertilizer production costs. Authors attempt to determine the effects of alternative natural gas prices, and consequently alternative fertilizer prices, on input demand, production costs, and agricultural income. A variable profit function is used to derive input demand functions and an aggregate supply function for agriculture output. From these relationships the effects of alternative fertilizer price on input use, production costs, and farm income are determined.

A five-equation system of profit function and demand equations for 4 inputs (fertilizer, energy, labor, feed-seed) is estimated using maximum likelihood method. Given the estimated parameters, price elasticities are calculated. Fertilizer has the largest own-price effect and feed-seed the lowest. The cross-price relationships are generally small except for the substitution relationship between fertilizer and labor.

Then, simulations for 1981-1990 are conducted with four different natural gas and fertilizer prices paths: annual change of -1%, 0%, +2.5% and +5%, these path are combines with assumptions about output prices: annual change of -1%, 0% and +1%. Increases in fertilizer prices have a small negative effect on energy and feed-seed, but a relatively large positive effect on the demand for labor. Furthermore, the alternative fertilizer price paths generate large differences in profits. Profits, however, vary more between output price assumptions than between fertilizer price assumptions because of the large effects that output price has on output supply and revenue.

24. Li et al. (2016)

Authors study impact of energy costs on the welfare of rural household which produce potato. Income of the household is estimated as a function of average energy cost to produce 1 unit of potato, labor, land and capital costs, and a set of controlling variables representing demographic characteristics.

25. Lundberg et al. (2021)

Paper studies the pass-through relationship between oil prices and agricultural commodity prices, since it is a relationship that has the potential to disrupt farm-level decision making.

Since economics relationship between oil prices and agricultural commodity prices substantively differs over different time horizons, to address this homogeneity, authors apply multiple-horizon regression.

In simple equation $\ln p_{i,t} = \beta_0 + \beta_1 \ln p_{o,t} + \epsilon_{i,t}$, where β_1 is the marginal effect of oil prices on agricultural commodity price, log of oil price is decomposed to allow the pass-through elasticity to vary by

time horizon: $\ln p_{o,t} = \mathcal{P}_{1t} + \mathcal{P}_{2t} + \dots + \mathcal{P}_{kt}$, where $\mathcal{P}_{jt} = \sum_{\ell=-2^j+1}^{2^j-1} w_{j,\ell} \ln p_{o,t-\ell}$. Then, obtained equation is estimated by OLS.

Data used is time series of daily corn, soy, wheat, broilers, hors, cattle and oil, from 21 August 1971 through 29 November 2019.

26. Ma et al. (2022)

Study uses the methodology similar to Tewari (1988). Authors construct a price-endogenous partial equilibrium model (comparative static approach) to evaluate impacts of increased energy price on agricultural production, energy consumption, and carbon emission in China. Four scenarios are designed for upward and downward price fluctuations in crude oils. Additionally, high (50%) and low (25%) amplitudes of energy price fluctuation are considered. Therefore, downward-low amplitude (scenario I), downward-high amplitude (scenario II), upward-low amplitude (scenario III) and upward-high amplitude (scenario IV).

It is found that the impacts on agricultural production are relatively limited. However, a higher energy price pushes up agricultural production costs, resulting in the loss of social welfare in the agricultural sector, by around 0.6% to 1.4% for different scenarios; Rapeseed and wheat are the most and least sensitive crops to energy price fluctuations.

27. Mapp and Dobbins (1976)

Authors use recursive programming model, to determine optimum farm organization for a five-year period. At the end of five years, water use is calculated, drawdown and well yield for the following period are estimated, and pumping costs are adjusted. An optimum organization is reestablished and assumed constant for the next five-year period. This procedure continues for ten five-year periods, or for fifty years. Optimum organizations are developed for representative farms in poor, moderate, and good water resource situations for conventional versus reduced and conventional tillage practices, with both low and high crop prices, under conditions of constant and increasing natural gas prices. It is assumed that natural gas price is 0.75\$ in period 1, 1.75\$ in period 2 and gradually increases up to 10\$ in period 10. It is found that the price increase causes pumping costs to grow and reduces net revenue. Magnitude of these changes is more interesting, under constant gas prices scenario, pumping costs rise from 0.99\$ to 3.24\$ per acre and net revenues decline by 45%, while under rising gas prices scenario, pumping costs grow up to 10.75\$ and net revenues decrease by 63%. Pumping costs increase leads to gradual shift from irrigated to dryland production under both scenarios, with increasing gas price making this shift more rapid.

28. Marshall et al. (2015)

Authors use a model of US agriculture, based on FAPSIM model, developed by USDA. To assess the impact of crude oil and natural gas prices in 2015-2016, two scenarios were developed: the first (baseline) scenario is based on higher energy prices assumptions from USDA Agricultural Projections to 2024 (USDA, 2015) and second, alternative scenario, that assumes 43.4% and 25.0% crude oil price decrease in 2015 and 2016 respectively and 20.6% and 14.7% natural gas price decrease for the same period.

It is found that such energy price decrease, as expected, leads to costs decrease, ranging from -3.5% for cotton up to -6.0% for rice. Such differences in cost decrease can affect planting decisions in the aggregate, as well as cropping choices between competing crops. Effect on acreage is present as well, but relatively small. Model suggests 0.4% total acreage increase in 2015 and 0.5% in 2016. Price reductions for studied crops are small, with none larger than 1.5% in both 2015/16 and 2016/17.

Besides that, decreased oil and gas prices lead to reduction in energy-related inputs expenses: -3.4% for fertilizer, -2.6% for electricity and -12.9% for pesticides in 2016, with total energy-related expenses reduction being -7.7% including direct fuel use.

29. McDonald et al. (1991)

A multiregional computable general equilibrium (CGE) model was used to assess the long run effects of higher energy prices on agricultural production, prices, and trade. Scenario of 25% increase in price of energy inputs is compared to the baseline results. A 25% increase in the energy price is assumed to result from approximately a 60-percent increase in the crude oil price. Economy is divided into 5 sectors: crops, livestock, fertilizer, manufacturing and other services.

The fertilizer sector is hit by the energy price increase the hardest because of its greater than 20-percent direct energy cost share. Among the other sectors, crops output falls the most, crops being the sector that employs the most energy, both directly and indirectly (through fertilizer and pesticide use). The reduction in crops production is greatest in the other OECD region, where output falls 2.2 percent. Higher energy prices affect the livestock sector indirectly by causing an increase in feed prices. Production levels of the livestock sectors in the United States and other OECD regions decline only slightly (0.6 percent and 0.4 percent)

30. Miranowski (1979)

Author uses linear programming model to estimate the effect of energy price increase on representative Iowa farm. A model is developed to select the optimum mix of activities for a representative farm, subject to given resource constraints and specified input and output price.

The baseline solution of the model is based upon the input cost and output price assumptions equal to the prices and costs prevailing in Iowa during the spring of 1976. The baseline solution specifies the production of 250 acres' continuous corn (high fertilization) and 40 acres C-C-O-M rotation (high fertilization). Alternative scenario assumes twofold, fivefold and tenfold energy price increase. Twofold energy price increase affects only net returns (-13%) and does not change the set of optimum activities. Fivefold energy price increase changes mix of optimum activities and implies 46% net returns decrease. Tenfold energy price increase also changes the mix of optimum activities towards more acreage devoted to soybean and decreases net returns by 83%, as compared to the baseline solution.

31. Mondt et al. (2011)

Paper examines relationship between rice market and crude oil price shocks. VAR model is estimated. Oil shocks are treated as endogenous and are structurally divided into crude oil production shocks and crude oil price shocks. Data used is October 1980 – December 2009 monthly data on world petroleum production, real crude oil price, world rice supply and export price of rice.

From VAR model, four different shocks are identified, and three different responses can be estimated. Therefore, there are 12 relationships among the various shocks and response44s. The estimated responses of the variables are to be interpreted as the reactions of the level of the variables.

Model shows that an oil price shock causes rice supply to move in the same direction, increasing unexpectedly despite higher production costs. This implies that rising production cost deriving from higher oil prices have mostly only a repercussion on the price of rice, without causing farmers to decrease the quantity of rice they produce.

With regard to the price of rice, strong linkage with oil price shocks starts to be evident only from the late nineties. Two months after an oil shock the price of rice rises by 2.5%, and six months after the shock it stabilizes at a level 5% higher than the original one.

32. Moss et al. (2010)

Study examines the effect of increased energy prices on agriculture by estimating industry's elasticity of demand for energy. Authors estimate elasticities using differential approach. Data used is KLEM

(Jorgenson, 2010), which includes quantities of agricultural output and inputs (Capital, Labor, Energy, Materials), prices for inputs, farm-gate and consumer prices for 1960-2006. Authors do not select specific crops, but rather use data for all of the agricultural producers.

Derived equation (3) is estimated with symmetry and homogeneity conditions imposed.

$$(3) \quad \bar{f}_{it} D \ln(q_{it}) = \theta_i D \ln(z_t) + \sum_{j=1}^n \pi_{ij} D \ln(p_{ijt}) + \varepsilon_{it}$$

Then authors bootstrap the estimation 10000 times. And 55 of those samples obey the concavity restrictions. Main findings of the study are that after imposing concavity, agriculture's energy demand, although inelastic, appears to be more sensitive to price changes than any other input. The estimated input demand elasticity for energy is -0.3403 . The largest cross-price elasticity effect between inputs appears to be between energy and labor. Thus, it is concluded, that increase in energy prices has the biggest effect on agricultural production and it has a significant effect on producers' labor demand. However, expanding the specification in an attempt to estimate the effect of energy prices on the supply of agricultural inputs is limited due to the concavity concerns.

33. Musser et al. (2006)

Authors estimate fuel demand system to study factors, which determine the energy use in corn production. Two equations are estimated: direct fuel consumption (total fuel expenditures per acre is a dependent variable) and indirect fuel consumption (per acre nitrogen consumption as a dependent variable). Explanatory variables are farm structural variables, management decisions, farm characteristics, farm equipment, and regional characteristics. Data used is 2001 USDA's Resource and Management Survey. Model is estimated as bivariate censored regression, because some farmers did not use nitrogen and some incurred no fuel costs.

Main findings are that higher acreage decreased fuel use, as well as reduced tillage; soil tests decreased nitrogen use; higher education of operators decreased nitrogen use; that irrigation increased use of both inputs, on-farm drying increased fuel use; yield goal increased fertilizer use; manure use decreased fertilizer use. If energy prices remain high, one would expect that some of these practices that reduce energy use will become more widely used.

34. Nkang (2018)

Paper simulates 50% decline in world crude oil price using a computable general equilibrium model and data from 2006 Social Accounting Matrix (compiled by IFPRI) for Nigeria. CGE model is used to determine the impact of an oil price shock on agriculture sector and households' expenditures (proxy for household welfare). CGE model uses the extended representative household approach.

Findings: "GDP recorded a significant increase, while aggregate government income, households' income and total savings all recorded a decline. Sectoral results show that gross domestic output and supply of composites in the food and other agriculture sectors increased substantially forcing prices in the two agriculture sectors to decline. Moreover, while there was an increase in capital demand in the agricultural sector following the shock, there was however a fall in labor demand in the food sector although same went up in the other agriculture sector"

35. OECD-FAO (2008)

A jointly developed modelling system, based on the OECD's Aglink and FAO's Cosimo models is used in the analysis. To give some idea of the sensitivity of the baseline to alternative assumptions regarding these factors, the economic model underlying those projections was used to perform sensitivity analysis. Two kinds of simulations were performed. In one, five versions of the baseline were simply reproduced, progressively replacing original assumptions about key determining variables with plausible alternative values. In the second, a stochastic simulation was undertaken wherein the assumptions of normal weather and a stable macroeconomic environment are replaced by a range of plausible yield values and macroeconomic variables.

In the first simulation, projections of world agricultural commodities prices are made for 2008-2017 for 5 different scenarios: (1) constant biofuel production at 2007 level; (2) scenario 1 and constant oil prices at 2007 level; (3) Scenario 2 and Lower income growth in EE5 countries (half annual growth rate); (4) Scenario 3 and Progressive appreciation of the USD exchange rates to reach 10% higher rates in 2017; (5) Scenario 4 and yields for wheat, oilseeds and coarse grains 5 % higher than over the projection period.

The second scenario shows that wheat, coarse grains and vegetable oil price projections are all shown to be highly sensitive to petroleum-price assumptions. This sheds light on the important role that the recent sharp escalation in crude oil prices is playing in driving up food commodity costs. This single external factor not only is a crucially important feature of the macroeconomic context but also directly affects the energy costs of agricultural production, transportation, and food processing. Many countries tend to have better economic growth if the oil price is low, but others benefit from a high oil price. Under the constant oil price assumption, the prices of maize and vegetable oil are about 10% lower and the wheat price falls 7% in 2017 when compared with the baseline projection.

36. Parsons et al. (1978)

Authors use input-output model of UK agriculture to estimate the effect of increased oil price. Reaction coefficients are incorporated into basic input-output model. It is assumed that, in every sector, entrepreneurs have the objective of maintaining the ratio of profit to market price, and have sufficient market power to raise prices to the necessary degree, and this allows to derive new price change equation.

Agricultural sector from UK 1971 input-output table is decomposed into 34 sub-sectors, it includes spring/winter wheat, barley, oats; sugar beet; maincrop potatoes; field beans; carrots; livestock (different kinds of meat producers); dairy. Authors estimate 5 different subcases: (1) all the reaction coefficients are zero; (2) all the reaction coefficients are 1; (3) wages react to commodity price movements, import prices are held constant; (4) import prices react to commodity price movements, wages are held constant; (5) both wages and import prices to react to commodity price movements;

The obtained results suggest that agriculture as a whole is not really any more strongly affected by the oil-price increase than the economy as a whole. The percentage cost/price changes for comparison being (in sub-cases 1, 3, 4 and 5) 3.72 vs. 3.18, 9.43 vs. 8.45, 6.42 vs. 6.00 and 34.72 vs. 32.60. It should be noticed that the cereals producing sectors are affected to an extent above the agricultural sectors' mean.

37. Raulston et al. (2005)

Authors use farm-level simulation model (FLIPSIM) developed by Richardson and Nixon (1986) to estimate the impacts of increases in energy prices on net incomes of representative farms in 10 western states of the USA. The FLIPSIM model draws random crop yields, livestock production variables, and prices from a multivariate empirical probability distribution allowing projections to incorporate production and price risk.

The following fuel cost scenarios are analyzed

- Baseline - Assumed the percent change in Consumer Price Index from the FAPRI 2005 Baseline is the annual inflation rate for fuel related expenditures (custom application cost, irrigation fuel, tractor fuel and lube, drying and hauling) and nitrogen fertilizer, i.e., fuel and fertilizer prices increased 1.6 to 2.3% per year;
- "Average" - Used historical inflation rates for fuel from a more favorable era, 1996-1999, to calculate an average inflation rate (5.97%) as the assumed inflation rates for fuel related expenses and nitrogen fertilizer throughout the 2003-2009 study period;
- "FAPRI" - Utilized inflation rates for fuel related expenses and nitrogen fertilizer from the FAPRI August 2005 Baseline.

Net cash farm income was calculated for thirty representative farms. "It is found that, farms with less energy consumption and farms that share a portion of the energy costs with landowners are less vulnerable to the rising costs, but no one is completely insulated from this trend. The results suggest that farmers will likely face increasing cashflow pressures that may accelerate their adoption of energy conserving crop rotation patterns and production systems."

38. Sands et al. (2011)

Authors analyze the flow of energy prices through the agricultural system, from farm to retail. It is assumed that carbon emissions regulation will lead to the increase in energy prices. To assess the impact authors, construct three scenarios: a reference scenario of agricultural production for 2012-2018, and two alternative scenarios with low and high energy price increases. Low increase scenario assumes 3.2% petroleum, 5.4% natural gas and 10.7 electricity prices increase. High increase scenario assumes 6.6-7.8% petroleum, 13.4% natural gas and 14% electricity price increases. Authors use Food and Agriculture Policy Simulator (FAPSIM) and the Farm-Level Partial Budget Model.

Impacts of carbon dioxide emissions regulation on electricity, natural gas and petroleum products are taken from the studies by U.S. Environmental Protection Agency and the U.S. Energy Information Administration. These impacts are used as input to FAPSIM to estimate national agricultural sector effects. The Farm-Level Partial Budget Model is used to convert national impacts into changes in farm business net cash income. Then, regression analysis is used to estimate the effect of increased farm-gate prices on retail food prices, including energy costs in processing and distribution. Crops studied are corn, sorghum, barley, oats, wheat, rice, upland cotton, and soybeans.

Main findings are: energy-related costs vary highly for different crops, with the highest for corn and rice and lowest for soybeans. Total acreage for the eight studies decreases on average for 0.2 (low price change scenario) and 0.4 (higher price scenario) percent over 2012-2018. Planted area decreases for all the crops,

except for soybeans. Besides that, producers of fertilizer-intensive crops like cotton suffer higher cash income decline. In terms of effect on farm county economies and populations, no substantial impact is found.

