Instruments Reducing Climatic Risk for Russian Agriculture

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ABSTRACT

The paper evaluates technical solutions and two main tapes of index-based insurance: area yield insurance and weather-based index insurance regarding their efficiency in reducing climatic risks of Russian farms in the steppes zone. The analysis considers area yield insurance at two levels of aggregation - oblast and rayon (county) level. Weather-based index insurance products are drawn up by combining two weather parameters – daily precipitation and daily average air temperature. We employ yield and weather data of an experimental station in the Central Volga Russia for the period from 1979 to 2000. In addition experts' assessments are used to specify alternative levels of production technology and respective yield distributions for the considered region. To assess utility-efficiency of the defined insurance products a programming model were formulated for 22 states of nature and 3 levels of the decision-maker risk aversion. The model estimation results show that area yield insurance based on oblast and rayon yields stabilize farm income mostly efficiently. The weather-based index insurance follows immediately after. So, both index-based insurance types provide the considered farm with a higher utility than farm yield insurance with deductibles. This points at a high potential of index-based insurance as an instrument reducing climatic risk of Russian farms situated in the steppes zone.

Keywords: Risk-management instruments, climatic risk, index-based crop insurance, utility efficiency programming model, Russia.

1 INTRODUCTION

Production risk is an important determinant of production development in Russian agriculture. Climatic risk as a part of production risk caused by unfavourable weather conditions not only seriously affects Russian farms income, but also significantly defines the national agricultural output in individual years (LIEFERT, 2002). In this context, assessment of production risk and determination of effective risk coping instruments play an important role in both terms: - stabilization of farms incomes and consequently reduction of agricultural output volatility in Russia.

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High level of production risk in Russian agriculture is primarily to explain by unfavourable climatic conditions in vast areas of the country. A significant part of the country's agricultural area is defined either as *area of risky agriculture*, or as *area of increased risk* (SHELTIKOV ET AL.,2001). Indeed, most important agricultural regions are situated in the steppes climate zone in Russia (LOSEV, ZHURINA, 2001). The steppes zone covers the Low and Central Volga region, Northern Caucasus, Southern Ural, southern areas of Western and Eastern Siberia. A main feature of the steppes zone is that the annual evaporation typically exceeds the annual rainfall that varies between 250 and 450 mm. Average daily temperature of July amounts 20...25°C there. While snow coverage in winter is rather moderate, the average air temperature can go down to - 35...- 45°C (LOSEV, ZHURINA, 2001). With drought and dry wind as main natural hazards, such climatic conditions seriously affect agricultural production and make indispensable application of risk management instruments.

Agricultural commodity producers have many opportunities to cope with risks. They can be classified in two basic groups: (1) on-farm instruments and (2) risk-sharing tools (FLEISCHER, 1990). The first group includes such risk management instruments as diversification of production branches, holding sufficient liquidity, creation of reserves, a choice of less risky products and ways of production and having the short production cycles, stage-by-stage investment, etc. Production based on contracts, hedging on the markets of futures and options, vertical integration, insurance and availability of additional sources of incomes ascribe to risk-sharing strategy (MEUWISSEN ET AL., 2004). While on-farm risk management instruments can be employed by farmers independently, risk-sharing strategies assume availability of corresponding institutional environment and market infrastructure.

At the current stage of the economic development technological instruments and crop insurance present the most accessible risks reducing tools in Russian agriculture. Technological solutions include maintenance of soil humidity, right timing in implementing technological operations, adoption of new plant sorts etc. Crop insurance has a long tradition in Russia. Currently crop insurance is provided in the form of farm yield insurance (FYI) only. However, as historical experience shows this type of insurance is strongly prone to asymmetric information problems. Actually, Russian agricultural insurers stress increasing moral hazard occurrence (INTERFAX, 2007). A traditional way of moral hazard prevention is provision of crop insurance with lower loss coverage levels. This, however, may seriously affect effectiveness of crop insurance for farmers and thus reduce demand for this risk management instrument. Introduction of index-based insurance presents a new approach for solving moral hazard problems at insurance market. However, yet the applicability of such insurance products to Russian agriculture has been not evaluated in the literature to the best of the authors' knowledge. Considering this, the objective of the study is to determine

appropriate index-based insurance products for Russian agriculture and analyse their efficiency in comparison to traditional FYI. Therefore, based on the weather and yield time series of a study farm in Saratov oblast we first draw up alternative index-based insurance products. Then by applying a utility-efficient programming model we evaluate comparatively their efficiency taking into account decision maker's risk attitude and different levels of risk exposure subject to production technology choice.

