4.4. CONTEMPORARY FEATURES OF AGRICULTURAL ECONOMICS MODELING

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Modeling is a powerful tool in agricultural economics that offers a range of benefits that help us understand and navigate the complexities of the agricultural sector. The major approach is to break down the complicated agricultural operations into manageable components that can be represented and analyzed through models of differen nature. In a straightforward way modeling is the process of creating a bit simplified representation of a real-world system or concept. Nowadays the most usable form of modeling are mathematical or computer-based ones. It explains features of the described full-scale thing and allows us to make predictions about its behavior. The key missions of models are simplification, representation, analysis, understanding, and prediction. It implies that researchers intentionally leave out some excessive details to focus on the most important aspects of the object in question. By doing this, simulating is able to capture the essence without getting bogged down in secondary elements. Mathematical forms in agricultural economics make it possible to unveil relationships between prices, production costs, yields, consumer demand and so on. It could also be a computer simulation that mimics how farms might respond to different internal conditions and external factors. Model can be used as a "black box" to track how the outputs change if we modify model inputs. Such experiments and observations help us understand the key drivers of the system behind the model and how different factors interact. A main purpose of many models is to forecast what might happen in the future. So, modeling is about building a useful, but simplified version of reality, in particular for tackling the complex essence of agricultural economics. The key areas of farming in Ukraine that need urgent systematic modeling are as follows (Vasylieva et al., 2023).

1. Planning of crop production means simulating the entire cycle from deciding on what to cultivate (considering market prices, local soil conditions, and expected regional weather patterns), to sowing schedules, fertilizer and pesticide application (taking into account current legal regulations), irrigation management, harvesting logistics and machinery, labor availability, storage options (market risks and demand), and finally, selling strategies (direct to consumers, wholesalers, importers from other countries).

2. Livestock management is about modeling the processes encompassed in raising animals, such as breeding schedules, feeding regimes (optimal with regard to cost and growth), protocols of disease management, housing and pasture management (given the regional features), and the processes for selling livestock (to slaughterhouses and markets).

3. Farm machinery investment suggests simulating the decision-making process that revolves around purchasing new or used farm technical resources. This could cover modeling the expenditures and advantages of different types of machinery (tractors, combines,

planters), considering factors like fuel usage, costs of equipment repair, labor savings, and the influence on total productivity for the specific crops cultivated in the region.

4. Irrigation system optimization is dedicated to modeling specific irrigation technologies in order to determine the most efficient water usage for grown crops, taking into account water availability, energy costs, and the harvested yields under different climatic scenarios.

5. Storage and logistics are in need of simulating the diversified flows of harvested crops from the field to storage facilities, and then the logistics of transporting these goods to market (focusing on transport expenses, distances to potential clients, and infrastructure availability in the region).

6. Financial planning and risk management depend on modeling the farm's financial flows, including input costs of seeds, fertilizers, fuel, loan repayments, income from sales, and potential risks such as price fluctuations, crop failures due to the adverse weather or disease outbreaks. This might need simulating various insurance strategies or hedging techniques.

7. Agri-tourism operations are meant for farms that diversify into green tourism. Then simulating involves attracting and managing visitors, marketing efforts, advertising, booking systems, staffing, and providing the best customer experiences.

8. Processing of agricultural products are essential for farms that process their own goods (for example, manufacturing dairy products, jams, juice, dried fruit, canned vegetables). Then it is advisable to simulate the production process, including raw material inputs, packaging, quality control, and marketing of the ready-to-sale products.

9. Supply chain management modeling is aimed at the interactions between the farm and other actors in the corresponding supply chain, combining input, processing, distribution, and retailing to optimize efficiency and profitability via appropriate contracts, arrangements or logistics strategies.

10. Labor management implies simulating the hiring, training, and scheduling of farm workers, balancing labor availability in the local agriculture, seasonal peaks in demand, wage costs and workers' qualifications.

Focusing specifically on the financial and marketing sides of agricultural operations, we can consider some business processes ripe for modeling (Bryant, 2018; Cramer et al., 2011). Firstly, financial business processes combine loan acquisition and working capital management; budgeting and cash flow forecasting; investment in assets; insurance strategy optimization; government support and policy impact; financial risk assessment and so on. In particular, modeling agricultural loans with different lenders, interest rates, repayment terms and schedules can deliver reasonable assessment of the debt impact on the farm's financial condition subject to various income scenarios. Through simulating annual or seasonal budgets, tracking expenses for inputs, for example, seeds, fertilizers, fuel, laborforce, and for outputs like crop and livestock sales, we empower farmers to forecast cash flow, seasonal variations in income and expenditures so that they are able to identify potential deficits or surpluses typical for farming. The development of models of financial evaluation for future investments in purchasing new machinery, upgrading irrigation systems or building storage facilities provides farmers with optimal payback periods and clarifies a rational financial structure. Simulating the effectiveness of different agricultural insurance options makes it possible to mitigate financial losses under various adverse events that happen in farming. The goal of modeling the management of short-term assets and liabilities would be to optimize the use of working capital to guarantee profitable operations and prevent financial liquidity issues. Modeling available agricultural subsidies might have a positive effect on farm's viability and sustainability. Models which calculate the farm's vulnerability to various financial risks, mostly caused by price fluctuations, could be based on stress testing as well as scenario analysis.

