"Models on providing food security: case of Ukraine"

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ARTICLE INFO	Natalia Vasylieva and John R. Kruse (2018). Models on providing food security: case of Ukraine. *Problems and Perspectives in Management*, *16*(4), 344-352. doi:10.21511/ppm.16(4).2018.28
DOI	http://dx.doi.org/10.21511/ppm.16(4).2018.28
RELEASED ON	Tuesday, 11 December 2018
RECEIVED ON	Wednesday, 11 April 2018
ACCEPTED ON	Wednesday, 14 November 2018

JOURNAL	"Problems and Perspectives in Management"
ISSN PRINT	1727-7051
ISSN ONLINE	1810-5467
PUBLISHER	LLC "Consulting Publishing Company "Business Perspectives"
FOUNDER	LLC "Consulting Publishing Company "Business Perspectives"

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10, Sumy, 40022, Ukraine
www.businessperspectives.org

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MODELS ON PROVIDING FOOD SECURITY: CASE OF UKRAINE

Abstract

Providing food security is a top issue of agricultural economics in a global scale. Although Ukraine helps other countries become more food secure through its exports of wheat, corn, barley, and sunflower, low per capita income levels create challenges for Ukrainians to keep their diet nutrition balance in animal food basket. The research objective supposed applying mathematical apparatus to support solving this problem. The offered consumption optimization model has been developed to ensure inelastic customers' food preferences by animal products subject to income and calories constraints. The proposed econometric models have been designed to project broiler, pork, eggs, milk, and beef productions. Complex implementation of the set mathematical models maintained the tool to analyze scenarios by expected export/import and demands for grain and oilseed crops used for feed in animal husbandry. The results of this research provide state authorities, livestock and poultry producers, Ukrainian consumers and other interested parties with management guidance focused on developing animal husbandry in the presence of income, as well as animal product price variability.

Received on: 11th of April, 2018
Accepted on: 14th of November, 2018

Keywords food security, consumption optimization model, production econometric model, scenario analysis, animal husbandry

JEL Classification C10, C61, O13, Q10

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INTRODUCTION

Providing food security is one of the core global economic and social issues. According to the definition of the Food and Agriculture Organization (FAO) of the United Nations, "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (Food security statistics, 2018). At present, food insecurity by countries ranges between hunger in African countries, e.g. Central African Republic, Ethiopia, Liberia, Madagascar, Namibia, Rwanda, Somalia, Uganda, Zimbabwe, to unbalanced diet in the developed countries, e.g. Australia, Brazil, Canada, the USA, Turkey, the United Kingdom.

Being the second European state by total and cultivated area in Europe, Ukraine belongs to the bunch of countries, which provide world food security by grain and oilseed crops such as wheat, corn, barley, and sunflower. At the same time, Ukraine itself is in the condition of food insecurity by animal food products.

The FAO uses four indicators to measuring food insecurity including availability, access, stability, and utilization (Food security statistics, 2018). In 2017, among the European countries, Ukraine had next to the worst gross domestic product per capita in purchasing power equivalent, unstable political situation, and undeveloped financial market instruments, which together affect national food security (Hudym & Khalatur, 2016). These factors have resulted in the third poorest average protein supply from animal sources among the 51 European countries, which implies

http://dx.doi.org/10.21511/ppm.16(4).2018.28

a poor nutritional demand for animal food products due to low per capita income levels. For the majority of animal food products, domestic production in Ukraine is insufficient to meet demand and imports are required. Subsequently, Ukrainian consumers have limited choices in assembling their animal food basket.

In order to assess possible options to improve the Ukrainian nutritional profile, this research developed an optimization model to demand for animal food in combination with econometric models of broiler, pork, eggs, milk, and beef supply to evaluate alternative scenarios for facilitating production and consumption, identifying their mutual impact, and decreasing risks of undesired variants. The results of this research provide insight to state authorities, livestock and poultry producers, domestic consumers, and foreign analysts on the implications of changes in real per capita income, retail animal food prices, and volatilities in export/import of animal products, grain and oilseed crops applied for feed purposes. The general methodology of the presented study could be extended to other economies with similar nutritional imbalances (Dovgal et al., 2017).

