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Foreword

The paper focuses on implications of recent agricultural reforms and trade liberalization on agriculture and rural areas development in Ukraine. The paper develops a decision theoretic framework for designing forward looking national and sub-national agricultural policies regarding optimal agricultural production composition, intensification and allocation with a specific concern to revive and consolidate small and medium scale producers and services in rural areas.

Traditional general equilibrium (GE) approaches may not be adequate for planning development strategies because they are too aggregate to include appropriate sustainability indicators with safety/security constraints and horizons of planning. A serious issue of GEs is also "demand-price-supply" relations which are often largely driven by inherent uncertainties and current policies, e.g., weather conditions or export-import quotas, and thus can differ from ideal "demand-price-supply" dependencies. Using in these cases aggregate GE models may cause various "unexpected" shocks such as bankruptcy, non-payments, prices increase, noncompliance to market agreements, etc.

The paper develops a stochastic optimization model following general ideas of economic modeling outlined in Nobel Memorial Lecture by Tjalling C. Koopmans, who admits that economics is the study of "… best use of scarce resources …". Because of the existence of "… alternative ways of achieving the same end result that a genuine optimization problem arises" that may have different efficiency allocation criteria and constraints regarding available resources, capital, equipment, etc. Yet, "… with an optimal solution of the given problem, whether of cost minimization or output maximization, one can associate … shadow prices, one for each resource, intermediate commodity or end-product". Koopmans acknowledges that these shadow prices or dual variables can be used as a price system for the decentralization of decision, either through the operation of competitive markets, or as an instrument of national planning. In other words, although the optimization model may be the same, the post-optimization institutional framework can be fundamentally different. This paper considers only a pre-institutional optimization framework, i.e., primal stochastic optimization resource allocation model. The analysis of dual problem, emerging pricing system, and decentralized solutions requires extension of the paper. In general, the model may consider alternative objective functions that incorporate or emphasize various aspects of sustainability and security concepts.

The model is applied for the analysis of optimal investments allocation into expansion of agricultural activities and rural services to employ potential workers migrating between Ukrainian regions as a result of job losses or financial/production instabilities.

Abstract

In Ukraine, the growth of intensive agricultural enterprises with a focus on fast profits contributes considerably to food insecurity and increasing socio-economic and environmental risks. Ukraine has important natural and labor resources for effective rural development. For example, more than 50% of food production is still managed in small and medium farms despite the difficulties associated with economic instabilities and the lack of proper policy support. The main issue for the agro-policy nowadays is to use these resources in a sustainable way enforcing robust long term development of rural communities and agriculture.

In this paper, we introduce a stochastic geographically explicit model for designing forward looking policies regarding robust resources allocation and composition of agricultural production enhancing food security and rural development. In particular, we investigate the role of investments into rural facilities to stabilize and enhance the performance of the agrofood sector in view of uncertainties and incomplete information. The security goals are introduced in the form of multidimensional risk indicators.

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The paper builds on data and expands the approach that Oleksandra Borodina developed in 2009 during the Young Scientists Summer Program.

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Table of Contents

List of Figures

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1. Introduction

Production intensification with a focus on fast profits is among the main drivers that restructure food markets and distribute resource management rights in an imbalanced way in Ukraine. Intensification is advantageous for large producers, while small and medium agricultural businesses abandon the market due to an inability to compete for scarce and costly resources without a proper policy support. As a result, a lack of producers diversification increases risks associated with food and water security, environmental pollution, loss of food diversity, deterioration of socio-economic conditions in rural areas, rural-urban migration, and loss of cultural heritage investigating the dilemma between the economic growth and the degradation of rural areas in Ukraine requires the development of integrated approaches specifying interdependent socio-economic, demographic and environmental criteria of long-term sustainable rural community development. A set of such criteria has already been identified and implemented in the USA as well as in the EU in LEADER I, LEADER II, LEADER+ programs [1], [24].

In Ukraine, similar to LEADER, rural development planning includes goals of stimulating investments into improving quality of life and social conditions; protection and friendly use of environmental and cultural values; introduction, utilization, and expansion of new technologies and markets of local producers and services. The aim of this paper is twofold; first, to analyze implications of recent agricultural reforms and trade liberalization on agriculture and rural areas development in Ukraine; second, based on this analysis, to develop a decision theoretic framework for designing forward looking national and sub-national agricultural policies. The focus is to support policy choice regarding optimal agricultural production structure with a specific concern to revive and consolidate small and medium scale producers and services in rural areas.

There exist different approaches to the analyses of optimal production structure and resources allocation in agriculture. Studies involving trade liberalization often rely on the concept of general equilibrium (GE). While the GE models may provide useful information on several economic aspects of policy reforms, it may be inappropriate, and in some cases misleading, to rely extensively only on their use for planning sustainable development strategies [29]. There exists vast literature summarizing the limitations of the GE analysis [6], [7], [29]. Two main concerns dominate the discussion.

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The first is that GEs are too aggregated to include appropriate sustainability indicators with safety/security constraints and horizons of planning. The second raises the issue about "demand-price-supply" relations which are often largely driven by inherent uncertainties and current policies [11], e.g., weather conditions or export-import quotas, and thus can differ from ideal "demand-price-supply".