Secondly, marketing business processes are in need of modeling the market channel selection; optimization of pricing strategies; sales and distribution logistics; market analysis; contract negotiation and many others. Namely, modeling farmers' decision-making processes for choosing the most profitable marketing channels could cover several vectors of sales online or directly to consumers at local markets as well as to wholesalers and processors. When researching export opportunities, the model might consider market access, prices, and transportation costs. Simulating different pricing strategies for the farm's products means defining production costs, market demand, competitor pricing, sales volume and overall revenue. Models of product distribution take into account order fulfillment, transportation arrangements, available storage, and manage relationships with buyers. Simulating the process of collecting and processing market data supports production and marketing decisions dependent on price trends, consumer preferences, and competitor activities. Branding efforts and promotional activities need models for developing customer relationships and implementing marketing strategy. Simulating the financial viability of processing raw products into higher-value goods and marketing these value-added products to consumers or businesses is also one of major avenues of modeling in agricultural economics. At last, negotiation models can secure favorable prices and terms for the farm products.

By modeling these financial and marketing business processes, farmers and agricultural economists in the Dnipro region can gain valuable insights into how to optimize their operations, manage risks, and improve profitability in a dynamic and often challenging agricultural environment.

Agricultural economics modeling of have to address numerous intrinsic and external challenges explored in fundamental studies like (Carpentier et al., 2015; Naik, 2008) Overall they can be generalized as shown in Fig. 4.4.1. Indeed, agriculture deeply intertwined with biological systems, weather patterns, and volatile commodity markets. Climate, pests, diseases directly impact production leading to the essential variability and uncertainty driven by nature itself. Unlike other sectors of economics where people can tightly control outputs, farming is heavily dependent on factors like precipitation, temperature, soil quality, and outbreaks of plant diseases and pest infestation. Modeling harvests or livestock growth demands incorporating probabilistic methods and optimization under uncertain conditions. In other words, specialists and experts in agricultural economics meet strong interdependence of production and environment that is out of their direct control in many cases. Besides, the biological complexity of agricultural production also one of the reasons for the intricate modeling. Living organisms do not always behave as they are intended to. This phenomenon is attributed to genetics, nutrition, and environmental fluctuations that distort the predicted rates of growth and levels of yields. Modeling these biological aspects usually includes complex systems of dynamic approaches which are good at capturing interactions between different controversial elements.

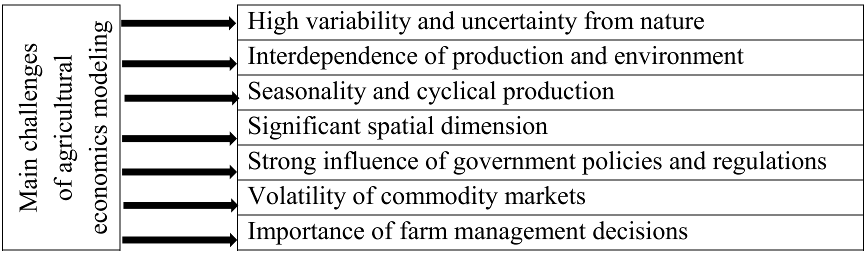

Fig. 4.4.1. Main challenges of agricultural economics modeling

Another key peculiarity is the seasonality and cyclical nature of production observed in agriculture. This is because all stages in growing, harvesting, and marketing frequently follow particular seasonal patterns, which can essentially influence cash flow, storage constraints, and labor demands. Models need to correlate with these cycles and the time lags that accompany major agricultural processes. Decisions made now might not have outcomes for months or years due to long production cycles. This steps are unavoidable being dictated by nature so that business processes have to align with it.

When it comes to spatial dimension is also far more crucial in agriculture than in many other sectors of economy. Namely, locations of farms determine their suitability for different crops or livestock because of access to agricultural lands and water resources as well as to transportation and market infrastructure especially when it comes to perishable fruit and vegetables. To put it simply, these geographical factors can significantly reshape modeling agricultural supply chains and logistics. Therefore, understanding the landscape might bring success to the business process in agriculture.

Agricultural economics relies on government policies and regulations. It is no surprise that subsidies, price supports, environmental regulatory rules, and trade limitations can all have a substantial impact on farmers' management decisions and the total profitability of different agricultural activities. To be effective, agricultural economics modeling ought to incorporate these policy factors and account for how changes in legislation might affect outcomes of farming. However, this is a difficult task as sometimes government decisions stemming from global instability could be completely unpredictable. Meanwhile, the volatility of commodity markets adds another layer of complexity. Prices for agricultural products can demonstrate huge fluctuations owing to tangible factors like global supply and demand, natural disasters or speculative trading. Farmers and agribusinesses have to make management decisions in the face of such price uncertainty. Models that incorporate price forecasting and risk management strategies are invaluable. It is not an exaggeration because these models deal with market swings and do whatever possible to protect farmers from potential losses.

At last, the extremely fragmented nature of the agricultural sector can present challenges for collecting data and modeling. It is typical of small and medium-sized family farms that provide livelihood to population in rural areas. However, large scale farms often consist of many branches scattered around the region. Differences in record-keeping systems and lack of transparencies degrade quality of modeling due to the diversity mentioned above.

To sum up, agricultural economics modeling requires deep insights of economic principles, biological systems, environmental factors, and the specific institutional context of agriculture. Scientists need to address the dynamic interplay between nature and market forces to provide solutions and recommendations that will aid farmers and agricultural stakeholders to make more informed decisions regarding food security.

When mapping out the strengths, weaknesses, opportunities, and threats associated with modeling in agricultural economics, one can conclude that advantages essentially overweigh potential drawbacks (Barkley et al., 2016; Nehrey et al., 2019). Being a powerful tool, modeling proposes a wide range of benefits that help us cope with influential features of agricultural economics.