Analyzed scenarios did not account for potential technology changes due to sustained energy price increase. Declining trend in energy use per unit of output in the agricultural sector is likely to continue, which is only partly represented in the scenarios by increasing yields. For these reasons, impacts found in the scenario may be somewhat overestimated.

39. Taghizadeh-Hesary et al. (2019)

Study examines linkages between energy prices and agricultural products prices in several Asian economies. Authors use Panel-VAR model. Dependent variable is agriculture food price in a country, and explanatory variables are agriculture land used, global oil price, real interest rate, price inflation rate, employment in agriculture sector, GDP, biofuel prices, exchange rate. Data used is panel dataset consisting of variables mentioned above, covering 2000-2016 for Bangladesh, PRC, Indonesia, India, Japan, Sri Lanka, Thailand and Vietnam.

It is found that food price has a positive response to any impulse from global oil price and biofuel price and negative response to impulse from interest rate. Other variables show no significant impact on food price.

40. Tewari and Kulshreshtha (1988)

Authors use sectoral price-endogenous quadratic model to estimate impact of rising prices of energy-related inputs. Comparative static approach is used, so authors (1) estimate baseline solution of a model, (2) change the parameter (price of energy-related inputs) and solve model again, (3) compare the obtained results. Authors create two alternative scenarios, in which prices for oil and natural gas double and triple. Impacts analyzed are impact on energy use and expenditures; impact on crop composition, yield and land use pattern; impact on gross farm income, net returns over energy-related inputs and consumer surplus.

The limitation of methodology is such that it captures only short- to medium-term impacts, since in the long-term, production technology is not fixed and substitution between energy and non-energy inputs would take place.

Main findings: energy prices increase affects quantity of outputs, low-value crops are hit more severely than the high value crops; under the doubled energy prices scenario, prices for crops and livestock increase by about 20% and 10% respectively; rising energy prices induce producers to curtail energy use; fertilizer consumption would decline by an amount greater than that estimated for fuel (due to inelastic demand); despite reduced energy consumption, energy expenditures are still expected to rise significantly.

41. Tewari et al. (1989)

Using quadratic programming sector model of Saskatchewan agriculture, similar to Tewari (1988), magnitudes of rising energy-price impacts are estimated for cases of different trade-demand elasticities, which producers might face.

42. Tokgoz et al. (2008)

Using partial equilibrium modelling approach, impact of increased crude oil prices and drought on biofuel (ethanol) crops production (sugarcane and corn, soybean, wheat) is estimated. The structure used is a modeling system that contains models of supply and demand for important temperate agricultural products in all major producing and consuming countries in these markets. The underlying modeling approach relies and expands upon a recently created biofuels model that extends an already established multimarket model of world agriculture and food markets

The baseline is set up using U.S. and international commodity models calibrated on 2006 historical data. Projections cover 2007/08 – 2016/17 marketing years. Two alternative scenarios are analyzed: (1) 10\$ crude oil price increase and (2) drought scenario (reduced yields). In the second scenario, yield patterns from the 1988 drought are used to reduce yields in barley, corn, soybeans, and wheat in the 2012-13 marketing year.

The increased oil price is found out to have positive impact on corn production: 11% increase in acreage and production, 20% increase in farm gate price, 30% export reduction and 12% reduction of corn feed use. On the other hand, impact on wheat and soybeans is quite the opposite: 6% reduction of planted area, 8.5% and 6.6% (wheat and soybean, respectively) reduction in production, but still 9% farm gate price increase.

43. Türkekul and Unakitan (2011)

The study aims to estimate the long- and short-run relationship of energy consumption, agricultural GDP, and energy prices via cointegration and error correction (ECM) analysis. Authors model the demand for per-capita agricultural diesel/electricity consumption as a function of per-capita real agricultural GDP, real diesel/electricity prices, and substitute prices. The long-run income and price elasticities of demand for diesel are 1.47 and 0.38, respectively. For the electricity, income and price elasticities were found to be 0.19 and 0.72, respectively.

44. Uri and Boyd (1997)

Authors analyze impact of the increased energy prices on the Mexico economy. They use Computable General Equilibrium model (comparative static) with 13 production and 14 consumption sectors, government and 4 types of households. Year 1988 is taken as a baseline and alternative scenario with 26.2% increased prices for gasoline and electricity is designed. For agriculture, no significant change for equilibrium price and -0.22% decrease of equilibrium quantity was found.

45. Uri (1998)

Study similar to Uri (1996), author uses Granger causality to study the effect of the fluctuations in crude oil prices on the use of conservation tillage in the USA. Data used covers 1967-1997, includes crude oil price as a proxy for the price of energy (simple correlations are 0.93, 0.97, and 0.96 between the unit price of crude oil and the unit prices of diesel fuel, gasoline, and liquefied petroleum gas, respectively over the period 1970-1997), and conservation tillage use data from Conservation Technology Information Center annual reports.

Autoregressive model is estimated and then causality tests are implemented. The results indicate unidirectional causality running from the price of crude oil to the percentage of total planted acres on which conservation tillage is used during the period.

To quantify this relationship, logistic regression is used, with total planted acres devoted to conservation tillage being the dependent variable, and crude oil price is an explanatory variable. The results are significant, but small: a 10% increase in the real price of crude oil leads to 0.4% increase in the total planted acres devoted to conservational tillage.

46. Uri (1996)

Granger causality is used to determine whether fluctuations in crude oil prices have effect on agricultural employment. Data used is 1947-1995 time series of crude oil prices (deflated) and agricultural employment. Model used in the study is autoregressive-moving average.

The results of this study suggest that at least part of the trend in agricultural employment can be explained by the changes in the crude oil price. Results suggest that the increase in the real price of crude oil on average has accounted for an annual decrease in the agricultural employment of approx. 0.21%.

47. Vincent et al. (1979)

A general equilibrium model of Australian economy (ORANI 78) is used to estimate the short-term effect of domestic oil price increases on the Australian economy and agricultural sector in particular. Model consists of 109 industry sectors, agriculture is disaggregated into six product groups: sheep, cereal grains, meat cattle, milk cattle and pigs, poultry and other farming. The core of the model database consists of the ABS 1968/69 Input-Output (I/O) tables. 4 key assumptions are implemented in the model: (a) fixed industry specific capital stocks (implies the results are short-run); (b) fixed real aggregate consumption, investment and government spending (indicates that the simulations abstract from any effects which oil prices may have on real domestic absorption); (c) a slack labor market for all occupations with 100 per cent indexation of wage costs to the ORANI consumer price index; and (d) a fixed exchange rate.

The alternative scenario analyzed is the 40% post-refinery oil price increase. Model results suggest the following impacts on agriculture: a contraction in aggregate employment of 0.8% and in employment of rural workers of 2.8%; contractions in the outputs of export oriented agricultural industries of about 0.9% to 1.8%; contractions in the incomes of export oriented farm industries of 6-8% in real terms.

48. Wang and McPhail (2014)

Authors use structural VAR model to examine the impacts of energy price shocks on agricultural productivity in the U.S. and commodity prices' volatility. Model is specified as follows:

$$A_0 x_t = \alpha + \sum_{i=1}^p A_i x_{t-i} + \varepsilon_t$$

, where x is a vector of five annual variables (US gasoline price index, US agricultural total factor productivity, real US agricultural export, US GDP, and US farm commodity price index).

The results indicate that an energy price shock has a negative impact on productivity growth in the short run (1 year). An energy price shock and an agricultural productivity shock each account for about 10 percent of U.S. agricultural commodity price volatility with the productivity shock's contribution slightly

higher. However, the impact from energy prices outweighs the contribution of agricultural productivity in the medium term (3 years). With more persistent impacts, energy shocks contribute to most (about 15%) of commodity price's variation in the long run.

49. Du and McPhail (2012)

Authors examine dynamic evolutions of ethanol, gasoline and corn daily prices over the period of March 2005 – March 2011. First, a GARCH model is estimated and a structural change is found around March 2008 in the pairwise dynamic correlations between the prices. A structural VAR (SVAR) model is then estimated on two subsamples, one before and one after the identified change point. In the more recent period, ethanol, gasoline, and corn prices are found to be more closely linked with a strengthened corn-ethanol relation. Variance decomposition shows that for each market a significant and relatively large share of the price variation could be explained by the price changes in the other two market.

50. Zaferiou et al. (2018)

Paper examines relationships between crude oil-corn and crude oil-soybean using ARDL cointegration approach. Data used is July 1987 – February 2015 futures prices for corn, soybean, and oil, indexed based on August 1999 price. Futures prices are chosen because they incorporate all available information and thus are more efficient at identifying shocks.

Authors apply ARDL bounds cointegration process to estimate relationship between corn/soybean prices with crude oil prices. Then, having validated the existence of cointegration, the Unrestricted Error Correction Modes is estimated. The results derived indicate the existence of interactions among agricultural commodities and crude oil prices, as expected.

3. Review of changes in cost shares of production of agricultural and food commodities in Ukraine before and after the Russian invasion

To assess the impact of the Russian invasion on agriculture production we compare costs structure before and after the invasion. Mean values of 2017-2019 cost shares obtained from SH-50 and SH-29 forms are taken as a baseline for comparison (the latest pre-invasion data available is 2019). Data of costs structure after the invasion was obtained from the producers' interviews. A total of 57 respondents who produced wheat, corn, sunflower, soybeans, barley or peas were interviewed. Production costs structures for the six selected crops before and after the invasion are presented below in tables 3-1 – 3-6. Additionally, we surveyed five organic producers and obtained expert-level data.

The limitation of this costs map is that the latest pre-invasion data available is 2019 data. Thus, the observed changes in costs structure might also capture the impact of Covid-19 crisis, as well as other factors in 2020-2021.

Table 3-1: Costs structure of wheat production before and during the war (conventional production technology)

Costs	Crop		
	Wheat		
Period	Before war (mean 2017-2019)	After invasion (2022)	Share change, percentage points
Direct material cost, including:			
Mineral fertilizers	22.6%	34.5%	11.90%
Fuel (oil and gas for machinery) and lubricants	14.4%	33.6%	19.20%
Remaining direct material costs (including seeds and planting material)	20.1%	12.1%	-8.00%
Labor costs (including payments for third party services)	19.7%	11.0%	-8.75%
Land costs	23.1%	8.8%	-14.35%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

Table 3-2: Costs structure of corn production before and during the war (conventional production technology)

Costs	Crop		
	Corn		
Period	Before war (mean	After invasion (2022)	Share change, percentage points

Costs	Crop		
	Corn		
	2017-2019)		
Direct material cost, including:			
Mineral fertilizers	18.7%	24.3%	5.6%
Fuel (oil and gas for machinery) and lubricants	9.9%	12.6%	2.7%
Remaining direct material costs (including seeds and planting material)	22.4%	19.5%	-2.9%
Labor costs (including payments for third party services)	26.4%	29.3%	2.9%
Land costs	22.6%	14.3%	-8.3%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

Table 3-3: Costs structure of sunflower seed production before and during the war (conventional production technology)

Costs	Crop		
	Sunflower seeds		
Period	Before war (mean 2017-2019)	After invasion (2022)	Share change, percentage points
Direct material cost, including:			
Mineral fertilizers	20.2%	25.3%	5.1%
Fuel (oil and gas for machinery) and lubricants	14.4%	12.4%	-2.0%
Remaining direct material costs (including seeds and planting material)	22.9%	21.1%	-1.7%
Labor costs (including payments for third party services)	19.6%	26.0%	6.3%
Land costs	22.9%	15.2%	-7.7%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

Table 3-4: Costs structure of peas production before and during the war (conventional production technology)

Costs	Crop		
	Peas		
Period	Before war (mean	After invasion (2022)	Share change, percentage points

Costs	Crop		
	Peas		
	2017-2019)		
Direct material cost, including:			
Mineral fertilizers	14.6%	25.5%	10.9%
Fuel (oil and gas for machinery) and lubricants	11.0%	26.6%	15.6%
Remaining direct material costs (including seeds and planting material)	20.7%	8.9%	-11.8%
Labor costs (including payments for third party services)	30.9%	21.6%	-9.2%
Land costs	22.9%	17.4%	-5.4%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

Table 3-5: Costs structure of barley production before and during the war (conventional production technology)

Costs	Crop		
	Barley		
Period	Before war (mean 2017-2019)	After invasion (2022)	Share change, percentage points
Direct material cost, including:			
Mineral fertilizers	10.1%	14.2%	4.1%
Fuel (oil and gas for machinery) and lubricants	19.5%	13.5%	-6.0%
Remaining direct material costs (including seeds and planting material)	26.3%	22.7%	-3.7%
Labor costs (including payments for third party services)	26.0%	17.0%	-9.0%
Land costs	18.1%	32.6%	14.6%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

Table 3-6: Costs structure of soybeans production before and during the war (conventional production technology)

Costs	Crop		
	Soybeans		
Period	Before war (mean	After invasion (2022)	Share change, percentage points

Costs	Crop		
	Soybeans		
	2017-2019)		
Direct material cost, including:			
Mineral fertilizers	16.5%	21.4%	4.9%
Fuel (oil and gas for machinery) and lubricants	12.1%	16.4%	4.3%
Remaining direct material costs (including seeds and planting material)	21.1%	20.2%	-1.0%
Labor costs (including payments for third party services)	26.9%	23.3%	-3.6%
Land costs	23.5%	18.8%	-4.7%

Source: own elaboration based on 50-SH and 29-SH forms and agricultural producers survey.

From the map of costs, it is seen that fertilizer costs increased relative to other categories. Depending on a crop, increase in fertilizer cost share ranges from 4.1 percentage points up to 11.9 percentage points. Fuel share increased on average for all crops except for barley and sunflower (-0.04 and -0.02, respectively). The most significant fuel share increase is observed for peas and wheat production (0.16 and 0.19, respectively). Labor, land and miscellaneous material costs shares have mostly decreased after the invasion, with a few exceptions. Land costs share in barley production have increased by 14.6 percentage points, and labor share in sunflower production have increased by 6.3 percentage points.

To assess the change in technology in 2022, as compared to the pre-war situation, we calculate the per-hectare use of production inputs, as presented in Table 3-7. Calculations of pre-war use are made with the 2017-2019 data obtained from SH-29 and SH-50 forms. Agricultural producers survey data is used to calculate the post-war 2022 use of inputs. Per-hectare use of inputs is calculated as expenditures divided by price and divided by total area. Due to heterogeneous nature of “other material costs” category, its pre-invasion and after-invasion are not comparable, and, thus, not reported.

Table 3-7. Per-hectare use of production inputs.

Wheat		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	0.26	0.30
Fuel, ton	0.06	0.07
Fertilizer, 100 kg	2.66	2.99
Land, hectare	1.00	1.00
Corn		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	0.44	0.34
Fuel, ton	0.07	0.07
Fertilizer, 100 kg	3.31	2.03

Land, hectare	1.00	1.00
Sunflower		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	0.25	0.29
Fuel, ton	0.07	0.18
Fertilizer, 100 kg	2.85	5.56
Land, hectare	1.00	1.00
Soybeans		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	0.61	0.38
Fuel, ton	0.07	0.15
Fertilizer, 100 kg	2.84	1.14
Land, hectare	1.00	1.00
Barley		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	0.26	0.47
Fuel, ton	0.07	0.18
Fertilizer, 100 kg	3.35	7.55
Land, hectare	1.00	1.00
Peas		
	Use per hectare, average 2017-2019	Use per hectare, 2022
Labor, 1 month	2.22	0.17
Fuel, ton	0.18	0.03
Fertilizer, 100 kg	5.39	0.29
Land, hectare	1.00	1.00

Source: own calculations based on 2017-2019 data from SH-29 and SH-50 forms and 2022 data from agricultural producers' survey.

In wheat production technology remained relatively unchanged. Only a slight increase in the use of fuel, fertilizer and labor is observed. Corn production – use of fuel remained unchanged, but a decrease in labor and fertilizer use is observed (-23% and -39%). Use of fuel and fertilizer doubled in sunflower production. For soybeans production use of fuel doubled, while use of fertilizer decreased by 60%. In peas production per-hectare amount of labor, fuel and fertilizer decreased. For barley production, change in use of inputs is similar to the sunflower production, increase in fuel and fertilizer use is observed.

The limitation of these estimates is that the latest pre-invasion data available is from 2019. Thus, causes of the observed changes might be related to Covid-19 crisis in 2020-2021, as well as other factors, such as the launch of land market in 2020.

For wheat flour, expert interviews of the Ukrainian Millers Association have been conducted. The costs structure changes for a wheat producer on along “farm-to-fork” chain is presented in the table below.

Table 3-8. Per-kg percentage shares of costs of production of wheat flour.

Direct material cost, including:			
Energy (fuel, electricity, gas)	3.72%	4.39%	0.67%
Labor	2.07%	2.10%	0.04%
Materials	80.17%	68.53%	-11.64%
Capital costs (including rent and amortization)	1.51%	2.48%	0.97%
Other inputs	12.53%	22.50%	9.96%
Total expenses			8.01%

Source: own calculations based expert interviews

Additionally, survey of organic agricultural producers has been conducted. Data of costs structure before and after the invasion was obtained from them. 395 contacts of organic farmers were obtained from the organic certification body Organic Standard and state register of organic producers.⁷ Due to small number of certified organic producers in Ukraine, the number of potential respondents was highly limited. Among the 31 respondents who agreed to take part in survey, only 5 produced the crops of our interest.