The main task of planning sustainable agriculture in Ukraine is to design necessary resources allocation and regulations for rehabilitation of rural areas [4]-[6], [25]-[27]. Therefore, in this paper, we introduce an optimization model following general ideas of economic modeling outlined in Nobel Memorial Lecture by Tjalling C. Koopmans [23]. He admits (pp. 240-243) that according to a frequently cited definition, economics is the study of "… best use of scarce resources …". Because of the existence of "… alternative ways of achieving the same end result that a genuine optimization problem arises" that may have different efficiency allocation criteria and constraints regarding available resources, capital, equipment, etc. Yet, "… with an optimal solution of the given problem, whether of cost minimization or output maximization, one can associate … shadow prices, one for each resource, intermediate commodity or end-product". Koopmans further acknowledges that these shadow prices or dual variables can be used as a price system for the decentralization of decision, either through the operation of competitive markets, or as an instrument of national planning [8], [18]-[20], [22], [23]. In other words, although the optimization model may be the same, the post-optimization institutional framework can be fundamentally different. In this paper, we consider only a pre-institutional optimization framework, i.e., primal stochastic optimization resource allocation model.

The analysis of dual problem, emerging pricing system, and decentralized solutions would require considerable extension of the paper. In particular, important issues concern relations among emerging spot prices and safety/security constraints. In this paper we also don't consider issues connected with data analysis, which are vital for proper treatment of inherent uncertainties. We simply assume that the data can always be characterized by scenarios. Therefore, the main issue is the design of policies (decisions) robust with respect to all potential scenarios. This framework assumes the existence of a policy analyst who may perform efficient allocation of resources. In general, the analyst may consider alternative objective functions that incorporate or emphasize various aspects of sustainability and security concepts.

In the presence of uncertainties and resource constraints, (financial, land, water), the irreversibility of deterministic solutions may incur high sank costs [3]. Therefore, there is a need for a two-stage decision making framework with anticipative and adaptive decisions [3], [10]. The strategic (ex-ante) first-stage decisions taken before the uncertainties become known cannot be altered. In order to ensure the flexibility of the system under such decisions, they are supplemented by a set of corrective (ex-post) decisions implemented after the uncertainties are resolved. Thus, in the presence of uncertainty, e.g., climatic variability, markets shocks, demand and price fluctuations, etc., the strategic decisions are only partially implemented in the first stage, and can then be corrected in the second stage by learning from experience and further observations. Within the same modeling framework, the optimal combination of adaptive and anticipative decisions can be derived only by methods of two-stage stochastic optimization (STO). The two-stage STO model proposed in this paper is geographically explicit. The application of the model is illustrated with an example of optimal investments into expansion of agricultural activities and rural services to employ potential workers migrating between Ukrainian regions as a result of job losses or financial/production instabilities.

The structure of the paper is as follows. Section 2 summarizes main structural changes and current agricultural development trends in Ukraine and identifies key factors contributing to the worsening situation in rural communities. Section 3 outlines main criteria of rural community development as formulated in LEADER programs [1], [24]. It formulates a model that employs these criteria in the context of Ukraine. Section 4 discusses model application with selected numerical calculations and Section 5 concludes.

2. Structural changes in Ukrainian agricultural sector

Agricultural enterprises in Ukraine are being actively restructured and integrated forming large agro-holdings. During 2005 and 2006 the number of the enterprises, which operate more than 10 thousand hectares of land, has increased by 27%; the average size of the total area in these enterprises has increased by 7% to more than 20 thousand hectares. Large agricultural farms may rather freely choose among the commodities to produce and in what amounts. This freedom induces specialization in more profitable products. As a result, agro-holdings concentrate primarily on intensive profitable production such as raw-materials for biofuels, which increases socio-economic and environmental risks in rural areas. Decreasing production diversity and diversion of land and water resources from direct food production undermines food security. It also worsens environmental quality through high fertilization rates and absence of necessary crop rotations. Without adequate regulations, these trends may lead to further land degradation, loss of fertile soils, water, air, soil pollution [1], [30].

Apart from mono cropping which disturbs the supply of grains for direct consumption, food security problem has been exacerbated by inadequate import-export quotas and weather uncertainties. Imbalanced and unstable grains production affects, in particular, livestock sector, foremost, large animals and cows (see Section 3). Reasons for the decreasing number of animals in Ukraine are different for different locations and years. At the beginning of agricultural reforms, the loss of state subsidies following the collapse of the Soviet Union increased feed and production costs and reduced profitability of livestock enterprises. Further, in 2003, 2004 and 2005, the majority of large animals were slaughtered because of insufficient feeds due to low yields and intensive international trade [32]. Decreased number of animals and declined meat production resulted in a substantial increase of meat prices. From March 2004 to March 2005 the price for meat increased by 56.8%. Due to the high share of meat in goods' basket (about 13%), meat deficit contributed about a 15% increase to the yearly inflation rate [16]. This shows how inadequate policies in the agricultural sector may produce dramatic effects within the sector with a spillover into the whole national economy. Large systems of bovine meat production turned to be most prone to frequent reforms and governmental regulations. Currently, large animals (among them cows) and bovine meat production in Ukraine concentrate primarily in household systems. Because of high production costs and risks, these producers will not invest into larger scale production. Livestock production is one of the most labor intensive agricultural activities, which may provide employment and social protection for many out of work in rural areas. However, without targeted investments this is unlikely to happen given high risks and strict quality norms imposed by the WTO accession [17], [30].