Firstly, modeling provides better explanations and clearer clarifications when it comes to:

- simplifying complexity and building structured framework for analysis of a multitude of interacting factors like weather, markets, policies, and biological processes. Models help us break down such complexity into manageable components that are easier to explore;
- identifying key drivers by representing the fundamental elements and highlighting pivotal factors that affect agricultural productivity and profitability;
- exploring scenarios for "what-if" analysis without the cost and time of real-world experiments. This enables quantitative assessment of scenarios and helps in forecasting potential consequences of making decisions in reply to changes in input prices, government policies, or climate patterns;
- revealing unexpected connections. Modeling facilitates understanding of complex interactions and feedback loops that could not be obvious through other traditional research methods.

Secondly, modeling is a perfect method created to assist advanced decision-making by means of:

- informed strategic planning including crop selection, resource allocation, technology implementation, and risk management adoption aiding in the development of contingency plans;

- effective policy design intended for policymakers, who are interested in evaluating the potential impacts of agricultural policies on production, markets, trade, and environmental sustainability before practical use. This approach can ensure precisely targeted interventions.

Thirdly, modeling is an excellent source of quantitative recommendations:

- forecasting and prediction are based on mathematical and statistical techniques, bringing substantiated conclusions concerning agricultural economics. In addition, its assumptions are always clearly stated, provide the logical consistency and reliable verification;
- integrating diverse data because models can synthesize large datasets, identify trends, and generate logical inferences related to effective agricultural practices.

Finally, modeling is good at encouraging innovative development and sustainability:

- identifying collaboration opportunities across disciplines for richer models. By doing so, modeling can help pinpoint areas where cutting-edge technologies generate more viable economic and environmental benefits;
- promoting sustainable practices that are eco-friendlier and are more adaptable to emerging environmental challenges that have a negative effect on agricultural economics.

By and large, modeling in agricultural economics performs as a virtual laboratory, allowing scientists to study and examine agriculture that is vital for food security and economic development.

From a critical assessment perspective, there are some weaknesses and threats posed by agricultural economics modeling. These drawbacks appear when developed models are overly simplistic; neglect real-world complexities; are highly dependent on quality data that is inaccessible; require special knowledge and skills to interpret the calculated results; are prone to bias because of design and parameterization; need validation against real-world data that time-consuming and intricate. Threats linked to agricultural economics modeling may occur when stakeholders misinterpret or misuse model outcomes. It also happens owing to lack of trust and resistance to adopting model-based recommendations in decision-making. However, quick changes in agricultural environment can rapidly make qualitative model results obsolete. Then over-reliance on found solutions can play a cruel joke on farmers who neglect inevitable changes. Besides, models are unable to capture unpredictable force major events. Other potential threats are related to funding limitations on the model development and updates as well as ethical concerns with regard to data privacy and model transparency.

Models of agricultural economics are the most effective when scientists apply system thinking introduced by Ludwig von Bertalanffy's approach (Katrenko, 2023). By doing so, researches recognize that simulating is not just about individual farms or markets, but a complex system of closely interacting elements. In this context, a model element could be a single agribusiness, a consumer, a government agency, a specific input (like seeds, fertilizers, fuel), or even a weather pattern, depending on the scope of the model developed. For example, in a model analyzing the impact of a new subsidy, the elements might include individual corn farmers, ethanol producers, consumers of gasoline, and government regulators. A subsystem might be the dairy industry within a larger agricultural system, possessing its own distinct characteristics while still being influenced by and having some effect on other parts. For instance, a model of the US agricultural sector could have subsystems for the beef industry, the grain industry, and the dairy industry, each with its own supply and demand dynamics. A model component could be a group of all grain producers, sharing similar characteristics but not necessarily acting as a single decision-making unit with system-level properties. For instance, when modeling the global wheat market, we might consider "wheat farmers in Ukraine" as a component, distinct from "wheat farmers in France or Argentina".

The structure of the agricultural economy model shows how these elements, groups (components), and subsystems relate – the essential, relatively stable connections like market linkages, supply chains, and policy frameworks. These ensure the agricultural system's core functions. For example, the structure of a vertically integrated poultry industry includes the connections between feed producers, hatcheries, poultry farms, processing plants, and distributors. Interconnections are crucial. These represent the flows of goods (crops, livestock), capital (investment, credit), information (market prices, weather forecasts), and energy (fuel, electricity) between different elements. These connections define the constraints on individual actors and create the integrated nature of the agricultural economy. We can analyze these connections by their direction (who is supplying whom?), strength (how dependent are they?), and type (like a buyer-seller relationship or a regulatory link). A strong connection exists between fertilizer prices and corn production costs. A weak connection is observed between consumer preferences for organic food and the adoption of specific farming practices by a small subset of farmers.

The state of our agricultural economic model at any point in time is defined by key variables like crop yields, market prices, input costs, land use, and farmer' income. System events occur when these states change, perhaps due to a drought affecting yields (a change in an element state) or a policy shift impacting prices (a response to an external event). The behavior of the agricultural sector is its ability to move between these states over time. A process could be the evolution of commodity prices over a growing season, represented by a series of changes in price levels. For example, the state of the US corn market in a certain month might be described by variables like average corn price, total corn stocks, ethanol production volume, and export demand. A system event could be the release of the USDA's crop production forecast, which then leads to price adjustments.

We can model the agricultural sector as an open system, heavily influenced by the external environment – things like global markets, climate change, technological advancements, and consumer preferences, with which it constantly exchanges resources, information, and energy. We might choose to model a specific, highly controlled agricultural market as a relatively closed system for a particular research question, but generally, agriculture is very open. For instance, the global coffee market is an open system, influenced by weather patterns in Brazil, changes in consumer tastes in Europe, and trade policies in Asia. A model focusing on a small, isolated community garden could potentially treat it as a closed system for certain purposes.