Production costs structures for wheat and barley before and after the invasion are presented below in tables 3-9 – 3-10. Due to small sample size, these numbers are viewed not as a representative comparison, but rather as an illustrative material.

Table 3-9. Costs structure of organic wheat production before and during the war (N=3).

Year	Share of organic fertilizer	Share of mineral Fertilizer	Share of fuel	Share of labor	Share of third-party services	Share of land	Share of other material inputs
2021	0.04	0.00	0.07	0.49	0.09	0.22	0.09
2022	0.07	0.06	0.07	0.31	0.13	0.28	0.08

Source: own calculations, based on survey of organic producers.

Table 3-10. Costs structure of organic barley production before and during the war (N=2).

Year	Share of organic fertilizer	Share of mineral fertilizer	Share of fuel	Share of labor	Share of third-party services	Share of land	Share of other material inputs
2021	0.02	0.03	0.04	0.32	0.06	0.14	0.39
2022	0.11	0.04	0.07	0.32	0.06	0.26	0.14

Source: own calculations, based on survey of organic producers.

⁷ Organic Standard. <https://organicstandard.ua/clients>

Due to the fact that organic production relies less on machinery and mineral fertilizer use, magnitude of relative change in expenditures is found to be small. For wheat production, labor costs share decreased (49% to 31%), and share of expenditures on fertilizers, services and land increased.

For barley production, shares of expenditures on fertilizers, services, and land are found to increase as well, while the biggest decrease is observed for miscellaneous material inputs, other than fertilizer and fuel.

Among the surveyed farms, increase in sown areas is observed for wheat, barley, sunflower, and soybeans. The only crop for which sown area decreased in 2022, as compared to 2021, is corn (-25%). The highest increase in sown area is observed for barley (+22%).

Table 3-11. Changes in sown land area (organic production)

Crop	Change in area (2021-2022)
Wheat	7%
Corn	-25%
Barley	22%
Sunflower	6%
Soybeans	10%

Source: own calculations, based on survey of organic producers.

3.1 Questionnaires

The questionnaire for agricultural producers of conventional technology was conducted in Ukrainian and is provided here in the original Ukrainian version and the translated English version.

Структура собівартості за видами продукції сільського господарства

1. Чи вирощували ви пшеницю, кукурудзу, соняшник, ячмінь, сою, горох в 2022 році?
2. Якщо так, яка була посівна площа під цими культурами?
3. Якщо посівна площа >50 га:
 - 3.1. Якими були витрати на насіння та посадковий матеріал в 2022 році? (тис. грн.)
 - 3.2. Якими були витрати на мінеральні добрива та засоби захисту рослин в 2022 році? (тис. грн.)
 - 3.3. Якими були витрати на пальне та мастильні матеріали в 2022 році? (тис. грн.)
 - 3.4. Якою була решта матеріальних витрат в 2022 році? (тис. грн.) (будівельні матеріали, запасні частини, матеріали для ремонту, тощо)
 - 3.5. Якими були витрати на працю в 2022 році? (тис. грн.)
 - 3.6. Якими були витрати на оплату послуг сторонніх організацій в 2022 році? (тис. грн.)
 - 3.7. Якими були витрати на оренду землі в 2022 році? (тис. грн.)
4. Середньорічні ціни в 2022 році:
 - 4.1. Якою була ціна дизельного палива? (за тонну)
 - 4.2. Якою була середня ціна закуплених мінеральних добрив? (за центнер)

- 4.3. Якою була ціна оренди землі? (за гектар)
- 4.4. Якою була ціна насіння / посадкового матеріалу? (за кг)
- 4.5. Якою була середня місячна заробітна плата найманого робітника?

Cost structure by types of agricultural products

1. Did you grow wheat, corn, sunflower, barley, soybeans, peas in 2022?
2. If yes, what was the sown area for these crops?
3. If the sown area >50 hectares:
 - 3.1. What were the expenses for seeds and planting material in 2022? (thousand UAH)
 - 3.2. What were the expenses for mineral fertilizers and plant protection agents in 2022? (thousand UAH)
 - 3.3. What were the expenses for fuel and lubricants in 2022? (thousand UAH)
 - 3.4. What were the remaining material costs in 2022? (thousand UAH) (building materials, spare parts, materials for repairs, etc.)
 - 3.5. What were the labor costs in 2022? (thousand UAH)
 - 3.6. What were the expenses for payment of services by external organizations in 2022? (thousand UAH)
 - 3.7. What were the expenses for land lease in 2022? (thousand UAH)
4. Annual average prices in 2022:
 - 4.1. What was the price of diesel fuel? (per ton)
 - 4.2. What was the average price of purchased mineral fertilizers? (per hundredweight)
 - 4.3. What was the land rental price? (per hectare)
 - 4.4. What was the price of seeds/planting material? (per kilogram)
 - 4.5. What was the average monthly wage of hired workers?

The questionnaire for organic producers has been prepared and used in Ukrainian. Below the original Ukrainian and the translated English versions are demonstrated.

Добрий день/ранок/вечір.

Я представляю Агроцентр Київської школи економіки, що виконує проєкт Європейського Банку Реконструкції та Розвитку. Ми проводимо опитування, що має дати змогу краще зрозуміти вплив підвищених цін на енергоресурси на виробників органічної сільськогосподарської продукції, та розробити відповідні рекомендації для уряду України.

В жодному з документів, розроблених за результатами опитування, не буде вказано ні ваше ім'я, ні назву вашої організації. Участь в опитуванні добровільна й ніяк не впливає на доступ до будь-яких державних послуг, виплат та доступу до пільг. Ви можете відмовитися від участі в будь-який момент.

Ми були би дуже вам вдячні якби ви могли приділити до 30 хвилин вашого часу, щоб прийняти участь в опитуванні?"

Наступні формулювання можна використати як відповіді на питання респондентів:

«Звідки у вас мій номер телефону?» - «Вашу установу було вибрано випадковим чином для участі в опитуванні, номер телефону взято з відкритих джерел в інтернеті»

«Я маю декілька побажань/ зауважень щодо опитування, куди я можу звернутись?» - «Якщо у вас виникли питання чи зауваження з приводу опитування, просимо вас зв'язатися за електронною адресою agrifood@kse.org.ua яка вказана на сайті КШЕ Агроцентру»

Блок 1. Культури і посівні площі

1.1 Які культури ви вирощували в 2022 році з використанням органічного підходу до виробництва:

- Пшениця
- Кукурудза
- Ячмінь
- Соняшник
- Соя
- Горох

1.2. Які культури ви вирощували в 2021 році з використанням органічного підходу до виробництва:

- Пшениця
- Кукурудза
- Ячмінь
- Соняшник
- Соя
- Горох

1.3. Якою була посівна площа під зазначеними культурами (пшеницею, кукурудзою, ячменем, соняшником, соєю, горохом) в 2022 році

1.4. Якою була посівна площа під зазначеними культурами (пшеницею, кукурудзою, ячменем, соняшником, соєю, горохом) в 2021 році

Блок 2. Виробничі витрати в 2022 році

2.1. Якими були витрати на мінеральні добрива та засоби захисту рослин в 2022 році? (тис. грн.) (якщо використовувались)

2.2. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)

2.3. Якими були витрати на паливе та мастильні матеріали в 2022 році? (тис. грн.)

2.4. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)

2.5. Якою була решта матеріальних витрат в 2022 році? (тис. грн.) (насіння, будівельні матеріали, запасні частини, матеріали для ремонту, тощо)

2.6. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)

2.7. Якими були витрати на працю в 2022 році? (тис. грн.)

2.8. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)

- 2.9. Якими були витрати на оплату послуг сторонніх організацій в 2022 році? (тис. грн.)
- 2.10. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)
- 2.11. Якими були витрати на оренду землі в 2022 році? (тис. грн.)
- 2.12. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)
- 2.13. Якими були витрати на органічні добрива в 2022 році? (тис. грн.) (якщо використовувались)
- 2.14. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.1)? (у %)

Блок 3. Виробничі витрати в 2021 році

- 3.1. Якими були витрати на мінеральні добрива та засоби захисту рослин в 2022 році? (тис. грн.) (якщо використовувались)
- 3.2. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.3. Якими були витрати на паливе та мастильні матеріали в 2022 році? (тис. грн.)
- 3.4. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.5. Якою була решта матеріальних витрат в 2022 році? (тис. грн.) (насіння, будівельні матеріали, запасні частини, матеріали для ремонту, тощо)
- 3.6. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.7. Якими були витрати на працю в 2022 році? (тис. грн.)
- 3.8. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.9. Якими були витрати на оплату послуг сторонніх організацій в 2022 році? (тис. грн.)
- 3.10. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.11. Якими були витрати на оренду землі в 2022 році? (тис. грн.)
- 3.12. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)
- 3.13. Якими були витрати на органічні добрива в 2022 році? (тис. грн.) (якщо використовувались)
- 3.14. Яка частина з цієї суми була витрачена на виробництво кожної з рослин, зазначених у питанні (1.2)? (у %)

Блок 4. Середньорічні ціни

- 4.1. Якою була ціна дизельного палива? (за тонну): в 2021 році; в 2022 році.
- 4.2. Якою була середня ціна закуплених мінеральних добрив? (за центнер) (якщо використовувались): в 2021 році; в 2022 році.
- 4.3. Якою була ціна оренди землі? (за гектар): в 2021 році; в 2022 році.
- 4.4. Якою була середня місячна заробітна плата найманого робітника?: в 2021 році; в 2022 році.

4.5. Якою була середня ціна закуплених органічних добрив? (за центнер): в 2021 році; в 2022 році.

Блок 5. Обсяг виробництва

5.1. Скільки було зібрано врожаю в 2022? (тон)

за культурами:

- Пшениця
- Кукурудза
- Ячмінь
- Соняшник
- Соя
- Горох

5.2. Скільки було зібрано врожаю в 2021? (тон)

за культурами:

- Пшениця
- Кукурудза
- Ячмінь
- Соняшник
- Соя
- Горох

Good day/morning/evening. I represent the Agrocenter of the Kyiv School of Economics, executing a project for the European Bank for Reconstruction and Development. We are conducting a survey aimed at better understanding the impact of increased energy resource prices on organic agricultural producers and developing corresponding recommendations for the government of Ukraine. None of the documents resulting from this survey will contain your name or the name of your organization. Participation in the survey is voluntary and will not affect access to any government services, payments, or benefits. You can opt out of participation at any time. We would greatly appreciate it if you could spare up to 30 minutes of your time to participate in the survey.

The following statements can be used as responses to respondents' questions: "Where did you get my phone number?" - "Your institution was randomly selected to participate in the survey, and the phone number was taken from publicly available sources on the internet." "I have some suggestions/complaints regarding the survey, where can I address them?" - "If you have any questions or complaints about the survey, please contact us via the email address agrifood@kse.org.ua, which is indicated on the KSE Agrocenter website."

Block 1: Crops and Cultivated Areas 1.1 Which crops did you grow in 2022 using an organic production approach:

- Wheat
- Corn
- Barley
- Sunflower
- Soy
- Peas

1.2 Which crops did you grow in 2021 using an organic production approach:

- *Wheat*
- *Corn*
- *Barley*
- *Sunflower*
- *Soy*
- *Peas*

Block 2: Production Costs in 2022

2.1. What were the expenses for mineral fertilizers and plant protection products in 2022? (thousands of UAH) (if used)

2.2. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.3. What were the expenses for fuel and lubricants in 2022? (thousands of UAH)

2.4. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.5. What were the remaining material costs in 2022? (thousands of UAH) (seeds, construction materials, spare parts, repair materials, etc.)

2.6. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.7. What were the labor costs in 2022? (thousands of UAH)

2.8. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.9. What were the expenses for payment of services from external organizations in 2022? (thousands of UAH)

2.10. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.11. What were the expenses for land rental in 2022? (thousands of UAH)

2.12. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

2.13. What were the expenses for organic fertilizers in 2022? (thousands of UAH) (if used)

2.14. What portion of this amount was spent on the production of each of the plants mentioned in question (1.1)? (in %)

Block 3: Production Costs in 2021

3.1. What were the expenses for mineral fertilizers and plant protection products in 2022? (thousands of UAH) (if used)

3.2. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)

3.3. What were the expenses for fuel and lubricants in 2022? (thousands of UAH)

3.4. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)

3.5. What were the remaining material costs in 2022? (thousands of UAH) (seeds, construction materials, spare parts, repair materials, etc.)

3.6. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)

- 3.7. What were the labor costs in 2022? (thousands of UAH)
- 3.8. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)
- 3.9. What were the expenses for payment of services from external organizations in 2022? (thousands of UAH)
- 3.10. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)
- 3.11. What were the expenses for land rental in 2022? (thousands of UAH)
- 3.12. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)
- 3.13. What were the expenses for organic fertilizers in 2022? (thousands of UAH) (if used)
- 3.14. What portion of this amount was spent on the production of each of the plants mentioned in question (1.2)? (in %)

Block 4: Average Annual Prices

- 4.1. What was the price of diesel fuel? (per ton): in 2021; in 2022.
- 4.2. What was the average price of purchased mineral fertilizers? (per hundredweight) (if used): in 2021; in 2022.
- 4.3. What was the price of land rent? (per hectare): in 2021; in 2022.
- 4.4. What was the average monthly wage of hired workers?: in 2021; in 2022.
- 4.5. What was the average price of purchased organic fertilizers? (per hundredweight): in 2021; in 2022.

Block 5: Production Volume

- 5.1. How much crop was harvested in 2022? (tons) for crops:

- Wheat
- Corn
- Barley
- Sunflower
- Soy
- Peas

- 5.2. How much crop was harvested in 2021? (tons) for crops:

- Wheat
- Corn
- Barley
- Sunflower
- Soy
- Peas

3.2 Surveys statistics

The survey of organic producers provided only with 5 relevant responses. The rest of 29 interviewees did not grow the crops of interest. The summary of the survey is presented below. The five interviewees were located on the West, North-East, North and Center of Ukraine. Overall, 387 producers were contacted.

Location	Result
Kyiv oblast	Completed interview
Ternopil oblast	Completed interview
Kyiv oblast	Completed interview
Poltava oblast	Completed interview
Odesa oblast	Completed interview
Ternopil oblast	Completed interview
Vinnytsya oblast	Completed interview
Volyn oblast	Completed interview
Kyiv oblast	Completed interview
Lviv oblast	Completed interview
Poltava oblast	Completed interview
Zakarpattia oblast	Completed interview
Dnipro oblast	Completed interview
Symtska oblast	Completed interview
Ivano-Frankivska oblast	Completed interview
Kyiv oblast	Completed interview
Volyn oblast	Completed interview
Kyiv oblast	Completed interview
Volyn oblast	Completed interview
Volyn oblast	Completed interview
Sumy oblast	Completed interview
Zakarpattia oblast	Completed interview
Kharkiv oblast	Completed interview
Vinnytsya oblast	Completed interview
Poltava oblast	Completed interview
Kyiv oblast	Completed interview
Zaporizka oblast	Completed interview
Odesa oblast	Completed interview
Volyn oblast	Completed interview
Volyn oblast	Completed interview
Vinnytsya oblast	Completed interview
Vinnytsya oblast	Completed interview
Volyn oblast	Completed interview
Vinnytsya oblast	Completed interview
Zhytomyr oblast	Completed interview
Ternopil oblast	Completed interview
Vinnytsya oblast	Completed interview

The statistics of the survey of 57 conventional producers is presented below.

Row Labels	Average of s_seeds	Average of s_land	Average of s_fert	Average of s_labor	Average of s_serv	Average of s_mat	Average of s_fuel	SUM
Wheat	0.0714	0.3327	0.1906	0.1298	0.0125	0.0737	0.1893	1
Barley	0.0564	0.3263	0.1421	0.1191	0.0506	0.1702	0.1353	1
Corn	0.1141	0.1429	0.2431	0.1253	0.1674	0.0814	0.1258	1
Peas	0.0098	0.1744	0.2549	0.1274	0.0891	0.0788	0.2656	1
Soybeans	0.0298	0.1883	0.2140	0.1733	0.0594	0.1717	0.1636	1
Sunflower	0.0716	0.1524	0.2530	0.2011	0.0586	0.1397	0.1237	1
Wheat	0.0719	0.0876	0.3451	0.0635	0.0461	0.0493	0.3365	1
Grand Total	0.063744	0.20254892	0.23495185	0.139238864	0.06308556	0.11120262	0.1852278	1

4. Energy price change impacts: estimation of production inputs demand (short- and long-run) elasticities

This chapter describes the estimation of production inputs' price elasticities of demand. The first section presents the methodology developed according to the past research and provides theoretical background. Data description and sample summary statistics are provided in the second section. Estimation of the production inputs demand elasticities, including preliminary data analysis, model fitting and model diagnostics are presented in the third section. The last section presents the results.