Production intensification and land concentration have led to many adverse problems, but most harmful are impacts on demographic and socioeconomic situation in rural areas. Intensive large scale enterprises and agro holdings require much fewer workers than soviet-type agro businesses. They make use of qualified labor force from cities, better educated with special skills and experience. This has released a rather substantial part of rural workers and inspired rural – urban migration in strive for short-term jobs (primarily in construction sector), what led to rural area depopulation and degradation [25]-[27]. Depopulation and deterioration of living conditions and infrastructure in rural areas are also due to the fact that unlike the Soviet times when almost all expenses on the development, social security, health and fiscal provision of rural areas were taken by the state and local collective agrarian enterprises, during and after the reform "market" rules were introduced, i.e. agrarian enterprises make profits while local communities have to develop rural areas. It should be noted that a majority of large scale producers are registered in cities and rarely pay taxes into local budgets.

There are good reasons to believe that agro-holdings will dominate the agricultural sector of Ukraine in the future. Considering their rash emergence and the increasing risks they cause to food security and rural development, new approaches for organization and planning need to be properly designed in order to enable agriculture and rural development with a multitude of farming activities. Government may impose regulations that provide equal and transparent financial support for doing business by all forms of enterprises in agricultural production and service sectors. Such measures may reduce unequally distributed opportunities for subsidies and, possibly, replace them by direct governmental/public investments, such as investment in practical education of rural community members, creation of market information systems, support of farm advisory services, and – most important – investments in rural infrastructure (roads, energy and water supply, health care, schools). Furthermore, it is necessary to put more emphasis on the impact of fiscal support measures to agriculture. Currently, the bias is strongly in favor of agro-holdings and urban areas.

3. Analysis of pathways towards sustainable rural area development: An Integrated model based approach

The trends highlighted in previous sections are alarming and call for adequate approaches for organization and forward-looking agricultural policies. There exists encouraging experience in planning rural development within "LEADER" programs which originally stands for "Liaison Entre les Actions de Development Rural", the English translation meaning "Links between actions of rural development". The programs implement incentives to encourage integrated, high-quality and original strategies for sustainable development, have a strong focus on partnership and networks for exchange of experience. In Ukraine, similar programs focus on revival of old and introduction of new rural activities to create rural jobs and enhance food security.

In this section we propose a two-stage stochastic optimization model to assist optimal agricultural development under inherent risks, incomplete information, and resource constraints. Optimal adjustments of production and services by geographical locations are derived as a tradeoff between costs minimization, food security goals, targeted level of rural jobs, and the suitability criteria. The security goals are introduced in the form of multidimensional risk measures having direct connections (see remark in Section 5) with Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) or expected shortfalls type indicators [28]. For planning livestock production expansion, the suitability criteria include feeds and pastures requirements per unit livestock. The model is temporally explicit. In the current two-stage setting, it involves two stages (periods), contemporary and future. Each of these stages may include many time intervals. In other words, it may be easily expanded to a multi-period dynamic framework. The model is also geographically detailed.

For now, it is implemented at the level of 25 Ukrainian regions, but may be disaggregated to finer resolutions. The model comprises three main modules with respective parameters, technical coefficients, criteria, and risks - socio-economic, environmental, and agricultural. The socio-economic module defines a balance between costs minimization and social goals including additional production to ensure jobs and food security; the environmental module controls pressure stemming from agricultural production in locations; the agricultural module imposes technical coefficients of agronomically sound practices. The model distinguishes producers of different agricultural commodities i in regions l and by production systems j. Production systems are characterized by different intensification levels, say, traditional (household), medium or intensive large scale producers. In general, there are considerable data requirements which cannot be fulfilled by traditional estimation procedures. The lack of repetitive observations of the same phenomenon raises important issue about using different sources and generators of data, explicit treatment of uncertainties and designing decisions robust with respect to inherent uncertainties.

Food security and rural development goals require allocating targeted production and respective rural workers by regions. Food targets include direct demand for food and feeds and indirect demand, e.g., international export obligations and inter-regional trades. Let $x_{ijl} \geq 0$ denote potential production of commodity i in region l and management system j. Increased production creates additional rural agricultural and nonagricultural (service) jobs. Define β_{ijl} as a number of workers needed to produce a unit of commodity x_{ijl}, and L_l - a targeted level of rural employment in location l. Ignoring so far uncertainties, the goal to ensure required employment in location l is defined by the following constraints:

$$\sum_{i.j} \beta_{ijl} x_{ijl} \geq L_l . \quad (1)$$

In general, L_l may not be known with certainty as it is difficult to predict, for example, how many people are likely to return from short-term urban jobs to rural areas. Therefore, constraint (1) as well as the following constraints (2) can be defined in terms of probabilistic constraints (7)-(8) or, within general two-stage stochastic optimization framework defined by functions (11)-(18). Migration of labor force between rural-urban areas and within regions depends on various factors, including availability of infrastructural (schools, trade centers, etc.), health and social provisions, transportation networks, entertaining and cultural centers, incomes, etc. The model may account for the behavioral components similarly to the model developed for the analysis of agricultural development in China [12]-[14] where behavioral criteria are combined with strictly planned governmental policies. In general, variable L_l may be characterized by alternative scenarios.

