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METHODOLOGY FOR MODELING INNOVATIVE STRATEGIES FOR FINANCIAL SECURITY OF COMPETITIVE AGRO-INDUSTRIAL SMART ENTERPRISES IN THE STARTUP MANAGEMENT SYSTEM

ABSTRACT

The article examines the theoretical and applied foundations of modeling innovative strategies for the financial security of competitive agro-industrial SMART enterprises within the startup management system. The study emphasizes that today's agribusiness environment in Ukraine is characterized by accelerating technological turbulence, deep digitalization of production processes, and the growing importance of innovation-driven mechanisms for ensuring financial stability. Under these conditions, financial security is no longer limited to risk control; rather, it transforms into a multidimensional system shaped by investment activity, technological renewal, business model adaptability, digital maturity, and the enterprise's capacity to integrate startup technologies into core operational processes.

The study substantiates that the competitiveness of agro-industrial SMART enterprises depends on their ability to develop innovative financial strategies that simultaneously enhance resilience, adaptability, and long-term growth. The article highlights the strengthened interdependence between investment decisions, technological upgrades, productivity, and risk exposure in the digital economy. Practical aspects of utilizing financial and analytical tools for evaluating innovation project performance, as well as mechanisms for incorporating startup management practices into the strategic framework of financial security, are also addressed.

The scientific novelty lies in an expanded understanding of the role played by digital innovations, flexible managerial decisions, and intensified investment processes in shaping the financial resilience of SMART enterprises. The paper demonstrates that systematic implementation of innovative strategies contributes to higher financial stability, reduced vulnerability to risks, and strengthened participation in the agro-industrial startup ecosystem. The findings have practical value for designing effective security mechanisms, improving financial policy, and developing an innovation-oriented model for the sustainable growth of agro-industrial SMART enterprises.

Keywords: financial security, innovation strategy, startup management, agro-industrial SMART enterprises, venture financing, digital economy, risk management, investment attractiveness

JEL Classification: C51, G32, O32, Q14, M21

INTRODUCTION

Modern transformational processes in Ukraine's agro-industrial sector highlight the need for financially resilient and innovation-oriented development models capable of functioning under conditions of technological turbulence, business digitalization, and intensifying global competition. The recovery of the agricultural economy during wartime and the post-war period is accompanied by rising financial risks, instability of investment flows, limited access to capital, and the necessity for rapid adaptation to volatile market conditions. These challenges enhance the importance of financial security as a fundamental component of economic sustainability.

Recent scientific studies demonstrate significant progress in the areas of financial security, innovative management, and digital transformation in agricultural enterprises. However, despite the broad theoretical contributions to innovation management and risk-oriented governance, the existing literature insufficiently addresses the formation of innovative financial security strategies specifically for competitive SMART enterprises. These enterprises rely on digital technologies, autonomous systems, precision agriculture tools, and the integration of startup projects into production and managerial systems.

The topic of startup management in agricultural technology remains fragmented, often explored only in the context of venture financing or digital operational tools. Yet, there is a lack of comprehensive models that unite financial stability assessment, investment activity analysis, innovation potential, and the enterprise's ability to scale startup solutions. This research gap determines the relevance and scientific novelty of the present article.

A critical issue involves coordinating financial instruments, innovative strategies, and digital technologies to ensure business continuity and sustainable growth of SMART enterprises. The absence of unified, practically applicable approaches to modeling such strategies in Ukraine's agro-industrial sector necessitates an integrated study of financial and economic parameters of enterprises whose competitiveness is based on innovation and startup technologies.

Thus, the above forms a logical basis for further research into the processes of modeling innovative strategies for financial security of competitive agro-industrial SMART enterprises in the startup management system, which is a necessary scientific condition for developing effective mechanisms for strengthening their economic sustainability and investment attractiveness.

LITERATURE REVIEW

The presented scientific and analytical sources form an interdisciplinary basis for our research, as they comprehensively cover financial, innovative, managerial, digital, institutional, and environmental aspects of enterprise development. The combination of these sources allows us to substantiate the modeling methodology, correctly interpret empirical data, and ensure the scientific novelty of the article in the field of financial security of agro-SMART enterprises.

Davydenko et al. (2021) emphasize regional disparities in financial potential, which allows our study to take into account the territorial risks of innovative strategies of agro-SMART enterprises. Their findings help to substantiate the need for adaptive financial security mechanisms depending on the investment capacity of regions. This strengthens the explanation of differences in income and investment activity of enterprises in the sample.

Dmytryshyn & Blahun (2016) reveal a model of efficient allocation of credit resources, which provides a methodological basis for the correct choice of discount rates in NPV and PI calculations in our article. Their approach reduces the risk of overestimation of innovative projects. This ensures the accuracy of financial forecasts in modeling the security strategy.

Sitnicki (2018) forms the institutional framework for knowledge and innovation management, which allows us to explain the different levels of innovation maturity of enterprises in our study. These provisions help to interpret the gaps between the Berkus assessments of companies. Due to this, innovative potential is considered a significant component of financial security.

Kovalchuk et al. (2024) prove that digital technologies enhance the efficiency of management decisions, which directly explains the high financial results of SmartFarming in our sample. Their findings help to link digital integration with profitability indicators. This supports the key thesis of the article about the role of digital maturity in financial sustainability.

Ushenko et al. (2023) emphasize the importance of blockchain for the transparency of financial transactions, which is useful for the formation of secure digital environments of agro-SMART enterprises. Their findings strengthen the argument about cyber threats in the startup management system. This expands our approach to financial security, including the digital component.

Kalinichenko et al. (2024) demonstrate the positive impact of eco-innovations on the financial results of enterprises, which is consistent with the patterns identified in the Sentera and SmartFarming indicators. Their findings allow us to show that innovations provide not only technological, but also financial benefits. This is integrated into the general model of innovation security.

Davydenko (2015) emphasizes the importance of risk-based approaches, which supports our need to apply AR corrections in regression models. This helps to avoid statistical distortions in financial modeling. Due to this, the forecasting results become more reliable.

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Ushenko et al. (2021) investigate the impact of ethical corporate governance on business stability, which allows our study to take into account non-financial aspects of security. Their provisions strengthen the thesis that management culture affects investment attractiveness. This makes the model of financial security more comprehensive.

Antypenko et al. (2022) analyze the economic adaptability of enterprises to global shocks, which allows us to explain the stability of some agro-SMART firms, despite market turbulence. Their findings help to interpret the persistent trends in investment forecasts in our model. This strengthens the argument for the strategic resilience of companies.

Sitnicki et al. (2025) demonstrate that scientific collaboration stimulates technological development, which directly correlates with the high Berkus indicators of technology companies in our sample. Their approach supports the thesis of the importance of innovation ecosystems. This allows us to explain the sources of innovation power of companies in more depth.

Kubitskyi et al. (2024) show that digitalization leads to increased productivity and financial efficiency, which coincides with the trends of our empirical results. This reinforces the relationship between digitalization and increased investment indicators. Their approach helps to justify the high PI fixation of FarmRTK.

Guk et al. (2024) emphasize the role of IT projects in the strategic development of companies, which supports the key propositions about the technological drivers of financial sustainability of agro-SMART companies. Their findings explain the investment demand for Sentera and SmartFarming platforms. This strengthens the interpretation of innovation potential.

Blahun et al. (2022) propose a model for monitoring the financial sustainability of innovative companies, which helps us scientifically substantiate the use of predictive models in the article. Their approach reveals patterns in innovatively active enterprises. This makes the analysis more methodically verified.