4.1 Methodology

To assess the changes in the inputs mix and agricultural production technology as responses to the change in energy prices, we estimate own-price elasticities of demand for inputs and elasticities of substitution.

4.1.1 Own-price elasticities of demand for inputs and elasticities of substitution

Analysis of demand for energy is one of the research areas dedicated to assessing the impacts of changing energy prices on agriculture (see the literature review). The purpose of estimation of own- and cross-price elasticities of demand for production inputs is to measure responses to changes in energy prices. Elasticity of substitution allows to assess how difficult it is to adjust the production to the change in energy prices.

Past studies mostly review aggregated agricultural production of a given country, only differentiating crops and livestock production. Studies by Gopalakrishnan (1989), Adelaja (1986), Lambert (2010) and Fei (2022) estimate both, the price elasticities of demand and elasticities of substitution (ES). Lambert (2010) uses formulation of ES suggested by Morishima (1967), while the rest of the studies mentioned above use partial Allen-Uzawa formulation of ES. Moss (2010) and Turkekul (2011) estimate only own-price elasticities. To our knowledge, the only study, in which short-term price elasticities of input demand were estimated along with the long-term ones, is Lambert (2010). Author uses dynamic translog cost function to differentiate between long- and short-run adjustments to energy price changes.

Price elasticity of demand is defined as a percentage change in the demanded quantity of good X per one percent change in its own (own-price elasticity) or other good's price (cross-price elasticity). In case of demand for production inputs, elasticities are derived from the cost function (Nicholson, 2012):

$$(1) C = f(y, \mathbf{w})$$

where C is total costs of production, y is output, and $\mathbf{w}$ is a vector of input prices.

Using Shephard's lemma, input demand functions are derived:

$$(2) x_i(\mathbf{w}, y) = \frac{\partial C(\mathbf{w}, y)}{\partial w_i}$$

Own- and cross-price elasticities are estimated directly from the input demand functions:

$$(3) \varepsilon_{ii} = \frac{\partial x_i(w, y)}{\partial w_i} \times \frac{w_i}{x_i} - \text{own-price elasticity of demand for input } i;$$

$$(4) \varepsilon_{ij} = \frac{\partial x_i(w, y)}{\partial w_j} \times \frac{w_j}{x_i} - \text{cross-price elasticity of demand for input } i \text{ with respect to price of input } j;$$

The elasticity of substitution (s_{ij}) is designed as a measure of the ease with which the varying factor can be substituted for others. It is defined as a ratio of the percentage change in production factor proportions to a one percent change in the respective inputs' prices. Large values of s_{ij} indicate that firms change their input proportions significantly in response to changes in relative input prices, whereas low values indicate that changes in input prices have relatively little effect. Shephard's lemma allows to derive it from the cost function:

$$(5) s_{ij} = \frac{\partial \ln(C_i/C_j)}{\partial \ln(w_j/w_i)}, \text{ where } C_i \text{ and } C_j \text{ are the partial derivatives of the total cost function with respect to prices of inputs } i \text{ and } j.$$

The alternative definition of the elasticity of substitution is Allen-Uzawa elasticity of substitution (Allen, 1938; Uzawa, 1962). It builds directly on the production function-based definition of the elasticity of substitution:

$$(6) A_{ij} = \frac{C_{ij}C}{C_i C_j}, \text{ where the subscripts indicate partial differentiation with respect to various input prices.}$$

Using Shephard's lemma, Allen-Uzawa elasticity of substitution can be rewritten as:

$$(7) A_{ij} = \frac{\varepsilon_{ij}}{s_j}.$$

One more elasticity of substitution is the one proposed by Morishima. It is defined as the percentage change in the input quantity ratio divided by the percentage change in the MRS⁸ (or price ratio) among the two inputs, staying constant the production level and all the other marginal rates of substitution (price ratios). (Morishima, 1967):

$$(8) \sigma_{ij}^M = \frac{\partial \log(x_i/x_j)}{\partial \log(f_j/f_i)}, \text{ where } f_i \text{ and } f_j \text{ denote partial derivatives of the production function with respect to inputs } i, j.$$

Blackorby and Russell (1981, 1989) later argued that the Allen-Uzawa elasticity of substitution preserves none of the salient properties of the original Hicksian notion (elasticity of substitution as logarithmic derivative of a quantity ratio with respect to a technical rate of substitution or price ratio) and proposed the elasticity formulated by Morishima as a better alternative. Koizumi showed that Morishima elasticity of substitution can be rewritten in terms of price elasticities of demand for inputs as follows (Koizumi, 1976):

$$(9) \sigma_{ij}^M = \varepsilon_{ij} - \varepsilon_{jj}$$

⁸ Marginal rate of substitution

4.1.2 Short-run implications

Short-term and long-term do not have precise temporal definition, as production technologies differ highly. For agricultural crop production, we can assume that a short term is a period of no more than one marketing year, implying that during the growing season, it is impossible to change the capital costs, which include amount of rented land, equipment and depreciation of assets. What could be changed in the short-run is amounts of fertilizer and labor, wages, machinery maintenance, and other variable costs.

Considering the inability of producers to adjust costs to the changes in market conditions in the short run, assumption about firms being in the (long-term) equilibrium⁹ could not be satisfied. As quasi-fixed¹⁰ costs can not adjust to the equilibrium values in the short-run, in the short-run firms are in equilibrium only with variable costs¹¹, conditional on the levels of other inputs.

4.1.3 Outline of the empirical model

Methodology is based on the study by Gopalakrishnan et al. (1989), which uses pooled cross-section data to estimate price elasticities of demand for production inputs. System of cost share equations is estimated as seemingly unrelated regressions. From obtained regression coefficients, own- and cross-price elasticities of input demand, as well as substitution elasticities are estimated. Berndt (1996) argues that a combination of cost and cost share functions in regression can reduce the possible multicollinearity problem, so the cost function equation is added to the system.

In our case, we are aiming to estimate short-run elasticities in addition to the long-run ones. Among the papers reviewed, only Lambert (2010) estimated short-run price elasticities of demand for inputs. Dynamic cost function was estimated with time-series data, which is not applicable to the data available in our case. Thus, short-run variable costs function (SRVC) is added to the previously adopted methodology and is estimated separately from the long-run costs function. Translog formulation of SRVC is used according to Berndt (1996), as well as the cost share equations.

So the formulation of the translog short-run variable costs function is adopted from Berndt (1996).

It is needed to estimate short-run variable costs function, which, to our knowledge, was not done in the past research dedicated to the energy demand analysis in agriculture.

The long-term cost function mentioned above is estimated econometrically. It's translog expansion is given as follows:

⁹ A firm is in long-term equilibrium when its marginal revenue equals long-term marginal costs and equals average total costs. Long-term implies considering all of the production cost categories.

¹⁰ Quasi fixed costs are defined here as costs that can be changed in the long-run, such as, quantity of machinery and agricultural land.

¹¹ A firm is in short-term equilibrium when its marginal revenue equals short-term marginal costs and equals average variable costs. Long-term implies considering only variable production costs.

$$\begin{aligned}
(10) \ln C = & \alpha_0 + \sum_{i=1}^N \alpha_i \ln w_i + \alpha_y \ln y \\
& + \frac{1}{2} \sum_{i=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j \\
& + \frac{1}{2} \alpha_{yy} (\ln y)^2 + \sum_{i=1}^N \alpha_{iy} \ln w_i \ln y + u,
\end{aligned}$$

Where w_i, w_j denote prices of respective inputs i and j , and y denotes output. For the homogeneity in prices assumption to hold, the following restrictions should be imposed on the coefficients:

$$(11) \sum_{i=1}^N \alpha_i = 1; \sum_{i=1}^N \alpha_{ij} = 0; \sum_{i=1}^N \alpha_{iy} = 0;$$

Further, Shephard's lemma allows to derive cost share functions of each input as:

$$(12) S_i = \frac{x_i w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_{j=1}^N \alpha_{ij} w_j + \sum_{i=1}^N \alpha_{iy} \ln y + u_i$$

From the input cost share functions, Allen-Uzawa elasticity of substitution is obtained as (Thompson, 1997):

$$(13) \sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \text{ for all } i \text{ and } j, i \neq j; \sigma_{ii} = \frac{\alpha_{ii} + S_i^2 - S_i}{S_i^2} \text{ for all } i;$$

From the elasticity of substitution, the price elasticity of demand for inputs is obtained as (Thompson, 1997):

$$(14) \varepsilon_{ij} = S_j \sigma_{ij} \text{ for all } i \text{ and } j, i \neq j; \varepsilon_{ii} = S_i \sigma_{ii} \text{ for all } i;$$

Morishima elasticities of substitution are estimated as given in the equation (9). To estimate all the coefficients of the cost function, cost share equations given in (12) and cost function equation given in (10) are estimated simultaneously as seemingly unrelated regressions.

Thus, using R statistical software, we are going to estimate the cost function and input cost shares equations as seemingly unrelated regressions using maximum likelihood method:

$$\begin{aligned}
\ln C = & \alpha_0 + \sum_{i=1}^N \alpha_i \ln w_i + \alpha_y \ln y + \frac{1}{2} \sum_{i=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j + \frac{1}{2} \alpha_{yy} (\ln y)^2 + \sum_{i=1}^N \alpha_{iy} \ln w_i \ln y + u \\
S_i = & \frac{x_i w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_{j=1}^N \alpha_{ij} w_j + \sum_{i=1}^N \alpha_{iy} \ln y + u_i,
\end{aligned}$$

where S_i is a share in total costs of cost category i . Cost categories include the following: seeds and planting material; other agriculture goods purchased for production; mineral fertilizers; fuel (oil and gas

for machinery) and lubricants; electricity; fuel (coal, wood, natural gas); spare parts and materials for repairs; direct labor costs; contributions for social purposes; land rental; equipment rental; depreciation and amortization; payment for services of third-party entities. Amount of output is denoted by y and corresponds to “the amount of production in the initially marketed mass” variable from the SH-29 forms. Inputs’ prices are denoted by w and are calculated using data from SH-50 forms as “cost of purchased resources” / “quantity of purchased resources”.

After the system of equations is estimated, Allen-Uzawa and Morishima elasticities of substitution (σ^A , σ^M), as well as own- and cross-price elasticities of demand for inputs (ε) are calculated as follows:

$$\sigma^A_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j}; \quad \sigma^M_{ij} = \varepsilon_{ij} - \varepsilon_{jj}; \quad \varepsilon_{ij} = S_j \sigma_{ij} \text{ for all } i \text{ and } j, i \neq j; \quad \varepsilon_{ii} = S_i \sigma_{ii} \text{ for all } i$$

Short-term cost function differs from the long-term such that the firm is considered to be in the equilibrium in variable costs conditional on non-adjustable quasi-fixed costs, instead of full equilibrium. It is estimated separately from the long-run cost function described above, as the reformulation of cost-function is required. Translog expansion of the short-run variable costs is given as follows:

$$\begin{aligned} (15) \ln C_v = & \alpha_0 + \sum_{i=1}^N \alpha_i \ln w_i + \alpha_y \ln y + \frac{1}{2} \sum_{i=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j \\ & + \frac{1}{2} \alpha_{yy} (\ln y)^2 + \sum_{i=1}^N \alpha_{iy} \ln w_i \ln y + \sum_{k=1}^M \alpha_k \ln x_k \\ & + \frac{1}{2} \sum_{k=1}^M \sum_{l=1}^M \alpha_{kl} \ln x_k \ln x_l + \sum_{k=1}^M \alpha_{ky} \ln x_k \ln y + \sum_{i=1}^N \sum_{k=1}^M \alpha_{ik} \ln w_i \ln x_k + u, \end{aligned}$$

where w denotes prices of corresponding variable inputs i and j , x denotes quantities of corresponding quasi-fixed inputs k and l , and y denotes output. In order to ensure homogeneity in input prices, restrictions from (9) and $\sum_k^M \alpha_{ik} = 0$ should hold. In the short-run, cost shares of inputs become:

$$(16) S_{vi} = \frac{x_i w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_{j=1}^N \alpha_{ij} w_j + \alpha_{iy} \ln y + \sum_{k=1}^M \alpha_{ik} x_k + u_i;$$

Allen-Uzawa and Morishima elasticities of substitution and price elasticities of demand for inputs are obtained as given in the equations (9), (13) and (14). To estimate all the coefficients of the cost function, cost share equations given in (16) and short-run variable cost function equation given in (15) are estimated simultaneously as seemingly unrelated regressions.

Thus, using R statistical software, we are going to estimate the short-term variable cost function and input cost shares equations as seemingly unrelated regressions using maximum likelihood method:

$$\ln C_v = \alpha_0 + \sum_{i=1}^N \alpha_i \ln w_i + \alpha_y \ln y + \frac{1}{2} \sum_{i=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j + \frac{1}{2} \alpha_{yy} (\ln y)^2 + \sum_{i=1}^N \alpha_{iy} \ln w_i \ln y$$

$$+ \sum_{k=1}^M \alpha_k \ln x_k + \frac{1}{2} \sum_{k=1}^M \sum_{l=1}^M \alpha_{kl} \ln x_k \ln x_l + \sum_{k=1}^M \alpha_{ky} \ln x_k \ln y + \sum_{i=1}^N \sum_{k=1}^M \alpha_{ik} \ln w_i \ln x_k$$

$$+ u;$$

$$S_{vi} = \frac{x_i w_i}{C} = \frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_{j=1}^N \alpha_{ij} w_j + \alpha_{iy} \ln y + \sum_{k=1}^M \alpha_{ik} x_k + u_i ;$$

where S_i is a share in total costs of cost category i . Cost categories include the following: seeds and planting material; other agriculture goods purchased for production; mineral fertilizers; fuel (oil and gas for machinery) and lubricants; electricity; fuel (coal, wood, natural gas); spare parts and materials for repairs; direct labor costs; contributions for social purposes; land rental; equipment rental; depreciation and amortization; payment for services of third-party entities. Amount of output is denoted by y and corresponds to “the amount of production in the initially marketed mass” variable from the SH-29 forms. Inputs’ prices are denoted by w and are calculated using data from SH-50 forms as “cost of purchased resources” / “quantity of purchased resources”. Amount of quasi-fixed inputs is denoted by x and is calculated using data from SH-50 forms as expenditures divided by price w_k .

After the system of equations is estimated, Allen-Uzawa and Morishima elasticities of substitution (σ^A , σ^M), as well as own- and cross-price elasticities of demand for inputs (ε) are calculated as follows:

$$\sigma^A_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} ; \quad \sigma^M_{ij} = \varepsilon_{ij} - \varepsilon_{jj} ; \quad \varepsilon_{ij} = S_j \sigma_{ij} \text{ for all } i \text{ and } j, i \neq j ; \quad \varepsilon_{ii} = S_i \sigma_{ii} \text{ for all } i$$

4.1.4 Estimation of impacts on agricultural production quantities and prices

Step I

Using the cost functions estimated in previous section, we can estimate the change in (equilibrium) quantity and price due to increased energy prices. Assuming markets for the agricultural commodities of our interest (wheat, corn, barley, sunflower seed, soybeans, peas) are perfectly competitive, the equilibrium (profit-maximizing) quantity and price are obtained at the intersection of marginal costs and average total costs curves:

$$(17) \quad \frac{TC(Q)}{Q} = \frac{\partial TC(Q)}{\partial Q}$$

Then, from the estimated cost function in (10), marginal costs and average total costs functions are obtained as:

$$(18) \quad \ln MC = \alpha_y + \alpha_{yy} \ln y + \sum_{i=1}^N \alpha_{iy} \ln w_i ;$$

$$(19) \ln ATC = \frac{\alpha_0}{\ln y} + \frac{1}{\ln y} \sum_{i=1}^N \alpha_i \ln w_i + \alpha_y + \frac{1}{2 \ln y} \sum_{n=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j + \frac{1}{2} \alpha_{yy} \ln y + \sum_{i=1}^N \alpha_{iy} w_i ;$$

$$(20) \frac{\alpha_0}{\ln y} + \frac{1}{\ln y} \sum_{i=1}^N \alpha_i \ln w_i + \frac{1}{2 \ln y} \sum_{n=1}^N \sum_{j=1}^N \alpha_{ij} \ln w_i \ln w_j - \frac{1}{2} \alpha_{yy} \ln y = 0$$

By equating $\ln MC = \ln ATC$ and solving the obtained equation (20) for $\ln y$, the equilibrium quantity and price could be obtained. Thus, the impact of increased energy prices on production quantity and price could be assessed by solving the equation using 2021 non-energy inputs' prices and 2022 energy inputs' prices.

Step II

In order to support the estimations of Step I which are based on microeconomic theory, we will run the regressions of production quantities and producer prices against the energy prices. The regressions will use the database described above.

4.2 Data

The data used to estimate the cost function of Ukrainian agricultural producers includes 3241 observations of farm-level cost shares, prices and production quantities. Data includes pooled observations of 2017-2019 and is treated as cross-sectional in the estimation (analysis with similar data was conducted by Adelaja & Hoque (1986)). The idea behind pooling the observations of three years is to increase the sample size as the estimations must be conducted for several crops. The repeated observations have been deleted from the sample in order to avoid the time-series related bias, and the monetary values of variables have been adjusted at 2017 level of prices according to the inflation data by National Bank of Ukraine (NBU).