The paper proceeds as follows. In the next section, we describe methodology and data applied. Sections 3 present and discusses the empirical results of the study. Section 4 concludes.

2. METHODOLOGY AND DATA

In the first step of the analysis alternative schemes of index-based crop insurance products were drawn up taking into account climatic conditions and structural characteristics of the Central Volga region. Thereby, area yield insurance (AYI) was formulated at *oblast* and *rayon* (county) levels. Weather-based index insurance (WBII) was designed by employing different hydro-meteorological indices. In the second step efficiency of the considered insurance products were analyzed comparatively by applying a utility-efficient programming model and taking into account differences in intensity of farm's risk exposure subject to choice of production technology.

2.1. Insurance products design

Index-based insurance contracts that are applied in crop production use either a weather index or an area-yield index for pricing insurance contracts. In case of an AYI contract, average area yield triggers an indemnity payment which is equal to the difference, if positive, between the annual area yield and some predetermined critical yield (MIRANDA, 1991). In WBII contracts insurance payoffs are subject to the occurrence of a special weather event, which can be described by a meteorological index (SKEES, 1999). Index-based insurance allows to solve problems caused by information asymmetries at the insurance market. This advantage of index-based insurance is to explain due to objective nature of the parameters that they are based on. At the same time risk-reducing potential of index-based insurance contracts depends strongly on the extent to which individual farmers are affected by systemic risk in relation to AYI or an individual natural hazard (as for example drought) concerning WBII. Thus the level of basis risk which cannot be insured through index-based insurance will determine effectiveness and hence demand for such insurance contracts. In this regard, a particular task of the study is to find out parameters of insurance contracts that allow maximum reduction of a farm's basis risk.

Area yield insurance

According to MAHUL (1999) an individual farmer's stochastic yield can be related to a corresponding area yield as follows:

$$\tilde{y}_i - \mu_i = \beta_i(\tilde{y} - \mu) + \tilde{\varepsilon}_i, \tag{1}$$

with

$$\beta_i = \mathrm{cov}(\tilde{y}_i, \tilde{y}) / \mathrm{var}(\tilde{y}), \tag{2}$$

$$E\tilde{\varepsilon}_i = 0; \quad \mathrm{cov}(\tilde{\varepsilon}_i, \tilde{y}) = 0, \tag{3}$$

$$E\tilde{y}_i = \mu_i; \quad E\tilde{y} = \mu, \tag{4}$$

where $\tilde{y}_i$ - the farmer's stochastic individual yield, $\tilde{y}$ - the stochastic area yield. The coefficient β_i measures the sensitivity of farm yield to changes in area yield. The formula (1) divides total yield risk into a component that perfectly correlates with the area yield, i.e. systemic risk, and a component $\tilde{\varepsilon}_i$ that does not correlate with the area yield, i.e. farm's idiosyncratic risk. Consequently, an AYI contract covers only systemic risk involved, i.e. idiosyncratic risk remains uninsured in this case. The optimal coverage of the AYI contract is equal to the farmer's individual β_i-coefficient. Accordingly, the indemnity payments are defined by the following rule:

$$indemnity_t = \begin{bmatrix} 0, & if\ y_t \geq \mu \\ \beta_i(\mu - y_t), & if\ y_t < \mu \end{bmatrix}, \tag{5}$$

where y_t - actual realization of the area yield in the year *t*.