Verhun et al. (2022) prove that innovative logistics reduces the crisis risks of enterprises, which explains the resilience of some of the companies in our sample. Their findings allow for a better interpretation of the financial performance of enterprises with high operational efficiency. This strengthens the managerial aspect of the article. Bakhmat et al. (2022) reveal the importance of managers' innovative competencies, which adds a human component to our model of innovation security. Their findings allow us to explain the flexibility of companies in the startup environment. This strengthens the HR component of the analysis. Kalinichenko & Lesyuk (2021) show the macro-financial risks of the country, which gives us an external framework for analyzing the financial security of agro-SMART enterprises. This strengthens the understanding of general environmental threats. Their approach helps to correctly interpret investment behavior.

Nitsenko et al. (2024) analyze corporate responsibility as a factor of financial sustainability, which allows us to include ESG indicators in a broader understanding of security. Their results are consistent with the approach to assessing innovation maturity. This expands the conceptual framework of the article. Kubitskyi et al. (2022) demonstrate the effectiveness of flexible team models, which supports our interpretation of startup management as an adaptive system. Their findings explain the resilience of companies to market uncertainty. This deepens the management block of the article. Skydan et al. (2022) show how the combination of financial and environmental mechanisms stimulates innovation, which adds systematicity to our model. Their approach strengthens the understanding of long-term sustainability. This helps to substantiate the importance of ecosystem thinking.

Sitnicki et al. (2024) prove the effectiveness of clustering to increase investment attractiveness. This explains why some SMART companies demonstrate high innovation dynamics. Their results help to detail the role of network interactions. Dmytryshyn & Blahun (2014) offer tools for optimizing credit policy, which we apply in determining the cost of capital. This ensures methodological accuracy of the model. Their work helps to correctly calibrate investment calculations. Zhukorskyi et al. (2022) demonstrate the role of biotechnological innovations in the development of the agricultural sector, which expands the innovation field of our article. This helps to emphasize the multi-vector nature of technological development. Their results strengthen the strategic block of the model. Sitnicki et al. (2022) emphasize the importance of innovation education, which explains the personnel capacity of enterprises to adapt digital technologies. This adds depth to the analysis of human capital. Their approach strengthens the innovation maturity component.

Lepeyko et al. (2023) describe adaptive management models that explain the resilience of startups in a changing environment. This is consistent with the financial results of our enterprises. Their conclusions strengthen the managerial dimension of security. Yasnolb et al. (2023) studied anti-crisis management, which allows us to explain the resilience of enterprises in stressful situations. This is important for the analysis of innovation strategies during war. Their provisions correlate with our predictive models. Nimko et al. (2024) (e-Government) prove that digital transparency reduces financial risks. This strengthens our argument about the importance of digital infrastructure. Their findings complement the institutional block of the model. Furman et al. (2023) demonstrate that the incentive system promotes staff innovation. This explains the

ability of enterprises to maintain high innovative activity. Their provisions strengthen the HR direction of our analysis. Kvasha et al. (2018) emphasize the importance of macroeconomic forecasting, which strengthens the forecast methodology in the article. This allows for a more accurate interpretation of trends until 2028. Their approach is consistent with the use of AR models. Vavdiiuk et al. (2022) emphasize the role of soft skills in creating an innovative environment, which is important for startups. This explains the human factor of financial sustainability. Their findings deepen the understanding of human capital.

Pronko et al. (2025) analyze the digitalization of labor potential management, which is consistent with our concept of innovation-oriented enterprises. This helps to interpret the managerial effectiveness of the sample companies. Their results strengthen the startup management methodology. Varava et al. (2025) demonstrate the role of strategic analysis in clarifying innovation priorities. This is consistent with our practice of combining NPV, PI, and Berkus indices. Their findings justify the multifactorial approach of the article. Shumilova et al. (2023) describe the emotional-ethical competence of managers, which helps to explain the behavioral aspects of financial stability. This is important for enterprises in high-risk sectors. Their results add a humanitarian dimension to the model. Andriushchenko et al. (2021) demonstrate the role of digital skills in the formation of competitive teams, which supports the personnel aspect of our article. This explains the innovative success of startups in the agricultural sector. Their findings reinforce the concept of digital maturity. Kubitskyi et al. (2023) analyze the development of digital education, which helps to explain the evolution of the qualification characteristics of employees of agro-SMART enterprises. This is important for the strategy of providing innovative security. Their findings form the personnel foundations of innovation. Skydan et al. (2022) (bioeconomy) emphasize the importance of environmental innovations. This expands the innovation-strategy block of the article. Their findings emphasize the integration of environmental factors into financial security. Sitnicki et al. (2024) (cyberinsurance) reinforce the importance of protecting digital infrastructure. This is especially relevant for agro-SMART enterprises. Their results justify the inclusion of cyber risks in the model.

Latifundist, Navifarm.tech, Skokagro, PreAgri, Companiesmarketcap, Opendatabot provided the empirical basis necessary for building regression models, forecasts, and assessments of innovation potential. These sources provided the factual basis for the formation of graphs and tables. Their information strengthens the reliability of the results.

In summary, it can be stated that all the works considered have significantly enriched the theoretical and methodological basis of the article, providing a reliable conceptual framework for the study of financial security in the conditions of an innovative economy. Each source has introduced its own component into the model - from financial modeling, risk management, and digital transformation to human resources competencies, ecosystem interactions, and state regulation. However, the mentioned works are fragmentary and do not comprehensively examine our problem.

AIMS AND OBJECTIVES

The purpose of the study is to scientifically substantiate and develop methodological principles for modeling innovative strategies for the financial security of competitive agro-industrial SMART enterprises in the startup management system. The focus is on clarifying how digitalization, innovative potential, investment activity, technological maturity, and integration of startup solutions determine the ability of enterprises to ensure the stability of financial flows, counteract risks, and achieve sustainable development in conditions of market turbulence.

To achieve the set goal, the study is aimed at generalizing modern theoretical approaches to the formation of innovative strategies and financial security of SMART enterprises, identifying key factors that influence their investment, technological and organizational dynamics, and building a conceptual model of the relationship between innovative activity, financial stability, and startup management. An important component of the tasks is the analysis of financial and economic indicators of selected agro-SMART companies based on the integration of discounted cash flow methods (NPV, PI), assessment of innovation potential according to the Berkus methodology, as well as the use of regression modeling and autoregressive adjustments to identify the real elasticity of income with respect to investment. The study also involves building forecast models for the development of enterprises in the medium term, interpreting investment and financial trends in the context of a security strategy, and formulating recommendations for improving innovation management mechanisms, increasing investment attractiveness, and strengthening the financial stability of agro-industrial SMART enterprises in a startup-oriented environment.

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METHODS

The methodological architecture of this study is based on the integration of financial modelling, innovation assessment, and econometric analysis to ensure a comprehensive examination of the mechanisms through which technological modernization and investment activity influence the financial security of agro-industrial SMART enterprises functioning within the startup management system. Given the high volatility and innovation-driven nature of such enterprises, the methodological design emphasizes multi-layered analytical procedures, allowing for the identification of financial dependencies, technological capabilities, and long-term sustainability patterns.

The empirical foundation of the research consists of official financial statements and open corporate data of representative agro-industrial SMART enterprises operating in the precision agriculture subsector. These data sources provide consistent quantitative indicators-primarily investment volumes, net income, and profitability metrics- that form the basis for evaluating enterprise-level financial dynamics. The inclusion of companies with different degrees of digital maturity ensures analytical variability and strengthens the robustness of the model by capturing heterogeneous responses to innovation and investment stimuli.