Production expenditures of agricultural producers were obtained from Section 1 of 50-SH statistical form, submitted by farmers to the State Statistical Service of Ukraine. It includes the following expenditure categories:

- contributions for social purposes;
- depreciation and amortization;
- electricity;
- fuel (coal, wood, natural gas);
- fuel (oil and gas for machinery);
- fertilizer;
- labor;
- land;
- other agriculture goods purchased for production;

- seeds and planting material, mineral fertilizers;
- spare parts and materials for repairs;

Spare parts and materials for repairs, seeds and planting material, and other agriculture goods purchased for production were grouped into a single materials expenditures category. Contributions for social purposes, depreciation and amortization, electricity and fuel (coal, wood, natural gas) were dropped from the dataset because of high number of missing (non-reported) values and low average share in total costs (<2% on average). Thus, cost shares were calculated for the following categories: fuel, fertilizer, labor, land, materials. Observations with costs values equal to zero in two or more categories are considered outliers (imperfectly reported data) and are dropped from the dataset. Cost shares for each of the categories were calculated dividing category expenditure by total costs.

Prices of fuel and fertilizer were calculated based on data from the section 4 of the 50-SH statistical forms, where farmers' materials purchases are reported. Fertilizer price is the aggregate price of all fertilizer types (N, P, K, complex, phosphate flour) purchased by a producer, thus reflecting the exact mix of fertilizers used. Price of land is calculated as land expenditures divided by total sowed area of each respective farmer. Yearly averages of monthly salaries by region in agriculture are obtained from the SSSU and are used as labor price values. Materials price is challenging to estimate due to heterogeneity of materials purchased by different farmers. It is calculated by summing up farmers' expenditures on repair parts, seeds and building materials and dividing them by total quantity of purchased goods. Price variables are deflated at the 2017 level of prices according to the inflation data by NBU. Total production quantity for each farm is obtained from the 29-SH statistical forms.

Producers' specializations are determined based on the sown areas data from the 29-SH statistical forms. Farmer is considered to be a producer of a certain crop if the sown area devoted to the certain crop is >50% of the farmer's total sown area. The dataset is split into 6 separate parts based on main crop produced: wheat, corn, sunflower, barley, soybeans and peas. Due to the low number of observations for barley and peas producers (1 and 6 observations, respectively), these crops were dropped from the estimation.

In the dataset we pool data for 2017, 2018 and 2019 years. Due to different mean values of independent variables for each year's subsample, year dummy variables are added to the model to control for these differences. We do not expect different relationships for different years.

Descriptive statistics of core variables used for cost function estimation is provided in the tables below.

Table 4-1: Descriptive statistics of core variables in the dataset

Variable	Mean	St. dev.	Min	Max
Share of labor costs	0.180275	0.10687	0.021571	0.557230
Share of fuel costs	0.152102	0.059121	0.009944	0.346726
Share of fertilizer costs	0.230693	0.096129	0.036994	0.525937
Share of land costs	0.205021	0.080896	0.021024	0.438812
Share of other material costs	0.231909	0.079923	0.071863	0.504155

Variable	Mean	St. dev.	Min	Max
Total sowed area, hectares	9117.568	18764.08	26.17	119305.5
Price of labor, UAH per month	6175.314	1072.161	4251.38	8961.027
Price of fuel, UAH per ton	19767.45	2330.449	13676.93	27700
Price of fertilizer, UAH per 100 kg	767.1434	116.1007	496.9172	1173.733
Price of land, UAH per hectare	2145.759	881.7425	617.0725	4865.636
Price of other material expenditures, UAH, aggregated	45367.11	112189.1	118.1512	641306.4
Total output, tons	64344.11	108831.5	545	777670.8

Source: own elaboration

Table 4-2: Mean values of core variables across different producer specializations

Variable	Wheat	Corn	Sunflower	Soybeans
Share of labor costs	0.143239	0.210408	0.146489	0.251087
Share of fuel costs	0.167213	0.130075	0.167787	0.137204
Share of fertilizer costs	0.266648	0.213357	0.231883	0.199765
Share of land costs	0.213117	0.19907	0.201579	0.209922
Share of other material costs	0.209783	0.24709	0.252261	0.202022
Total sowed area, hectares	4594.958	19564.09	1765.851	11902.44
Price of labor, UAH per month	5155.488	7028.534	6019.553	6658.303
Price of fuel, UAH per ton	18720.62	20172.63	20495.87	19416.88
Price of fertilizer, UAH per 100 kg	673.2809	807.3045	789.0116	810.5817
Price of land, UAH per hectare	1752.953	2691.877	1871.856	2325.937
Price of other material expenditures, UAH, aggregated	278.3555	71867.37	59484.32	47252.98
Total output, tons	42902.78	126510.4	22977.68	67133.74

Source: own elaboration

Observed cost shares of fuel are higher for wheat & sunflower, as well as shares of fertilizer, while corn and soybeans have higher labor shares. Land cost shares are relatively equal across all 4 producer specializations. Corn and sunflower on average have higher materials cost shares. Sunflower and wheat

are produced by smaller farms (total sown area of 1766 and 4595 hectares on average), while corn and soybeans producers have much higher average total sown areas (19564 and 11902 hectares, respectively).

4.3 Estimation

This section describes the estimation of the regression model, according to methodology presented previously. First sub-section provides preliminary data analysis, with correlation and multicollinearity tests. Obtained regression coefficients are presented and discussed in the second sub-section. Then, in the third sub-section, model diagnostics is provided. It includes tests for influential outliers using Cook's distance and the goodness of fit tests.

4.3.1 Preliminary data analysis

Although some multicollinearity is always present in multiple regression models, severe cases might cause untrue significance levels of the variables (for details see Williams, 2009)¹². In the current analysis examination for multicollinearity is conducted in two steps: (1) estimation of correlation coefficients between the regressors and (2) estimation of Variance inflation factors (VIF).

The second step is the main. VIF value measures the linear association between the regressor and a set of the other regressors. The easiest interpretation of this diagnostic is derived from its formula:

$$VIF_j = \frac{1}{1 - R_j^2}, j = 1, \dots, p \quad (1)$$

where p is the number of predictors in the model; R_j^2 is a coefficient of determination of a linear regression with one of the regressors as dependent variable and the others – as explanatory variables. If R_j^2 approaches 1 which indicates high linear association between the X_j and the other variables, VIF_j approaches infinity. Thus, high value of VIF indicates presence of multicollinearity in the model (Chatterjee and Hadi, 2006). The use of only VIF values is not always sufficient, since they do not indicate what the correlated variables are. To find out the latter, correlation coefficients between pairs of the variables should be estimated.

Since there are only continuous variables, Pearson's correlation coefficient is used to evaluate the association between them (for details see Yount, 2006). Pearson's correlation coefficient ranges from -1 to 1 that indicates strong negative and positive associations respectively. Squared values of these coefficients indicate the percentage of the distribution of one variable explained by the other one. The significance of the coefficients is estimated at the level of 0.05 by a two-tailed t-test statistic with $N-2$ degrees of freedom, where N is the sample size.

¹² Williams, R. (2009). "Multicollinearity." Mimeo., Department of sociology, University of Notre Dame, Notre Dame, Indiana. Available on-line: <http://www.nd.edu/~rwilliam/stats2/l11.pdf> (accessed on 27.10.2010).

Different studies suggest different values of the correlation coefficients as indicators of multicollinearity in the model (Allison, 2001; Carriquiry, 2004; Grewal et al., 2004; Williams, 2009). In the current analysis absolute values of at least $|0.35|$ will be treated suspiciously.

The values of the correlation coefficients between the variables are presented below.

Table 4-3: Correlation coefficients

	lp _{labor}	lp _{fuel}	lp _{fert}	lp _{land}	lp _{mat}	l _q
lp _{labor}	1.000	0.001	0.368	0.310	0.479	0.222
lp _{fuel}	0.001	1.000	0.207	0.090	0.155	-0.042
lp _{fert}	0.368**	0.207	1.000	0.196	0.346	0.075
lp _{land}	0.310	0.090	0.196	1.000	0.189	0.236
lp _{mat}	0.479**	0.155	0.346**	0.189	1.000	0.056
l _q	0.222	-0.042	0.075	0.236	0.056	1.000

Note: l – natural logarithm, labor – price of labor, fuel – price of fuel, fert – price of fertilizer, mat – price of other material expenditures, q – total output, ** - 0.05 significance level

Source: own elaboration

There are three pairs of variables that have values of the correlation coefficients higher or equal than $|0.35|$. Materials price and fertilizer price have correlation coefficient equal to 0.346, labor price and fertilizer price have correlation coefficient equal to 0.368, and materials price has correlation 0.479 with labor price. The correlation coefficients are significant at 5%. These indicate that materials, fertilizer and labor prices are positively correlated.

To further analyse the correlation among the variables, we test the assumption of multicollinearity with VIF. There is no certain cutoff value for VIF that indicates the presence of multicollinearity in the model. In the present analysis the threshold of 2.5, suggested by Allison (2001), is used. Variables with VIF values higher than 2.5 will be deleted from the further analysis step by step. Only those regressors with the values of VIF lower than 2.5 will be left. The values of the VIF are presented below.

Table 4-4: VIF values

Variable	lp _{labor}	lp _{fuel}	lp _{fert}	lp _{land}	lp _{mat}	l _q
VIF	1.031831	1.246570	1.257010	1.047169	1.042336	1.018983

Source: own elaboration

Neither of the variables' VIF values exceeds the threshold of 2.5. Although Pearson's coefficients show relation among the three variables, with VIF not rejecting the hypothesis of no multicollinearity, we continue with fitting the model for all of the independent variables.

4.3.2 Model fitting

According to the methodological approach described previously, long-run total costs and short-run variable costs functions were estimated, separately for each of the selected crops (wheat, corn, sunflower, soybeans). Each of the models is estimated as a system of costs share equations, derived from the translog cost function, and with symmetry (1) and homogeneity (2) restrictions imposed:

$$(2) \alpha_{ij} = \alpha_{ji};$$

$$(3) \sum_{i=1}^N \alpha_i = 1; \sum_{i=1}^N \alpha_{ij} = 0; \sum_{i=1}^N \alpha_{iy} = 0;$$

The number of observations used for the estimation is 854, 917, 960, 503 for wheat, corn, sunflower and soybeans samples, respectively.

Tables 4-6 - 4-9 present coefficient estimates of long-run costs models for the 4 selected crops. Tables 4-10 – 4-13 present coefficient estimates of short-run variable costs models for the 4 selected crops. The first column from the table contains the explanatory variables, dependent variable and constant term. The second column presents estimates of the coefficients. Subscripts on coefficients in the table denote corresponding variables: “l” denotes labor price, “e” denotes fuel price, “f” denotes fertilizer price, “d” denotes land price (in the short-run model, where land is quasi fixed “d” denotes the total acreage of sown area), “m” denotes materials price, “y” denotes total output and 18 and 19 denote 2018 and 2019 binary variables, respectively. Coefficients are not interpreted directly, and used to calculate elasticity estimates, which are presented in the section 5 of this report. “Std. Error” states for the standard error of the coefficient's estimate and “t value” is the t-statistic which tests the significance of the coefficient. “Pr(>|t|)” corresponds to the p-value of t-statistic. In the lower part of the table general estimates of the model are presented. “SSR” is sum of squared residuals and “R2” is McElroy's measure of goodness-of-fit for seemingly unrelated regressions. It can be used to compare the fit of two models but cannot be interpreted as R² for the ordinary least squares regression.

Table 4-5: Wheat production long-run cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	0.05103	0.06769	0.75391	0.45096
α_e	-0.29369	0.06233	-4.71147	0.00000***
α_f	0.08394	0.07887	1.06433	0.28726
α_d	1.12936	0.04157	27.16963	0.00000***
α_m	0.02936	0.25046	0.11721	0.39608
α_{ll}	-0.04409	0.01980	-2.22607	0.02608**
α_{ee}	0.03463	0.01766	1.96060	0.05001**
α_{ff}	0.04842	0.02341	2.06820	0.03870**
α_{dd}	0.12814	0.00480	26.67350	0.00000***
α_{mm}	0.01223	0.19040	0.06422	0.39799
α_{le}	0.02880	0.01399	2.05798	0.03967**
α_{lf}	-0.00963	0.01713	-0.56240	0.57388
α_{ld}	-0.00643	0.00572	-1.12364	0.26124
α_{lm}	0.03136	0.05665	0.55348	0.34212
α_{ef}	-0.00189	0.01421	-0.13287	0.89430
α_{ed}	-0.05517	0.00425	-12.98078	0.00000***
α_{em}	-0.00636	0.05011	-0.12696	0.39561
α_{fd}	-0.03310	0.00706	-4.69200	0.00000***
α_{fm}	-0.00379	0.06180	-0.06131	0.39807
α_{dm}	-0.03343	0.021834	-1.53123	0.123523
α_{ly}	0.00732	0.00234	3.13418	0.00174***
α_{ey}	-0.00531	0.00164	-3.23876	0.00121***
α_{fy}	-0.00019	0.00299	-0.06205	0.95052
α_{dy}	0.00225	0.00181	1.23962	0.21520
α_{my}	-0.00408	0.00878	-0.46409	0.35806
$\alpha_{18,l}$	0.00235	0.00736	0.31942	0.74943
$\alpha_{19,l}$	0.00704	0.00844	0.83331	0.40473
$\alpha_{18,e}$	0.00382	0.00514	0.74291	0.45759
$\alpha_{19,e}$	0.00010	0.00617	0.01545	0.98767
$\alpha_{18,f}$	-0.00504	0.00935	-0.53894	0.58996
$\alpha_{19,f}$	0.02792	0.01011	2.76236	0.00577***
$\alpha_{18,d}$	0.00438	0.00561	0.78025	0.43530
$\alpha_{19,d}$	-0.01035	0.00591	-1.75002	0.08021*
N = 3416	DF = 3390	R2 = 0.239	SSR = 17.999	

Source: own elaboration

Table 4-6: Corn production long-run cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	-0.04169	0.08284	-0.50327	0.61481
α_e	-0.22293	0.04908	-4.54171	0.00001***
α_f	-0.18169	0.05822	-3.12095	0.00182***
α_d	1.26245	0.04129	30.57392	0.00000***
α_m	0.18387	0.23143	0.79447	0.29080
α_{ll}	0.04990	0.02782	1.79353	0.07297*
α_{ee}	0.01198	0.01511	7.93008	0.00000***
α_{ff}	0.05094	0.01571	3.24192	0.00120***
α_{dd}	0.14400	0.00487	29.53862	0.00000***
α_{mm}	-0.10031	0.18667	-0.53740	0.34514
α_{le}	-0.05768	0.01554	-3.71279	0.00021***
α_{lf}	0.05327	0.01751	3.04202	0.00237***
α_{ld}	-0.04603	0.00834	-5.51840	0.00000***
α_{lm}	0.00054	0.06921	0.00777	0.39881
α_{ef}	-0.03838	0.00991	-3.87425	0.00011***
α_{ed}	-0.02306	0.00438	-5.26103	0.00000***
α_{em}	0.10715	0.04494	2.38436	0.02339**
α_{fd}	-0.06668	0.00589	-11.31450	0.00000***
α_{fm}	0.00085	0.04903	0.01741	0.39876
α_{dm}	-0.00822	0.023493	-0.35001	0.375095
α_{ly}	0.00781	0.00274	2.84618	0.00445***
α_{ey}	-0.00582	0.00125	-4.64529	0.00000***
α_{fy}	0.00177	0.00198	0.89371	0.37153
α_{dy}	-0.00443	0.00141	-3.14570	0.00167***
α_{my}	0.00067	0.00739	0.09093	0.39717
$\alpha_{18,l}$	-0.01220	0.01074	-1.13625	0.25593
$\alpha_{19,l}$	-0.03963	0.01259	-3.14873	0.00165***
$\alpha_{18,e}$	0.01631	0.00490	3.33063	0.00088***
$\alpha_{19,e}$	0.04237	0.00673	6.29499	0.00000***
$\alpha_{18,f}$	-0.00130	0.00769	-0.16850	0.86620
$\alpha_{19,f}$	-0.00382	0.00858	-0.44529	0.65614
$\alpha_{18,d}$	0.00752	0.00536	1.40275	0.16078
$\alpha_{19,d}$	0.01741	0.00562	3.09752	0.00197***
N = 3668	DF = 3642	R2 = 0.252	SSR = 21.1637	

