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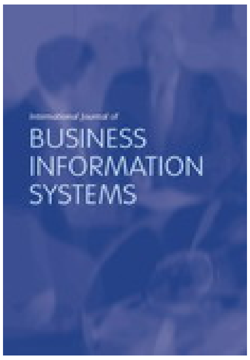

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Searching for a risk-efficient production structure on crop-livestock farms

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Abstract: This article examines the combined influence of entrepreneurs' attitudes toward risk and subsidies on the choice of production structure in agriculture on farms in the steppe zone of Kazakhstan. Data from farm survey for the period from 2020 to 2024 were used to construct a programming model effective in terms of utility. The hypothesis was that subsidy has a significant impact on farmer's attitude towards risky decisions and choice of enterprise mix. Developing just a few sectors on farms appears to be sufficient to significantly reduce the economic risk. The obtained results tend to confirm this view. Crop production in the region is found to have a relative economic advantage over livestock production. Under current market conditions, the successful development of beef and dairy cattle breeding in the region is only possible thanks to government subsidies.

Keywords: agricultural entrepreneurship; risk; subsidies; programming model; utility function; whole-farm planning; production structure.

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1 Introduction

In agriculture of developing and transit economies, production diversification is the most commonly used tool to counter risk (Adhikari et al., 2023; Smith and Skinner, 2002). Ways that rely on the use of diversification in response to abrupt changes in economic environment can be divided into two broad groups:

1 just growing more types of crops or/and livestock

2 introducing or scaling up more adapted crops and livestock and livestock breeds.

In developing economies, livestock farming has increasingly been viewed as a diversification strategy in response to environmental changes (Bell et al., 2021; Delgado and Siamwalla, 2018; Gondwe et al., 2025). The focus is on those animals that have proven their ability to adapt to changing conditions over many decades or even centuries. In line with the climatic characteristics of the territories, horse and sheep breeding are more common in the northern and central regions, while camel breeding is more common in the western regions of the country. Kazakhstan is no exception in its return to traditional animal husbandry for commercial purposes. For example, some researchers (e.g., Faye, 2016) note that cattle are being replaced by camels in many parts of Africa.

These processes are explained by the fact that the climate in these regions is becoming even more arid. Attempts to combine crop and livestock farming are accompanied by the introduction of water-saving technologies and fairly simple and inexpensive ways to preserve soil fertility. There have also been more or less successful attempts to adjust sowing and harvesting times to changing natural conditions (Dinar et al., 2012; Rabin et al., 2023; Schlenker and Lobell, 2010; Vigouroux et al., 2011).

Nevertheless, enterprises engaged in both crop and livestock production have not lost their position, both in developed and developing economies (Baker et al., 2023; Bell and Moore, 2012; Steinfeld et al., 2006). However, we should note that such mixed production seems to be more characteristic of small farms in developing regions. In countries with developed agriculture, there is a trend toward farm specialisation. This trend is largely explained by the use of advanced technologies and complex technical systems in agricultural production in such countries (Almeida-Furtado et al., 2025; Garrett et al., 2020).

Climatic peculiarities of Northern Kazakhstan significantly limit the agriculture possibilities. Taking into account these conditions and pursuing the goal of ensuring food security in times of crisis, the government of the country allocates rather large subsidies to the agricultural sector. In 2024, for example, the amount of subsidy and other forms of state financial support amounted to 450 billion tenge, or a little less than 1 billion US dollars. In addition, the state-owned company 'Prodcorporation' buys some produce from farmers in years of high harvest at fixed prices. Nevertheless, there is considerable variability in the level of marginal income in different years. This is due to large fluctuations in yields and quality, as well as instability in the prices of produce and inputs. It may be important to take these sources of risk into account in whole-farm planning.