1. LITERATURE REVIEW

Recent scientific research on food security delivered a new concept of sustainable development with respect to the principle "more food with less environmental impact". It comprised rational human nutrition and ecological conservation of biodiversity, multifunctional landscapes, and animal welfare (Godfray & Garnett, 2014). The similar approach should be a strategic goal in reestablishing Ukrainian agriculture to pass undamaged national natural resources to the future generations. Barrett (2010), Headey and Ecker (2013), Stavytskyy and Prokopenko (2014), Grafton et al. (2015) focused their studies on improving criteria and indicators to integrated measuring food security by means of daily calorie consumption, prices for basic food products, yields of crops, total area of agricultural land, water quality, shares of poverty and undernourishment, average wage, gross value added per capita, direct foreign investments, and employment level.

A possible option to improving food security via arranging effective domestic agricultural production was presented by Beierlein et al. (2013), Norton et al. (2014), Salter (2017). The authors concluded that food security could be improved via optimizing inputs while raising outputs using cost-benefit analysis. Other authors suggested that food security could be perfected by reinforcing consumption through correcting prices and purchasing power (Norwood & Lusk, 2007; Dewbre et al., 2008; Gregory & Coleman-Jensen, 2013; Davis & Geiger, 2017; Reeves et al., 2017).

Thornley and France (2007), Mitchell (2011) demonstrated in theory and practice that mathematical methods are affordable and effective to solve agricultural tasks in crop and animal husbandry. In such case, the most developed mathematical applications are econometric and optimization models (Allen, 1994; Bessler et al., 2010; Meyers et al., 2010; Babenko, 2013; Shorikov & Babenko, 2014). Mathematical modeling over production and consumption components of food security made it possible to evaluate disproportions and set grounded options for improving demand and supply of beef, milk, and pork (Vasylieva, 2015; Velychko, 2015; Vasylieva, 2017; Vasylieva & Velychko, 2017). At the same time, these results should be enhanced by applying scenario analysis relevant to agricultural activity capturing the volatile economic environment. Exploring scenarios is at the top of the agenda of the international scientific community (Kavallari et al., 2014; FAO global perspectives studies, 2016; Bogonos & Stepaniuk, 2017; Nayyar & Dreier, 2017). Scenario analysis helps prevent shocks in providing food security, decrease risks in planning agricultural production, and support consumption as close as possible to the rational norms of annual human nutrition, i.e. 35; 20; 20; 290 kg of broiler, pork, beef, milk, and 265 eggs per capita (State Statistics Service of Ukraine, 2017). These issues are extremely important in improving Ukrainian deficient demand and supply for animal food products.

2. AIMS

Thus, the goal of this investigation was to establish mathematical grounds to enhancing Ukrainian food security by animal food products.

The set goal meant solving the next tasks:

- to propose optimization model connecting consumptions of the basic animal proteins;
- to create econometric models explaining dynamics of production in animal husbandry;
- to clarify links between demand and supply balancing food security by animal products.

3. MATERIALS AND METHODS

3.1. Ukrainian agricultural market background

Main sources of animal proteins provided by Ukrainian animal husbandry are broiler, pork, eggs, milk, and beef. For the last 27 years broiler became a dominant kind of meat in Ukraine with the share of 52% instead of 16.6% in 1990. Nevertheless, it was unprofitable at the average level of –12.5% in 2007–2015. Results in 2016 and 2017 were more reassuring with profitability of 3.4% and 7%. In general, broiler production and consumption remained on an upward trend being increased by 7.6 and 6.7 times in 1996–2017 (State Statistics Service of Ukraine, 2017). However, it is far from demand and supply of over 40 kg of poultry per capita in Australia, Israel, Malaysia, Saudi Arabia, and the USA.

Pork production practically saved its niche at Ukrainian domestic market with the share of 32.2% in 2017 compared with 36.9% in 1990. Meanwhile, total pork production shrank by a half. Financial results of pork production demonstrate instability. Indeed, a successive activity in 2015 with profitability of 12.7% was followed by a negative activity at the level of –4.1% in 2016 and then a regained profitability of 3.5% in 2017 (State Statistics Service of Ukraine, 2017). Being situated in Europe, Ukraine might pattern agricultural experience of the EU countries, which fill annual demand of over 30 kg of pork per capita.

Eggs production is the most prosperous part of Ukrainian husbandry. Since 2005, Ukrainian eggs farmers have been successfully saturating domestic market. Total production increased by 20.3% for 1990–2014. Net exports rose up to 32% in 2014. Average annual number of laying eggs per chicken reached 293 pieces in 2012. Profitability ranged between 48% and 61% in 2012–2015. But the succeeding results were crucial with a drop-in eggs production by 15.8% in 2016 and a negative profitability of –9% in 2017 (State Statistics Service of Ukraine, 2017).