Weather-based index insurance

Correspondingly, for WBII the farmer's individual yield $\tilde{y}_i$ can be decomposed into a component $\tilde{y}_w$ that depends on actual realization of a weather parameter (or index) in the year *t* and a component $\tilde{\varepsilon}_i$ that is determined by other factors:

$$\tilde{y}_t = \tilde{y}_t^w + \tilde{\varepsilon}_t, \tag{6}$$

with

$$y_t^w = const + \alpha\ I_t, \tag{7}$$

$$E\tilde{\varepsilon}_t = 0; \quad \mathrm{cov}(\tilde{\varepsilon}_t, \tilde{y}_t^w) = 0, \tag{8}$$

$$E\tilde{y}_t^w = \mu^w, \tag{9}$$

where the component y_t^w is defined by regressing the farm's yield on a selected weather-based index I_t.

Indemnity payments are defined as follows:

$$indemnity_t = \begin{bmatrix} 0, & if\ y_t^w \geq \mu^w \\ \mu^w - y_t^w, & if\ y_t^w < \mu^w \end{bmatrix}, \tag{10}$$

Farm yield insurance

In our study we evaluate efficiency of index-based insurance products by comparing them with traditional FYI that is defined on the basis of the farm's historical yield. In this case indemnity payment is defined according to the following:

$$indemnity_t = \begin{bmatrix} 0, & if\ y_t \geq \mu_i \\ c(\mu_i - y_t), & if\ y_t < \mu_i \end{bmatrix}, \tag{11}$$

where y_t - actually realized farm yield in the year *t*, *c* is the coverage level.

2.2. Utility-efficient modelling framework

Comparison of the efficiency of different insurance products was conducted by estimating their utility-efficiency for the decision maker. Expected utility approach provides a convenient way to represent decision maker's risk preferences: its basic idea is that decision-makers maximize his expected utility. When income increases, utility increases less than proportionately for risk-averse decision-makers (the more risk-averse a person is, the more he will be prepared to pay to eliminate risk). Hence, utility is an increasing but downward bending function of income. Expected utility estimates can be transformed into certainty equivalents (CE) that is the inverse of the utility function. CE represents a sure monetary value that provides a decision maker with the same utility as a risky alternative, thus making him indifferent to facing the risk or accepting the sure sum (HARDAKER ET AL., 2004). An important advantage of CE is that it allows quantitatively compare different risky alternatives. Knowing certainty equivalent outcomes not only permits the ranking of risky alternatives, but also facilitates estimating risk premiums. CE simultaneously accounts for the probabilities of risky prospects and the preferences of the decision maker (ANDERSON ET AL., 1977).

Each production activity and risk management instrument may influence a decision-maker's expected utility. Examining CE is an approach to investigate the magnitude of this influence. The utility efficient programming model (HARDAKER ET AL., 2004) formulated as follows:

$$\max CE = \left[(1-r)E(U)\right]^{1/(1-r)}, \tag{12}$$

where CE - certainty equivalent, r - absolute risk aversion coefficient, U - a utility function defined in this study as the following negative exponential function:

$$U = 1 - \exp(1 - r)z \tag{13}$$

subject to

$$Ax \leq b, \tag{14}$$

$$Cx - Iz = uf, \tag{15}$$

and

$$x \geq 0, \tag{16}$$

where A is a matrix of technical coefficients for all activities, b is a vector of capacities, x is a vector of activity levels, C is a matrix of activity net revenues by state of nature, I is an identity matrix, z is the annual net income in each state, u is a vector of ones, and f is fixed or overhead costs.

The absolute risk aversion range for the model was derived from the plausible range of relative risk aversion coefficients - r_r, defined as the marginal utility of wealth. ARROW (1965) has shown that

$$r_a = \frac{r_r}{w}, \tag{17}$$

where w is wealth. HARDAKER ET AL. (2004) suggest that r_r should be a number close to 2. In our study we employ three levels of relative risk aversion - 0.5 (hardly risk averse at all), 2 (rather risk averse) and 4 (extremely risk averse).