In models for decision making that takes into account uncertainty, it is important to consider farmers' attitudes towards risk. The results of many studies that have taken into account the phenomenon of farmers' risk aversion show that risk aversion has an important influence on the choice of the farm production plan [from early works (e.g., Kaiser and Apiand, 1989; Kingwell, 1994; Nanseki and Morooka, 1991; Pannell and Nordblom, 1998), to more recent ones (e.g., Datta et al., 2025; Grilli et al., 2025; Liao et al, 2023; To-The et al., 2025)]. However, it should be borne in mind that these works analysed regimes in which political intervention to stabilise farmers' incomes is very different in its content from that in Kazakhstan, in the Eurasian steppe.

The economic literature argues that the utility function should exhibit positive but decreasing absolute risk aversion (Arrow, 1996; Phelps, 2024; Pratt, 1964). However, empirical studies show that there is no universal consensus on this issue (Garcia et al., 2024; Saha et al., 1994). It should also be emphasised that almost all studies have been based on the utility of wealth, with very few exceptions (see, e.g., Lien and Hardacker, 2001), while agricultural entrepreneurship is aimed at generating income. This paper investigates farmers' attitudes towards risky decisions related to income volatility. It is also possible that the form of the utility function chosen to reflect the degree of risk aversion will affect farmers' responses to different forms and amounts of subsidies.

This paper presents a programming model of the whole-farm planning problem on a farm with diversified production. One of the key problems when using programming models is the choice of the utility function. Studies of recent years appear to confirm the validity of using the power function to reflect the attitude of entrepreneurs to risky decisions (Gupta et al., 2025; Pan et al., 2023). The results obtained by Ascari et al.

(2021) show that the potential range of variation in relative risk aversion is quite wide. Brown et al. (2024) conduct a meta-analysis of loss aversion (a concept related to, but slightly different from, relative risk aversion commonly used in economics) and find that relative loss aversion averages around 2. Meanwhile, other researchers conclude that the bias of the relative risk aversion estimates is between 0.95 and 0.97 (Imai et al., 2021). A more detailed review of the meta-analysis results is presented in a paper by Elminejad et al. (2025).

The utility function with consistent adjustment of the risk aversion parameter is used. The objective is to empirically study the impact of subsidies and farmers' attitudes towards risky decisions on choice of whole-farm plan and enterprise mix.

2 Materials and methods

2.1 Study area

The developed model is designed for an enterprise functioning under typical agricultural conditions of the steppe chernozem zone, occupying 96.3% of all arable land in the North-Kazakhstan region. The zone has geographical, soil and climatic conditions that are more favourable for rainfed agriculture than in other regions of the country. The growing season lasts 150–180 days: from April–May to September–October. The conditions allow for crop and livestock farming.

Table 1 Crop yields and hayfields and pasture productivity, centners/ha

Crop	*Year (state of nature)*				
	2020	*2021*	*2022*	*2023*	*2024*
Wheat, soft	22.1	30.0	37.0	18.0	16.8
Barley	15.5	13.6	29.9	30.0	31.8
Rapeseed	6.5	7.3	13.1	14.7	19.6
Flax	5.9	4.9	9.3	5.5	8.8
Perennial grasses					
• For hay	21.6	12.4	13.1	11.5	16.4
• For green fodder	57.6	33.2	34.9	30.6	43.7
Annual grasses					
• for haylage	72.1	41.5	43.7	38.2	54.6
• for silage	172.9	99.6	104.8	91.7	131.0
• for green fodder	76.9	76.9	76.9	76.9	76.9
Hayfields					
• for hay	6.6	3.8	4.0	3.5	5.0
• for green fodder	17.6	10.1	10.7	9.3	13.3
Pasture	26.4	15.2	16.0	14.0	20.0
Nature state probability	0.2	0.2	0.2	0.2	0.2

Source: Authors survey

2.2 Data

Planning of whole-farm income in diversified industries has a number of peculiarities associated with the presence and nature of stochastic relationship between the levels of various production and economic indicators, as well as the uncertainty of production and market conditions of the planning period. Therefore, to calculate the expected values of indicators, the method is applied which uses the principles of expert evaluation in combination with probabilistic analysis of the farm performance historical data.