Agricultural economic systems can range from well-organized (highly regulated markets) to more diffuse (smallholder farming in remote areas). Importantly, we can simulate the capacity of agricultural systems for self-organization (like farmer cooperatives), self-adaptation (when farmers rotate crops and their varieties in response to climate change), and innovation (think of the implementation of new technologies). For instance, the development of online platforms connecting farmers directly to consumers represents self-organization within the agricultural market. Farmers adopting drought-resistant crop varieties is an example of self-adaptation.

The strength of connections within the agricultural economy can vary. Homogeneous sectors (like large-scale monoculture farming) might show a trend towards standardization, while heterogeneous systems (with diverse farming practices and market channels) exhibit more independent actors. Similarly, the market for commodity corn is relatively homogeneous, with strong price links across different regions. The market for organic vegetables is more heterogeneous, with far more independent prices and greater product differentiation.

Key properties of the agricultural economic system to consider in our models include:

- the interconnectedness of different sectors;
- the fact that the overall behavior is not simply the sum of individual actions;
- the number of variables and the complexity of their relationships;
- the degrees of freedom individual actors have;
- the hierarchical structure of farm-level decisions consistent with regional and national policies;
- the need for multiple perspectives to fully understand it.

For example, a change in biofuel policy can have emergent effects on corn prices, livestock feed costs, and land use patterns that are not immediately obvious from analyzing each sector in isolation. When connecting our agricultural economics model to the external environment, we need to define the input and output channels, the degree of autonomy of the agricultural sector, the intensity of information and resource exchange, and its compatibility with the broader economy and environment. It means that the model of the regional agricultural economy would need to incorporate input channels like weather forecasts, national farm policies, and global commodity prices, and output channels like crop exports, greenhouse gas emissions, and impacts on local water quality. The dynamics witnessed in the agricultural economics are often driven by:

- the long-term goals of food security and rural development;
- the influence of higher-level policies and market forces;
- the cumulative effects of technological adoption;
- the reliability of supply chains;
- the efficiency and emergent properties of different agricultural markets;
- the inherent uncertainties in weather, markets, and policy.

For instance, the long-term goal of increasing food security in a developing country drives policies that affect land use, technology adoption, and market development. When modeling the dynamic development in agricultural economics, we consider its ongoing ability to produce and adapt, the various pathways for achieving goals, the synergistic effects of combining different agricultural practices or technologies, the time lags in response to changes, the capacity for adaptation, the organization around optimal production and sustainability goals, the impact of innovation, the role of standardization and quality grades. For example, the adoption of precision agriculture technologies can lead to a synergistic effect that manifests itself in increasing yields while reducing the use input resources. However, the full impact may take several years to materialize due to learning curves and infrastructure investments. Finally, there are the principles of systematical modeling which can bring enormous benefits to agricultural economics.

1. The "global goal" principle always complies with top objectives like food security, economic viability, environmental sustainability. Indeed, a model analyzing the impact of trade liberalization on the agricultural sector should consider its effects on food security, farm incomes, and environmental sustainability, not just export volumes.

2. The "unity" principle analyzes the agricultural economy both as a whole and by examining its individual components and their interactions. Namely, to understand the impact of a drought, we need to ponder about its effects on certain farms, regional production, and national market prices.

3. The "modularity" principle breaks down the complex system into manageable sub-models for different levels of detail. In particular, a global agricultural trade model might consist of modules for different regions or commodity sectors.

4. The "connectivity" principle recognizes that the behavior of each element is influenced by its connections to others. Indeed, farm-level decisions on crop selection are influenced by market prices, which are, in turn, affected by aggregate supply and demand.

5. The "hierarchy" principle reflects on decisions and processes at different levels including farm, regional, national, and global ones. Namely, a land use priority model might encompass farm-level decisions about crop planting, regional policies on land zoning, and national policies on agricultural subsidies.

6. The "functionality" principle prioritizes understanding the functional relationships over the structural elements. In particular, understanding how price transmits through the supply chain is more reasonable than only describing the structure of the supply chain.

7. The "development" principle focuses on how the agricultural system evolves and improves over time. Indeed, a model of agricultural technology adoption should cover the dynamic process of innovation, learning, and diffusion.

8. The "decentralization" principle investigates the balance between centralized control (for example, government regulations) and decentralized decision-making (for instance, individual farmer choices). Namely, a model analyzing the effectiveness of water management policies needs to look into both top-down regulations and bottom-up farmer responses.

9. The "uncertainty" principle explicitly accounts for unpredictable factors like weather, market volatility, and policy changes in the models in question. In particular, a model of crop production should incorporate the uncertainty associated with weather patterns and potential yield variations.

By applying these system analysis principles and incorporating relevant examples, we can build more comprehensive and relevant models of agricultural economics, leading to better understanding and more effective policy and management decisions.

The intersection of globalization and digitalization presents both significant challenges and substantial benefits for agricultural economics modeling. Major challenges are as follows:

- huge data volume and complexity since digitalization generates vast amounts of data from various physical and online sources. Ensuring data interoperability and standardization across different platforms requires advanced analytical tools and expertise;
- market volatility as globalization increases the interconnectedness of agricultural markets, making them more vulnerable to global shocks of political, economic, and environmental nature;
- accounting for environmental factors such as climate change, resource depletion, and environmental regulations is challenging. But models in agricultural economics should incorporate these dynamic uncertain components;
- social equity and inclusivity are often under threat because digitalization and globalization can exacerbate inequalities between large-scale and small-scale farmers, as well as between developed and developing countries. Models need to address these social dimensions and see to it that technological advancements benefit all stakeholders;
- rapid technological change brings constant evolvement in the agricultural sector, so keeping models up-to-date with these advancements is a continuous challenge.