The model includes 4 different types of insurance products – FYI with coverage level 0.75, AYI based on oblast yield (OYI), AYI based on rayon yield (RYI) and WBII and considers three levels of production technology related to the degree of intensification - intensive, medium and extensive. The formulation of technologies was done by means of experts' assessments with one of the regarded technologies being based on historical yields of the study farm (farm yields were detrended by employing linear and second-degree polynomial functional forms). We consider 22 states of nature that correspond to the individual years in our data set. The basic descriptive statistics of the considered technologies are presented in Appendix A.

To assess the effect of alternative insurance products on the farm's production decisions, income and certainty equivalent were estimated for different scenarios that are described in Table 1.

Table 1: Model scenarios

Scenario	Description
R	Reference scenario: all technologies are available, no access

	to insurance
1	All technologies are available, access to all insurance products
2 (FYI-AYI)	All technologies are available, access to farm yield and area yield insurance products
3 (FYI-WBII)	All technologies are available, access to farm yield and weather based index insurance products
4 (AYI-WBII)	All technologies are available, access to area yield and weather based index insurance products

Source: authors' own estimates.

2.3. Data

In our empirical analysis we employ yield and weather data from an experimental station situated in Saratov oblast (the Central Volga region) for the period from 1979 to 2000. The weather data encloses daily precipitation (mm) and average daily temperature (°C). Additionally, official statistics on oblast and rayon yields were used for the same period in the study.

The study farm produces winter wheat and spring wheat, winter rye, barley, sunflower seeds and has typical for Saratov oblast production structure. Farm's crop area is 4193 ha. The study farm applies primarily intensive technology and has a relatively low for the region yield variation[3]; nevertheless coefficients of variation of the farm's main crops are higher than 30 per cent. Average level of winter crops yields in the study farm is slightly higher than average yields formulated by experts for the intensive technology and, on the contrary, yield of spring crops is somewhat lower compared to experts' assessments for this level of technology. Average yield of sunflower corresponds to yields under medium technology.

22 states integrated into the model can be combined in 5 aggregated states; this is more convenient concerning discussion of the model results:

S1 - strong drought (1984, 1987, 1995, 1998);

S2 - average drought (1979, 1981);

S3 - weak drought (1985, 1988, 1991, 1992, 1994, 1996, 1999);

S4 - favourable weather conditions (1980, 1982, 1986, 1990, 1993);

S5 - very favourable weather conditions (1983, 1989, 1997, 2000).

[3] As can be seen from Appendix A yield variability strongly connected to the technology applied at farms of the considered region: - yield variation decreases with increasing level of production intensity.

3. ESTIMATION AND EMPIRICAL RESULTS

Area-yield index insurance

High correlation of farm yields with oblast and rayon yields (Appendix B) point at a relatively high level of systemic risk in Saratov oblast that is an important precondition for introduction of AYI. Correlation coefficients between farm and area yields at rayon and oblast levels vary within the interval 0.85-0.95. This means that the study farm's systemic component of risk is better represented by the yields of higher than rayon level of aggregation[4] and supposedly point's at relatively low level of idiosyncratic risks at the investigated farm compared to other farms in the respective rayon. Table 2 presents critical β-coefficients, that reflect the optimum insurance coverage for individual crops.

Table 2: β-coefficients estimated for AYI at oblast and rayon level

Crops	Oblast-yield index crop insurance (OYI)	Rayon-yield index crop insurance (RYI)
Winter rye	1.08	0.71
Winter wheat	1.14	0.83
Spring wheat	1.18	0.69
Barley	1.30	0.85
Sunflower	0.97	0.82

Source: authors' own estimates.

Weather-based index insurance

A weather index is usually built either from one or several weather parameters (BOKUSHEVA ET AL., 2006, KARUAIHE ET AL., 2006). In our study we tested different weather indices employing different combination of two weather parameters – cumulative precipitation and daily average temperature. To determine the weights of individual weather parameters considered for a weather index the (detrended) farm's yields were regressed on the selected weather parameters. On the whole, we regarded two critical periods of plant vegetation: 1) from April till September for all crops; and 2) from December till February for winter crops.[5] The composition of the individual weather indices which significantly determine the farm's crop yields is presented in Table 3.