Data [4] on employment rates in rural services per unit of produce x_{ijl} are used for estimation of the demand for jobs S_l in region l. Values S_l may be treated as random, i.e., defined either by probability distribution functions or by a set of potential scenarios. The willingness to work in infrastructure, for example in schools, depends on gender, age, educational level, i.e., values S_l can also be characterized by behavioral criteria. Thus, in addition to (1), x_{ijl} need to satisfy the condition on necessary expansion and employment in rural infrastructure:

$$\sum_{i.j} \gamma_{ijl} \beta_{ijl} x_{ijl} \geq S_l . \quad (2)$$

Expansion of production and services requires investments. Their limitations are included in our model either as an overall budget constraint or as minimization of total costs and investments:

$$\sum_{i.l} V_{il} (\sum_{j} x_{ijl}) + \sum_{ijl} c_{ijl} x_{ijl} + \sum_{l} C_l (y_l) + \sum_{kl} c_{kl} y_{kl} , \quad (3)$$

Where c_{ijl} are expenditures associated with production costs and wages of employees involved in production x_{ijl}. Investments V_{il} depend on the current level of regional development, i.e., depressive regions require higher investments. Cost functions C_l and c_{kl} may be associated with trades agreements and transportation of feeds between regions, as explained below. Uncertainties of criterion (3) are associated, first of all, with market prices.

Food security and environmental constraints are introduced by equations (4) (5) (6) respectively:

$$\sum_{jl} x_{ijl} \geq d_i \,, \tag{4}$$

$$\sum_{ij} \delta_i x_{ijl} \leq a_l + y_l + \sum_k y_{kl} - \sum_k y_{lk} \,, \tag{5}$$

$$\sum_{ij} \sigma_i x_{ijl} \leq b_l \,. \tag{6}$$

Constraint (4) ensures that production levels x_{ijl} satisfy targeted national demand d_i by commodity i, which reflects food security goals, and (5) ensures that allocation x_{ijl} satisfies availability of feeds in location l, where δ_i is a technical coefficient defining the feed requirements per unit livestock. Variables $y_i \geq 0$ reflect possibility to expand feeding capacity a_l at cost $c_l(y_l)$, and variables y_{lk} stand for possibility of feed trading between different regions at cost c_{kl}. The same type of additional decision variables can be introduced in equations (4) for trading production commodities. Equation (6) allows production expansion only in locations with sufficient resources, such as pastures or cultivated land, thus ensuring efficient recycling of wastes and manure associated with new x_{ijl} units of production, σ_i is an ambient coefficient reflecting diverse recycling capacities (e.g., manure storage and processing facilities). Constraints (5) and (6) comprise the environmental module that safeguards environmental targets, land use, and agronomic norms.

Uncertainties, in particular, stochastic variables S_l, L_l, still needs to be specified. We admit that information on S_l, L_l may be uncertain, and therefore solution x_{ijl} needs to satisfy constraints (1)-(2) with some guaranteed certainty level for all possible scenarios of $S_l(\omega)$, $L_l(\omega)$ of S_l, L_l, where ω indicates uncertain events (scenarios) which may affect S_l, L_l, e.g., $\omega \in \{1,2,...,N\}$. Say, chances that constraints (1)-(2) are satisfied (under derived x_{ijl}) must be higher than imposed levels $0 \leq p_l \leq 1$, $0 \leq q_l \leq 1$. This requirement is expressed in terms of probabilistic constraints

$$P[\sum_{ij} \beta_{ijl} x_{ijl} \geq L_l(\omega)] \geq p_l \,, \tag{7}$$

$$P[\sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl} \geq S_l(\omega)] \geq q_l \,, \tag{8}$$

$0 \leq p_l \leq 1, 0 \leq q_l \leq 1$, which are similar to the well-known in engineering safety or reliability constraints. In insurance business, they reflect solvency constraints of insurance companies or banks and often are defined by p_l, q_l of about 1- 10^-3^, insolvency may be regulated as an event that may occur once in 1000 years.