Source: own elaboration

Table 4-7: Sunflower production long-run cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	-0.22805	0.07043	-3.23797	0.00121***
α_e	-0.16659	0.05858	-2.84379	0.00448***
α_f	-0.28038	0.06800	-4.12304	0.00004***
α_d	1.39162	0.04117	33.80229	0.00000***
α_m	0.28340	0.23818	1.18984	0.19645
α_{ll}	0.09765	0.02200	4.43813	0.00001***
α_{ee}	0.05866	0.01632	3.59533	0.00033***
α_{ff}	0.09899	0.01798	5.50693	0.00000***
α_{dd}	0.15282	0.00460	33.22199	0.00000***
α_{mm}	0.00138	0.17976	0.00765	0.39881
α_{le}	-0.02439	0.01480	-1.64813	0.09941*
α_{lf}	-0.02969	0.01617	-1.83644	0.06637*
α_{ld}	-0.03821	0.00625	-6.11396	0.00000***
α_{lm}	-0.00536	0.05921	-0.09059	0.39718
α_{ef}	0.00272	0.01162	0.23395	0.81504
α_{ed}	-0.03930	0.00442	-8.88481	0.00000***
α_{em}	0.00230	0.04715	0.04888	0.39834
α_{fd}	-0.07451	0.00618	-12.05140	0.00000***
α_{fm}	0.00249	0.05194	0.04800	0.39836
α_{dm}	-0.00081	0.021455	-0.03769	0.398534
α_{ly}	0.00536	0.00272	1.96970	0.04894**
α_{ey}	-0.00669	0.00169	-3.95577	0.00008***
α_{fy}	0.00887	0.00278	3.18457	0.00146***
α_{dy}	-0.00510	0.00173	-2.95325	0.00316***
α_{my}	-0.00243	0.00892	-0.27264	0.38425
$\alpha_{18,l}$	-0.01286	0.00797	-1.61255	0.10692
$\alpha_{19,l}$	-0.02427	0.01003	-2.42003	0.01557**
$\alpha_{18,e}$	0.01135	0.00492	2.30953	0.02097**
$\alpha_{19,e}$	0.01201	0.00673	1.78477	0.07438*
$\alpha_{18,f}$	0.01221	0.00808	1.51128	0.13080
$\alpha_{19,f}$	0.03588	0.00920	3.89898	0.00010***
$\alpha_{18,d}$	0.00048	0.00496	0.09691	0.92281
$\alpha_{19,d}$	0.00274	0.00541	0.50641	0.61260
N = 3840	DF = 3814	R2 = 0.249	SSR = 23.3962	

Source: own elaboration

Table 4-8: Soybeans production long-run cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	0.07344	0.10060	0.73002	0.46546
α_e	-0.15083	0.06381	-2.36376	0.01819**
α_f	-0.36190	0.08117	-4.45836	0.00001***
α_d	1.16816	0.05973	19.55846	0.00000***
α_m	0.27112	0.30531	0.88801	0.26879
α_{ll}	-0.05833	0.02916	-1.99999	0.04564**
α_{ee}	0.05943	0.01850	3.21336	0.00133***
α_{ff}	-0.01715	0.02167	-0.79119	0.42893
α_{dd}	0.12665	0.00722	17.54462	0.00000***
α_{mm}	0.00330	0.22685	0.01452	0.39878
α_{le}	-0.00793	0.01592	-0.49825	0.61836
α_{lf}	0.10656	0.02067	5.15568	0.00000***
α_{ld}	-0.03328	0.01042	-3.19361	0.00143***
α_{lm}	-0.00702	0.07617	-0.09222	0.39712
α_{ef}	-0.02703	0.01452	-1.86085	0.06291*
α_{ed}	-0.02698	0.00557	-4.84291	0.00000***
α_{em}	0.00251	0.05451	0.04608	0.39839
α_{fd}	-0.06500	0.00804	-8.08016	0.00000***
α_{fm}	0.00261	0.06491	0.04026	0.39849
α_{dm}	-0.0014	0.031255	-0.04464	0.39842
α_{ly}	0.01119	0.00303	3.69799	0.00022***
α_{ey}	-0.00650	0.00140	-4.64984	0.00000***
α_{fy}	0.00523	0.00235	2.22503	0.02619**
α_{dy}	-0.00446	0.00174	-2.55790	0.01060**
α_{my}	-0.00547	0.00852	-0.64199	0.32448
$\alpha_{18,l}$	0.01469	0.01373	1.07038	0.28458
$\alpha_{19,l}$	0.06402	0.01389	4.60994	0.00000***
$\alpha_{18,e}$	0.02471	0.00671	3.68467	0.00024***
$\alpha_{19,e}$	0.01563	0.00734	2.13115	0.03320**
$\alpha_{18,f}$	-0.01474	0.01084	-1.36057	0.17380
$\alpha_{19,f}$	-0.02757	0.01047	-2.63450	0.00849***
$\alpha_{18,d}$	-0.01290	0.00783	-1.64723	0.09967*
$\alpha_{19,d}$	-0.00847	0.00744	-1.13786	0.25532
N = 2012	DF = 1986	R2 = 0.218	SSR = 12.0587	

Source: own elaboration

In the long-run models for wheat around half of the coefficients of the variables are found to be significant at least at 0.1 level. In the long-run models for soybeans, corn and sunflower nearly all of the variables are significant at 0.05 and 0.01 levels. Equation joint significance tests allow to reject the null hypothesis that all coefficients equal to 0 at the 0.05 level for all 4 long-run models.

Table 4-9: Wheat production short-run variable cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	0.09916	0.06814	1.45537	0.14569
α_e	0.38107	0.10004	3.80909	0.00014***
α_f	0.17159	0.06895	2.48869	0.01289**
α_m	0.34817	0.23713	1.46828	0.13572
α_{ll}	-0.02588	0.02606	-0.99317	0.32072
α_{ee}	-0.03213	0.03524	-0.91160	0.36206
α_{ff}	-0.00700	0.02007	-0.34881	0.72726
α_{mm}	0.00454	0.20701	0.02193	0.39872
α_{le}	0.01353	0.02532	0.53410	0.59332
α_{lf}	-0.02215	0.01686	-1.31399	0.18897
α_{ld}	0.02303	0.00327	7.03985	0.00000***
α_{lm}	0.00454	0.20701	0.02193	0.39872
α_{ef}	0.04340	0.02063	2.10309	0.03556**
α_{ed}	-0.01161	0.00402	-2.88489	0.00395***
α_{em}	-0.02479	0.08120	-0.30534	0.38063
α_{fd}	-0.00331	0.00253	-1.30791	0.19102
α_{fm}	-0.01425	0.05756	-0.24753	0.38677
α_{dm}	-0.00811	0.00982	-0.82585	0.28350
α_{ly}	-0.00430	0.00357	-1.20699	0.22755
α_{ey}	0.00881	0.00440	2.00233	0.04536**
α_{fy}	-0.00536	0.00276	-1.94161	0.05229*
α_{my}	0.00085	0.01072	0.07915	0.39757
$\alpha_{18,l}$	-0.00658	0.00907	-0.72542	0.46826
$\alpha_{19,l}$	-0.00179	0.01089	-0.16413	0.86964
$\alpha_{18,e}$	-0.00110	0.01108	-0.09916	0.92102
$\alpha_{19,e}$	0.02903	0.01297	2.23802	0.02531**
$\alpha_{18,f}$	0.01103	0.00702	1.57178	0.11613
$\alpha_{19,f}$	0.00599	0.00800	0.74767	0.45473
N = 2562	DF = 2541	R2 = 0.047	SSR = 22.1911	

Source: own elaboration

Table 4-10: Corn production short-run variable cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	0.01263	0.05867	0.21521	0.82962
α_e	0.57381	0.05922	9.68888	0.00000***
α_f	0.09108	0.04251	2.14242	0.03225**
α_m	0.32249	0.16040	2.01047	0.05303*
α_{ll}	0.05720	0.03505	1.63220	0.10275
α_{ee}	-0.09914	0.02742	-3.61608	0.00030***
α_{ff}	-0.02522	0.01402	-1.79915	0.07211*
α_{mm}	0.00490	0.19476	0.02518	0.39869
α_{le}	0.00690	0.02745	0.25141	0.80151
α_{lf}	-0.06435	0.01734	-3.71214	0.00021***
α_{ld}	0.01769	0.00260	6.80739	0.00000***
α_{lm}	0.00490	0.19476	0.02518	0.39869
α_{ef}	0.09348	0.01435	6.51340	0.00000***
α_{ed}	-0.00146	0.00203	-0.72048	0.47129
α_{em}	-0.00124	0.06922	-0.01797	0.39875
α_{fd}	-0.00960	0.00132	-7.29225	0.00000***
α_{fm}	-0.00391	0.04570	-0.08551	0.39736
α_{dm}	-0.00662	0.00594	-1.11450	0.21425
α_{ly}	-0.00264	0.00357	-0.73804	0.46055
α_{ey}	0.00036	0.00279	0.12879	0.89753
α_{fy}	-0.00225	0.00180	-1.24965	0.21153
α_{my}	0.00453	0.00817	0.55444	0.34194
$\alpha_{18,l}$	-0.00522	0.01240	-0.42062	0.67407
$\alpha_{19,l}$	-0.03905	0.01575	-2.48007	0.01320**
$\alpha_{18,e}$	0.01094	0.00964	1.13425	0.25679
$\alpha_{19,e}$	0.01061	0.01283	0.82732	0.40813
$\alpha_{18,f}$	0.01590	0.00631	2.52191	0.01173**
$\alpha_{19,f}$	0.04926	0.00776	6.35060	0.00000***
N = 2751	DF = 2730	R2 = 0.063	SSR = 26.7895	

Source: own elaboration

Table 4-11: Sunflower production short-run variable cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	0.02877	0.05879	0.48934	0.62464
α_e	0.40778	0.06991	5.83320	0.00000***
α_f	0.20167	0.05044	3.99789	0.00007***
α_m	0.36178	0.17915	2.01946	0.05208*
α_{ll}	0.09791	0.02878	3.40164	0.00068***
α_{ee}	-0.05128	0.02841	-1.80510	0.07116*
α_{ff}	-0.00218	0.01583	-0.13756	0.89060
α_{mm}	0.00148	0.18692	0.00794	0.39881
α_{le}	-0.02061	0.02491	-0.82739	0.40808
α_{lf}	-0.07006	0.01611	-4.34941	0.00001***
α_{ld}	0.00345	0.00612	0.56421	0.57266
α_{lm}	0.00148	0.18692	0.00794	0.39881
α_{ef}	0.06918	0.01594	4.34161	0.00001***
α_{ed}	-0.00691	0.00611	-1.12985	0.25863
α_{em}	0.00270	0.06925	0.03905	0.39851
α_{fd}	0.00037	0.00395	0.09416	0.92499
α_{fm}	0.00305	0.04787	0.06379	0.39801
α_{dm}	0.00308	0.01618	0.19027	0.39165
α_{ly}	0.00349	0.00488	0.71590	0.47411
α_{ey}	0.01164	0.00487	2.39040	0.01689**
α_{fy}	-0.01066	0.00314	-3.39168	0.00070***
α_{my}	-0.00447	0.01289	-0.34684	0.37551
$\alpha_{18,l}$	-0.01418	0.00950	-1.49262	0.13565
$\alpha_{19,l}$	-0.02244	0.01288	-1.74273	0.08149*
$\alpha_{18,e}$	0.01785	0.00941	1.89635	0.05801*
$\alpha_{19,e}$	0.03755	0.01257	2.98785	0.00283***
$\alpha_{18,f}$	0.01715	0.00615	2.78902	0.00532***
$\alpha_{19,f}$	0.02332	0.00775	3.00760	0.00266***
N = 2880	DF = 2859	R2 = 0.036	SSR = 28.7597	

Source: own elaboration

Table 4-12: Soybeans production short-run variable cost function estimation results

Coefficient	Estimate	Std. Error	t value	Pr(> t)
α_l	-0.19243	0.06083	-3.16321	0.00159***
α_e	0.51941	0.07575	6.85737	0.00000***
α_f	0.25232	0.06051	4.17023	0.00003***
α_m	0.42069	0.19708	2.13458	0.04106**
α_{ll}	-0.11128	0.03222	-3.45430	0.00057
α_{ee}	-0.17072	0.03234	-5.27969	0.00000***
α_{ff}	-0.00716	0.01946	-0.36821	0.71277
α_{mm}	0.00241	0.21357	0.01128	0.39879
α_{le}	0.13929	0.02771	5.02618	0.00000***
α_{lf}	-0.02627	0.01751	-1.49978	0.13388
α_{ld}	0.03824	0.00394	9.71608	0.00000***
α_{lm}	0.00241	0.21357	0.01128	0.39879
α_{ef}	0.03277	0.01956	1.67562	0.09402*
α_{ed}	-0.00934	0.00354	-2.63740	0.00844***
α_{em}	-0.00133	0.07960	-0.01676	0.39876
α_{fd}	-0.01554	0.00214	-7.26073	0.00000***
α_{fm}	0.00066	0.05652	0.01171	0.39879
α_{dm}	-0.01336	0.00962	-1.38892	0.15201
α_{ly}	-0.00223	0.00357	-0.62549	0.53175
α_{ey}	0.00784	0.00321	2.44558	0.01458**
α_{fy}	-0.00352	0.00193	-1.82529	0.06816*
α_{my}	-0.00209	0.00871	-0.24032	0.38745
$\alpha_{18,l}$	-0.01408	0.01453	-0.96942	0.33250
$\alpha_{19,l}$	0.03722	0.01686	2.20742	0.02744**
$\alpha_{18,e}$	0.00266	0.01335	0.19937	0.84200
$\alpha_{19,e}$	-0.03227	0.01543	-2.09192	0.03661**
$\alpha_{18,f}$	0.03921	0.00829	4.73068	0.00000***
$\alpha_{19,f}$	0.04371	0.00910	4.80271	0.00000***
N = 1509	DF = 1488	R2 = 0.176	SSR = 13.2555	

Source: own elaboration

In the short-run variable costs models for wheat only a few estimates are significant at least at 0.1 level, for sunflower and corn nearly a half of the coefficients are significant at at least 0.05 level and short-run variable costs models for soybean have nearly all of the coefficients are significant. R2 values are significantly lower for all short-run models, compared to corresponding long-run models.

4.3.3 Model diagnostics

In this subchapter examination of the influential outliers and measurement of fit of the model are performed. Influential outliers are the observations that fit the model poorly but affect the estimates of the parameters (Long and Freese, 2006).

Residuals and influential outliers

The fit of the model to a single observation is examined by estimation of the standardized Pearson residuals. A mathematical expression for the latter is:

$$r_i^{std} = \frac{r_i}{\sqrt{1 - h_{ii}}} \quad (4)$$

where r_i – Pearson's residual, h_{ii} – observation's leverage. Such residuals have constant variance and approximate normal distribution. The larger the value of the residual, the worse the fit of the model to the respective observation (Long and Freese, 2006). In the current analysis large residuals are identified as those that have bigger values in comparison to the others.

To check whether the outlier observations influence model's estimates, Pregibon's approximation to Cook's distance is calculated. This measure has the following mathematical form:

$$P_i = \frac{r_i^2 h_{ii}}{(1 - h_{ii})^2} \quad (5)$$

where r_i – Pearson's residual, h_{ii} – observation's leverage. It assesses how deleting of i-th observation affects the model. This measure is a standardized difference between estimates of the coefficients with and without i-th observation. It is also interpreted as a sum of squared distances between observed and fitted values with and without certain observation (for details see Pregibon, 1981).