[4] Yields of higher level of aggregation eliminates more strongly individual farms' yield effects.

[5] We could not find any dependence between the weather parameters considered for the winter period and winter crop yields.

Table 3: Whether conditions indices and characteristics of corresponding regression models (study farm, 1979-2000)

Crops	Weather parameter	Coefficient estimates [a)]	R-squared
Winter rye	Sum of rainfall during April 6 – June 4, mm (*R*)	0.05**	0.80
	Sum of average daily temperatures during May 11 – June 29, degrees (*T*)	-0.04***	
Winter wheat	Sum of rainfall during April 16 – June 4, mm (*R*)	0.10***	0.78
	Sum of average daily temperatures during May 6 – June 29, degrees (*T*)	-0.03***	
Spring wheat	Sum of rainfall during May 1 - June 4, mm (*R*)	0.05**	0.66
	Sum of average daily temperatures during May 1 – July 29, degrees (*T*)	-0.01***	
Barley	Sum of rainfall during April 26 – May 30, mm (*R*)	0.05**	0.69
	Sum of average daily temperatures during May 21 – July 29, degrees (*T*)	-0.03***	
Sunflower	Sum of rainfall during May 4 – May 20, mm (*R*)	0.07***	0.70
	Sum of average daily temperatures during May 4 – June 9, degrees (*T*)	-0.01*	

[a)] ***, **, * - significant at 0.01-level, 0.05-level, and 0.10-level, respectively.

Source: authors' own estimates.

Farm yield insurance

Farm yield insurance was constructed employing coverage level 0.75 that is typically used in the crop insurance practice. Introducing deductibles is aimed to prevent moral hazard of the insured; however, it can seriously affect the effectiveness of FYI.

Utility-efficiency of the index-based insurance products

Model estimation results for the reference scenario R (without access to insurance) presented in Table 4. According to the model estimates the farm uses its whole crop area, i.e. 4193 ha with 497 ha being under winter wheat, 2909 ha under barley and 786 ha under sunflower. Winter wheat production is more profitable, but at the same time more risky than barley production – this detains the farm from producing more winter wheat. All crops are produced under the intensive production technology. This result shows that this technology guarantees the farm the highest income utility.

Table 4: Technology choices, scenario R (for $r_r = 2$)

Crops	Intensive technology	Medium intensive technology	Extensive technology	Total
Winter rye	0	0	0	**0**
Winter wheat	497	0	0	**497**
Spring wheat	0	0	0	**0**
Barley	2909	0	0	**2909**
Sunflower	786	0	0	**786**
Total	**4193**	**0**	**0**	**4193**

Source: authors' own estimates.

Integration of insurance products into the model seriously alters optimal production plan of the investigated farm (Table 5). Provision of insurance allows the farm switch from barley to winter wheat production whose outcome is more uncertain. Demand for insurance depends strongly on the level of the decision maker risk aversion. A hardly risk averse decision maker would insurance only a part of his winter wheat crop area, while a rather risk averse and extremely risk averse farmer would prefer to insure all crops except sunflower. At the same time, it can be seen that the preferences concerning crops and technologies are preserved are quite stable over all considered levels of risk-aversion.

Moreover, purchase of insurance contracts allows considerably increase the farm's expected income and certainty equivalent. In the reference scenario expected income and certainty equivalent in case of hardly risk aversion decision makers are 5,741 и 5,584 thousand Roubles, respectively, in the scenario 1 (with access to all insurance products) their values amount to 6,295 and 6,146 thousand Roubles. These differences increase with increasing risk aversion.