For 1990–2017, milk production deteriorated by 2.4 times. Nevertheless, it is noteworthy that average annual milk yield per cow rose from 2,863 kg up to 4,820 kg. Since 2007, milk production has been staying profitable on average at the level of 12.8% and in particular 26.9% in 2017. It was even the most effective segment of Ukrainian animal husbandry in 2016 and 2017. At the same time, this result was still worse with regard to stable 22-42% of profitability in 1990–1993. Milk consumption in Ukraine dropped down to 69% of the recommended rational human nutrition. However, this indicator looks pretty good, since dairy consumption in the USA, according to traditions and tendencies in the contemporary diets, was slightly above 50% of the recommended rational human nutrition in 2017 (FAPRI-MU AgStat report, 2017).

Beef production is the most degraded part of Ukrainian agriculture. For 1990–2017, it was on the downward trend and decreased by over 5 times in total. Since 1995, beef production has been staying unprofitable between –18% and –61% after an average profitability level of 62.7% in 1990–1994. The first optimistic signal was obtained in 2017 concerning profitability of beef production at the level of 3.4%. Beef consumption in Ukraine dropped to 8.2 kg in 2017 (State Statistics Service of Ukraine, 2017). Meanwhile, it was around 31 kg per capita in 1990, which is compatible to the best present indicators of over 40 kg of beef per capita in Argentina and Uruguay.

In the case of Ukraine and to the extent that net exports are positive, one could argue that Ukrainian farmers work first for a domestic market and second for international consumers. For beef, pork, and poultry, the net trade is relatively small and often negative so that prices in the respective livestock sector are driven by domestic market devel-

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opments. For eggs and milk, net exports are larger and factors outside the domestic market will play a larger role in determining the prices for these products.

The model developed for this research consisted of two parts. The first one was an optimization model that solved for the available levels of meat, eggs and milk consumptions subject to a set of constraints. The second part of the model included a set of equations that estimate broiler, pork, eggs, milk, and beef productions. Each part is discussed in detail below.

3.2. Model development

Ukrainian consumers are thought to be very price inelastic with respect to their choices of animal food basket. The optimization model is designed to reflect this inelasticity by minimizing the sum of the squared normed differences between current and new consumptions subject to meeting the budget constraint and preventing loss of calories obtained from animal sources.

The objective function is given by:

$$Min \sum_{i=1,\dots,5} \left(\frac{z_i - Z_i}{Z_i} \right)^2 \tag{1}$$

subject to income share restriction:

$$\sum_{i=1,\dots,5} \frac{p_i \cdot z_i}{s} = \sum_{i=1,\dots,5} \frac{P_i \cdot Z_i}{S} \tag{2}$$

and calorie constraint

$$\sum_{i=1,\dots,5} (k_i \cdot z_i) \geq \sum_{i=1,\dots,5} (k_i \cdot Z_i), \tag{3}$$

where the variables are defined as: Z_i – current quantities of consumption per capita for each i, z_i – new quantities of consumption per capita for each i, P_i – current retail prices for each i, p_i – new retail prices for each i, S – current per capita income, s – new per capita income, k_i – nutrition calories for each i.

The index variable i spans the five animal product types with the following correspondence:

- $i = 1$ is defined as broiler;
- $i = 2$ is defined as pork;
- $i = 3$ is defined as eggs;
- $i = 4$ is defined as milk;
- $i = 5$ is defined as beef.

The model simultaneously optimizes the level of z_i subject to the income and calorie constraints. It is worth mentioning that in case of improved economic conditions, Ukrainian consumers would refocus on healthy nutrition. It will imply possible transforming of the objective function (1) into the minimum sum of the squared normed differences between current and recommended rational animal food consumptions.

The typical specification of an animal production equation is given by:

$$\begin{aligned} &Production(t) = f\big(Production(t-1), \\ &Output\ price(t-1),\ Input\ prices(t-1)\big). \end{aligned} \tag{4}$$

The lagged dependent variable reflects the inability to fully adjust production to the desired level in the short run. Plugged prices are often assumed to be the price in the previous year or even two years prior depending on the biological lags in the production process. The authors state that since feed expenditures account for over 50% of total cost, they are used as a proxy for input prices (Vasylieva, 2013). To face disproportion between input and output prices in conditions of high inflation in Ukraine and to improve numbers of degrees of freedom, own farm price and expenditure for feed were converted into one relative explaining factor depicting dynamics of share of feed cost in production revenue.