Prime benefits that go with globalization and digitalization are as follows:

- improved data availability and accuracy since digital technologies are good at providing access to real-time data on the weather, crop yields, soil conditions, pest infestation, disease outbreaks, market prices, and supply chains. Such inputs subsequently raise reliability of agricultural economic models;
- enhanced modeling capabilities are obtained via advanced analytical tools that can tackle the development of more sophisticated and accurate models that present complex interactions between different factors and generate more relevant forecasts;
- increased efficiency and productivity responding to tasks of resource allocation, input costs reduction, crop yields growth, that is to exploit opportunities to increase efficiency and productivity throughout the agricultural value chain;
- improved decision-making is rooted in models which can provide valuable insights to farmers, policymakers, and businesses regarding production, marketing, and investment for launching more sustainable and profitable agricultural practices;

- enhanced market transparency and accessibility as a result of modeling real-time prices and supply-demand dynamics that contribute to the bargaining power of farmers;
- greater capacity for sustainable development which stems from models on closer monitoring of environmental impacts and aid in more informed policy design.

In conclusion, globalization and digitalization shape contemporary agriculture that can be reinforced by means of advanced modeling.

Artificial intelligence (AI) is rapidly transforming various sectors, and agricultural economics is no exception as proven by numerous modern research (Altayeb et al., 2024; Mana et al., 2024). In compliance with these findings, Fig. 4.4.2 illustrates how AI can offer significant advantages in modeling this complex field.

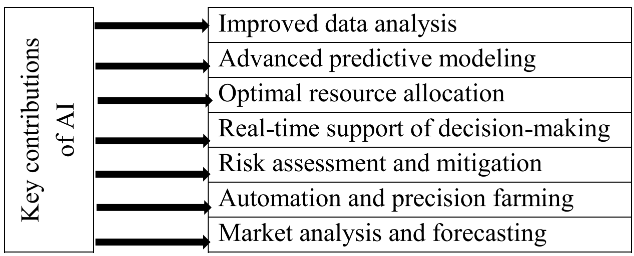

Fig. 4.4.2. Key contributions of AI to agricultural economics modeling

Namely, AI-driven software is excellent at processing vast miscellaneous data from sensors, satellites, weather stations, and market indicators. Therefore, AI is incredibly good at comprehensive analysis when modeling agricultural economics and substantiating strategies on production and sales. AI-propelled models surpass conventional mathematical models in identifying trends and non-linear relationships and producing more accurate forecasts of crop yields, market prices, and potential natural risks, such as disease outbreaks or weather-related disasters. AI can perform optimization of restricted valuable resources like water, fertilizers, and pesticides, leading to better efficiency and reduced environmental impact that are imperatives of sustainable agriculture. AI-powered systems can provide versatile insights into soil conditions, crop health, and market fluctuations, enabling farmers and policymakers to make timely reasonable decisions. This can shrink waste and boost market responsiveness. Given historical data, AI is capable of detecting unfavorable patterns and then build proactive risk management strategies to eliminate or at least mitigate potential losses. AI contributes to the development of automated farming systems, such as robotic harvesting, precision irrigation, and targeted pesticide application followed by increased productivity, reduced labor costs, and minimized environmental impact. As AI technology continues to advance, its role in agricultural economics will definitely become even more significant, contributing to a more resilient and sustainable food system.

Modeling the innovative development in agricultural economics is super important for a few reasons (Vasylieva, 2007). This is because currently agriculture is a dynamic field constantly facing new challenges and opportunities, from climate change and resource scarcity to evolving consumer demands and technological innovations. is good Models of innovative development help us see the bigger picture and anticipate how cutting-edge technologies, new policies, or emerged market shifts might play out in the agricultural economics. They can highlight promising areas for breakthrough achievements and potential setbacks. Modeling innovative development results in boosting efficiency and productivity. By simulating different scenarios, models can pinpoint the most perspective ways to use resources, optimize production processes, and ultimately increase agricultural output. This is crucial for providing food security on a global scale. Modeling innovative development goes with improved sustainability. Innovation in agriculture is not just about extra food; it is also about greener practices. Models can measure the environmental impact of different farming techniques and help identify innovations that reduce the ecological footprint. Models on innovative development in agricultural economics influence guiding policy and investment. Really, when governments and businesses are making decisions about agricultural development, they need solid information. Models provide a framework for analyzing the potential consequences of different policies and investments, leading to smarter choices. Agriculture is inherently risky caused by weather and market volatility. Models can help assess these risks and evaluate how innovations can build resilience in the face of uncertainty. Just because an innovation exists does not mean farmers will use it. Models on innovative development in agricultural economics can help us understand the factors that influence the adoption of new technologies and practices and pick out more effective strategies to promote beneficial changes. Agricultural economics is intertwined with so many other areas – the environment, technology, social issues, and other industries and sectors. Simulating helps us realize these complex relationships and the ripple effects of innovation. Overall, modeling innovative development in agricultural economics ensures a more secure and prosperous future for the agricultural sector and everyone it feeds.