As in the case with large residuals, influential observations can be identified from the graph: the farer the observation stands from the others on the plot of Cook's distance (Pregibon's approximation), the more influential it is (Figures 1-4). Cook suggested that a cutoff value for detecting highly influential observations is $P_i > 1$.¹³

¹³ Cook, R. Dennis; Weisberg, Sanford (1982). *Residuals and Influence in Regression*. New York, NY: Chapman & Hall

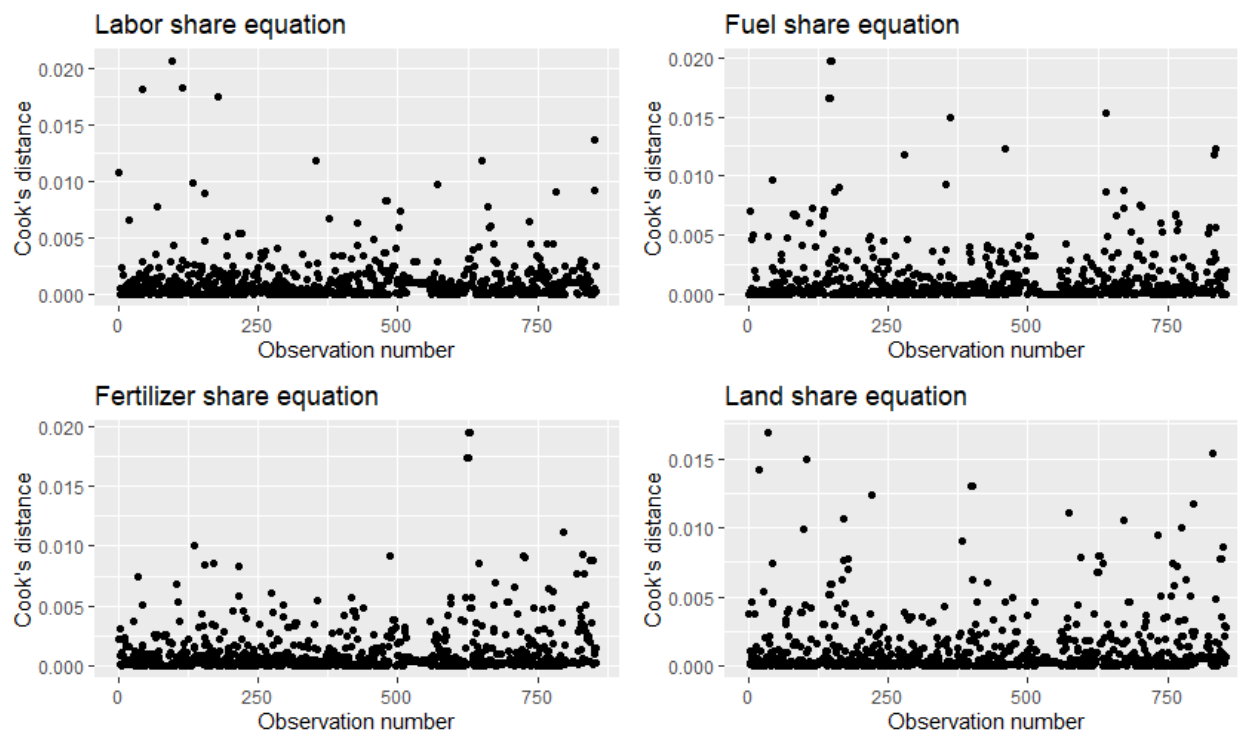


Figure 4-1: Pregibon's approximation to Cook's statistic for the long-run wheat production costs model
Source: own elaboration

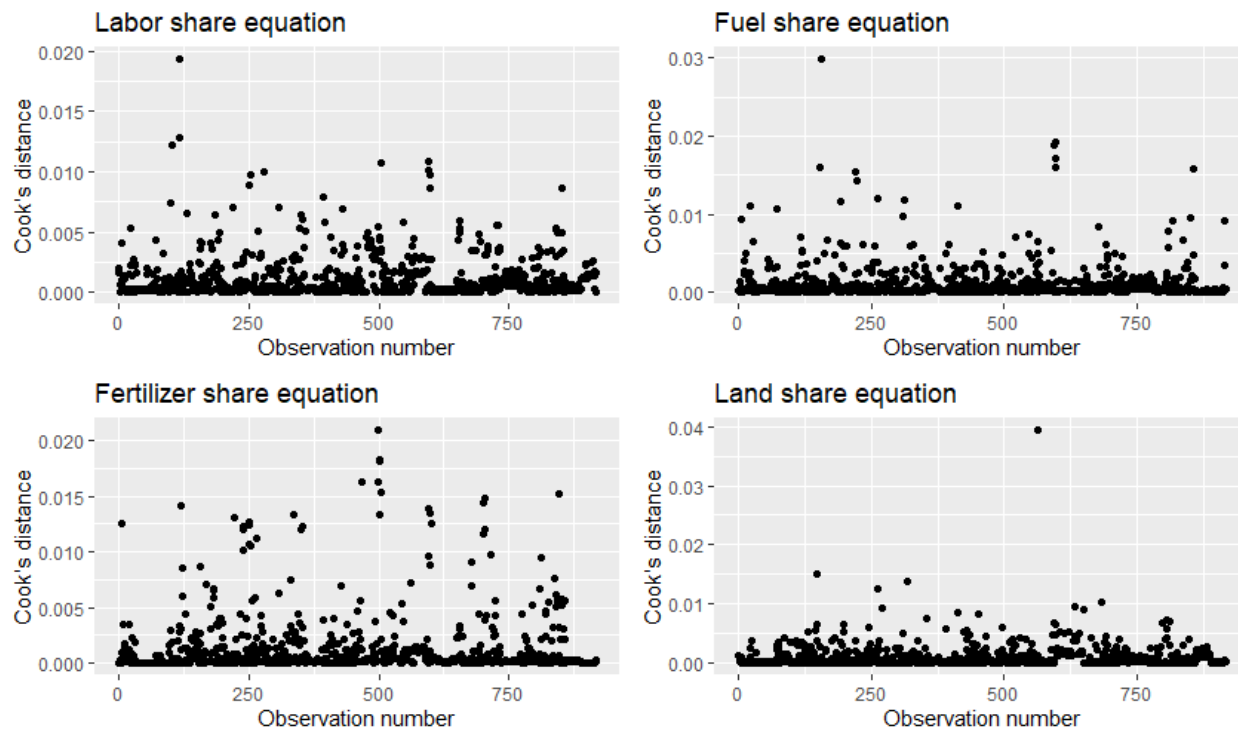


Figure 4-2: Pregibon's approximation to Cook's statistic for the long-run corn production costs model
Source: own elaboration

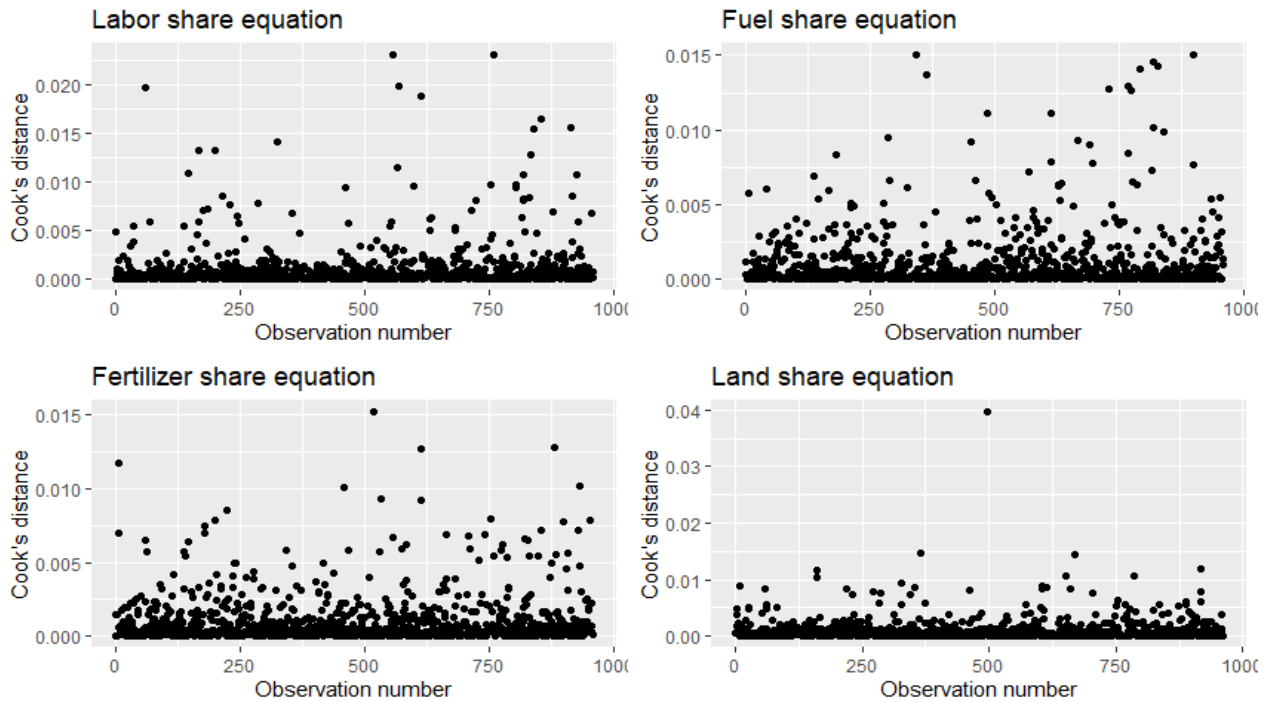


Figure 4-3: Pregibon's approximation to Cook's statistic for the long-run sunflower production costs model
Source: own elaboration

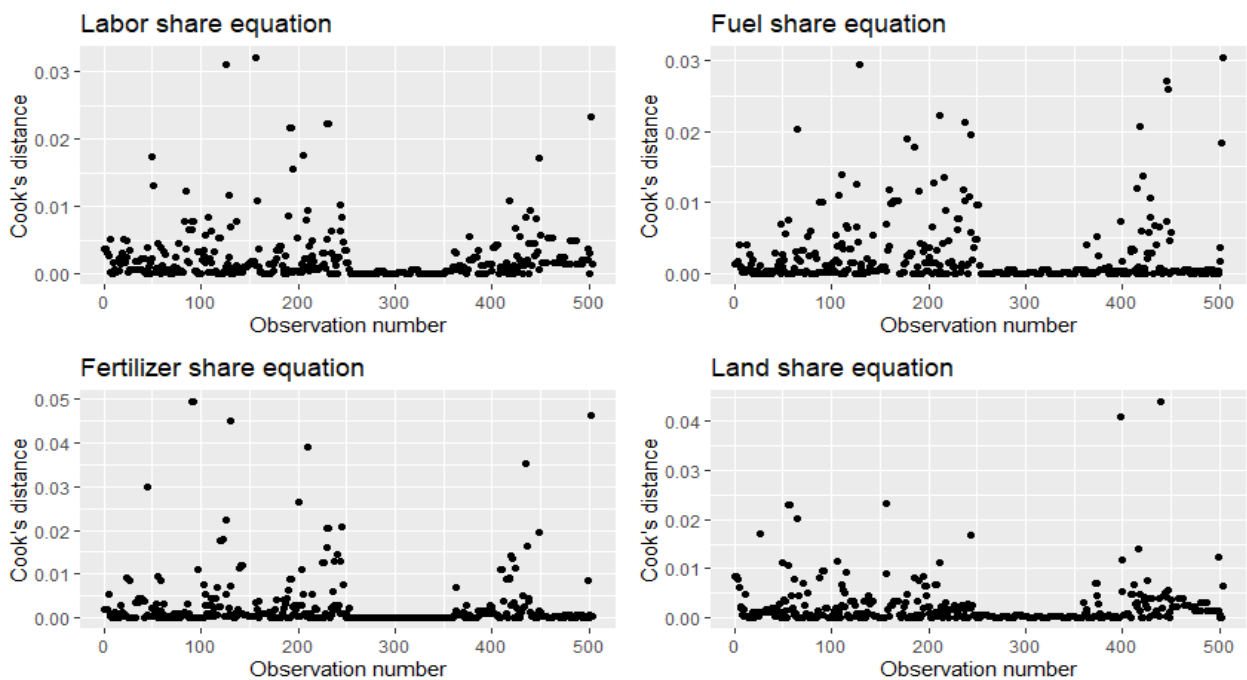


Figure 4-4: Pregibon's approximation to Cook's statistic for the long-run soybeans production costs model
Source: own elaboration

As seen on the figures 4.1-4.4, there are observations which stand out in each of the equations, but values of Cook's distance do not exceed 0.05. Thus, their influence on the estimates of the parameters

is not significant. Therefore, the corresponding observations are kept in the sample. Moreover, these cases represent certain characteristics of the general population which cannot be ignored.

Measurement of fit

Fit of the model is assessed by McElroy-R² statistic and by plotting predicted values against the estimates. This measure has the following mathematical form:

$$(4) \text{ McElroy } R^2 = 1 - \frac{U'W*U}{UY'W*Y'}$$

where U is the vector of residuals, Y is the vector of dependent variables and W is the covariance matrix of residuals. Thus, the statistic is within the interval of [0;1], where 1 is a perfect fit and 0 is an absence of explanatory power. Values of McElroy R² are presented in the table 4-14. Models do not fit the data perfectly, which is partially caused by the restrictions imposed in order for the model to align with the assumptions about agricultural production and microeconomic theory. Fit of the long-run models is noticeably better than the short-run models for wheat, corn and sunflower production. For soybeans production, difference in fit between the short- and long-run models is much lower.

Table 4-13: Values of McElroy-R² of the estimated models

Model	Long-run, wheat production	Long-run, corn production	Long-run, sunflower production	Long-run, soybeans production	Short-run, wheat production	Short-run, corn production	Short-run, sunflower production	Short-run, soybeans production
R ²	0.239327	0.252252	0.249441	0.218215	0.047571	0.063011	0.035692	0.176228

Source: own elaboration

To analyze the fit of the model more in detail, the plots of the dependent variable against predicted variable is produced (Figures 5-8). The values on the X-axis are actual values of the cost shares from the dataset. On the Y-axis – fitted values produced by the estimated models.

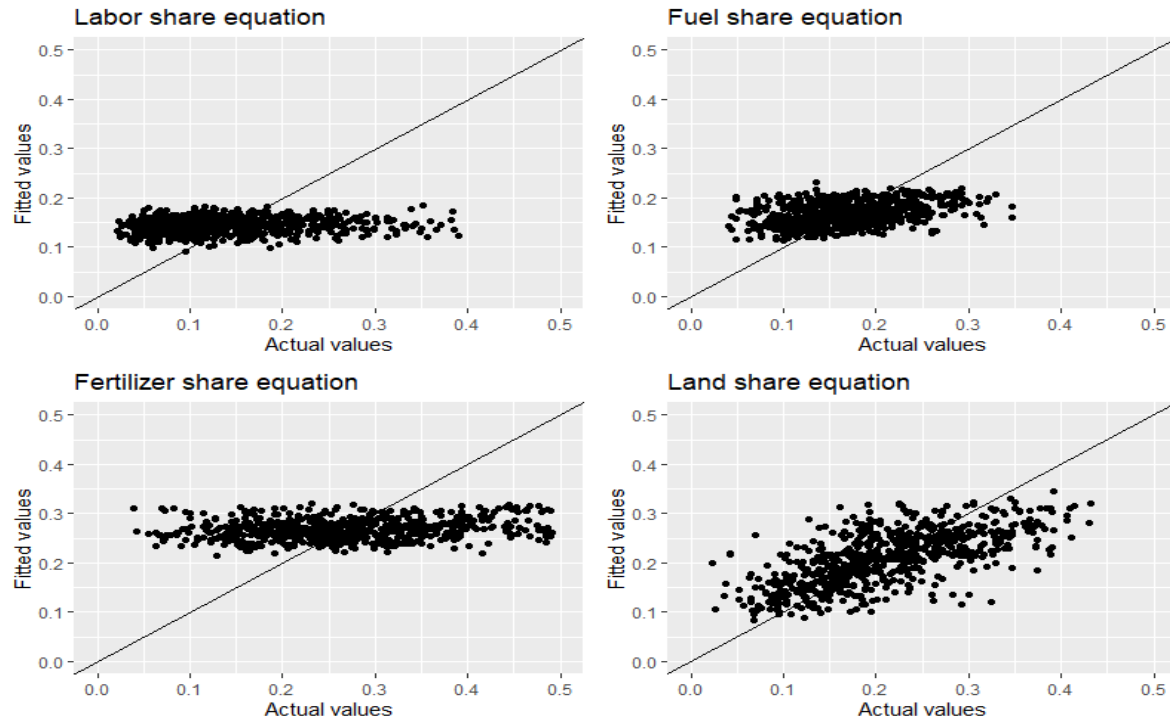


Figure 4-5: Plot of the dependent variable against predicted values of long-run wheat production costs model

Source: own elaboration

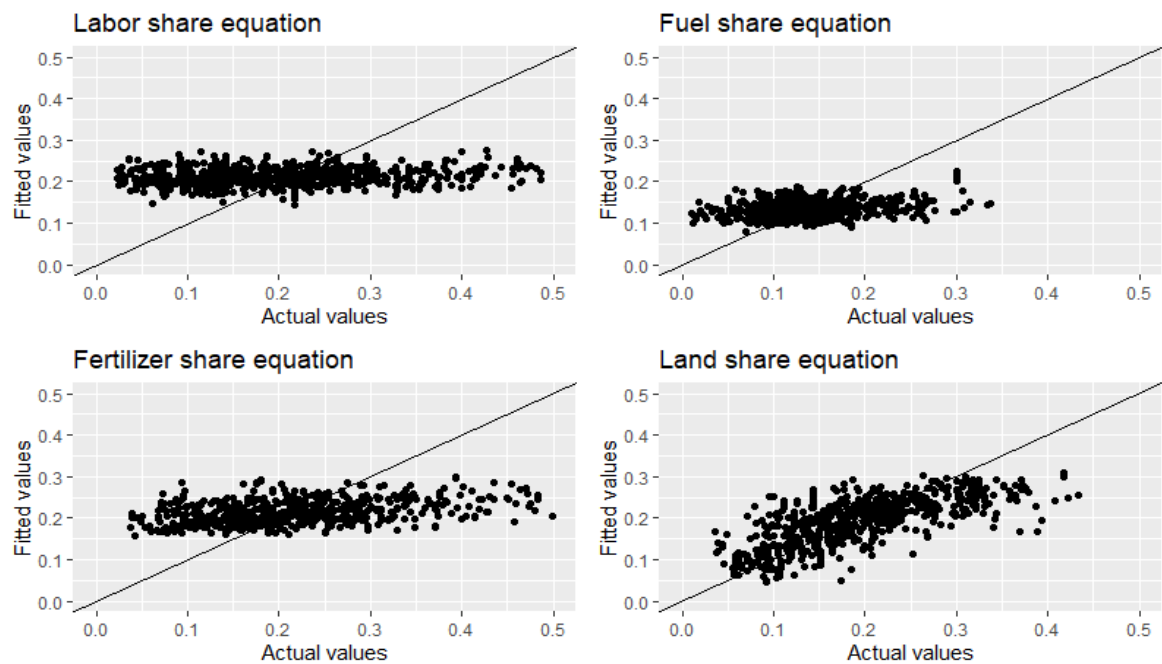


Figure 4-6: Plot of the dependent variable against predicted values of long-run corn production costs model

