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Scenario Modeling of the Impact of Innovative and Technological Modernization of Production on the Export Competitiveness of Grain Enterprises of Ukraine

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ABSTRACT

This paper develops scenario-based modelling to quantify how innovation-driven technological modernization of grain production translates into export competitiveness of Ukrainian enterprises. The study operationalizes modernization effects through a net-back model of net export revenue. Five modernization scenarios are specified and calibrated to the 2025/26 marketing year export forecast (Q = 40.6 Mt; benchmark price P = 183 USD/t; baseline LogCost = 50 USD/t; prem = 0.02; disc = 0.03; risk = 0.0075). The scenarios differ in targeted competitive advantage channels: S1 (inertial) maintains basic practices; S2 (technological leadership) reduces unit costs and enhances quality control; S3 (cluster/cooperative) consolidates batches and lowers logistics/transaction costs; S4 (adaptive resilience) minimizes supply disruptions and risk premiums; S5 (premium-standard) focuses on EU compliance, traceability, and certification to capture price premiums. Simulation results demonstrate that modernization packages monetize production-level technological effects into a 13.4–19.0% increase in net export revenue relative to the inertial trajectory – from 5.27 bn USD (S1) to 5.98–6.27 bn USD under active modernization (2026 projection). Sensitivity analysis confirms the dominant role of logistics: a 10 USD/t reduction in LogCost adds +0.406 bn USD; a 1 percentage point improvement in net price correction (premium–discount) adds ≈0.074 bn USD; a 0.5 pp reduction in risk losses adds ≈0.037 bn USD. These effects remain robust under moderate parameter variations. The findings establish an evidence-based policy hierarchy: priority must be given to reducing export-chain costs and war-related risks, while quality, traceability and compliance instruments are essential for accessing premium segments and ensuring long-term export resilience. Further research should focus on micro-level project valuation (NPV, IRR) for typical farm profiles and regionally differentiated risk parameters.

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KEYWORDS

scenario modelling, grain exports, technological modernization, net-back model, export competitiveness.

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Сценарне моделювання впливу інноваційно-технологічної модернізації виробництва на експортну конкурентоспроможність зернових підприємств України

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СТАТТЯ

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АНОТАЦІЯ

У статті розроблено сценарне моделювання для кількісного оцінювання трансформації інноваційно-технологічної модернізації зерновиробництва у експортну конкурентоспроможність підприємств України. Ефекти модернізації операціоналізовано через нет бек модель чистої експортної виручки. Визначено п’ять сценаріїв модернізації, каліброваних на прогноз МР 2025/26 (Q = 40,6 млн т; P = 183 дол./т; LogCost = 50 дол./т; prem = 0,02; disc = 0,03; risk = 0,0075). Сценарії відрізняються цільовими каналами конкурентної переваги: С1 (інерційний) – базові практики; С2 (технологічне лідерство) – зниження витрат і контроль якості; С3 (кластеризація/ кооперація) – консолідація партій, зменшення логістичних/ транзакційних витрат; С4 (адаптивна стійкість) – мінімізація збоїв і ризикових надбавок; С5 (преміально-стандартний) – комплаєнс із вимогами ЄС, простежуваність, сертифікація для отримання цінових премій. Результати моделювання свідчать, що модернізація експортних стратегій забезпечує приріст чистої експортної виручки на 13,4–19,0 % відносно інерційної траєкторії – з 5,27 млрд дол. (С1) до 5,98–6,27 млрд дол. (С2–С5) у прогнозі на 2026 р. Аналіз чутливості підтверджує домінування логістичного каналу: зниження LogCost на 10 дол./т дає +0,406 млрд дол.; покращення net-цінового коригування на 1 в.п. – близько +0,074 млрд дол.; зменшення risk на 0,5 в.п. – +0,037 млрд дол. Ефекти залишаються робастними за помірних змін припущень. Отримані результати обґрунтовують ієрархію імплементації: першочерговими є заходи зі зниження логістичних витрат і воєнних ризиків, тоді як інструменти якості, простежуваності та комплаєнсу є критичними для доступу до преміальних сегментів і довгострокової експортної стійкості. Подальші дослідження доцільно спрямувати на мікрорівневу оцінку інвестиційних проєктів (NPV, IRR) для типових профілів господарств із урахуванням регіонально диференційованих ризиків.

КЛЮЧОВІ СЛОВА

сценарне моделювання, експорт зерна, технологічна модернізація, нет бек модель, експортна конкурентоспроможність.