The sustainable side of agricultural economics also get benefits from modeling. It takes on even greater significance because it means not only some updates, but comprehensive progress that lasts and respects our planet. Simulating aids to figure out how to feed people now without messing things up for future generations. Modeling innovative development in sustainable agricultural economics gives us the tools to navigate the vulnerable balance between economic viability and environmental health. Sustainability is much broader than just go green. It is also about making sure that the agricultural sector can thrive economically. Models can reveal those spots where innovative practices boost profitability and productivity without environmental harm like pollution, soil degradation, and biodiversity loss. The consequences of unsustainable practices can take years, even decades, to fully materialize. Modeling allows us to simulate these long-term effects, showing us the potential cost of inaction and the advantages of adopting sustainable innovations. This foresight is essential for making responsible choices at present. Often, there are trade-offs involved in choosing one agricultural approach over another. For example, a high-yield method might have negative environmental consequences. Models can facilitate understanding and quantifying these trade-offs, making more informed decisions that weigh different priorities. Simulating is outstanding when it comes to identifying the most prospective sustainable techniques. Models make it possible to assess which of these approaches are the most appropriate in different contexts, considering their economic performance and environmental efficiency. Governments and officials play a big role in implementing sustainable agriculture. Modeling can help policymakers perceive how different regulations, subsidies, or carbon pricing mechanisms might impact the adoption of sustainable farming methods and achieve desired outcomes through designing effective policies and incentives. Agriculture is deeply connected to other systems, like water resources, energy markets, and the broader economy. Models analyze how sustainable agriculture might provide system-wide effects via these interconnected systems, both positively and negatively. Climate change is a major threat to agricultural sustainability. Simulating can help us evaluate how different sustainable practices and technologies can foster the resilience of farming systems to climate-related shocks like droughts, floods, extreme temperatures, and other natural disasters. Ultimately, modeling the sustainable development in agricultural economics is about creating a roadmap for a future where agriculture can meet the needs of a growing population while safeguarding the environment and ensuring food production in a way that is smart, responsible, and truly sustainable.

Contemporary agriculture also relies on circular economy. Modeling circular agricultural economics enables us to make the most of resources available and minimize waste in how people grow and produce food. The motto of circular economy is that everything gets used and reused in a loop, in other words, work with nature, not against it. Indeed, reusing crop waste and animal manure allows us to cut down on pollution from chemical fertilizers and excess waste. Modeling circular agricultural economics boosts resilience. In particular, when farmers are less reliant on outside inputs and able to find value in byproducts, they are better equipped to address price swings, supply chain disruptions and other troubles. Besides, turning waste into valuable resources can result in new business opportunities and income flows. As the population keeps increasing, farmers and scientists need secure ways to produce enough food without draining the planet's resources. To a great extent, modeling circular agricultural economics can support the development of an innovative sustainable food system where everything has a purpose.

Modeling agricultural economics in Ukraine during and after the war with Russia has a vital and multifaceted mission mostly revolving around critical insights for immediate crisis management and long-term sustainable recovery (Andrienko et al., 2024; El Bilali et al., 2024). During the war simulating agricultural economics should be focused on providing real-time analysis and forecasts to navigate the severe disruptions caused by the ongoing war. Firstly, models are well suited to quantifying damage to agricultural infrastructure such as land, livestock, equipment, storage facilities as well as evaluating sharp decrease in production due to fighting, landmines, displacement of labor, disrupted supply chains and export-import logistics. Secondly, agricultural economics simulating is responsible for maintaining data-driven insights to guide informed emergency response to meet the current needs of farmers and the food security condition by region. Thirdly, models support reasoning market instability through simulating price volatility for agricultural commodities in both domestic and international markets, raised production costs on account of fertilizers and fuel, and experienced export-import limitations. The obtained model outcomes contribute to understanding the economic pressures on farmers and consumers. Finally, modeling reveals the most effective avenues for government support programs and interventions, international aid, and trade policy adjustments to increase the resilience of the agricultural sector during wartime.

After the war the mission of modeling should shift towards supporting innovative reconstruction, economic recovery, and long-term sustainable development of the agricultural sector. Simulating would calculate the financial, material, and human capital required for the agricultural recovery, including the cost of demining agricultural land, restocking livestock, and repairing damaged infrastructure such as irrigation systems storage facilities. By creating and assisting reconstruction strategies, agricultural economics modeling can guide investment decisions on agricultural infrastructure, technology, and sustainable farming practices. This incorporates studying opportunities for diversifying production, processing, and market access. By exploring soil and water contamination as well as other environmental consequences of the war, modeling would make it possible to analyze long-term impacts of the war on soil health, land use, labor availability, and the global competitiveness of Ukrainian agriculture. Simulating sustainable growth in the post-war context could involve modeling rural development, support for smallholder farmers, and promotion of productivity through the introduction of innovative technologies like agricultural drones, robots, satellite images, and surveillance cameras. Models of agricultural economics would offer different recovery scenarios to project the long-term trajectory influenced by miscellaneous factors such as evolving technological advancements, global market conditions, and investment flows. Hence, simulating agricultural economics in Ukraine both during and after the war is able to provide a robust and sound analytical foundation for decision-making based on the foreseeable challenges and opportunities on the way to future prosperity.