Source: own elaboration

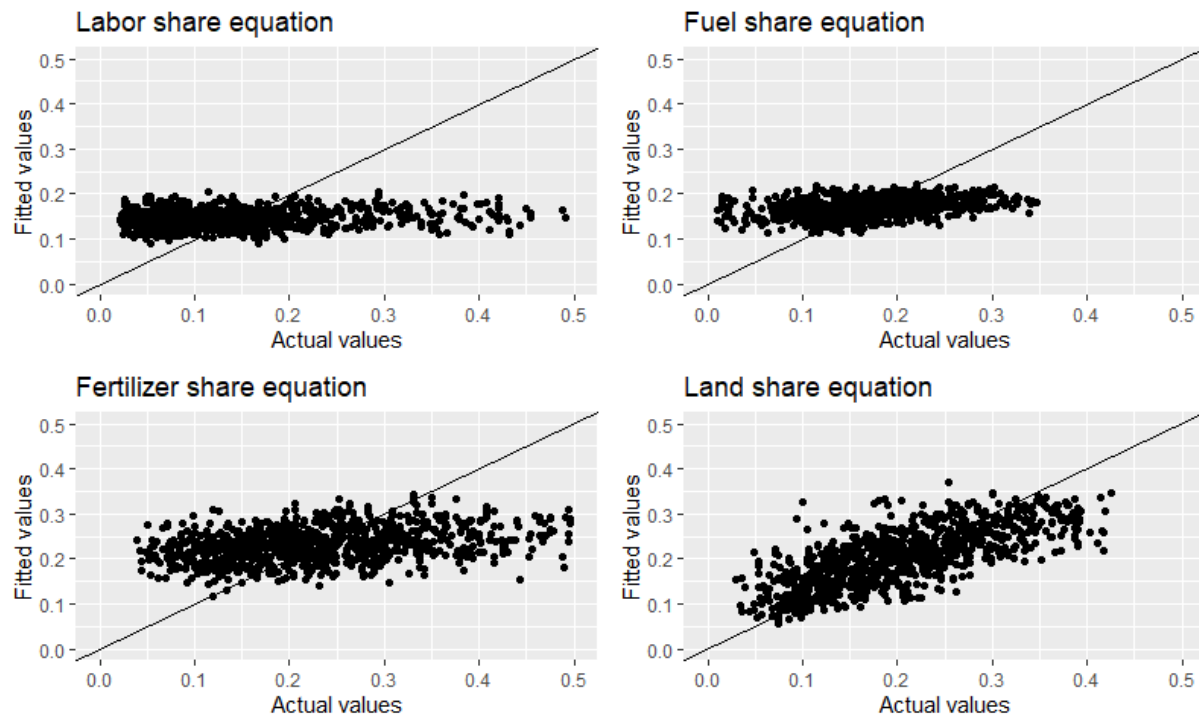


Figure 4-7: Plot of the dependent variable against predicted values of long-run sunflower production costs model

Source: own elaboration

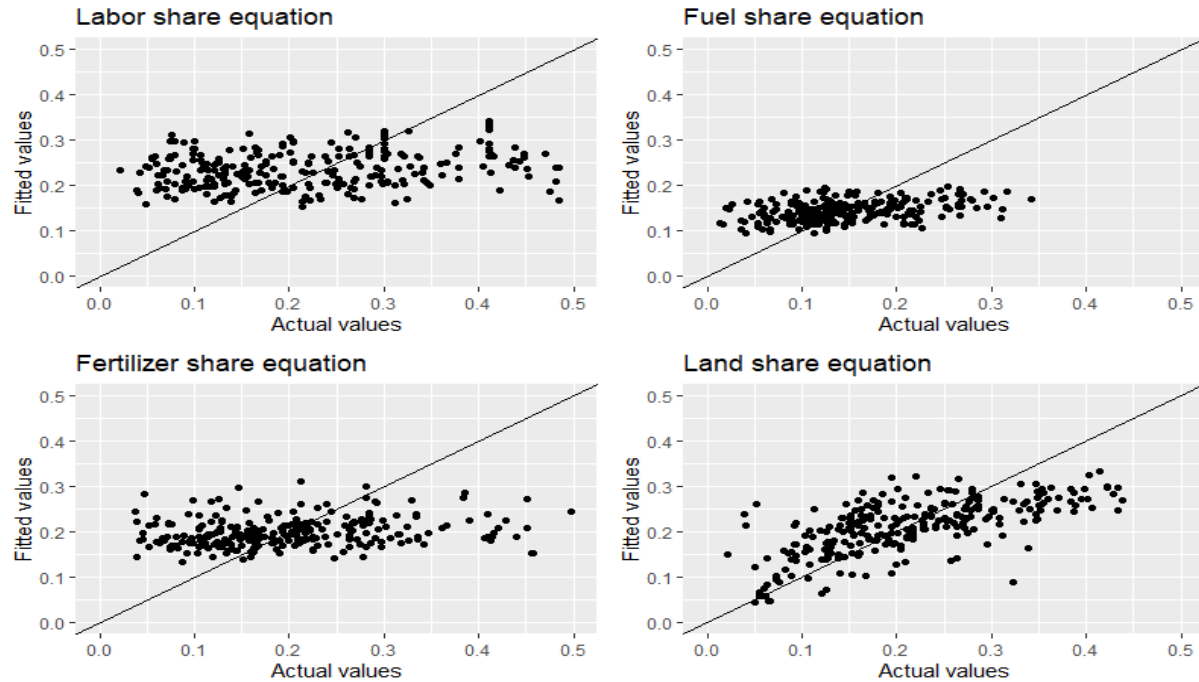


Figure 4-8: Plot of the dependent variable against predicted values of long-run sunflower production costs model

Source: own elaboration

According to Figures 5-8, estimated models are able predict the shares of labor, fuel, and fertilizer costs only when their values are close to the mean. Fitted values of the land costs shares are more accurate, but model still fits poorly for values above 0.3. As it was mentioned before, such imperfection of fit may partly be caused by the restrictions imposed on the model. It as well indicates that the elasticities which will be estimated from these coefficients are point-elasticities, i.e., that the production functions are not of constant elasticity. The latter implies that for every change in price the elasticities are different. Respectively, the models are able to predict well the values around the mean, and fit poorly the rest of the changes. In practical terms, we are able to estimate the elasticities at the mean values of input prices, and these elasticities shall be used with great precaution for predictive analysis.

4.4. Estimation results

Price elasticities of demand for production inputs and substitution elasticities were calculated based on the estimated regression coefficients.

Long-run own-price elasticities of demand for production inputs in wheat, corn, dunflower and soybeans production are presented in Table 14. As expected, demand for both, fuel and fertilizer, are found to be inelastic in the long run. Demand for fertilizer is found to be the least elastic for the production of sunflower (-0.34) and is the most elastic for production of soybeans (-0.89). Own-price elasticity of

demand for fuel ranges from -0.43 (soybeans production) up to -0.78 (corn production). These results are consistent with the past findings by Turkekul (2011) and Gopalakrishnan (1989).

Table 4-14: Long run own-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans

	Wheat	Corn	Sunflower	Soybeans
Labor	-1.16	-0.55	-0.19	-0.98
Fuel	-0.63	-0.78	-0.48	-0.43
Fertilizer	-0.55	-0.55	-0.34	-0.89
Land	-0.19	-0.17	-0.14	-0.17
Materials	-0.73	-1.30	-0.79	-0.77

Source: own elaboration

Long run cross-price elasticities of demand for production inputs are presented in the Table 15. Target of our interest are those elasticities depicting change in demand in response to change in price of fuel and fertilizer. Most of the estimates are fairly low indicating only a little response to price changes. Although, the highest change in use is observed for labor in response to fertilizer price (0.20, 0.47, 0.62 for wheat, corn, and soybeans production, respectively).

Table 4-15: Long-run cross-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans

Wheat					
Change with respect to price of:	Labor	Fuel	Fertilizer	Land	Materials
Labor	-1.16	0.32	0.11	0.11	0.29
Fuel	0.37	-0.63	0.16	-0.09	0.14
Fertilizer	0.20	0.26	-0.55	0.11	0.25
Materials	0.17	-0.12	0.09	-0.19	0.05
Land	0.43	0.17	0.20	0.05	-0.73
Corn					
Change with respect to price of:	Labor	Fuel	Fertilizer	Land	Materials
Labor	-0.55	-0.23	0.46	0.02	0.21
Fuel	-0.14	-0.78	-0.05	0.04	0.67
Fertilizer	0.47	-0.08	-0.55	-0.06	0.22
Materials	0.03	0.07	-0.07	-0.17	0.21
Land	0.20	1.02	0.20	0.17	-1.30
Sunflower					
Change with respect to price of:	Labor	Fuel	Fertilizer	Land	Materials
Labor	-0.19	0.00	0.02	0.00	0.12
Fuel	0.00	-0.48	0.18	0.01	0.18
Fertilizer	0.03	0.25	-0.34	-0.06	0.24
Materials	-0.01	0.02	-0.07	-0.14	0.25
Land	0.16	0.22	0.21	0.20	-0.79
Soybeans					
Change with respect to price of:	Labor	Fuel	Fertilizer	Land	Materials
Labor	-0.98	0.19	0.78	0.09	0.22
Fuel	0.11	-0.43	0.00	0.00	0.15
Fertilizer	0.62	0.00	-0.89	-0.12	0.21
Materials	0.07	0.01	-0.12	-0.17	0.20
Land	0.18	0.23	0.22	0.20	-0.77

Source: own elaboration

Long run substitution elasticities (Table 16) are mostly within $[-1;1]$ interval, indicating absence of substitution relationship between the inputs. For wheat production the exception is fuel-labor pair, for which substitutability is observed (2.20). For soybeans production substitutability is observed for fertilizer-labor pair (3.12).

Table 4-16: Long-run substitution elasticities for production of wheat, corn, sunflower and soybeans

Wheat					
	Labor	Fuel	Fertilizer	Land	Material
Labor	-8.13	2.20	0.75	0.79	2.04
Fuel	2.20	-3.74	0.96	-0.55	0.82
Fertilizer	0.75	0.96	-2.07	0.42	0.93
Materials	0.79	-0.55	0.42	-0.87	0.25
Land	2.04	0.82	0.93	0.25	-3.49
Corn					
	Labor	Fuel	Fertilizer	Land	Material
Labor	-2.63	-1.11	2.19	0.11	1.01
Fuel	-1.11	-5.98	-0.38	0.28	5.14
Fertilizer	2.19	-0.38	-2.57	-0.26	1.02
Materials	0.11	0.28	-0.26	-0.69	0.83
Land	1.01	5.14	1.02	0.83	-6.55
Sunflower					
	Labor	Fuel	Fertilizer	Land	Material
Labor	-1.28	0.01	0.13	-0.03	0.82
Fuel	0.01	-2.88	1.07	0.07	1.07
Fertilizer	0.13	1.07	-1.47	-0.27	1.05
Materials	-0.03	0.07	-0.27	-0.56	0.98
Land	0.82	1.07	1.05	0.98	-3.93
Soybeans					
	Labor	Fuel	Fertilizer	Land	Material
Labor	-3.91	0.77	3.12	0.34	0.87
Fuel	0.77	-3.13	0.01	0.03	1.09
Fertilizer	3.12	0.01	-4.44	-0.61	1.06
Materials	0.34	0.03	-0.61	-0.85	0.97
Land	0.87	1.09	1.06	0.97	-3.69

Source: own elaboration

In the short run demand for fuel is found to be more elastic than in the long run (Table 17). Similar results were observed in analysis by Turkekul (2011). Increase in elasticity is the highest for soybeans (-1.80). Demand for fertilizer becomes more elastic as well, but to a lesser extent. Corn and soybeans production demand for fertilizer becomes close to unit-elastic, while wheat and sunflower production demand remains inelastic.

Table 4-17: Short-run own-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans

	Wheat	Corn	Sunflower	Soybeans
Labor	-0.96	-0.52	-0.28	-1.04
Fuel	-0.94	-1.44	-1.03	-1.80
Fertilizer	-0.68	-0.83	-0.72	-0.78
Materials	-0.72	-0.67	-0.68	-0.73

Source: own elaboration

Short run cross-price elasticities of demand are similar to those estimated for the long run (Table 18). Change in fuel consumption in response to change in fertilizer price becomes higher in the short run (0.54, 0.84, 0.62, 0.44 for wheat, corn, sunflower and soybeans production, respectively). Reversely, fuel consumption response to the change in fertilizer price is higher that in the long run as well (0.34, 0.52, 0.45, 0.30 for wheat, corn, sunflower and soybeans production, respectively).

Table 4-18: Short-run cross-price elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans

Wheat				
	Labor	Fuel	Fertilizer	Materials
Labor	-0.96	0.25	0.12	0.35
Fuel	0.29	-0.94	0.34	0.09
Fertilizer	0.22	0.54	-0.68	0.27
Materials	0.46	0.15	0.22	-0.72
Corn				
	Labor	Fuel	Fertilizer	Materials
Labor	-0.52	0.30	0.02	0.26
Fuel	0.19	-1.44	0.52	0.16
Fertilizer	0.02	0.84	-0.83	0.25
Materials	0.31	0.30	0.29	-0.67
Sunflower				
	Labor	Fuel	Fertilizer	Materials
Labor	-0.28	0.09	-0.06	0.15
Fuel	0.10	-1.03	0.45	0.22
Fertilizer	-0.09	0.62	-0.72	0.30
Materials	0.28	0.33	0.33	-0.68
Soybeans				
	Labor	Fuel	Fertilizer	Materials
Labor	-1.04	1.11	0.21	0.31
Fuel	0.62	-1.80	0.30	0.17
Fertilizer	0.17	0.44	-0.78	0.26
Materials	0.25	0.25	0.26	-0.73

Source: own elaboration

Similarly, the substitutability relationship between inputs is higher in the short run (Table 19). For wheat and corn production, observed pairs are fuel-labor and fuel-fertilizer (1.35, 1.60 and 1.16, 3.14, respectively). For soybeans production also a substitutability is observed for labor-fuel pair (3.54), as well as for fuel-fertilizer (1.74).

Table 4-19: Short-run substitution elasticities of demand for inputs for production of wheat, corn, sunflower and soybeans

Wheat				
	Labor	Fuel	Fertilizer	Materials
Labor	-5.25	1.35	0.64	1.90
Fuel	1.35	-4.40	1.60	0.45
Fertilizer	0.64	1.60	-2.02	0.80
Materials	1.71	0.56	0.84	-2.68
Corn				
	Labor	Fuel	Fertilizer	Materials
Labor	-1.99	1.16	0.07	1.00
Fuel	1.16	-8.77	3.14	0.96
Fertilizer	0.07	3.14	-3.11	0.93
Materials	1.00	0.98	0.95	-2.18
Sunflower				
	Labor	Fuel	Fertilizer	Materials
Labor	-1.54	0.47	-0.32	0.80
Fuel	0.47	-4.90	2.14	1.06
Fertilizer	-0.32	2.14	-2.50	1.05
Materials	0.88	1.04	1.03	-2.13
Soybeans				
	Labor	Fuel	Fertilizer	Materials
Labor	-3.31	3.54	0.67	0.97
Fuel	3.54	-10.31	1.74	0.96
Fertilizer	0.67	1.74	-3.08	1.01
Materials	0.98	0.97	1.01	-2.83

Source: own elaboration

4.5. The results summary

Long-run

Demand for fuel and fertilizer are own-price inelastic for sunflower, corn, wheat and soybeans (for fertilizer ranges from -0.34 to -0.89, and for fuel ranges from -0.43 to -0.78

Cross-price elasticities of demand for production inputs are fairly low. The highest change in use is observed for labor in response to fertilizer price (0.20, 0.47, 0.62 for wheat, corn, and soybeans production, respectively).

Long run substitution elasticities are mostly within $[-1;1]$ interval, indicating absence of substitution relationship between the inputs. For wheat production the exception is fuel-labor pair, for which substitutability is observed (2.20). For soybeans production substitutability is observed for fertilizer-labor pair (3.12).

Short-run

In the short run demand for fuel and fertilizer are found to be more elastic than in the long run.

Short run cross-price elasticities of demand are quite similar to those estimated for the long run. Change in fuel consumption in response to change in fertilizer price becomes higher in the short run. Conversely, fuel consumption response to the change in fertilizer price is higher than in the long run as well.

Substitutability relationship between inputs is higher in the short run (Table 19). For wheat and corn production, observed pairs are fuel-labor and fuel-fertilizer. For soybeans production also a substitutability is observed for labor-fuel pair (3.54), as well as for fuel-fertilizer (1.74).

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