1. Introduction

Grains and leguminous crops form a key export segment of Ukraine's agricultural economy, but in 2014–2024. The sector operated in the context of a combination of production volatility and increasing transaction and logistics constraints. Statistics show that from 2014 to 2019. the sown area of cereals remained relatively stable (14.4–15.3 million hectares), the gross harvest increased from 63.9 to 75.1 million tons, and the average yield – from 43.7 to 49.1 c/ha; In 2021, the maximum gross harvest (86.0 million tons) and yield (53.9 c/ha) was recorded, while in 2022 there was a sharp reduction in production (53.9 million tons) under the influence of military events, and in 2024, the gross harvest was 56.2 million tons with a yield of 50.6 c/ha [1].

Under such conditions, the increase in competitiveness is determined not only by the level of gross production, but by the ability to transform technological effects (quality stability, batch controllability, resource efficiency) into measurable parameters of the export operation – logistics costs per ton, risk losses and price premiums/discounts for compliance with market requirements [2].

2. Literature Review

The analysis of the latest research shows a shift in focus from "production innovation" as an end in itself to the applied logic of monetization of technological changes through the channels of export competitiveness – price/quality, stability of supply, chain costs and evidence of compliance. Thus, Hrynevych et al. [3] emphasize the role of smart farming tools as drivers of cooperation and data management in agriculture in Ukraine, which creates the basis for increasing the manageability of quality and traceability of grain batches. At the level of a broader regional generalization, Petrović et al. [4] systematize the practices of precision agriculture in the countries of Central Europe, demonstrating that the productive effects of technologies significantly depend on the institutional capacity of implementation and staffing. In addition, Sanyaolu et al. [5] focus on the economic conditions of the effectiveness of precision farming, where the effect is enhanced in the presence of complementary management decisions (digital management systems, monitoring, risk analytics).

In the parallel corpus of works, attention is rapidly increasing to the digital evidence of compliance as a separate source of competitive advantage in agri-food markets. In particular, Charlebois et al. [6] a comparative analysis of OECD countries, showing that digital traceability forms not only information transparency, but also applied mechanisms for reducing transaction costs and barriers to access to demanding sales segments. In the development of this logic, Pakseresht et al. [7], based on a systematic review, prove that blockchain architectures in agri-food value chains are most relevant when "immutability" and "distributed trust" are directly translated into reduced verification costs and risks of non-compliance with contracts/standards.

A separate layer of literature forms the military-logistical dimension of the competitiveness of Ukrainian grain exports, where the decisive factor is not so much the production potential as the ability of the supply chain to maintain margins under shocks and restrictions. Thus, Yanovska et al. [8] identify logistical bottlenecks in grain exports from Ukraine during the war period and argue for the priority of infrastructure and organizational solutions that reduce costs and losses in the export chain. At the macro level, Jia et al. [9] model production/trade shocks and demonstrate large-scale consequences for global food security and price dynamics under scenarios of escalation of trade restrictions. The empirical picture of trade restructuring is detailed by Countryman et al., estimating counterfactual losses and redistribution of grain and oilseed flows after the full-scale invasion [10].

The literature on market reactions to the "grain deal" and related political and logistical events is also important for setting up a scenario analysis. Goyal and Steinbach, based on high-frequency futures data, show that war shocks and institutional decisions to recover/support exports are reflected in tangible premiums to counterfactual prices, and the effect is not the same across crops [11]. Instead, Steinbach and Yildirim focus on the reaction of agricultural commodity markets to Russia's withdrawal from the Black Sea Grain Initiative, emphasizing the role of expectations and risk revaluations in the formation of volatility [12].

Generalizations of the global effects of export restrictions are complemented by work on quantifying beneficial effects and systemic risks. Thus, Countryman et al. [10], within the framework of the computable model of general equilibrium, estimate global losses of welfare from Ukraine's export failures under scenarios of the impossibility of full-fledged sea exports [13]. At the level of conceptual diagnostics of systemic "vulnerabilities" of international food security, Benhassi and Haiba emphasize that the war reveals the structural weaknesses of the global food supply system and increases the importance of tools for reducing risks and stabilizing supply chains [14].

Despite the intensive development of the topic, the available array of works contains limited integrated productions that simultaneously operationalize production innovation and technological modernization, translate its effects into the parameters of the export operation (chain costs, premiums/discounts, risk adjustments) and compare alternative implementation trajectories in the format of scenarios. Such a gap reinforces the feasibility of scenario modeling focused on monetization of modernization through indicators of export competitiveness of grain enterprises in Ukraine.