Thus, the proposed regressions to forecast per capita productions of broiler, pork, eggs, and milk took the form

$$y_i(t) = a_{i0} + a_{i1} \cdot x_{i1}(t-1) + a_{i2} \cdot x_{i2}(t-1) \tag{5}$$

with numerical parameters $a_{i0}, \dots, a_{i2}$, $i = 1, \dots, 4$,

and where $y_i(t)$ – quantities of production per capita in year t, $x_{i1}(t-1)$ – quantities of production per capita in year $t-1$, $x_{i2}(t-1)$ – share of expenditure for feed in output price, $i = 1, \dots, 4$, as defined above, excluding beef.

Since beef production is characterized by almost two-year gap between inputs and revenues, the regression for forecasting beef production was adjusted to

$$y_5(t) = a_{50} + a_{51} \cdot x_{51}(t-1) + \\ + a_{52} \cdot \frac{1}{2}\left(x_{52}(t-1) + x_{52}(t-2)\right), \quad (6)$$

where $a_{50},...,a_{52}$ are numerical coefficients.

Eventually, the optimization and econometric models are combined to provide a scenario analysis evaluating export/import or feed use in animal husbandry after shocks in retail prices or consumers' incomes. Indeed, in the meat, eggs and milk markets, supply carryover stocks are typically very minimal if they exist and often are not measured. Therefore the market clearing identity is often reduced to:

$$Production = Consumption + \\ + Net\ exports / imports$$

$$\text{or } y_i(t) = Z_i + NEI_i,$$

where NEI_i – net per capita exports (if positive) or imports (if negative), $i = 1,...,5$.

To meet expected changes in consumption after shocks in retail prices and incomes under an assumption of the steady NEI_i, an increase or decrease in feed use (i.e. domestic demand for grain and oilseed crops) for animal production could be assessed via the formula

$$\Delta f_i = \frac{z_i - Z_i}{y_i(t)} \cdot 100\%, \; i = 1,...,5. \quad (7)$$

To compensate expected changes in consumption after shocks in retail prices and incomes under an assumption of the steady $y_i(t)$, corresponding export or import could be determined by means of the formula

$$\Delta NEI_i = \left(1 - \frac{z_i}{y_i(t)}\right) \cdot 100\%, \; i = 1,...,5. \quad (8)$$

4. RESULTS AND DISCUSSION

Practical approbation of the proposed optimization model to consumption component of food security by animal products was accomplished at statistical data valid in 2017 (Table 1). Current retail prices P_i were measured in US$ per a kilogram or piece, nutrition k_i – in kilocalories per kilogram or piece, current annual consumption Z_i – in kilograms or pieces per capita, $i = 1,...,5$.

Table 1. Data to consumption optimization model

Source: Composed by the authors.

Indicator	Broiler	Pork	Eggs	Milk	Beef
Current retail price	3	4.9	0.11	0.78	5.9
Nutrition	1400	3700	80	520	2400
Current consumption	26.8	16.7	273	200	8.7

Current minimal annual salary S was US$ 1,680. The considered most probable 8 scenarios to consumption of animal food products in Ukraine after shocks in retail prices p_i, $i = 1,...,5$, and minimal annual salary s were the following ones:

- scenario no. 1 was an increase in minimal annual salary by 10% $(s = 1848)$;
- scenario no. 2 was a decrease in minimal annual salary by 5% $(s = 1596)$;
- scenario no. 3 was an increase in retail price for broiler by 5% $(p_1 = 3.15)$;
- scenario no. 4 was an increase in retail price for pork by 5% $(p_2 = 5.15)$;
- scenario no. 5 was an increase in retail price for eggs by 5% $(p_3 = 0.12)$;
- scenario no. 6 was an increase in retail price for milk by 5% $(p_4 = 0.82)$;
- scenario no. 7 was an increase in retail price for beef by 5% $(p_5 = 6.20)$;
- scenario no. 8 was a simultaneous increase in retail prices for all products by 5% $(p_1 = 3.15,\ p_2 = 5.15,\ p_3 = 0.12,\ p_4 = 0.82,\ p_5 = 6.20)$.

If not mentioned in scenario, s and $p_1,..., p_5$, were, respectively, equal to S and $P_1,...,P_5$. After running model (1)-(3) by means of Microsoft

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Excel tools, calculated changes in animal food basket were collected in Table 2.

Table 2. Calculated changes (%) in animal food consumption

Source: Calculated by the authors.