To quantify the financial effectiveness of innovation-driven development, the study employs discounted cash-flow methodology, including the calculation of net present value and profitability index, which allows for the estimation of future financial flows under uncertainty. These measures capture the capacity of enterprises to sustain long-term financial resilience and to generate risk-adjusted economic returns from digital transformation initiatives. The assessment of innovation potential is further enhanced through the Berkus model, which provides a structured evaluation of qualitative components of technological development, such as conceptual quality, prototype readiness, team competence, market scalability, and early validation. This combination of quantitative and qualitative indicators enables a multi-dimensional interpretation of innovation capacity in the context of financial security.

To uncover the causal linkages between investment inputs and income generation, the study employs regression modelling based on the production-function approach. Linear regressions were constructed to estimate investment elasticity of income; subsequent diagnostic testing revealed the presence of autocorrelation in residuals, a characteristic feature of financial time series in innovation-intensive sectors. To address this, autoregressive transformations were introduced, allowing for the correction of serial correlation and providing statistically consistent coefficient estimates. Such an approach ensures that the resulting models capture authentic economic mechanisms rather than distortions caused by temporal dependencies.

Forecasting procedures constitute the final analytical component of the methodology. Based on the corrected regression models, forward-looking projections of income and investment dynamics were obtained for the subsequent three-year horizon. These projections serve not only as a predictive tool but also as an evaluative mechanism for testing the sustainability of innovation-driven development trajectories. Graphical representations of model outputs were used to identify structural patterns, deviations, and potential risk zones, thereby strengthening the interpretation of financial-security outcomes.

Overall, the methodological framework integrates financial, econometric, and innovation-analytical tools to construct a holistic model of financial security for agro-industrial SMART enterprises. This integrative approach – combining investment modelling, innovation assessment, and statistically corrected regression analysis – aligns with contemporary methodological standards of high-impact journals and provides a scientifically rigorous basis for developing and validating innovative financial-security strategies in technology-intensive agricultural systems.

RESULTS

The innovative development of Ukraine's agricultural sector is increasingly shaped by the dynamics of venture capital flows and the accelerated growth of technological startups, which today function as key drivers of digital modernization within the agro-industrial domain. In the context of the expanding SMART-economy, agro-industrial enterprises actively rely on startup-generated solutions—ranging from precision-farming platforms and geospatial analytics to autonomous monitoring systems and data-driven decision support tools. Therefore, their financial security becomes directly dependent not only on internal resource management but also on the systemic maturity, stability, and investment capacity of the national startup ecosystem. Such an ecosystem determines the availability of technologically advanced instruments, the speed of innovative diffusion, and the accessibility of external financing necessary for the implementation of innovation-oriented financial strategies. Venture investors, accelerators, and technological hubs shape the environment in which agro-industrial SMART enterprises can scale operations, diversify revenue streams, mitigate financial risks, and build long-term resilience.

Strengthening the interconnection between startups and agricultural enterprises increases the predictability of financial flows, expands opportunities for digital transformation, and enhances the efficiency of investment decisions within the startup management system. In this context, analyzing current trends in the Ukrainian startup landscape is essential for forming a methodological foundation for modeling innovative financial security strategies. Figure 1 presents the top 10 Ukrainian startups that received the largest investment volumes in 2024, reflecting the key directions of capital allocation and illustrating the technological areas that will determine the future innovative trajectory of agro-industrial SMART enterprises.

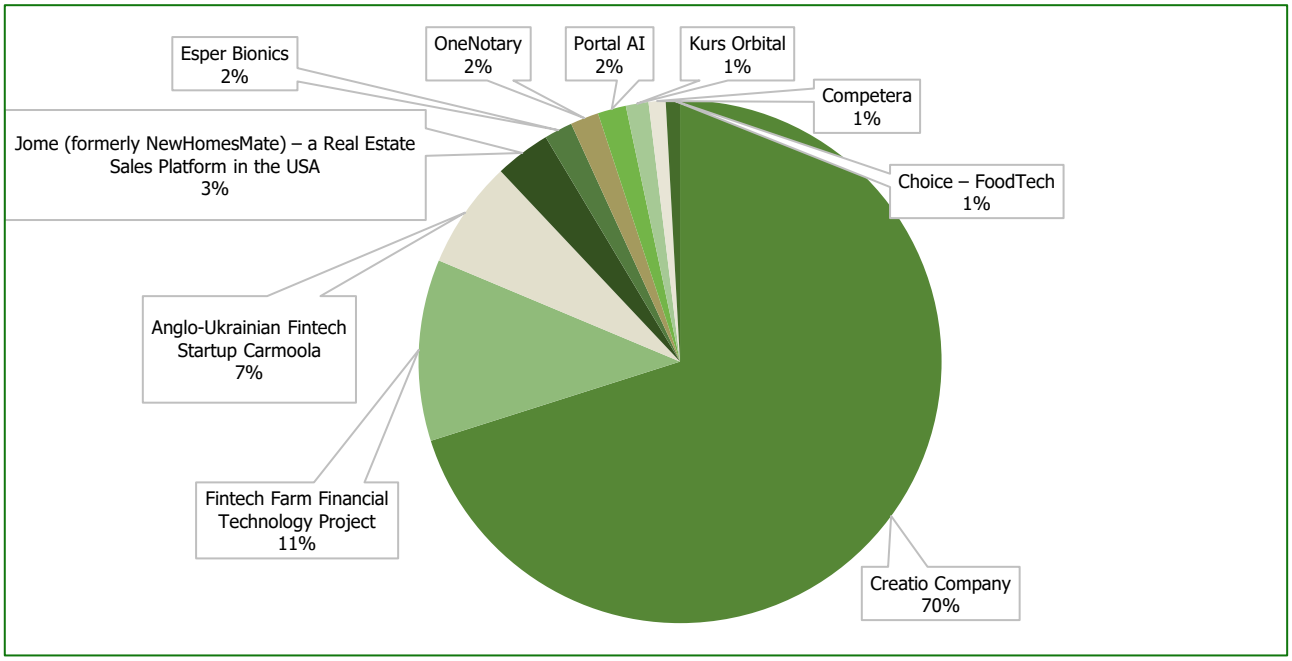

Figure 1. Top 10 Ukrainian startups that attracted the most investments, 2024.

To form a solid empirical basis for modeling innovative strategies of financial security, a representative group of agro-industrial SMART enterprises operating within the precision agriculture subsector was selected (Agro Flow System (AFS) GmbH, AGRONIX, FarmRTK, FlyAgData, Frendt, GeoPard Agriculture, etc.). The choice of these companies is justified by several criteria: their active integration of digital technologies in production processes, the intensive use of data-driven tools and sensor-based monitoring systems, high innovation capacity, and the availability of sufficiently detailed financial reporting. Such enterprises represent the core of Ukraine's precision-farming ecosystem and are crucial for understanding how digitalization affects financial sustainability, risk resilience, and investment attractiveness in the startup management system.

The empirical analysis relied on official financial statements, which made it possible to assess fundamental indicators such as net income from sales, net profit, and the dynamics of revenue formation in technologically intensive business models. These financial indicators not only reflect the operational efficiency of enterprises but also their strategic ability to commercialize digital solutions, scale innovative services, and convert technological advancements into stable financial flows. Moreover, the comparative assessment allows us to identify enterprise typologies in terms of innovation maturity—distinguishing between firms with high monetization potential, those focused on experimental technologies, and those transitioning towards more advanced SMART-business models.

Figure 2 presents the comparative financial performance of the analyzed enterprises for 2024 and visualizes differences in income structure, profitability levels, digital transformation outcomes, and the efficiency of innovation-driven business scaling. This graphical representation forms the empirical starting point for further modeling of financial security strategies and supports the identification of key factors influencing the financial resilience of agro-industrial SMART enterprises operating within the startup management environment.