Historical data on crop yields and livestock productivity, variable costs and selling prices from 2020 to 2024 were used in the analysis and model building. This period includes years with the full range of weather types and market conditions. All historical data has been adjusted for trends and inflation.

When adjusting historical cost data using the Consumer Price Index, 2024 was taken as the base year for recalculation.

Table 1 presents baseline data on crop yields and hayfields and pasture productivity for 2020–2024.

Table 2 summarises the livestock productivity in 2020–2024.

Table 2 Livestock productivity, centners/head

Year (state of nature)	*Cattle*		*Horses*	
	Milk	*Meat*	*Milk*	*Meat*
2020	53.1	4.9	-	3.3
2021	60.7	4.2	-	4.3
2022	64.0	4.6	-	3.5
2023	53.1	4.9	-	3.3
2024	59.0	4.4	-	4.9

Source: Authors survey

Sale prices of crop products are presented in Table 3.

Table 3 Crop product prices, thousand tenge/centner

Year (state of nature)	*Wheat, soft*	*Barley*	*Rapeseed*	*Flax*
2020	7.8	5.6	10.1	8.9
2021	9.9	7.9	18.9	14.2
2022	11.7	8.9	27.2	25.6
2023	9.2	6.5	18.2	17.1
2024	8.2	5.4	17.2	21.4

Source: Authors survey

Table 4 shows sale prices of livestock products.

In the analysed farm, crop insurance was not carried out during the specified period, and therefore there is no data on insurance payments.

Amounts of variable costs in crop production, including costs of mineral fertilisers, fuel, plant protection, wages, as well as insurance premiums, are shown in Table 5.

Table 4 Sale prices of livestock products, thousand tenge/centner

Year (state of nature)	*Cattle*		*Horses*	
	Meat	*Milk*	*Milk*	*Meat*
2020	11.9	62.2	-	79.7
2021	13.7	72.1	-	111.3
2022	16.6	84.1	-	108.0
2023	18.6	94.4	-	111.8
2024	18.4	85.3	-	115.2

Source: Authors survey

Table 5 Amounts of variable costs in crop production, hayfields and pasture, thousand tenge/ha

Crop	*Year (state of nature)*				
	2020	*2021*	*2022*	*2023*	*2024*
Wheat, soft	80.7	83.6	121.0	107.0	103.2
Barley	59.6	70.6	121.5	96.6	100.0
Rapeseed	21.8	35.6	33.7	43.2	40.5
Flax	29.1	47.4	44.9	57.6	50.6
Perennial grasses					
• for hay	18.1	21.1	24.4	28.5	32.6
• for green fodder	15.4	17.9	20.8	24.2	27.7
Annual grasses					
• for haylage	16.9	19.6	23.1	27.3	30.8
• for silage	36.5	43	50.5	58	65.5
• for green fodder	14.4	16.6	19.6	23.2	26.2
Hayfields					
• for hay	3.3	3.8	4.4	5.1	8.0
• for green fodder	2.8	3.2	3.7	4.4	5.0
Pasture	0.8	1.0	1.1	1.3	2.0

Source: Authors survey

Table 6 Variable costs (except fodder costs) in livestock production, thousand tenge/head

Year (state of nature)	*Cattle*		*Horses*	
	Adults	*Youngsters*	*Adults*	*Youngsters*
2020	261.2	117.5	323.5	388.2
2021	210.0	94.5	217.0	260.4
2022	337.7	151.9	446.1	535.3
2023	367.5	165.4	448.4	538.1
2024	371.5	167.2	310.5	372.6

Source: Authors survey

The amounts of variable costs in livestock production (except for feed costs) are shown in Table 6.

Actual prices for purchased feeds are shown in Table 7.