Constraints (7)-(8) describe in a sense a stochastic supply – demand relations regarding employment: the demand $\beta_{ijl} x_{ijl}$ may not be completely satisfied by the random supply $L_l(\omega)$; similar relates to $\gamma_{ijl} \beta_{ijl} x_{ijl}$ and $S_l(\omega)$. If we know analytical distributions of $L_l(\omega)$, $S_l(\omega)$, equations (7), (8) are reduced to linear equations defined by quantiles of these $L_l(\omega)$, $S_l(\omega)$. In general cases, accounting for potential uncertainties of β_{ijl}, γ_{ijl} requires specific methods, in particular, (7), (8) may represent discontinuous constraints. To account for possibly highly discontinuous equations (7)-(8), we convert them into expected imbalances defined by convex functions

$$E \max\{0, L_l(\omega) - \sum_{ij} \beta_{ijl} x_{ijl}\}, \tag{9}$$

$$E \max\{0, S_l(\omega) - \sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl}\}. \tag{10}$$

Minimization of functions (9)-(10) implies costs π_l, ψ_l to decrease the gaps or expected deficits of employment in agriculture and services. Therefore, functions (9), (10) are modified to the following cost functions

$$\pi_l E \max\{0, L_l(\omega) - \sum_{ij} \beta_{ijl} x_{ijl}\} \tag{11}$$

$$\psi_l E \max\{0, S_l(\omega) - \sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl}\}. \tag{12}$$

Accounting for goals (3) and (11)-(12), the problem can be formulated as the following: find production x_{ijl} minimizing the cost function

$$\begin{aligned} &\sum_{i.l} V_{il}(\sum_j x_{ijl}) + \sum_{ijl} c_{ijl} x_{ijl} + \sum_l C_l(y_l) + \sum_{kl} c_{kl} y_{kl} \\ &\qquad + \sum_l \pi_l E \max\{0, L_l(\omega) - \sum_{ij} \beta_{ijl} x_{ijl}\} \\ &\qquad + \sum_l \psi_l E \max\{0, S_l(\omega) - \sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl}\} \end{aligned} \tag{13}$$

subject to constraints (4)-(6).

Function (13) can be considered as a stochastic version of scalarization functions, traditionally used in multicriteria analysis for aggregation of component achievement functions that represent the satisfaction level of reaching a certain value of the corresponding criterion. Formally, function (13) corresponds to a multicriteria stochastic minimization model with cost function (3) and risk functions (11)-(12). As analyzed in [10], [13], appropriate choice of values π_l and ψ_l allows controlling the safety/security constraints (7), (8). We may also formulate a robust stochastic optimization model with an alternative scalarization function:

$$\sum_{i.l} V_{il}(\sum_j x_{ijl}) + \sum_{ijl} c_{ijl} x_{ijl} + \sum_l C_l(y_l) + \sum_{kl} c_{kl} y_{kl}$$

$$+ E \max_l \pi_l \max\{0, L_l(\omega) - \sum_{ij} \beta_{ijl} x_{ijl}\} \quad (14)$$

$$+ E \max_l \psi_l \max\{0, S_l(\omega) - \sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl}\},$$

i.e., instead of the aggregate “expected” deficit defined by (13) as the sum of functions (11), (12), function (14) focuses on extreme random deficits (events) of the most suffering regions. The advantage of this optimization problem is its focus on country-wide extreme events (scenarios) regarding demand-supply relations defined by $L_l(\omega), S_l(\omega)$, and $\sum \beta_{ijl} x_{ijl}$, $\sum \gamma_{ijl} \beta_{ijl}$. The minimization of function (13), (14) has important two-stage decision making formulation. Let us consider only the case when parameters of the model do not depend on x_{ijl}. In this case, the minimization of functions (13), (14) may be reduced to linear programming (LP) problem using ex-ante decisions of the model defined by equations (4)-(6), (13) or (14), and additional second-stage ex-post decisions emerging after observations of random variables.

Let us consider the LP problem corresponding to minimization of (13) subject to constraints (4), (5), (6). In general, ex-ante decisions x_{ijl}, y_{ijl} may lead to deficits defined by (9), (10). Let us consider a finite number of scenarios L_l^s, $s = \overline{1:N_l}$, S_l^t, $t = \overline{1:M_l}$ of random variables $L_l(\omega)$ and $S_l(\omega)$. Two-stage model assumes that after the observation L_l^s and S_l^t of real random variables L_l and S_l, the arising deficit can be corrected by second stage ex-post decisions Z_l^s and U_l^t. In our model, the second stage decisions Z_l^s in constraint (1) and U_l^t in constraint (2) may be associated with the use of better technologies or more qualified employees with higher wages. Decision variables Z_l^s and U_l^t ensure satisfaction of constraints

$$\sum_{i.j} \beta_{ijl} x_{ijl} + Z_l^s \geq L_l^s, \quad (15)$$

$$\sum_{i.j} \gamma_{ijl} \beta_{ijl} x_{ijl} + U_l^t \geq S_l^t \quad (16)$$

For all possible random scenarios L_l^s and S_l^t, $s = \overline{1:N_l}$, and $t = \overline{1:M_l}$. Therefore, the second-stage feasible variables Z_l^s and U_l^t are, in general, random variables $Z_l(\omega)$ and $U_l(\omega)$ depending on random observations L_l^s and S_l^t. The two-stage stochastic programming problem is formulated as minimization of the following function:

