CLIMATE CHANGE ADAPTATION THROUGH ROBUST LAND USE PLANNING: TWO-STAGE STOCHASTIC OPTIMIZATION FOR RISK-INFORMED DECISION MAKING

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Аннотация. *Uncertainty and variability of climate changes are key challenges for adaptation planning. In the face of uncertainty, the decision-making can be addressed in two interdependent stages: make only partial ex-ante anticipative actions to keep options open until new information is revealed; and adapt the first-stage decisions with respect to newly acquired information. This decision-making approach corresponds to the two-stage stochastic optimization (STO) incorporating both anticipative ex-ante and adaptive ex-post decisions within a single model. The paper develops a two-stage STO model for climate change adaptation through robust land use and irrigation planning in the condition of uncertain water supply. The model identifies the differences between the decision-making in the cases of perfect information, full uncertainty, and uncertainty with perspectives of learning about uncertainty. The two-stage anticipative and adaptive risk-informed decision-making with safety constraints induces risk aversion characterized by quantile-based Value-at-Risk and Conditional Value-at-Risk risk measures. The ratio between the ex-ante and ex-post costs and the shape of uncertainty* *determines the balance between the anticipative and adaptive decisions. Selected numerical results illustrate that the alteration of the ex-ante agricultural production costs can affect crop production, land management technologies, and natural resource utilization.*

Ключевые слова: *uncertainties and risks, climate change adaptation, robust land use and irrigation planning, two-stage optimation, VaR and CVaR risk measures*

Climate changes affect socio-economic and environmental systems directly and indirectly, through exogenous shocks from natural disasters and endogenous systemic risks due to interactions among systems and policies [1-5]. The impacts of climate changes are expected to increase triggered by the growing complexity of systemic interdependencies, introduction of new policies and technologies, growing demands, increasing variability and magnitude of natural disasters. Many prominent economic assessment models involved in climate change analysis are deterministic and fail to account for the uncertainties and risks inherent in climate change. What is also important – they are unable to account for the increasing variability and frequency of extreme events and catastrophic risks which currently dominate the climate change debates [6-8]. This paper discusses the need for important improvements of the methods to incorporate central issues in climate change adaptation such as uncertainty, treatment of irreversibility, safety and security requirements, and robustness of decisions.

Uncertainty and variability of climate changes are the key challenges for adaptation planning [8-9]. In the conditions of uncertainty and possibility of irreversible decisions [9], the decision-making can be addressed in two interdependent stages: in the first stage, make only partial ex-ante anticipative actions to keep options open until new information is revealed; and adapt the first-stage decisions after more information about the true state of environment (true scenario) is acquired. A portfolio of robust interdependent ex-ante and ex-post strategies can be designed by using two-stage stochastic optimization (STO). The two-stage STO naturally integrates the two types of decisions [1], [10-14]: anticipative ex-ante and adaptive ex-post decisions. The robustness of the two-stage decisions [12-14] is characterized by the representation of the feasible decisions, potential threats, and adequate quantile-based performance functions and constraints. The two-stage STO approach enables to deal with situations of imbalances, disequilibrium, thresholds, and quantile-based safety constraints, typical for non-smooth and often discontinuous and nonconvex interdependent socio-economic and anthropogenic systems. In particular, the anticipative and adaptive measures reduce the chances of critical imbalances and exceedances of vital thresholds, which otherwise could lead to systemic failures [1-5], [15].

This paper develops a two-stage STO model for climate change adaptation through robust land use and irrigation planning in the presence of uncertainty and risks associated with water availability. The model identifies key differences between the decision-making in the cases of perfect information (full certainty), full uncertainty, and in the case of the two-stage anticipative and adaptive approach. The risk-informed decision-making with anticipative and adaptive actions and safety constraints induces risk aversion characterized by quantile-based VaR (Value at Risk) and CVaR (Conditional Value at Risk) risk measures that are used for regulating the safety of nuclear plants, insolvency of insurance companies, in financial applications, extremal value theory, and catastrophic risk management [12-14], [12-14], [17], [19-22]. The safety of systems' performance and the robustness of the anticipative and adaptive decisions strongly depends on the interactions between the ex-ante and ex-post costs and the shape of uncertainty. With selected numerical results we show that the alteration of agricultural production costs (ex-ante costs) can reshape production allocation and management decisions and therefore affect the overall systemic security and sustainable performance in the presence of uncertainty and risks.

A proper combination of ex-ante anticipative and ex-post adaptive decisions enables to minimize costs associated with irreversible and lock-in situations. In economics literature, the framework with the two types of decisions was first discussed in connection with irreversible investments in land use changes (land conversion) in 1974 in Arrow and Fisher (1974) [9] without an overall two-stage model being formulated. Most of integrated assessment models use the concept of expected impact as they cannot properly capture and analyze the effects of abrupt changes, threshold exceedances, and catastrophic risks. In these models, climate changes are considered as if they occur on average and continuously, and climatic and policy impacts can eventually be reversed through ex-post adjustments [12-14], [19-22]. Instead of using expected impacts, the introduction of safety constraints into two-stage STO enforces a required likelihood of vital constraints satisfaction enabling to avoid systemic failures with a predefined probability. The risk-informed decision-making with anticipative and adaptive actions and safety constraints induces risk aversion characterized by quantile-based VaR (Value at Risk) and CVaR (Conditional Value at Risk) risk measures that are used for regulating the safety of nuclear plants, insolvency of insurance companies, in financial applications, extremal value theory, and catastrophic risk management [1], [16], [12-14], [18-22].

Литература.