3. Problem Statement

The article is aimed at quantifying how innovative and technological modernization of production and organizational and economic decisions for its implementation can be monetized in an increase in the export competitiveness of grain enterprises of Ukraine. To achieve the goal, scenario modeling was used within the net export revenue model, which combines the production effects of modernization with the parameters of the export operation.

4. Methods and Materials

The empirical basis of the study is the reconstruction of the parameters of the production environment and scenario configurations for the modernization of the export strategy. Statistical parameters of production are taken from the official ranks of the State Statistics Service of Ukraine [1]. To calibrate the export volume, the USDA/FAS forecast for MY 2025/26 was used [2], and the base selling price was formed on the basis of a standardized series of primary commodity prices from the IMF [15]. The order of military logistics costs is consistent with the estimates of the transport and logistics component of the export chain [16], and the parameterization of compliance restrictions and risk losses is aligned with the requirements of the EU market and reviews of the system of official notifications on food and feed risks and the regulation of residue limit levels [17–19]. The theoretical framework of interpretation is the approaches to competitive advantage (cost leadership/non-price differentiation) [20] and the economics of transaction costs [21]. Public materials on war insurance are taken into account [22–24].

The choice of a net-back approach is due to the need to compare scenarios on a single "currency" metric, where technological decisions affect through four channels: export volume (Q), price adjustments (prem/disc), risk losses (risk) and military logistics costs (LogCost):

$$R = Q \cdot [P \cdot (1 + prem - disc) \cdot (1 - risk) - LogCost] \quad (1)$$

where R is the net export revenue;
Q is the volume of grain exports (million tons);
P is the base selling price (USD/t);
prem is the premium for quality/compliance with market requirements (share of the base price);
disc is the discount for non-compliance/market restrictions (share of the base price);
risk is the share of expected losses/additional costs from war and contract risks;
LogCost is the generalized logistics costs per tonne.

For Q in million tonnes and P and LogCost in USD per tonne, the R indicator is interpreted as USD million; for USD billions, a division by 10^3 is used.

Calibration of basic parameters was carried out on aggregate series: Q = 40.6 million tons according to the forecast of MY 2025/26 [2], P = 183 USD. USD/t as a weighted average value for crops based on IMF benchmarks [15], LogCost = 50 USD/t as a generalization of export chain costs in wartime conditions [16]. Basic price adjustments are accepted as prem = 0.02 and disc = 0.03, taking into account the requirements for safety, traceability and control of balances [17–19]. The share of risk losses is taken as risk = 0.0075 (0.75%) as a conservative parameterization of insurance and contract premiums of the war period [22–24]. To ensure the comparability of scenarios in Table 3, the volume of Q exports is fixed at the forecast level of 40.6 million tons, and changes in competitiveness are interpreted through (prem−disc), risk and LogCost. Figure 4 additionally shows the simulated sensitivity to LogCost reduction with a possible moderate increase in Q in case of successful modernization (as a "potential" effect, not the basic assumption of the calculations in Table 3).

Modernization scenarios are formed as packages of managerial and institutional decisions that affect the parameters of the R model through a combination of: technological changes in production (resource efficiency, stability and quality control), infrastructure and logistics solutions, mechanisms for reducing contract risk and increasing the evidence of compliance.

5. Results and Discussion

The dynamics and forecast of export volumes form the basic "volume space" of scenario analysis. According to the marketing years 2020/21–2023/24, the total grain exports exceeded 43.9–50.8 million tons, while the forecast for 2024/25 is 40.0 million tons, which reflects the structural limitations of the war period and strengthens the role of non-price channels of competitiveness [2].

Table 1. Grain exports of Ukraine by main crops (marketing years 2020/21–2024/25), thousand tons t

Marketing Year	Wheat	Corn	Barley	Total grain volume, million tons
2020/21	16 413	22 596	4 210	43.9
2021/22	18 741	23 535	5 752	48.5
2022/23	16 894	29 228	2 712	49.2
2023/24	18 402	29 389	2 491	50.8
2024/25	15 723	21 963	2 318	40.0

Source: Summarized by the author according to USDA/FAS data (Grain and Feed Quarterly/Update reports) [2].

The structure of exports in 2024/25 MY is highly concentrated: the share of corn is about 52.5%, wheat – 40.0%, barley – 7.3% of the total volume of 40.0 million tons.