It is important to understand that agricultural economics modeling is not a one-size-fits-all approach. Fig. 4.4.3 comprises main specific aspects which shape agricultural economics and compel scientists build and use particular models adjusted to the EU and Ukraine. This insight is especially valuable as it defines the precise vector for farmers and policymakers who focus on changes necessary to make Ukrainian agricultural economics compatible with the EU market environment. The core aspects of modeling agricultural economics in the EU countries are as follows (Bocean, 2024; Georgescu et al., 2025; Giuliani et al., 2023). The EU's Common Agricultural Policy (CAP) is a massive framework that determines agricultural practices across member states. That is why simulating considers direct payments to farmers and the way these payments affect production decisions, farm incomes, and market prices; rural development programs to find out the economic and social effects of investments in local infrastructure, diversification, and environmental measures; impacts of price supports, export subsidies, import tariffs, and other interventions on trade flows and market stability; the development of environmental regulations aimed at reducing pollution, conserving biodiversity, and mitigating climate change and their relationship with farm practices and economic performance. The EU countries have access to comprehensive, standardized data over long periods available from established statistical agencies that allows sophisticated and reliable modeling. Owing to integrated markets, the EU models of agricultural economics consistently analyze price transmission, trade flows and competitiveness between member states. Agricultural economics simulating in the EU persistently explores and promotes sustainable agriculture. They demonstrate special interest in policies aimed at climate change mitigation, reducing greenhouse gas emissions associated with farming, agricultural practices designed to support climate change adaptation, advanced technology that foster agricultural sustainability, protect natural habitats and species, encourage the biodiversity conservation.

Main aspects of agricultural economics modeling

The EU countries	Ukraine
• policy-driven modeling; • data richness; • integrated markets; • sustainability focus; • advanced technology	• transition and reform; • data challenges; • trade dependence; • sustainability concerns; • farm structure dualism; • geopolitical influence

Fig. 4.4.3. Key peculiarities of agricultural economics modeling in the EU and Ukraine

In contrast to the listed aspects observed in the EU, modeling agricultural economics in Ukraine needs to consider a bit different factors. Namely, Ukrainian agricultural sector is still undergoing significant transition and reform, stemming from its post-Soviet history. It means it explores how land ownership and land markets affect farm structure and efficiency; studies find the economic consequences of privatizing state-owned agricultural enterprises; addresses the evolvement of agricultural competitiveness with regard to the growth of large agro-holdings and the persistence of small family farms. While statistics availability is improving, simulating agricultural economics may still face challenges in terms of data quality, consistency, and historical comparability. This can slow down and brake many modeling efforts. Stimulating agricultural economics provides insights on Ukrainian export potential and trade dependence. The topics in question are about the barriers to Ukrainian agricultural exports and the ways to overcome them, especially for grains and oilseeds. Models also have to handle the impacts of trade agreements with the

EU and other countries on Ukrainian agricultural trade as well as how vulnerable the national agricultural economics is to fluctuations in global commodity prices. Sustainability concerns are a little different from those related to the simulating the EU agricultural economics. Ukrainian models of agricultural economics highlight farming practices which can prevent soil erosion and maintain soil fertility; promote approaches that can reduce pollution from agricultural runoff and industrial activities; emphasize implications of climate change which would affect vulnerable agricultural production in different regions of Ukraine. Modeling agricultural economics in Ukraine is complicated due to farm structure dualism. There is coexistence of large-scale agro-holdings and small-scale family farms. The former are often vertically integrated companies that produce wholescale commodities. The latter are focused on producing a wider range of crops and livestock for both subsistence and retail market sales. That is why models need to account for the different behaviors and constraints of these two groups. On top of that, modeling agricultural economics in Ukraine have to take into account significant risks of geopolitical and economic instability, including the consequences of the ongoing war which has drastically impacted agricultural production, trade, and land use.

By and large, despite the identified peculiarities both the EU and Ukrainian modeling grapple with uncertainties and limitations while shaping policies and improving decision-making in agricultural economics. Model types and mathematical apparatus have much in common, using cluster-based, econometric, dynamic programming, partial and general equilibrium, optimization, fuzzy logic, system dynamics, and agent-based approaches for planning, balancing, and forecasting in agricultural economics. However, specific examples are different. On the one hand, in the EU stimulating is used for projections and policy assessment at EU and member state levels, evaluates the impact of CAP instruments, provides for farm-specific policy impacts. On the other hand, contemporary models in Ukraine are applied to Ukrainian agri-food markets amid war and recovery, to forecast the competitiveness of the agricultural sector, to optimize the structure of arable land for sustainable farming. Table 4.4.1 contains key distinctions between the EU and Ukrainian models of agricultural economics. In anticipation of further integration combined agricultural economics modeling in the EU and Ukraine will contribute to

- quick aligning Ukrainian agricultural system with the EU standards and market requirements;
- a special emphasis on leveraging Ukraine’s significant agricultural potential such as land and lower production costs;
- a broader simulation landscape historically integrated into a unified framework of the EU member states.

However, it is smart to look beyond the EU for agricultural economic models that could benefit Ukraine (Carpentier et al., 2015; Nehrey et al., 2019).

1. North American models from the USA and Canada often elevate market-oriented approaches, commodity price forecasting, and the influence of government support programs provided by the Food and Agricultural Policy Research Institute (FAPRI). These sophisticated models can empower Ukraine in grain and oilseed production via

advanced techniques designed for exploring price volatility, global market trends, and export competitiveness. By simulating policy impact, these models help assess the impacts of different subsidy schemes, trade policies, and insurance offers on farm incomes and production decisions. Besides, with a special focus on technological adoption, some models aid to promote new agricultural practices, such as cutting edge biotechnology and precision farming, which could be relevant for modernizing Ukrainian agriculture and enhancing its economic efficiency.