$$\sum_{i.l} V_{il} (\sum_j x_{ijl}) + \sum_{ijl} c_{ijl} x_{ijl} + \sum_l C_l (y_l) + \sum_{kl} c_{kl} y_{kl} \\ + \sum_l \pi_l EZ_l (\omega) + \sum_l \psi_l EU_l (\omega) \tag{17}$$

subject to constraints (4), (5), (6), (15), (16). If costs V_{il} and c_l , c_{kl} are linear (or piecewise linear convex function), then (17) may be solved by linear programming methods. Assume that scenarios L_l^s, $s = \overline{1:N_l}$, and S_l^t, $t = \overline{1:M_l}$, have probabilities ϑ_l^1, …, $\vartheta_l^{N_l}$ and μ_l^1, …, $\mu_l^{M_l}$. This is a natural assumption since results of questionnaires are usually quantified by likelihoods, e.g. with equal probabilities. Let us denote by Z_l^s and U_l^t the ex-post decision under scenarios L_l^s and S_l^t. Then, the proposed model can be formulated as the following linear programming problem in the space of ex-ante and ex-post decisions: minimize

$$\sum_{i.l} V_{il} (\sum_j x_{ijl}) + \sum_{ijl} c_{ijl} x_{ijl} + \sum_l C_l (y_l) + \sum_{kl} c_{kl} y_{kl} \\ + \sum_l \pi_l \sum_s \vartheta_l^s Z_l^s + \sum_l \omega_l \sum_t \mu_l^t U_l^t \tag{18}$$

subject to constraints (4), (5), (6), (15) and the constraints (15)-(16). It is easy to see that optimal decisions Z_l^s and U_l^t are calculated as $Z_l^s = \max\{0, L_l^s - \sum_{ij} \beta_{ijl} x_{ijl}\}$, $U_l^s = \max\{0, S_l^s - \sum_{ij} \gamma_{ijl} \beta_{ijl} x_{ijl}\}$, for all scenarios $s = \overline{1:N_l}$ and $t = \overline{1:M_l}$. Therefore, the model defined by equations (4), (5), (6), (18), (19), (20) is indeed equivalent to the model defined by equations (4), (5), (6), (13), (15), (16) under random scenarios L_l^s and S_l^t.

4. Numerical application

In this section we summarize some results of recent joint studies [4] between the Institute of Economics and Forecasting (IEF), NAS Ukraine and IIASA. The application of the model at regional levels, $l = \overline{1:25}$, is illustrated with a case of livestock sector expansion and rural services development. Scenarios of migrants L_l^s and S_l^t in (15)-(16) are derived in [4] from experts opinions and national surveys. About 100 alternative scenarios are identified by ranges (Figure 2). Other model parameters are also summarized in [4]. Costs per animal operations, the ranking regions by depreciation level, transportation and production costs are available from the Statistical Year Books of Ukraine.

The model operates in two modes: deterministic and stochastic. The solution of the deterministic model is optimal with respect to one scenario of migrants, e.g., expected values of L_l^s and S_l^t. In stochastic mode, the number of migrants is not known in advance, and therefore the model derives a solution robust with respect to all scenarios.

To understand why two-stage STO produces robust risk-focusing solutions, it is important to discuss the main differences between the deterministic (solution of the deterministic model) and the two-stage solutions.

Deterministic model assumes complete information about agents, and therefore creates activities for the known number of migrants, which formally restrains the analysis to the case $s = 1$ and $t = 1$ in (15)-(18). In reality, it may happen that jobs are created for an expected or targeted number of migrants, while the real number of them is lower or higher. Both cases, i.e., deficit and surplus, lead to direct and indirect costs. If activities are expanded (which also includes infrastructure – roads, schools, medical and cultural facilities, etc.), but the number of workers is overestimated, the investments may be lost. The situation may be improved by offering higher incomes and privileges in order to attract workers. Conversely, if jobs and facilities are in deficit, this may either cause regret situations among population or would require upfront investments to immediately accommodate newcomers.

In contrast to the deterministic model, the two-stage solution is calculated knowing in advance the number of migrants. The costs and risks associated with situations of deficit and surplus described above are controlled by the second stage decision. Thus, the main idea of robust two-stage solution is to choose first-stage decisions x_{ijl} before knowing the true number of migrants such that the total expenses incurred by implementations of x_{ijl} and the costs of their possible corrections determined by second-stage decisions Z_l^s and U_l^t are minimized. In the event of "more-than-expected" migrants, the costs of second-stage decisions Z_l^s and U_l^t may reflect foreseen at stage 1 feasible adjustments of infrastructure, houses, farms, roads, etc. In the "less-than-expected" case, they may correspond to foreseen at stage 1 feasible increases of incomes or social benefits to attract more laborers. In fact, for the simplicity of model formulation, functions (13), (14) ignore costs associated with the underestimation of migrants. Adjustments of the model for general case are trivial, and the discussion of the dual model is easy (see next section) for functions (13), (14).