Table 7 Actual prices for purchased fodder, thousand tenge/centner

Purchased feed	*Year (state of nature)*				
	2020	*2021*	*2022*	*2023*	*2024*
Combi-feed	5.4	6.5	7.5	8.3	8.8
Feed additives	6.0	7.5	8.2	9.0	10.3

Source: Authors survey

The norms of animal feed requirements, as well as the structure of animal feeding rations depending on productivity are taken from the recommendations of the North-Kazakhstan Research Institute of Livestock Production and Veterinary.

To reflect the chance that conditions similar to those in each of the data years will prevail in the planning period, we assigned differential probabilities to the historical years or ‘states of nature’ 2020–2024. There are many possible ways of assigning these probabilities. We asked an expert group (a group of regional agricultural research workers) about their subjective relative weights with respect to yield and revenue conditions for the specific years 2020–2024. These assessed probabilities are reported in the lower line of Table 1.

Starting from 2025, subsidies are assumed only for livestock products in the amount of 4.5 thousand tenge per centner of milk and 30.0 thousand tenge per average annual head of cattle raised for meat.

2.3 Model

Structurally, the model consists of several interrelated blocks. The first block is a record of conditions for commercial crop production. The second block includes conditions for livestock production, including fodder production. The third block is a record of conditions linking crop and livestock blocks into a single complex. The model implements a scenario method to analyse the problem with appropriate probabilities. Weather and economic conditions that took place in each of the last five years – from 2020 to 2024 – are taken as scenarios.

The main variables are the area under crops and the number of cattle and horses (broken down into adult animals and youngsters).

The main constraints are conditions on the use of available land (arable land, natural hayfields, and pastures) and labour resources. Labour resources consumption is presented in man-hours per 1 hectare of crops and per one head of livestock. The conditions of crop rotations, feeding norms and the ratio between the number of adult animals and youngsters are also reflected. In addition, the model includes conditions related to the financing of current production costs, fulfilment of contractual obligations, limitations on the capacity of the product market, as well as on insurance premiums and payments.

Note that measures of financial support of the state are accounted for in the model through their impact on the level of income from crops and animals (per hectare of agricultural land and per head of livestock).

The norms of animal feed consumption by species are accounted for in feed units.

Figure 1 The programming model in MS Excel (a fragment) (see online version for colours)