Table 4.4.1

Prime differences between the EU and Ukrainian models of agricultural economics

Feature	The EU agricultural modeling	Ukrainian agricultural modeling
Data sources	Eurostat; OECD databases; Farm accountancy data network (FADN); national statistical agencies	State statistics service of Ukraine; regional statistical agencies; FAO statistics
Constraints	Agro-climatic and structural heterogeneity within the EU member states for harmonized rural development; CAP instruments and impacts; environmental regulations and targets through Green Deal, Farm to Fork; globalized market and trade agreements	Implementation of sustainable agricultural practices; ensuring food security and optimizing export potential; adapting management approaches to EU standards; enhancing competitiveness for EU market integration; addressing challenges posed by the war and reconstruction
Purpose	Assessment of environmental sustainability and alleviation of climate change impacts; prediction of agricultural policy implications on markets and trade at EU and member state levels; farm-level analysis with economic and social aspects	Optimizing resource management at the national level; analyzing diversification for sustainable farming; estimating the impact of war and subsequent recovery on food security and agri-food markets; assessing labor potential and development of agricultural practices in the context of EU integration; forecasting competitiveness in the EU market

2. Australian agricultural models often concern about climate change, water scarcity, drought risk, and the long-term sustainability of farming in a challenging environment. Adaptation of these strategies through simulating can be valuable for Ukraine in resource management. Australian models can support the economic trade-offs between agricultural production and sustainability, including issues like soil degradation, pollution, and biodiversity conservation. On the way to open market liberalization, modeling agricultural economics in Ukraine can benefit from Australian findings on the effects of deregulation and privatization that are positive for competitive farming.

3. Latin American models from Brazil and Argentina study large-scale agricultural production and export-oriented strategies aimed at economic development. Simulating agricultural economics in Ukraine could benefit from best Latin American practices on large-scale farming and infrastructure patterns implemented in agricultural enterprises. Brazil and Argentina are major agricultural exporters. As a result, their models introduce approaches for enhancing export competitiveness, accessing global markets, and overcoming trade barriers. Latin American models can also assess ambiguous consequences of land use change, such as deforestation and the biodiversity protection.

4. Asian models from China and India are invaluable concerning food security, population growth, smallholder farming, and the role of agriculture in rural development. Thus, models of agricultural economics in Ukraine can adapt the most effective methods on balancing food security in the face of domestic needs and international responsibilities. While Ukraine has large-scale agricultural enterprises, models from Asia can enrich policies and programs that support smallholder farmers, who may be a key agricultural player in certain sectors. Moreover, models from China and India can reveal the link between agricultural growth and poverty reduction in rural areas, which are crucial for long-term economic development in Ukraine.

5. African models mostly grapple with issues like subsistence farming, land tenure, and poor agricultural development caused by limited resources and adverse environmental conditions. African models show economic impacts of land ownership changes and analyze the potential of resilient agricultural systems built in developing economies in order to withstand climate change, economic shocks, and political instability. This ideas and considerations can be embodied in agricultural economics modeling in Ukraine to assist resilience planning and ensure more robust recommendations.

To sum up, models developed in other countries will need to be adapted to specific context inherent in Ukraine, such as policy environment, market conditions, farm structure, and resources available. It is vital to build local expertise in agricultural economic modeling and collect high-quality data. Agricultural economics simulating has to resonate with the most pressing policy challenges facing Ukraine, such as promoting sustainable development, enhancing competitiveness, and supporting rural communities. Ukraine can benefit from combining elements from various models to create hybrids that suit its unique needs and circumstances.

A deeper understanding and integration of the labor force quality, human capital development, and psychological aspects of the human factor can considerably empower modeling agricultural economics in Ukraine (Carillo, 2024; Hill et al., 2021). The main ways of how these elements intertwine are as follows.

The human factor is intrinsically linked to labor productivity, a key driver of agricultural output. Wages as a primary motivator as well as socio-economic incentives like working conditions, motivation through opportunities for professional development, and job satisfaction via involvement in decision-making directly influence how efficiently people work in agriculture. Simulating in agricultural economics should take into account the availability and quality of the agricultural labor force. A shortage of skilled and experienced farmers is slowing down and sometimes braking the adoption of modern agricultural technologies and practices in Ukraine. Shifts in the demographic structure of the rural population in Ukraine due to aging personnel, employees' migration, and the ongoing war are significantly affecting the size and composition of the agricultural workforce with more women entering traditionally male-dominated positions and jobs. All of the above need to be considered in Ukrainian long-term models of agricultural economics to grapple with the observed skill mismatches.

Investments in human capital development through education, vocational training programs, and extension services will pay off through significant agricultural growth in farming, dissemination of agricultural innovations and their implementation for sustainable development. Policies aimed at improving human capital in farming deserve to be reflected in agricultural economics modeling.

Like all humans, farmers, agricultural managers, and other stakeholders are susceptible to cognitive biases and heuristics that can result in irrational decision-making. These mistakes, which stem from "common sense" that substitutes scientific knowledge, can range a lot showing significant deviations in how farmers process and interpret information. With principles of behavioral economics incorporated into agricultural models, we can alleviate human errors that destroy outcomes of agricultural performance. Psychological factors influencing risk perception should also be engaged in models aiming to predict agricultural responses to various scenarios.

Understanding the psychological factors underlying farmers' motivation and attitudes towards implementing innovative sustainable practices can bring more effective policy design and interventions. Indicators of psychological barriers and facilitators, risk perception, technology uptake should be introduced into models of agricultural economics. Thus, simulating will be able to provide a more realistic assessment of the farmers' ability to withstand challenges and recover from shocks like market fluctuations and climate change. Cooperation between agricultural specialists, economists, and psychologists will enable modeling to reach more comprehensive conclusions about the human dimension of agricultural economics.

Overall, versatile improvements of modeling agricultural economics in Ukraine is a top priority for scientists and practitioners as their advanced findings and vital recommendations will contribute to the sustainable development of thriving competitive innovative farming in Ukraine.