Scenario modernization packages are formed in such a way as to translate the production effects of technological renewal (reduction of resource intensity, reduction of losses, increase in traceability) into the variables of the export operation. The logic of the scenarios reflects different trajectories for achieving competitive advantage: from inertial reproduction to technological leadership, cooperation, risk-oriented sustainability and premium-standard positioning (Table 2).

Quantitative assessment of scenarios within the net-back model shows that the modernization of export strategies monetizes production technological effects into an increase in net export revenues in the range of 13.4–19.0% relative to the inertial trajectory (Table 3). The structure of growth in all modernization scenarios is two-component: the reduction of LogCost as the most elastic parameter of the export chain dominates, while the increase (prem−disc) and the decrease in risk form an additional effect critical for access to premium segments and reduction of contract losses. The highest result is provided by the scenario of technological leadership (C2), which simultaneously reduces cost and non-price constraints (logistics, discounts, risk losses) and reinforces premiums for compliance/quality. The adaptive resilience scenario (C4) gives a lower but more risk-based gain, relevant for the war period, when margin preservation is critical.

The stability of the results is confirmed by the properties of the model. In the baseline scenario, the net-back per ton is about $129.8/t, which sets the interpretive "base" for scenario deviations. At the base values of Q=40.6 million tons and LogCost=50 USD/t, a change in the logistics component by 10 USD/t changes R by Q·10=406 million USD. in the relevant direction, which makes logistics the dominant channel of influence within scenario comparisons. A change in the net price adjustment (prem−disc) of 0.01 changes R by approximately Q· P·0,01; at P=183 USD/t, this is about 74 million USD. Changing the risk fraction by 0.005 reduces R by approximately Q· P· (1+prem−disc)·0.005, i.e. tens of millions of dollars on the scale of the aggregated grain group. The relative differences between the scenarios remain robust to moderate changes in assumptions: the largest contributor to the scenario gap is formed by LogCost, while prem/disc and risk provide an additional but significant effect for accessing premium segments and reducing contract losses.

Table 2. Scenario packages for the modernization of grain exports: target groups, tools and monetization channels

Script	Target profile of the enterprise	Tools	The dominant channel of competitive advantage	Variables that are targeted
C1. Inertial	Businesses with limited access to capital; Conservative strategy	Support for basic practices without scaling precision farming and digital control systems; Local cost management improvements	Holding positions (without creating a new advantage); risk of gradual loss of market access in segments with high demands	Cost/t (without significant reduction); premiums/discounts (standard contracts); risk component (high sensitivity to shocks); Compliance costs (growing)
C2. Technology Leadership	Mainly agricultural holdings/large producers with the ability to integrate data and logistics	Scaling precision farming, farm management systems, and automation; Integration of production and supply management	Cost Leadership + Productivity Improvement; Partially reduced transaction costs due to data transparency	↓ cost/t; ↑ quality controllability; ↓ transaction costs (evidence of batch parameters); ↓ risk losses (control)
C3. Cooperation/ clustering	SMEs with batch scale and certification restrictions	Common contours of digital traceability; joint procurement and logistics; Institutional support for cooperation	Economies of scale through shared infrastructure; reducing barriers to market access	↓ specific costs (procurement/logistics); ↓ discounts due to the consolidation of parties; ↓ transaction costs (joint compliance circuit)
C4. Adaptive resilience	Enterprises in areas of increased military and logistical risks; Producers with high energy dependence	Resource-saving technologies (including minimum/zero cultivation), digital forecasting and risk management; Logistics diversification	Minimization of losses and supply disruptions; reducing the risk components of contracts	↓ logistic/transactional losses; ↓ risk premium; ↑ stability of contract performance; partially ↓ cost/t
C5. Premium standard (compliance/ quality/ traceability)	Enterprises focused on EU sales channels; Manufacturers willing to invest in verifiability	Biologization and management of technological maps, digital traceability, laboratory control/document management; Bringing processes to the buyer's requirements	Differentiation through compliance, reduced discounts, and access to higher-priced segments	↑ premiums/discount avoidance; ↓ transaction costs (verification); ↓ risks of non-compliance; ↑ Batch quality stability

Source: compiled by the author based on the materials of the dissertation research and consistent with the requirements of the EU market and the practices of digital transformation of the grain sector [17–19; 25].