According to expert estimates, it is anticipated that the number of migrants will exceed expected values (Figure 2) of the deterministic model. Total costs (13) for optimal solution of the deterministic model and the robust solutions are depicted in Figure 1. For the solution of the deterministic model, the costs include costs of optimal single scenario solution and additional costs associated with the corrections of these solutions with respect to other potential scenarios. Costs of robust two-stage solutions are optimal with respect to both stages. Total costs of deterministic and robust solutions are about 70 and 55 (x10^5) monetary units, respectively.

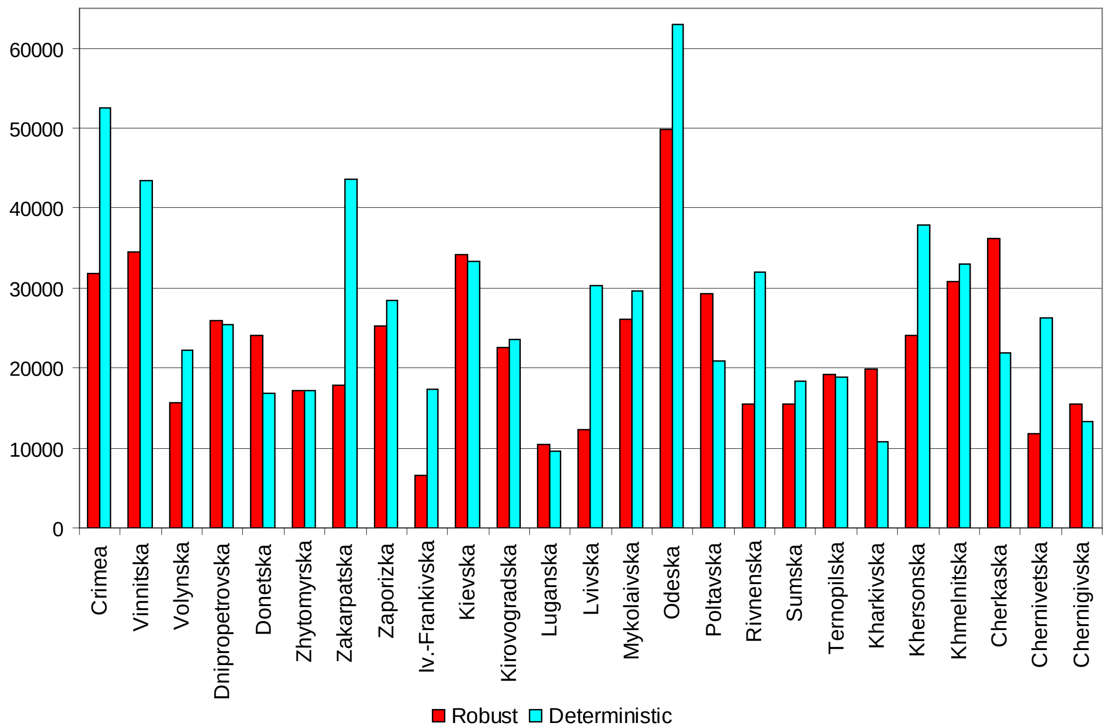

Figure 1 Total costs associated with robust solution & optimal solution of the deterministic model

Figure 2 displays solutions in terms of rural work-places. Robust solution suggests creating activities accounting for percentiles of outcome with respect to all scenarios, while the deterministic model solution accounts only for expected scenario. These results so far provide only an aggregate region-level perspectives regarding agricultural expansion, which may be downscaled to finer levels (i.e., villages, communities) applying technique developed in [14].