1. Ermoliev, Y., von Winterfeldt, D. Systemic risk and security management. In Managing safety of heterogeneous systems: Lecture notes in economics and mathematical systems; Ermoliev, Y., Makowski, M., Marti, K., Eds. - Springer Verlag, Berlin, Heidelberg, Germany, 2012. - P. 19–49.
2. Kaufman, G.G.; Scott, K.E. What is Systemic Risk, and do Bank Regulators Retard or Contribute to it? // Independent Review. – 2003. – Vol. 7(3). - P. 371–391.
3. Cassidy, A., Feinstein, Z., Nehorai, A. Risk measures for power failures in transmission systems. // Chaos: An Interdisciplinary Journal of Nonlinear Science, 2016. - Vol. 26(11).
4. Cummins, J. D., Weiss, M. Systemic risk and regulation of the U.S. Insurance Industry. In Modernizing insurance regulation; J. Biggs, M. Richardson, I. Walter, Eds. - John Wiley &Sons, NJ, Hoboken, 2014. - P. 85–136.
5. Hellström, T. New Vistas for Technology and Risk Assessment? The OECD Programme on Emerging Systemic Risks and beyond. // Technology in Society. – 2009. - Vol. 31(3). – P. 325-331.
6. Ermolieva T., Biewald A., Boere E., Havlik P., Hunt A., Ierland van E. (2016b). Overview report on major uncertainties related to climate impacts and socio-economic costs, and policy recommendations related to the effectiveness of adaptation

options. The Economics of Climate Change Adaptation (ECONADAPT, 603906, EU FP7) Deliverable 7.3. (http://econadapt.eu/resources).

7. Heal G., Kriström B. Uncertainty and climate change. // Environmental and Resource Economics. – 2002. - Vol. 22. - P. 3–39.
8. Kunreuther H., G. Heal, M. Allen, O. Edenhofer, C. B. Field, and G. Yohe (2013). Risk management and climate change. Nature Climate Change 3, 447 – 450. Available at: http: / / www.nber.org/papers/w18607.
9. Arrow, K.J. and Fisher, A.C. Preservation, uncertainty and irreversibility. // Quarterly Journal of Economics, 1974. - Vol. 88. – P. 312–319.
10. Ermoliev, Y., Wets, RJ-B.: Numerical techniques for stochastic optimization. - Springer Verlag, Heidelberg, Germany, 1988.
11. Ermoliev, Y.: Two-stage stochastic programming: Quasigradient method. In: Pardalos, P.M. (Ed.), Encyclopedia of optimization. - Springer Verlag, New York, USA, 2009. P. 3955-3959.
12. Ermoliev, Y., Hordijk, L.: Global changes: Facets of robust decisions. In: Marti, K., Ermoliev, Y., Makowski, M., Pug, G. (eds.) Coping with uncertainty: Modeling and policy issue. Springer Verlag, Berlin, Germany (2003).
13. Ermolieva, T., Havlik, P., Ermoliev, Y., Khabarov, N., Obersteiner, M. Robust Management of Systemic Risks and Food-Water-Energy-Environmental Security: Two-Stage Strategic-Adaptive GLOBIOM Model. // Sustainability, 2021. Vol. 13(2).
14. Borodina, O., Borodina, E., Ermolieva, T., Ermoliev, Y., Fischer, G., Makowski, M., van Velthuizen, H. Sustainable agriculture, food security, and socio-economic risks in Ukraine. In: Managing safety of heterogeneous systems, Lecture Notes in Economics and Mathematical Systems, Y Ermoliev, M Makowski, K Marti, Eds.; Springer Verlag, Heidelberg, Germany, 2012. P. 169-185.
15. Abrar, M. Power cut off and power blackout in India a major threat – An overview. // Int. Journal of Advancements in Research and Technology, 2016. – Vol. 5(7). – P. 8-15.
16. IAEA (1992). The Role of probabilistic safety assessment and probabilistic safety criteria in nuclear power plant safety. Vienna:

International Atomic Energy Agency (IAEA). (http://books.google.at/books?id=J-ZSAAAAMAAJ).
17. Rockafellar, T. and S. Uryasev. 2000. Optimization of conditional value-at-risk. // The Journal of Risk, 2000. – Vol. 2(3). – P. 21-41.
18. Embrechts, P., C. Klueppelberg, and T. Mikosch. 2000. Modeling Extremal Events for Insurance and Finance. Applications of Mathematics, Stochastic Modeling and Applied Probability, Springer Verlag, Heidelberg.
19. Ermoliev, Y., T.Y. Ermolieva, G.MacDonald, and V.Norkin. 2000. Stochastic optimization of insurance portfolios for managing exposure to catastrophic risks. // Annals of Operations Research, 2000. – Vol. 99. – P. 207-225.
20. Ermolieva,T., Ermoliev, Y.: Catastrophic risk management: flood and seismic risk case studies, in Wallace, S.W. and Ziemba, W.T., Applications of Stochastic Programming, SIAM, MPS (2005).
21. Ermolieva, T., Filatova, T., Ermoliev, Y., Obersteiner, M., de Bruijn, K. M., Jeuken, A.: Flood Catastrophe Model for Designing Optimal Flood Insurance Program: Estimating Location-Specific Premiums in the Netherlands. // Risk Analysis, 2016. - Vol. 2. – P. 1-17.
22. Ermoliev YM, Robinson SM, Rovenskaya E, Ermolieva T. Integrated Catastrophic Risk Management: Robust Balance between Ex-ante and Ex-post Measures. // SIAM News 2018. – Vol. 51 (6). – P. 4.