Table 3. Comparative estimate of net export income (net-back) by modernization scenarios (forecast for 2026, billion US dollars)

Script	Revenue, billion dollars	Change relative to C1, %
C1. Inertial	5.27	0.0
C2. Technology Leadership	6.27	1.0
C3. Clustering/Cooperation	6.25	18.5
C4. Adaptive resilience	5.98	13.4
C5. Premium Standard	6.12	16.0

Source: The author's calculations according to the net-back model based on calibrated parameters and scenario assumptions (Q, P, prem, disc, risk, LogCost) [2; 15–19; 22–24].

Practical implementation of scenarios requires a distinction between management decisions at the micro level (investment packages of enterprises) and the macro-level (policy of reducing transactional and infrastructure restrictions). At the macro level, the key indicator of policy effectiveness is the decrease in the average military-logistics costs LogCost (USD/t) in the export chain, while at the micro level – the standardization of processes and digital evidence of batch parameters that directly affect (prem–disc) and risk. The synergy of these levels is concentrated around the channels with the greatest elasticity in the net-back model: a decrease in LogCost gives the largest increase in R, while a decrease in risk and a reduction in disc discount become critical in markets with high requirements for compliance and contractual discipline [17–19].

Table 4. Comparative economic feasibility of scenario implementation and policy priorities (aggregate level, MY 2025/26)

Script	Micro level: investment focus (benchmark)	Expected effects profile in the R model parameters	Sensitivity of ΔR to ΔLogCost=−10 USD/t, billion USD.	Macro level: priority policy instruments
C1 Inertial	Minimal maintenance investment	Basic Q, P, prem, disc, risk, LogCost without improvement	+0.406	Support for basic regulatory and statistical infrastructure
C2 Technology Leadership	agricultural technologies/ precision farming/ farm management systems, automation	Q↑, disc↓, LogCost↓, partially risk↓	+0.426 (for Q=40.6·1.05)	Preferential instruments for financing modernization; support for digital data infrastructure
C3 Clustering/ Cooperation	Joint Investment + Joint Logistics/ Certification	Q↑, disc↓, LogCost↓ (scale effect), partially risk↓	+0.418 (for Q=40.6·1.03)	Cluster/cooperation development policy; reduction of certification barriers; Insurance/Guarantee Instruments [22–24]
C4 Adaptive Resilience	Zero tillage/ resource conservation + risk management	LogCost↓, risk↓, moderately Q↑	+0.414 (for Q=40.6·1.02)	War risk guarantees/insurance, support for alternative routes and infrastructure
C5 Premium Standard	Traceability/ compliance/ laboratory base	prem↑, disc↓, LogCost↓ moderate, risk↓ moderate	+0.422 (for Q=40.6·1.04)	Grants/vouchers for certification and laboratory capacity; harmonization of control procedures

Source: Summarized according to the results of scenario modeling and the hierarchy of elasticities of the net-back model; Theoretical interpretations of the channels of competitive advantage and transaction costs are consistent with [20; 21].

The limitation of the study is the aggregate nature of calibration: the net-back model does not detail the differences between crops within the grain group and does not include investment (CAPEX) modernization costs, and the prem/disc and risk parameters are set as conservative scenario assumptions based on regulatory and market requirements and public assessments of the war period [17–19; 22–24]. At the same time, the aggregate approach is appropriate for the purposes of scenario comparison, as it identifies the channels for monetization of modernization and ranks them according to the elasticity of impact on export revenues.

6. Conclusions

Scenario modeling within the framework of the net-back approach showed that innovative and technological modernization of production and the corresponding rethinking of the export strategy can provide an increase in the net export revenue of the grain group in the range of 13.4–19.0% relative to the inertial trajectory. In the forecast for 2026, this corresponds to the transition from USD 5.27 billion. (C1) to USD 5.98–6.27 billion. (C2–C5), where the maximum effect is formed by scenarios that simultaneously reduce logistics costs and reduce discounts/risk losses due to increased traceability and compliance.

The sensitivity analysis confirmed the practical hierarchy of implementation: the tools for reducing LogCost and military-contract risks have priority, since their elasticity in the model is the greatest. Quality, standardization and digital proofing tools form the second largest but critical effect for premium segments that determines long-term export capacity.

Further research should be directed to micro-level validation of scenario assumptions through project analysis (indicators of net present value and internal rate of return) for typical enterprise profiles, as well as to expand the parameterization of logistics and risk adjustments using regionally differentiated data and contract terms.

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