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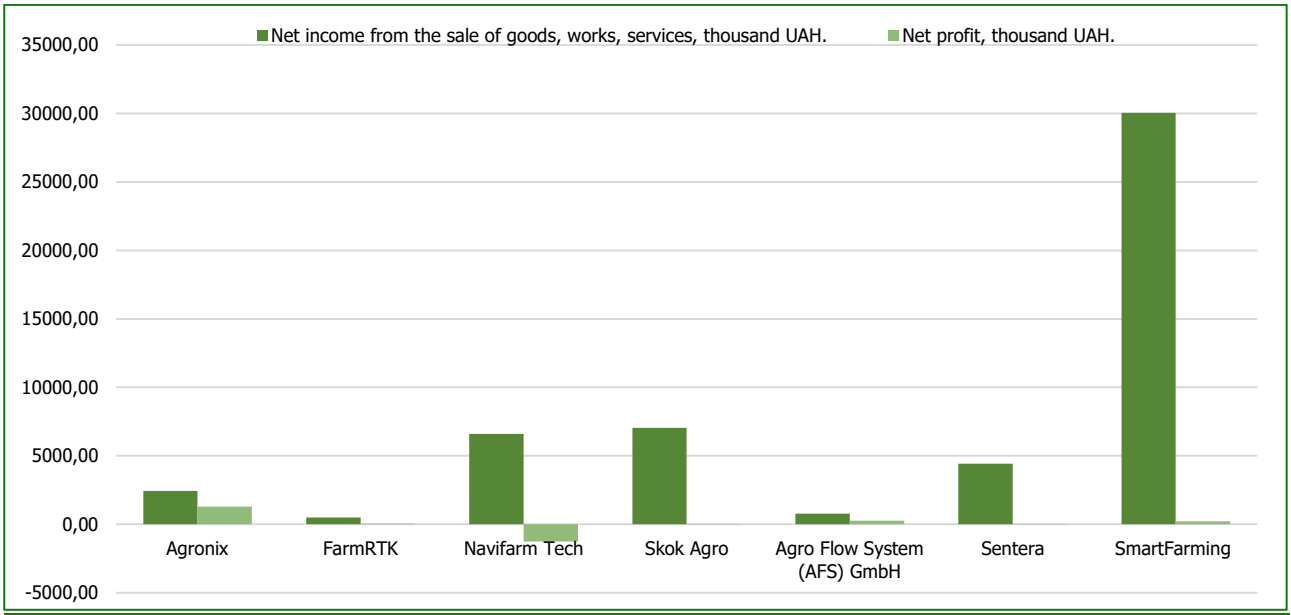

Figure 2. Graphical comparison of net income from sales of goods, works, services, and net profit of agro-industrial SMART enterprises in the precision agriculture subsector, 2024.

The analysis shows that SmartFarming generated the highest net sales revenue in 2024 due to the scalability of its digital service infrastructure, integration of multiple precision-agriculture functionalities, and diversified customer base. AGRONIX LLC demonstrated the highest net profit, attributed to its focus on high-margin technological solutions, cost-efficiency, and resource optimization. These differences in profitability and revenue-generation mechanisms underline the heterogeneous digital maturity of enterprises and justify the need for deeper financial-security modeling. To assess the financial feasibility and innovation potential of selected business entities, investment evaluation methods were applied: net present value (NPV), profitability index (PI), the Berkus method, and forward value (FV). The modelling was based on the following analytical expressions:

$$NPV = \frac{CFt}{T_{t=1}(1+r)^t} - IC \quad (1)$$

where CF denotes the cash flow in period t, T is the number of periods, r is the discount rate, and IC is the initial investment cost.

The Profitability Index *(PI)* was calculated as:

$$PI = \frac{\frac{T}{t=1}\frac{CFt}{(1+r)t}}{IC},$$

reflecting the efficiency of invested resources.

The integrated innovation potential was assessed using the Berkus method:

$$B = \mathrm{B}_1 + \mathrm{B}_2 + \mathrm{B}_3 + \mathrm{B}_4 + \mathrm{B}_5$$

where B_1 represents the value of the business idea, B_2 the degree of prototype readiness, B_3 team competence, B_4 market opportunity, and B_5 early customer traction.

Future capitalization of innovation-driven business models was assessed using the forward value:

$$FV = PV \cdot (1 + r)n,$$

The synthesized results of the modeling are summarized in Table 1.

Table 1. Main coefficients for modeling innovative strategies for financial security of agro-industrial SMART enterprises, 2024.

Enterprise	Net discounted income (NPV), UAH thousand	Profitability Index (PI)	Berkus score
Agronix	51.50	2.46	205
FarmRTK	54.94	11.19	181
Navipharm Tech	28.44	1.22	197
Skok Agro	1520.48	1.28	169
AFS GmbH	3.71	2.27	190
Sentera	42.88	1.75	235
SmartFarming	1013.70	1.59	229

The modelling results reveal substantial differentiation across enterprises in terms of their financial stability, innovative capacity, and ability to scale digital solutions within the startup management system. The highest net present value (NPV) was recorded for Skok Agro, which indicates not only strong long-term financial sustainability but also a high capability to convert technological solutions into predictable future cash flows. This result suggests that the company's precision-agriculture technologies demonstrate a high degree of market readiness, scalability, and operational efficiency, enabling it to generate stable revenue streams even under conditions of increased market volatility. In the context of financial security modeling, this positions Skok Agro as an enterprise with a robust investment profile and high strategic resilience. FarmRTK, in turn, showed the maximum profitability index (PI), which reflects the exceptional efficiency of capital utilization and the rapid return on innovation-driven investments. The high PI value demonstrates that the company's RTK-based digital products meet strong and stable market demand and require relatively modest investment inputs compared to the level of generated returns. From the standpoint of innovative financial security strategies, this confirms the effectiveness of FarmRTK's business model, which successfully combines technological specialization, narrow-segment digital expertise, and high commercialization potential. The highest Berkus score was recorded for Sentera, which achieved strong results due to its advanced analytical platforms, sensor-based monitoring systems, and strategic integration into agronomic and geospatial data markets. These factors significantly enhance the company's innovation capacity, allowing it to rapidly scale technological solutions, expand data-driven service portfolios, and strengthen competitive positions in the digital agriculture segment. In the context of startup-oriented financial security assessment, Sentera represents a technologically mature enterprise with high innovation intensity and strong readiness for accelerated growth.

A summarizing graphical representation of the NPV, PI, and Berkus coefficients is provided in Figures 3 and 4, enabling a comparative visualization of the enterprises' financial resilience, investment attractiveness, and innovation-driven development trajectories.