Scenario	Broiler	Pork	Eggs	Milk	Beef
No. 1	7.8	7.9	2.9	15.2	4.7
No. 2	–43.4	24.3	6.5	6.4	–34.6
No. 3	–4.8	2.8	0.7	0.8	–4.4
No. 4	–9.5	4.1	1.6	2.1	–7.7
No. 5	–8.6	4.3	1.2	1.4	–5.8
No. 6	–16.2	12.1	3.5	0.5	–13.3
No. 7	–3.3	1.9	0.3	0.5	–2.6
No. 8	–41.3	23.2	6.2	6.1	–33.0

All scenarios, except for no. 1, provided the same 671 kilocalories obtained from animal products that indicated misbalance between crop and animal components of rational daily diet of 2,000 kilocalories. Requirements to covering food expenses restricted spending on animal products at the level of 23.6% of minimal salary. For comparison, average share of total spending on food in the USA was less than 7% in 2017 (FAPRI-MU AgStat report, 2017). Ukrainian conditions are complicated by high retail prices for animal food products with regard to average low incomes of population. However, the present minimal annual salary of US$ 1,680 is significantly larger than that of US$ 97 in 1996 and 1997.

The data used in the production econometric models (5), (6) were collected from various issues of the "Agriculture of Ukraine" over the period from 1996 to 2017 period, published by State Statistics Service of Ukraine. Data contained quantities of annual per capita productions of broiler, pork, eggs, milk, and beef, measured in kilograms or pieces, as well as shares of expenditures for feed in farm prices of the listed animal food products.

Results of running models (5), (6) by means of Microsoft Excel tools are aggregated in Table 3. Overall coefficients of the obtained regressions and elasticity confirmed an expected straight connection between productions in consequent periods. At the same time, share of expenditure for feed in farm price has a logical reverse impact at quantity of animal production.

Exploring data in Table 2 made it possible to resume that an increase in salary (scenario no. 1) improved consumption of animal proteins on average by 7.7% up to 740 kilocalories. It should be stressed that under all scenarios eggs segment contributed to compensation of calories and expenses in animal food basket by overconsumed eggs with regard to the recommended rational human nutrition.

In case of decline in income and growth in all prices (scenarios no. 2 and no. 8), "inelastic" consumption reacted by slight increases in both eggs and milk segments by around 6.3%. Meanwhile, meat consumption shifted in favor of pork, which had advantages in "price and calories" against beef and broiler and amounted to its recommended rational human nutrition.

The similar but not so drastic tendencies were observed under scenarios no. 3-7 when changes in one price practically did not affect consumption of eggs and milk. At the same time, they resulted in shrinking shares of broiler and beef, respectively, by –8.5% and –6.8% in favor of pork's share, which rose by approximately 5%.

Table 3. Regression results for animal production

Source: Calculated by the authors.

Product	Intercept		Production per capita			Share of expenditure for feed in output price			*R*-square	*F*-significance	Forecasted production per capita in 2017
	1^a	1^b	1^a	1^b	1^c	1^a	1^b	1^c			
Broiler	2.85	0.01	1.00	0.00	0.92	–6.57	0.04	–0.11	0.99	0.00	28.7
Pork	2.53	0.11	0.90	0.00	0.90	–1.51	0.01	–0.08	0.83	0.00	17.5
Eggs	44.39	0.25	0.92	0.00	0.90	–40.88	0.20	–0.04	0.94	0.00	368
Milk	108.71	0.01	0.65	0.00	0.65	–110.33	0.08	–0.07	0.78	0.00	240.4
Beef	2.73	0.02	0.82	0.00	0.85	–2.46	0.13	–0.09	0.93	0.00	8.1

Note: 1^a – parameter, 1^b – *p*-value, 1^c – elasticity.

Table 4. Changes in feed use (%)

Source: Calculated by the authors.

Scenario	Broiler	Pork	Eggs	Milk	Beef
No. 1	7.3	7.6	2.2	12.6	4.8
No. 2	–40.5	23.2	4.8	5.4	–35.1
No. 3	–4.5	2.6	0.6	0.7	–4.5
No. 4	–8.9	3.9	1.2	1.8	–7.8
No. 5	–8.0	4.1	0.9	1.2	–5.9
No. 6	–15.1	11.6	2.6	0.4	–13.5
No. 7	–3.1	1.8	0.2	0.4	–2.7
No. 8	–38.5	22.1	4.6	5.1	–33.4

Studying data in Table 3 made it possible to conclude that all results of running econometric models to broiler, pork, eggs, milk, and beef productions are F-significant at the level of above 99.9%. Elasticity over the previous period production was around 0.9 for stronger broiler, pork, and eggs segments of Ukrainian agriculture, while it was lower for decaying cattle breeding.