Table 5: Technology and insurance product choices, scenario 1 – all insurance products

Level of risk aversion	Crop	Insurance product	Area, ha	Technology	Expected income, '000 Rub	Certainty equivalent, '000 Rub
Hardly risk averse at all ($r_r = 0.5$)	Winter rye	-	-	-	6295	6146
	Winter wheat	Without insurance	718	Intensive		
		RYI	798	Intensive		
		OYI	57	Intensive		
	Spring wheat	-	-	-		
	Barley	Without insurance	1834	Intensive		

	Sunflower	Without insurance	786	Intensive		
Rather risk averse ($r_r = 2$)	Winter rye	-	-	-	6111	5831
	Winter wheat	Without insurance	19	Intensive		
		RYI	870	Intensive		
		OYI	683	Intensive		
	Spring wheat	-	-	-		
	Barley	OYI	1834	Intensive		
	Sunflower	Without insurance	786	Intensive		
Extremely risk averse ($r_r = 4$)	Winter rye	-	-	-	6108	5581
	Winter wheat	RYI	1100	Intensive		
		OYI	473	Intensive		
	Spring wheat	-	-	-		
	Barley	OYI	1834	Intensive		
	Sunflower	Without insurance	786	Intensive		

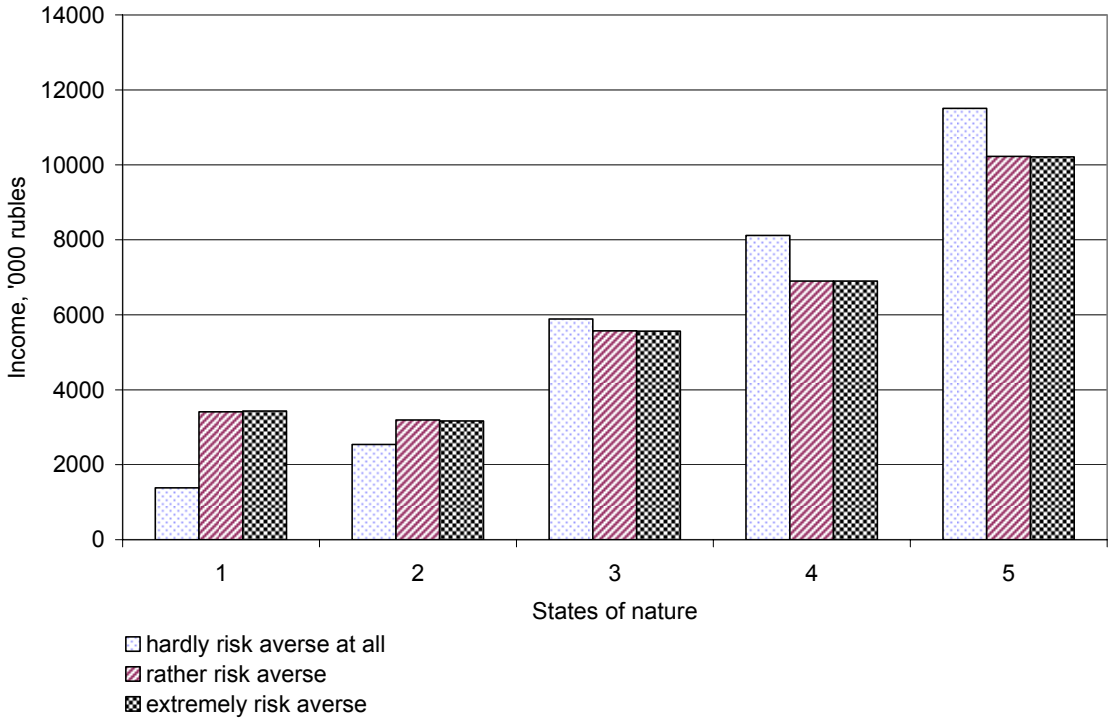
Source: authors' own estimates.

Among the insurance products analysed the farm prefers AYI to WBII and FYI. This result obviously points at the prevalence of systemic risk at the considered farm. Additionally, we can observe that the farm uses a combination of OYI and RYI. This supposes that the farm's yield risk is well captured by yields at both aggregation levels – oblast and rayon level. Examination of the annual indemnity payments shows that in some years OYI ensures a better indemnification of the farm's actual losses, in several years however RYI performs better.