	A	B	C	E	F	I	J	L	M	N	O	R	S	T	U	V	W	X	Y	Z	AA	AB	AE	AF	AG	AH
1	**The model**																									
2		Relative risk aversion coefficient			0,8																					
3	Constraints	State of nature	Cereals			Oilseeds		Annuals			Perennials		Natural hayfields		Pasture	Purchased feed and feed additives, grain residues			Cattle		Horses		Sum of products	Constraint type	Constraint volume	Remaining resources
4			Soft wheat	Barley for on-farm	Barley for sale	Rapeseed	Flax	Silage	Silo	Green mass	Hay	Green mass	Hay	Green mass	Green mass	Concentrates (compound feed and	Feed additives	Grain residues	Adults	Youngsters	Adults	Youngsters				
5			5489	48	0	2916	0	700	393	512	1218	387	207	0	1361	10000	0	4611	600	400	250	250				
6	Arable land	x	1	1	1	1	1	1	1	1	1	1											11 662,0	<=	11662	0,0
7	Natural hayfields	x											1	1									207,0	<=	207	0,0
8	Pasture	x													1								1 361,0	<=	1361	0,0
61	Balance between production and use of feed units			27,8				14,5	24,0	10,7	7,8	9,2	2,1	2,8	4,4	1,1	0,0	1,3	-56,4	-20,1	-49,4	-24,9	2 290,8	>=	0	
62	Digestible protein production (by state of nature)	2020		1,3				3,3	2,4	1,4	0,9	1,9	0,3	0,4	0,6	0,1		0,1					0,0		0	
63		2021		1,2				1,9	1,4	0,8	0,5	1,1	0,2	0,3	0,4	0,1		0,1					0,0		0	
64		2022		2,5				2,0	1,5	0,8	0,6	1,2	0,2	0,3	0,4	0,1		0,1					0,0		0	
65		2023		2,6				1,8	1,3	0,7	0,5	1,0	0,1	0,2	0,3	0,1		0,1					0,0		0	
66		2024		2,7				2,5	1,8	1,0	0,7	1,4	0,2	0,3	0,5	0,1		0,1					0,0		0	
103	Variable costs	2020	125,5	92,7	92,7	34,0	45,3	26,3	56,8	22,3	28,2	24,0	5,1	4,3	1,3	8,4	9,3		406,1	182,8	503,1	603,7	1 568 385,3			
104		2021	119,9	101,2	101,2	51,1	68,1	28,1	61,7	23,8	30,3	25,7	5,5	4,6	1,4	9,3	10,8		301,3	135,6	311,2	373,5	1 417 116,1			
105		2022	144,3	144,9	144,9	40,2	53,6	27,6	60,2	23,4	29,1	24,8	5,2	4,5	1,3	8,9	9,8		402,6	181,2	531,9	638,3	1 715 012,0			
106		2023	116,2	104,9	104,9	46,9	62,5	29,6	63,0	25,2	31,0	26,3	5,6	4,7	1,4	9,0	9,8		399,1	179,6	486,9	584,3	1 558 262,2			
107		2024	103,2	100,0	100,0	40,5	50,6	30,8	65,5	26,2	32,6	27,7	8,0	5,0	2,0	8,8	10,3		371,5	167,2	310,5	372,6	1 353 160,5			
108	Revenue from crop production, thousand tenge	2020	255,1		135,8	101,9	82,0																1 697 277,0			
109		2021	403,7		153,6	197,6	100,0																2 792 354,3			
110		2022	490,7		316,0	425,4	283,9																3 934 008,3			
111		2023	170,7		210,6	290,6	102,4																1 784 265,9			
112		2024	130,4		170,5	337,8	188,2																1 700 309,1			
113	Revenue from livestock farming, thousand tenge	2020																	550 104,9	188 223,1	0,0	101 344,4	839 672,4			
114		2021																	672 724,6	174 073,9	0,0	170 525,7	1 017 324,1			
115		2022																	714 833,3	183 018,8	0,0	111 390,3	1 009 242,4			
116		2023																	600 678,0	199 635,0	0,0	99 307,4	899 620,4			
117		2024																	612 812,6	151 297,3	0,0	141 755,9	905 865,8			
118	Marginal income	2020																					968 564,1			
119		2021																					2 392 562,3			
120		2022																					3 228 238,8			
121		2023																					1 125 624,1			
122		2024																					1 253 014,4			
123	Marginal income utility (by state of nature)	2020																					78,7400			
124		2021																					94,3502			
125		2022																					100,1759			
126		2023																					81,1426			
127		2024																					82,9013			
128	Objective function - utility of expected marginal income																						87,4620			

The ratio between the number of adult animals and the number of youngsters depends on the duration of growing young animals for realisation and the length of the inter-calving period. In our task, the duration of growing of young cattle is assumed to be eight months (at this age young animals reach 200 kg of live weight, after which they are delivered to the fattening enterprise), and the inter-calving period lasts 12 months; for horses these time parameters are the same – 18 months. Then, all other things being equal, the average annual number of young cattle will be two thirds of the number of adult cattle, and for horses, young and adult animals will be equal to each other in number.

It also makes sense to incorporate livestock farm capacity constraints into the model.

The aim is to maximise the expected utility of the whole-farm marginal income given production and market conditions:

$$E(U) = \sum_{s \in S} p^s U(z_s, r) = \sum_{s \in S} p^s \left[1/(1-r) z_s^{1-r} \right],$$

where $E(U)$ is the expected utility; r is the coefficient of relative risk aversion; s is a state of nature; S is the set of states of nature; z_s is the marginal income in state s; p^s is the probability of state s.