On the one hand, the basic reason of misbalancing Ukrainian animal husbandry is quite clear as farmers have to operate in volatile economic environment where national currency weakened by 14 times since 1996 (State Statistics Service of Ukraine, 2017). On the other hand, contemporary technologies allowed decreasing feed use in broiler, pork, and eggs productions by 17%, 71%, and 37%. However milk and beef farmers deteriorated feed use, respectively, by 34% and 40% in 1996–2017. Thus, it is entirely logical that high values of regressions' parameters, i.e. marginal effects, identified the share of expenditure for feed in output price to be an incentive driving factor to improving animal production by keeping high productive breeds, applying innovative feed technologies and implementing effective sales management. Forecasted productions per capita in 2018 were 368 eggs and 28.7, 17.5, 240.4, and 8.1 kilograms of broiler, pork, milk, and beef.

Economic signals conveyed to production from consumption after shocks were evaluated via formulae (7) and (8) and collected in Tables 4 and 5.

According to Table 4, a positive shock in consumers' incomes would originate additional demand of 6.9% for grain and oilseed crops applied for feed purposes (scenario no. 1). Rise in pork, eggs and milk productions under scenarios no. 2-8 will be compensated by supplementary feed use of 9.9%, 2.1%, and 2.1%. In reverse, quantities of grain and oilseed crops applied for feed purposes in broiler and beef segments would be reduced by 16.9% and 14.7%.

According to results of calculations aggregated in Table 5, eggs and milk farmers will be able to redirect at net export on average 23.8% and 13.4% of these products. Pork branch will need essential quantities of imported products under scenarios no. 2 and no. 8. Scenarios no. 3-5 and no. 7 would open opportunities for the local farmers to satisfy the domestic demand for pork products. It would be necessary to import 0.6% and 6.2% of broiler and beef under scenario no. 1. On the contrary, negative shocks in prices and consumers' incomes would bring extra opportunities to export, respectively, 47.2% and 45.3% of broiler, as well as 33.7% and 32% of beef under scenarios no. 2 and no. 8.

Table 5. Evaluation of net export/import (%)

Source: Calculated by the authors.

Scenario	Broiler	Pork	Eggs	Milk	Beef
No. 1	–0.6	–2.9	23.7	4.2	–6.2
No. 2	47.2	–18.5	21.1	11.4	33.7
No. 3	11.2	2.1	25.4	16.2	3.0
No. 4	15.6	0.8	24.7	15.0	6.4
No. 5	14.7	0.6	25.0	15.6	4.5
No. 6	21.8	–6.9	23.4	16.4	12.1
No. 7	9.8	2.9	25.7	16.4	1.2
No. 8	45.3	–17.4	21.3	11.7	32.0

http://dx.doi.org/10.21511/ppm.16(4).2018.28

CONCLUSION

The accomplished research could be completed by the following final conclusions. Namely, the adequate calculation results clarified applicability of optimization methods to supporting consumption component in animal sector of food security system. It revealed qualitative differences between "inelastic" and rational animal food consumptions. The primary reason of insufficient demand for animal food products and imbalanced diet in Ukraine is poor purchasing power, since around 51% of population in 2015–2016 and approximately 35% had lower incomes than the actual living wage.

The adequate calculation results confirmed applicability of econometric methods to supporting animal production component in food security system. It substantiated focus of Ukrainian animal farmers on domestic consumers, highlighted necessity to improve wholesale pricing and revise feed technologies in cattle breeding.

Complex application of the developed econometric and optimization models gave calculated ground to evaluating and comparing scenarios over expected export/import and demand for grain and oilseed crops used for feed purposes. This is extremely important for supporting recovery of meat segment in Ukrainian agriculture and saturating domestic market with qualitative affordable food.

Overall, the suggested recommendations and proposals addressed:

- farmers involved in animal husbandry in the area of defining anchor point of production for the next year;
- consumers in the area of advising about supporting rational diet with the balanced sources of calories, saving food preferences in case of price and income shocks, optimizing spending on animal products;
- state authorities in the area of forecasting food security and expected changes in export/import balance;
- international analysts in the area of evaluating Ukrainian potential in export/import subject to domestic demand for grain and oilseed crops used for feed purposes.

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