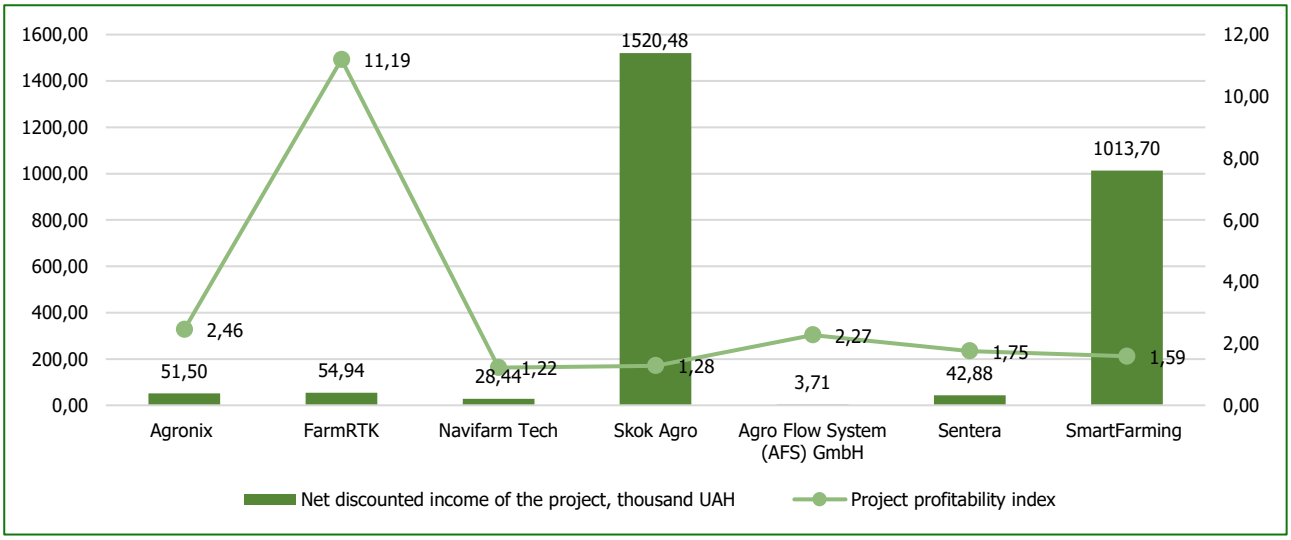

Figure 3. Net project income and project profitability index of competitive agro-industrial SMART enterprises in the startup management system, 2024 (PI; NPV).

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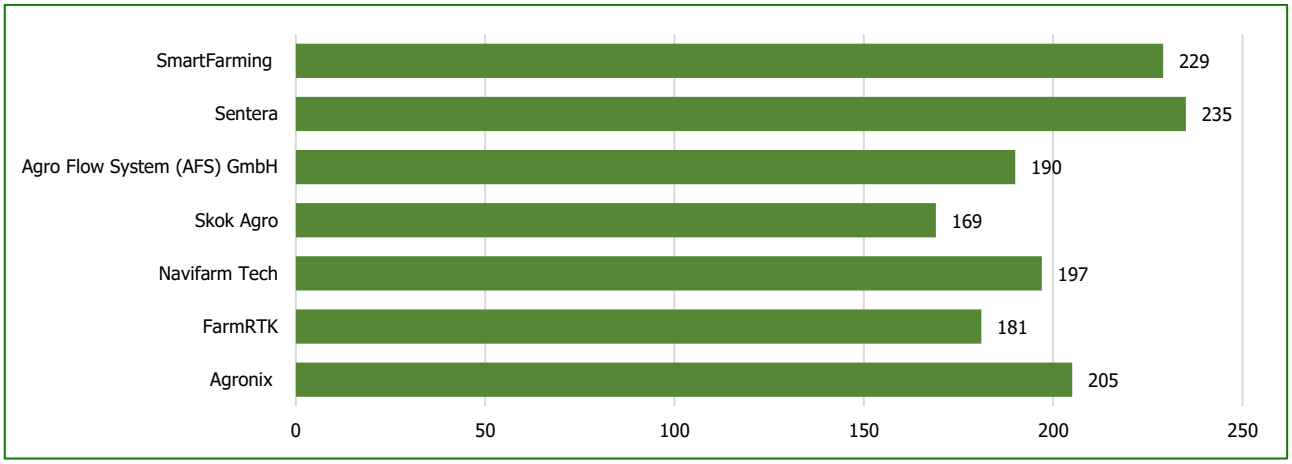

Figure 4. Cumulative empirical coefficient of accounting for startup potential by the Berkus method of competitive agro-industrial SMART enterprises in the startup management system, 2024 (Berkus- coefficient).

To deepen the assessment of investment-driven financial security and to identify the strength and direction of relationships between financial inputs and innovation-based outputs, regression modeling was applied as the next analytical step of the study. This approach makes it possible to quantify how investment flows stimulate the financial results of agro-industrial SMART enterprises and to determine whether capital injections into digital and technological solutions translate into measurable increases in net income. Such analysis is essential for understanding the efficiency of innovative strategies within the startup management system, where financial sustainability is closely linked to the ability of enterprises to convert technological modernization into stable revenue streams. Before constructing regression equations, the empirical dataset was systematized to reflect the dynamics of investments (X) and net income from sales (Y) for the selected enterprises over 2020–2024. This time interval captures several important phases of the development of precision agriculture in Ukraine: post-COVID recovery, acceleration of digital transformation, market shocks caused by military challenges, and the subsequent restructuring of business models based on data-driven tools and remote-sensing technologies. As a result, the dataset provides a sufficiently heterogeneous yet informative basis for analyzing how enterprises adapt to external instability through innovative and financial mechanisms.

The inclusion of multiple enterprises in the sample allows not only the estimation of individual regression models but also the comparison of investment responsiveness across different technological profiles. For example, enterprises with high degrees of digital integration may demonstrate faster and more stable income responses to each unit of investment, whereas companies at earlier stages of innovation maturity may show irregular or lagged revenue growth. Therefore, regression modeling becomes a tool for identifying which enterprises have already formed an effective innovation-investment cycle, and which remain vulnerable to financial risks despite technological activity.

Table 2 presents the structured dynamics of investments (X) and net income (Y) of the analyzed agro-industrial SMART enterprises during 2020–2024. These data form the empirical basis for building production linear regressions aimed at assessing the financial returns of innovative strategies and determining the investment elasticity of income under conditions of digital transformation.

Table 2. Dynamics of investments and net income of agro-industrial SMART enterprises, 2020–2024.

Enterprise	Year	Investments, UAH thousand (X)	Net income, UAH thousand (Y)
FarmRTK	2021	62.00	0.00
	2022	9.18	930.90
	2023	485.28	869.00
	2024	45.09	504.70
Agro Flow System (AFS) GmbH	2020	361.99	822.70
	2021	206.33	468.93
	2022	287.36	653.10
	2023	145.99	331.80
	2024	338.23	768.70

(continued on next page)

Table 2. Continued.

Enterprise	Year	Investments, UAH thousand (X)	Net income, UAH thousand (Y)
Sentera	2020	2882.43	5056.90
	2022	2196.78	3854.00
	2023	3244.33	5691.80
	2024	1757.71	3083.70
SmartFarming	2020	15948.14	25314.50
	2021	25916.44	41137.20
	2022	12797.82	20314.00
	2023	18063.80	28672.70
	2024	21886.07	34739.80

Linear production regression models were constructed to determine the dependency between investments and net income:

$FarmRTK: Y = 470.15 + 0.70X + \varepsilon$

$AFSGmbH: Y = 0.11 + 2.27X + \varepsilon$

$Sentera: Y = 0.52 + 1.75X + \varepsilon$

$SmartFarming: Y = 1.82 + 1.59X + \varepsilon$

Autocorrelation diagnostics indicated the need for an autoregressive transformation. Adjusted models are:

$FarmRTK: Y = 169.36 + 0.20X + \varepsilon$

$AFSGmbH: Y = -0.36 + 2.27X + \varepsilon$

$Sentera: Y = 0.68 + 1.75X + \varepsilon$

$SmartFarming: Y = -9.09 + 1.59X + \varepsilon$

For FarmRTK, the initial regression modelling indicated that each additional UAH 1 of investment was associated with an expected increase of UAH 0.70 in net income from sales. However, after applying the autoregressive transformation — which corrects for time-dependent distortions, irregular fluctuations, and the impact of atypical observations — the adjusted model demonstrated a much lower marginal effect of only UAH 0.20. This substantial difference between the two estimates shows that, without proper statistical correction, the effectiveness of investment-driven innovation strategies may be significantly overstated. In the context of financial security modelling, such discrepancies are critically important, as they reveal the hidden volatility and instability of revenue formation inherent in technologically intensive enterprises operating within a startup-oriented ecosystem. Correcting the model with autoregressive components allows for a more realistic assessment of the enterprise's ability to convert investments in precision-agriculture technologies into stable financial returns. This is particularly relevant for agro-industrial SMART enterprises, where income largely depends on the accuracy of technological implementation, the adaptability of digital solutions to field conditions, and the sensitivity of demand to innovation cycles. Therefore, the refined coefficient of UAH 0.20 more precisely reflects the actual financial behaviour of FarmRTK under conditions of dynamic market transformation and technological scaling.