As to specific forms of utility functions, obviously, the most appropriate functions are those that allow us to capture the behavioural property of most individuals in the decision-making process. This property is that relative risk aversion does not increase as wealth expands. In other words, the percentage of funds invested in risky assets (risky activities) remains constant or increases. Constant or decreasing relative risk aversion means that as wealth increases, the willingness of entrepreneurs to invest money (in absolute terms) in risky industries also increases. That is, absolute risk aversion decreases and the investor is more willing to spend money in risky assets. Both of the above considerations are quite consistent with common sense and observations. Therefore, as a utility function we take a power function of the form $U = \left(\frac{1}{1-r} \right) z^{1-r}$, where z is the total value of assets, r is the coefficient of relative risk aversion. The larger the value of r, the less the entrepreneur is inclined to take risky decisions, i.e., the less willingness to invest in risky activities. This function is very convenient in practical use. When $r = 0$ the function takes a linear form $U = z$; the linear function corresponds to the case when the entrepreneur's attitude to risk is neutral. When $r = 1$, the power function turns into a logarithmic function. Empirical studies and calculations show that the relative risk aversion coefficient equal to 1 is typical for the bulk of entrepreneurs and investors. Since the model estimates the risk aversion coefficient with respect to marginal income (and not the total value of agricultural assets), it is necessary to calculate the relative risk aversion coefficient by marginal income. For this purpose, a formula linking the risk aversion coefficients by wealth and income is used, i.e., $r = r(z) = (z/W)r(W)$, where z is the average annual income; W is the average annual total value of assets of the enterprise (the derivation of the above formula is given by Hardacker et al. (2015).

The model is constructed in MS Excel (see a fragment of the model in Figure 1). The search for the best solution is performed using the built-in Solver application.

3 Results and discussion

3.1 Results

The problem was solved in several variants: without subsidies and with subsidies at different levels of risk aversion. We assumed a range of relative risk aversion with respect to wealth, $r_r(w)$, between 0.5 and 4. The corresponding range for $r_r(z)$ is approximated by use of equation (2). In the analysis, we followed the interpretation of the coefficients of relative risk aversion proposed by Anderson and Dillon (1992): $r_r(w) = 0$ – individual shows indifference to risk; $r_r(w) = 0.5$ – hardly takes risk into account; $r_r(w) = 1.0$ – takes risk into account to a reasonable extent; $r_r(w) = 2.0$ – very wary of risk; $r_r(w) = 3.0$ – high level of risk aversion; $r_r(w) \geq 4.0$ – extremely high level of risk aversion.

Table 8 Production portfolio of the farm (without subsidies)

Indicator	*Unit of measure*	*Risk aversion coefficient*		
		$r_r(w) = 0$, $r_r(z) = 0$	$r_r(w) = 1$, $r_r(z) = 0.4$	$r_r(w) = 2$, $r_r(z) = 0.8$
Marginal income	Thousand tenge	1,549,080	1,548,841	1,548,841
Sown area				
Wheat, soft	Hectare	4,348	4,309	4,309
Barley for internal use	Hectare	259	167	167
Barley for sale	Hectare	0	0	0
Rapeseed	Hectare	2,916	2,916	2,916
Flax	Hectare	0	0	0
Perennial grasses				
• for hay	Hectare	1,611	1,611	1,611
• for green fodder	Hectare	459	525	525
Annual grasses				
• for haylage	Hectare	672	794	794
• for silage	Hectare	514	514	514
• for green fodder	Hectare	884	827	827
Hayfields				
• for hay	Hectare	207	207	207
• for green fodder	Hectare	0	0	0
Pasture grass for green feed	Hectare	1,361	1,361	1,361
Livestock				
• cows	Head	600	600	600
• cattle youngsters	Head	400	400	400
• mares (adult horses)	Head	250	250	250
• horse youngsters	Head	250	250	250