Optimal plans for all considered levels of risk aversion include sunflower production at the maximum rate of 786 ha (20 per cent of the total crop area). This can be explained primarily by a high profitability of this activity but also by relatively low compared to other crops yield variability of sunflower. The later fact indicates that sunflower production allows the farm to use the diversification effect. However, since traditional cultivating practices in Russia do not permit the farm to increase the sunflower crop area, the diversification effect of this crop can be used only to a limited extent.

The income stabilizing effect of crop insurance can be illustrated by means of Figure 2 that shows the distribution of the farm's income according to the 5 aggregated states of nature and the risk-aversion levels (for scenario 1). As can be seen, the more risk averse a decision maker is, the stronger he demands a crop insurance.

Figure 1: Income distribution in different states of nature for three levels of risk aversion (,) $r_r = 0.5$ $r_r = 2$ $r_r = 4$**, scenario 1 - all insurance products**



Source: authors' own estimates.

A subsequent elimination of one of the regarded insurance products from the model (scenarios 2-4) was conducted to rate their individual utility-efficiency. The results show that though WBII is less efficient than OYI and RYI, it provides the farmer with a higher income utility than FYI with coverage level 0.75.

4. CONCLUSIONS

The paper evaluates two main tapes of index-based insurance: area yield insurance and weather-based index insurance regarding their efficiency in reducing climatic risks of Russian farms in the steppes zone. The analysis considers area yield insurance at two levels of aggregation - oblast and rayon (county) level. Weather-based index insurance products are drawn up by combining two weather parameters – daily precipitation and daily average air temperature. To assess utility-efficiency of the defined insurance products a programming model were formulated for 22 states of nature and 3 levels of the decision-maker risk aversion. We employ yield and weather data of an experimental station in the Central Volga Russia for the period from 1979 to 2000. In addition experts' assessments are used to specify alternative levels of production technology and respective yield distributions for the considered region.

The estimation results show that area yield insurance based on oblast and rayon yields stabilize farm income mostly efficiently. The weather-based index insur-

ance follows immediately after. So, both index-based insurance types provide the considered farm with a higher utility than farm yield insurance with coverage level 0.75.

Moreover, our investigations show that Russian farms, similarly to farms in the other post-soviet countries, have only limited options for coping with risks on-farm (HEIDELBACH, 2006; BOKUSHEVA AND HOCKMANN, 2006). Most of available technologies and production practices used at Russian farms are not adjusted to the prevailing climatic conditions; this seriously limits the farms' prospectives for reducing high yield variability as well as adopting higher levels of crop diversification.

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Appendix A: Yield and yield variability for study farm's main crops by different levels of technology

Crops	Technology	Mean yield, 0.1t per ha	Standard deviation, 0.1t per ha	Variation coefficient, %
Winter rye	Intensive	18.71	5.61	30.01
	Medium intensive	16.28	6.91	42.48
	Extensive	11.10	6.97	62.75
Winter wheat	Intensive	19.31	6.52	33.77
	Medium intensive	16.52	7.77	47.05
	Extensive	11.69	7.86	67.29
Spring wheat	Intensive	13.49	3.57	26.43
	Medium intensive	7.37	3.63	49.29
	Extensive	5.35	3.66	68.35
Barley	Intensive	16.78	4.80	28.60
	Medium intensity	10.44	4.89	46.83
	Extensive	7.38	4.94	66.92
Sunflower	Intensive	9.37	2.56	27.28
	Medium intensive	6.12	2.90	47.38
	Extensive	4.71	2.90	61.48

Source: authors' own estimates.

Appendix B: Correlation coefficients of study farm's yields with respective oblast and rayon yields (1979-2000)[a)]

Crops	Correlation coefficient between farm level and oblast level yield	Correlation coefficient between farm level and rayon level yield
Winter rye	0.93	0.87
Winter wheat	0.93	0.92
Spring wheat	0.91	0.85
Barley	0.95	0.92
Sunflower	0.76	0.85

[a)] correlation coefficients were calculated by using detrended yields.

Source: authors' own estimates.