Forecasts for 2026–2028 based on both the initial and adjusted regression models are presented in Table 3.

These forecasts provide insight into the potential future financial trajectories of the enterprise, enabling a comparative evaluation of optimistic (non-adjusted) and realistic (autoregressive) investment-return scenarios. Such comparative modelling is essential for forming innovation-oriented financial security strategies, as it supports more accurate planning of investment portfolios, risk-adjusted decision-making, and long-term sustainability assessments for competitive agro-industrial SMART enterprises operating in the startup management system.

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Table 3. Forecast values of net income, 2026–2028.

Enterprise	Year	Forecasted Net Income (UAH thousand)
FarmRTK (Autocorrelated)	2026	681.09
FarmRTK (Autoregressive)	2026	229.17
FarmRTK (Autocorrelated)	2027	711.07
FarmRTK (Autoregressive)	2027	237.67
FarmRTK (Autocorrelated)	2028	741.05
FarmRTK (Autoregressive)	2028	246.17
AFS GmbH (Autocorrelated)	2026	783.83
AFS GmbH (Autoregressive)	2026	783.36
AFS GmbH (Autocorrelated)	2027	804.77
AFS GmbH (Autoregressive)	2027	804.30
AFS GmbH (Autocorrelated)	2028	830.26
AFS GmbH (Autoregressive)	2028	829.79
Sentera (Autocorrelated)	2026	3275.18
Sentera (Autoregressive)	2026	3275.34
Sentera (Autocorrelated)	2027	3495.64
Sentera (Autoregressive)	2027	3495.80
Sentera (Autocorrelated)	2028	3540.67
Sentera (Autoregressive)	2028	3540.83
SmartFarming (Autocorrelated)	2026	34401.42
SmartFarming (Autoregressive)	2026	34408.69
SmartFarming (Autocorrelated)	2027	35040.03
SmartFarming (Autoregressive)	2027	35047.30
SmartFarming (Autocorrelated)	2028	35713.56
SmartFarming (Autoregressive)	2028	35720.83

Graphical interpretations of forecasted net income and investment trends are presented in Figures 5–7. An illustration of the forecasted profit values and forecasting of innovative strategies for financial security of competitive agro-industrial SMART enterprises in the precision agriculture subsector is presented in Figure 5.

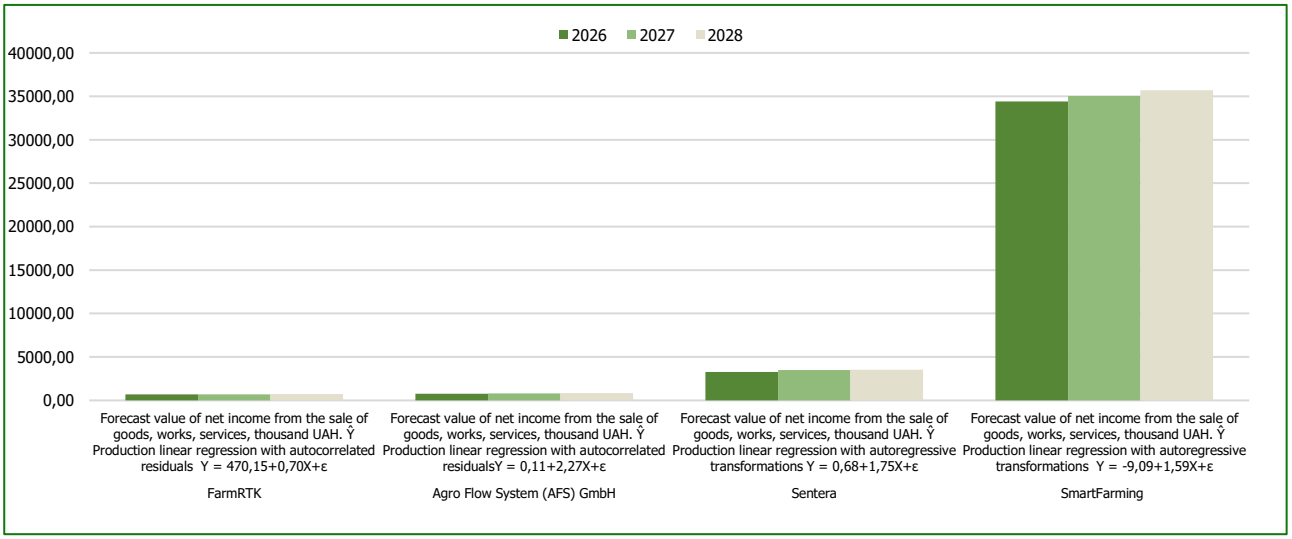

Figure 5. Forecast of net income of agro-industrial SMART enterprises of precision agriculture for 2026–2028, obtained by the best linear regression model with autoregressive corrections.

As a result of the forecasting procedures, a consistent upward trend in the effective indicator—net income from the sale of goods, works, and services—was recorded, which is logically explained by its direct dependence on the projected expansion of investment flows. This interconnection reflects a fundamental mechanism of innovation-driven financial development in agro-industrial SMART enterprises: investment growth typically precedes increases in technological capacity, operational digitalization, and the scaling of precision-agriculture tools. As enterprises integrate more automated systems, data-analytical platforms, and sensor-based monitoring technologies, their ability to generate stable and diversified revenue streams strengthens, resulting in a measurable improvement in financial security indicators. The obtained investment forecasts, therefore, serve not merely as numerical projections but as a key analytical basis for modelling innovative strategies of financial resilience within the startup management system. They demonstrate how capital inflows function as a catalyst for long-term sustainability, reduce operational uncertainty, and enhance the adaptive potential of technologically intensive enterprises. Moreover, the upward trend indicates that enterprises with higher levels of innovation maturity can maintain revenue stability even under volatile market conditions, as digital technologies facilitate more predictable and controllable production processes. Graphically, the forecast values of investments for the next three-year period are presented in Figure 6.

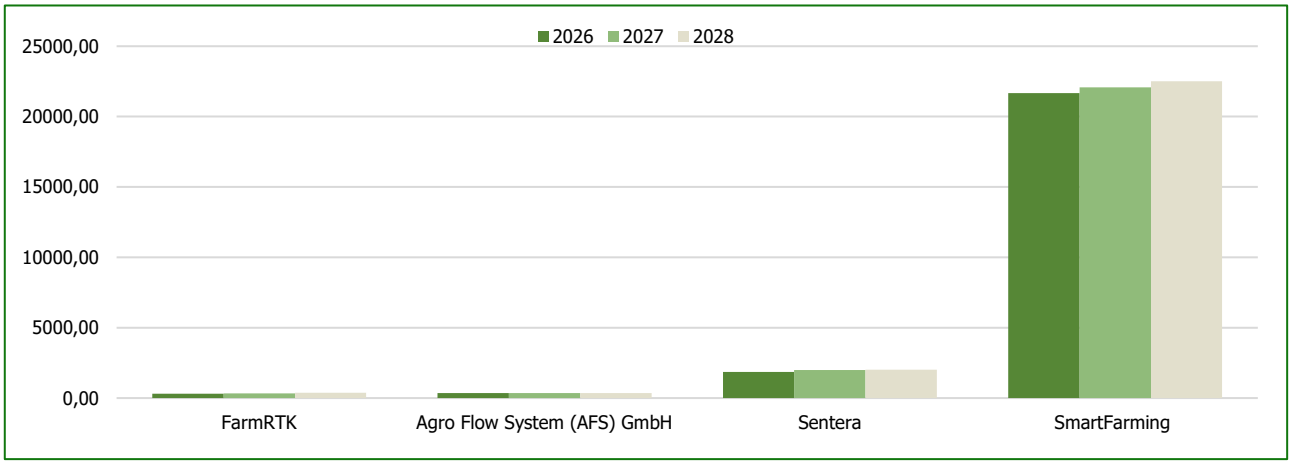

Figure 6. Forecasting investments of agro-industrial SMART enterprises in the startup management system, 2026-2028.