Table 8 shows the results of solving the problem without subsidies at different levels of risk aversion. At coefficients of wealth risk aversion between 0 and 1 (they correspond to coefficients of relative income risk aversion between 0 and 0.4), the production structure undergoes very little change, while at coefficients between 1 and 2 (respectively between 0.4 and 0.8) farmers tend to stick to the same production structure. At coefficients exceeding 2, there is an incomplete utilisation of production resources, first of all land resources. This can be interpreted as avoidance of doing business due to an individual's high degree of risk aversion.

Table 9 Production portfolio of the farm (with subsidies)

Indicator	*Unit of measure*	*Risk aversion coefficient*		
		$r_r(w) = 0$, $r_r(z) = 0$	$r_r(w) \approx 2$, $r_r(z) \approx 0.8$	$r_r(w) \approx 4$, $r_r(z) \approx 1.7$
Marginal income	Thousand tenge	1,750,932	1,743,339	1,173,829
Sown area				
Wheat, soft	Hectare	4,348	3,944	306
Barley for internal use	Hectare	259	286	1,408
Barley for sale	Hectare	0	0	916
Rapeseed	Hectare	2,916	2,916	2,123
Flax	Hectare	0	0	793
Perennial grasses				
• for hay	Hectare	1,611	1,692	1,844
• for green fodder	Hectare	459	566	1,215
Annual grasses				
• for haylage	Hectare	672	789	1,037
• for silage	Hectare	514	566	658
• for green fodder	Hectare	884	903	1,013
Hayfields				
• for hay	Hectare	207	207	182
• for green fodder	Hectare	0	0	25
Pasture grass for green feed	Hectare	1,361	1,361	211
Livestock				
• cows	Head	600	663	776
• cattle youngsters	Head	400	442	517
• mares (adult horses)	Head	250	250	250
• horse youngsters	Head	250	250	250

A somewhat different picture emerges when subsidies are included in the model. Table 9 summarises the results of the subsidy-adjusted problem for some coefficients of relative risk aversion. When the coefficients of relative risk aversion for wealth range from 0 to 2 (for income, respectively, from 0 to 0.8), insignificant changes in the production structure are observed. Noticeable changes in the production structure of an agricultural enterprise in favour of meat and dairy farming occur when the risk aversion coefficient exceeds 2.

Incomplete use of resources is observed when the risk aversion coefficient with respect to wealth (or income) exceeds 4 (or 1.7).

3.2 Discussion

The obtained results indicate that in the natural and economic conditions of Northern Kazakhstan the propensity of agricultural entrepreneur to risky decisions is largely predetermined by the presence or absence of subsidies and other forms of financial support of the sector. In the absence of financial assistance from the government, individuals with a fairly pronounced risk-taking nature are engaged in agribusiness in the region. The presence of subsidies allows for the involvement of individuals with a higher level of risk aversion into the orbit of agricultural entrepreneurship.

It is clear that in Northern Kazakhstan natural and economic conditions push farmers to form the structure of production in favour of growing grain and oilseeds. In other words, crop production in the region has a relative economic advantage over livestock production. Under current conditions, significant development of meat and dairy cattle breeding is only possible with the availability of appropriate government subsidies. Subsidies largely offset the influence of such a factor as risk aversion on choice of enterprise mix.

In the analysis we have assumed a wholly rational farmer, to explore what he might want to do. Rationality in this case includes the asset integration assumption and is in contrast to some empirical evidence showing, for example, that people assess losses and gains differently from how they view income and wealth (see, e.g., Thaler, 2015). Any conclusions should be interpreted with this assumption of rationality in mind.

Farmers in North-Kazakhstan region have limited flexibility in choice of enterprises, caused by specific geographical and climatic conditions. It seems that in such conditions having only two or three enterprises can often capture the majority of risk reducing benefits from diversification.