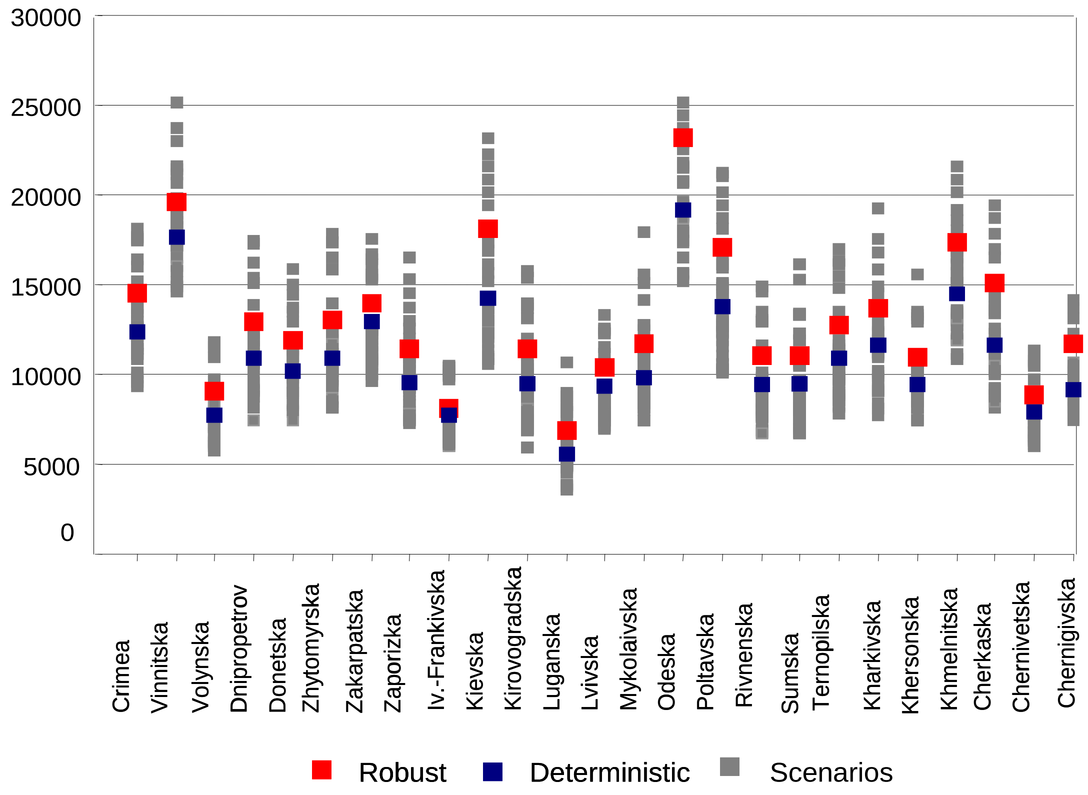

Figure 2 Deterministic and robust allocation of new rural activities per region
Alternative scenarios of migrants are depicted with grey color

Regarding financial support for additional livestock production allocation, the model estimates that the support may come either in the form of voluntarily contributions or taxation of the intensive enterprises and part of the investments may be covered by governmental support or through other investments. The analysis of these alternatives requires formulation of the dual model and optimality/equilibrium conditions.

5. Concluding remarks

This paper summarizes agricultural developments in Ukraine in the period from 1990 to current. It identifies diverse risks induced by production intensification and concentration, in particular, risks associated with food security, environment pollution, worsening socio-economic and demographic conditions in rural areas of Ukraine. The problem of sustainable rural development and necessary agriculture expansion is formulated as a two-stage STO, which permits to account for inherent complex interactions and to derive forward-looking policies.

Numerical results review recent joint studies between IEF and IIASA on planning new activities and jobs in agricultural sector and rural services at the level of Ukrainian regions. In Ukraine it is expected that large number of short-term urban workers will migrate between regions and from urban to rural areas. Robust solution suggested by the two-stage STO model identifies levels of rural activities optimal with respect to a majority of possible migrants' scenarios. We illustrate the advantages (e.g. cost effectiveness) of robust solution in contrast to optimal solution of the deterministic model. Costs and risks associated with the deterministic model solution are much higher than costs and risks associated with robust solution derived by two-stage STO.

According to the general discussion in Section 1, the main purpose of this paper is to develop only an integrated optimization model allowing a policy analyst to identify robust paths of future agriculture development in Ukraine improving socio-economic and environmental aspects of rural life, enhancing food security of the country.

Important remaining issue is the analysis of the dual problem, emerging optimality conditions, pricing system and decentralized solutions. The following example illustrates the type of important conclusions which can be derived from such analysis of a STO model. Risk functions (9), (10) embedded in cost function (13) (similarly in (14)) defines systemic risks of the whole food supply system. It is unclear a priory, that minimization of cost-function (13) imposes implicit regional risk measures. This becomes clear only from analysis of the dual model and optimality conditions. Consider a slight modification of risk functions (9), (10) that reflects the discussion in the previous Section. Let us introduce for each location l new decision variables h_l and g_l as risk reserves which have to be prepared ex-ante for making ex-post adjustments in the case of “less-than-expected” migrants flow. Then function (13) takes on the form

$$\sum_{i.l} V_{il}(\sum_j x_{ijl}) + \sum_{ijl} c_{ijl}x_{ijl} + \sum_l C_l(y_l) + \sum_{kl} c_{kl}y_{kl} + \sum_l (\rho_l g_l + \varepsilon_l h_l)$$

$$+ \sum_l \pi_l E \max\{0, L_l(\omega) - \sum_{ij} \beta_{ijl}x_{ijl} - g_l\}$$

$$+ \sum_l \psi_l E \max\{0, S_l(\omega) - \sum_{ij} \gamma_{ijl}\beta_{ijl}x_{ijl} - h_l\}$$

(19)

where ρ_l, ε_l are unit costs in a region l associated with creation at stage 1 a unit of the risk reserve. The optimality conditions with respect to h_l and g_l lead to VaR and CVaR type risk measures with respect to decision variables h_l and g_l:

$$\Pr ob[L_l(\omega) - \sum \beta_{ijl}x_{ijl} - g_l \geq 0] = \rho_l / \pi_l,$$

$$\Pr ob[S_l(\omega) - \sum \gamma_{ijl}\beta_{ijl}x_{ijl} - h_l \geq 0] = \varepsilon_l / \psi_l,$$

jointly with other optimality conditions written by using also other probability functions and dual variables. This becomes clear by taking the partial derivative with respect to x_{ljl} of function (19), assuming this derivative exists. In general, this requires the use of non-differentiable optimization techniques as in [9], or by formulating the dual problem for discrete approximation model similar as in [21] defined by (4)-(6), (15), (16) and function (17).

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