This visualization highlights not only the absolute growth in projected investment volumes but also the differing rates of investment dynamics across enterprises. Such differences allow identifying which enterprises are capable of maintaining innovation-intensive development trajectories and which may require additional strategic interventions to strengthen their financial security. Thus, Figure 6 acts as an instrumental component of the overall model, illustrating how forward-looking investment behaviour shapes the financial sustainability and competitive positioning of agro-industrial SMART enterprises within an innovation-oriented startup ecosystem. An illustration of the forecast value of investments of agro-industrial SMART enterprises in the startup management system, 2026, taking into account the efficiency indices of innovative strategies of financial security, 2024, is presented in Figure 7.

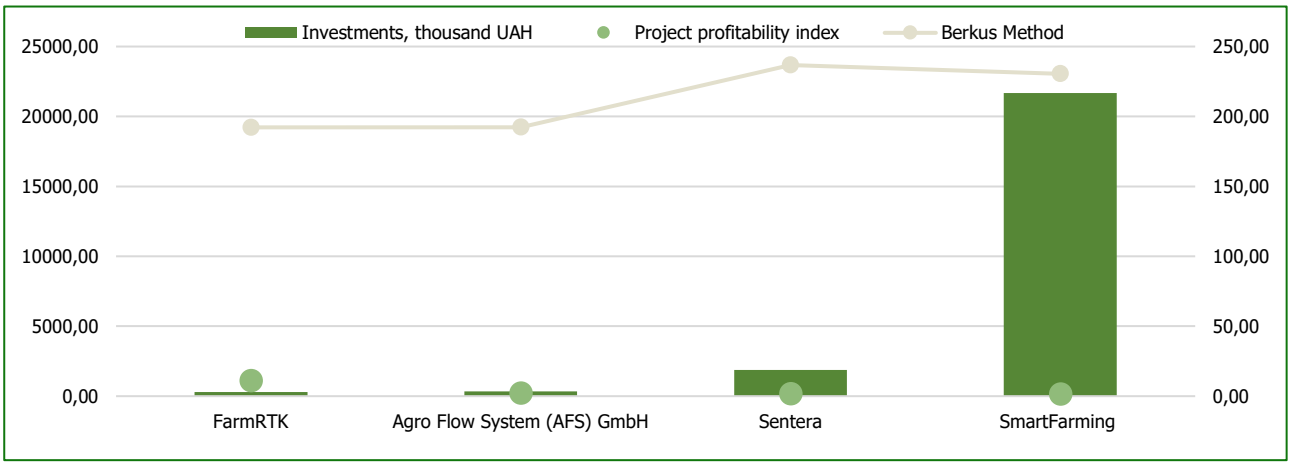

Figure 7. Illustration of the forecast value of investments of agro-industrial SMART enterprises in the startup management system, 2026, taking into account the efficiency indices of innovative strategies of financial security, 2024.

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Overall, the modelling results confirm that the application of economic-mathematical tools provides a scientifically grounded and reliable basis for assessing innovation-driven financial security strategies of agro-industrial SMART enterprises. The use of NPV, profitability index, Berkus scoring, regression analysis, and autoregressive adjustments makes it possible to detect hidden financial dependencies, identify structural patterns in revenue formation, and measure the real efficiency of investment flows. These methodological instruments prevent overestimation of expected outcomes—often typical for technologically intensive sectors—and instead generate objective conclusions regarding an enterprise's ability to maintain stable cash flows, withstand market shocks, and ensure predictable long-term development. Furthermore, the results demonstrate that innovative activity, digital integration, and technological maturity act as fundamental determinants of financial resilience and sustainability. Enterprises that actively deploy precision-agriculture tools, sensor-based monitoring systems, automated data-collection technologies, and advanced analytical platforms show stronger adaptability to external risks, higher operational efficiency, and faster monetization of digital solutions. Their financial trajectories tend to be more stable, displaying smoother growth patterns and a clearer correlation between investment inputs and revenue outcomes. In contrast, enterprises with lower innovation intensity exhibit greater fluctuations in financial performance, delayed responses to investment stimuli, and higher exposure to systemic risks. This differentiation underscores the strategic importance of innovation capacity as a key component of financial security within the startup management system. Models applied in the study clearly demonstrate that technological maturity not only enhances competitiveness but also strengthens the internal mechanisms of financial protection by ensuring diversification of income sources, reducing uncertainty, and increasing the predictability of future financial flows.

Thus, the obtained modelling results justify the necessity of integrating economic-mathematical instruments into the development of innovative financial security strategies and confirm that long-term resilience of agro-industrial SMART enterprises depends on the systematic implementation of digital technologies, innovation-oriented management practices, and the ability to scale technological solutions in dynamic market environments.

DISCUSSION

The obtained research results require a broader scientific understanding from the standpoint of modern approaches to financial security, innovative development, and startup management of agro-industrial SMART enterprises. Despite the significant number of works devoted to financial sustainability, digital transformation, or innovative development mechanisms, most of the existing research considers these phenomena in isolation, without forming a holistic methodology for modeling innovative strategies of financial security at the level of a real enterprise. This is especially noticeable in the agro-industrial sector, where financial results already directly depend on the intensity of the implementation of digital solutions, investment dynamics, and the ability of enterprises to integrate startup technologies into production and management processes. In view of this, this section is aimed at comparing the results obtained in the article with the work of leading scientists, identifying common positions and key differences, as well as substantiating the scientific novelty of the research conducted. Indeed, although previous works focused on individual aspects – financial risks, digitalization, innovation potential, or investment attractiveness – they mostly did not offer a comprehensive model that would simultaneously combine the assessment of financial flows, innovation capacity, investment efficiency, and adaptation of enterprises to the conditions of the startup ecosystem. That is why a comparative analysis of scientific sources allows not only to outline the methodological framework of modern research, but also to clearly show that the model proposed in the article has a higher level of integrativeness, ensures practical measurability of innovation strategies, and creates new opportunities for predicting the financial security of agro-industrial SMART enterprises in the startup management environment.

Davydenko et al. (2021) assess regional financial potentials, pointing to spatial disparities in investment capacity. This provides a useful macroeconomic perspective, but does not tie it to specific agribusinesses or explore how startup technologies can compensate for these disparities. Instead, our article zooms in on the entrepreneurial level, analyzing individual SMART agribusinesses – and shows how innovative financial and technological strategies can ensure financial sustainability even under regional constraints. In this way, we complement the macro approach of Davydenko et al. (2021) with an empirical business level, which is an important step towards the practical implementation of regional investment policies.

Dmytryshyn & Blahun's (2016) approach to optimizing credit resources is important for the banking or macrofinance segment, but it is focused on general lending, without taking into account the specifics of startups and innovative agribusinesses. In our work, we reorient these principles to agribusiness startups, using discounted cash flows (NPV, PI), taking into account technological risks and market volatility. This is a significant extension: credit/investment models are adapted to the specifics of agri-SMART enterprises, and not only to classical agribusiness or corporate lending.