Maximising expected utility is a somewhat difficult task. The question is whether the effort is justified. Theoretically, expected utility maximisation might be interesting to researchers, but is it really used in the business world? The answer appears to be: not very often. Risk aversion seems to be of practical concern in only 5% to 10% of business decision analyses (Winston and Albright, 2017). The use of appropriate models requires a very thorough study of the problem, which, in turn, predetermines the need to attract significant intellectual and financial resources. At the same time, the development of such models, their testing and practical application are quite justified when the task is to forecast and analyse the consequences of the implementation of regional and national agro-economic programs. Significant resources, including time, spent on careful problem-solving, are justified by the scale, societal relevance, and long-term effects of such programs.

On the other hand, information support for agriculture is currently developing rapidly – both in developed and developing economies, enabling data-driven decision-making through technologies like geographic information systems (GIS), farm management information systems (FMIS), and digital platforms (Ezeibe et al., 2024). In this context, it is worth mentioning the digital agriculture knowledge and information system (DAKIS), which employs digital technologies to make decisions aimed at diversifying and sustainably developing agriculture. As the system developers emphasise, multifunctional and diversified agriculture can address a variety of challenges and demands while simultaneously increasing productivity, biodiversity, and the provision of ecosystem services (Mouratiadou et al., 2023). These technologies will obviously change existing research paradigms for the better. The traditional paradigm of decision-making research, which assumes an idealised decision-making situation in which the farm manager knows all the relevant alternatives, their consequences and probabilities, has fixed preferences, and possesses the cognitive abilities to process them effectively, is clearly becoming a thing of the past.

4 Conclusions

Results of the literature review show the present study is one of the pioneering studies that addressed the key factors affecting the choice of production structure on diversified farms in transition post-soviet economies. The main advantage of the proposed approach to finding a risk-effective production structure on crop-livestock farms is the ability to ensure greater flexibility in planning and the simplicity of the model. If you have a farm with good organisation and maintaining production and market data on activities over some years, the method can easily be implemented even in a MS Excel.

A pitfall is that in transition countries, such as Kazakhstan and its neighbours, governments still play a significant role in the agricultural market. Restrictions related to state intervention in market processes represent an additional source of uncertainty. Therefore, more focus should be directed to obtaining good specifications of the probability distributions of outcomes rather than worrying about how risk averse farmers may be. Models that are not valid will provide little useful information about the actual system, and the results of analysis are unlikely to be believed. Furthermore, despite all the advantages of the power function used in the model as a utility function, it should be borne in mind that in some cases its use may give rise to insurmountable computational difficulties. For example, when an economic variable that can take negative and zero values (in particular, profit) is used as an argument, it is quite possible to try to extract the root from a negative number or divide by zero during optimisation.

The research leads us to a range of ideas and opportunities for further research. First, we have not included in our model any financial management options. In Kazakhstan, financial markets for agricultural commodities are not well developed, for price or for volume. A possible extension of the model would be to include some financial management activities such as private insurance arrangements. Second, for small farms it makes sense to include off-farm income opportunities in the model. Third, our model finds an optimal farm plan given a planning horizon of one year. This may be satisfactory if the production activities for one year do not affect the optimal activities for the following year. However, comprehensive changes in activities will often need investments that have impacts many years into the future. A multi-period programming approach may help simultaneously determine optimal investments and annual production decisions. Fourth, as we saw, subsidies seem to be a quite important factor for a farmer's choice of production structure. However, nowadays Kazakhstan is experiencing a reorientation of its agricultural policy towards a more market-oriented approach. As a result, farm subsidy schemes seem to be changed substantially or even eliminated at all in the future. All this means that a lot of work needs to be done to model political uncertainty as clearly and comprehensively as possible.

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Declarations

All authors declare that they have no conflicts of interest.

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