Sitnicki (2018), which focuses on knowledge management, institutional capacity, and innovation management, highlights the importance of human and organizational capital. However, it remains at the level of general concepts and does not offer quantitative models for assessing the impact of innovations on financial security. Our work combines an institutional-managerial approach with quantitative modeling, demonstrating how, through NPV, PI, and Berkus-score, the impact of innovations and managerial competencies on the financial stability of agribusinesses can be specifically measured.

Ushenko et al. (2023) and colleagues emphasize blockchain as a tool for digital security and financial transparency. This is important at the process level, but they do not link the technology to financial forecasting or investment strategies. Our article integrates blockchain and digital risks into a financial security model, recognizing that digital security is an integral part of the investment sustainability of SMART enterprises. In this way, we extend the technological-financial approach, making it more relevant for modern digital agribusinesses.

Davydenko (2015) emphasizes the importance of a risk-based approach in strategic financial management. However, the authors do not propose a specific set of tools for small or medium-sized agribusinesses with high innovation. Our contribution lies in a sharply detailed system of tools: NPV, PI, Berkus-score, regression models, and specifically for agri-SMART enterprises. We argue that risk-based strategies can be implemented at the level of individual companies, not just at the macro level.

Despite the significant number of works devoted to financial sustainability, digital transformation, or innovative development mechanisms, most of the existing research considers these phenomena in isolation, without forming a holistic methodology for modeling innovative strategies of financial security at the level of a real enterprise. This is especially noticeable in the agro-industrial sector, where financial results already directly depend on the intensity of the implementation of digital solutions, investment dynamics, and the ability of enterprises to integrate startup technologies into production and management processes.

In view of this, this section is aimed at comparing the results obtained in the article with the work of leading scientists, identifying common positions and key differences, as well as substantiating the scientific novelty of the research conducted. Indeed, although previous works focused on individual aspects - financial risks, digitalization, innovation potential, or investment attractiveness - they mostly did not offer a comprehensive model that would simultaneously combine the assessment of financial flows, innovation capacity, investment efficiency, and adaptation of enterprises to the conditions of the startup ecosystem.

That is why a comparative analysis of scientific sources allows not only to outline the methodological framework of modern research, but also to clearly show that the model proposed in the article has a higher level of integrativeness, ensures practical measurability of innovation strategies, and creates new opportunities for predicting the financial security of agro-industrial SMART enterprises in the startup management environment.

CONCLUSIONS

The study provides a comprehensive analytical and methodological framework for understanding how innovation activity, digital integration, and investment dynamics determine the financial security of agro-industrial SMART enterprises operating within the startup management system. The findings demonstrate that the financial sustainability of technologically intensive agricultural enterprises is shaped by the maturity of their digital infrastructure, the ability to commercialize precision-agriculture solutions, and the effectiveness of investment-driven development strategies. The integration of discounted cash-flow modelling, profitability diagnostics, innovation-potential assessment, and econometric analysis revealed significant differentiation among enterprises in terms of their capacity to transform technological innovations into stable long-term financial flows.

The evaluation of net present value, profitability index, and Berkus innovation scores showed that enterprises with higher levels of technological readiness, scalable digital platforms, and well-structured management practices achieve stronger financial outcomes and exhibit greater resilience to market volatility. Skok Agro demonstrated the highest discounted future income, confirming its potential to generate sustainable cash flows from digitalized production processes. FarmRTK showed the most efficient conversion of investment inputs into financial returns, while Sentera exhibited the strongest innovation potential due to its advanced data-analytic systems and sensor-based technologies. These results underscore the critical role of innovation maturity in strengthening financial resilience, improving investment attractiveness, and enhancing competitive positioning.

Regression modelling further clarified the nature of the relationship between investment and revenue formation. The comparison of initial and autoregressive models revealed that unadjusted regressions tend to overestimate investment

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efficiency, whereas corrected models provide statistically consistent estimates of income elasticity. This finding highlights the methodological importance of addressing autocorrelation when analysing financial data of innovation-intensive enterprises. The forecasting results for 2026–2028 confirmed stable upward trends in both investment volumes and net income, suggesting that enterprises with advanced digital integration are capable of maintaining growth trajectories even under conditions of external uncertainty. These projections illustrate how investment expansion acts as a catalyst for technological upgrading and reinforces the long-term financial security of agro-industrial SMART enterprises.

Overall, the study proves that the development of innovative strategies for financial security requires the systematic application of economic-mathematical tools and the incorporation of technological, financial, and managerial dimensions into a unified analytical model. The proposed methodological approach forms a scientifically grounded basis for designing resilient investment policies, optimizing innovation-driven decision-making, and enhancing the strategic adaptability of competitive agro-industrial SMART enterprises. The results confirm that financial security in the startup management system is not merely a function of capital availability, but a multidimensional outcome determined by innovation capacity, digital transformation, and the ability of enterprises to maintain predictable and sustainable revenue flows in dynamic market environments.

The obtained research results require a broader scientific understanding and further research in terms of modern approaches to financial security, innovative development, and management of startups of agro-industrial SMART enterprises.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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МЕТОДОЛОГІЯ МОДЕЛЮВАННЯ ІННОВАЦІЙНИХ СТРАТЕГІЙ ФІНАНСОВОЇ БЕЗПЕКИ КОНКУРЕНТОСПРОМОЖНИХ АГРОПРОМИСЛОВИХ SMART-ПІДПРИЄМСТВ У СИСТЕМІ СТАРТАП-МЕНЕДЖМЕНТУ

У дослідженні вивчено теоретико-прикладні засади моделювання інноваційних стратегій фінансової безпеки конкурентоспроможних агропромислових SMART-підприємств у системі стартап-менеджменту. Акцент зроблено на тому, що сучасні умови функціонування аграрного сектора України характеризуються зростанням технологічної турбулентності, поглибленням цифровізації виробничих процесів і зростанням ролі інноваційних інструментів у забезпеченні фінансової стабільності. У таких умовах фінансова безпека перестає бути лише функцією контролю ризиків – вона трансформується в багатовимірну систему, де взаємодіють інвестиційна активність, технологічні зміни, швидкість оновлення бізнес-моделей, цифрова зрілість підприємства та його здатність інтегрувати стартап-технології в ключові операційні процеси. У роботі обґрунтовано, що конкурентоспроможність агропромислових SMART-підприємств безпосередньо залежить від здатності формувати інноваційні фінансові стратегії, які одночасно забезпечують адаптивність, стійкість і розвиток. Показано, що в цифровому середовищі посилюється взаємозалежність між інвестиційними рішеннями, технологічним оновленням, продуктивністю та ризиками. Важливо, що в статті приділено увагу практичним аспектам застосування фінансово-аналітичних інструментів для оцінювання ефективності інноваційних проєктів, а також механізмам інтеграції стартап-управління в стратегічний контур фінансової безпеки підприємств агротехнологічного сектора.

Наукова новизна дослідження полягає в поглибленому розкритті ролі цифрових інновацій, гнучких управлінських рішень та інтенсифікації інвестиційних процесів у формуванні фінансової стійкості SMART-підприємств. Доведено, що системне застосування інноваційних стратегій створює умови для підвищення фінансової стійкості, зниження чутливості до ризиків і зміцнення позицій у стартап-екосистемах аграрного сектора. Результати роботи мають прикладне значення для розробки дієвих механізмів економічної безпеки, удосконалення фінансової політики та формування інноваційно орієнтованої моделі розвитку агропромислових SMART-підприємств.

Ключові слова: фінансова безпека, інноваційна стратегія, стартап-менеджмент, агропромислові SMART-підприємства, венчурне фінансування, цифрова економіка, ризик-менеджмент, інвестиційна привабливість

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