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Financial Drivers of Innovation in Kazakhstan's Agriculture: An Econometric Analysis

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Abstract
In the context of the transition to an innovation-driven economy and increasing demands for sustainable agricultural development, the effectiveness of innovation financing becomes particularly relevant. The aim of the study is to assess the impact of innovation financing on innovation activity in Kazakhstan's agricultural sector, using econometric modeling and controlling for government support and labor productivity. The methodological framework includes descriptive statistics, correlation analysis, econometric modeling using the ordinary least squares (OLS) method, and scenario analysis. The empirical database is based on statistical data for the period 2015–2025. The econometric analysis shows that innovation financing has the strongest impact ($\beta = 2.85$), while government support demonstrates a statistically significant but weaker effect ($\beta = 1.76$). Labor productivity also has a positive influence ($\beta = 0.09$), confirming the interdependence between technological development and production efficiency. The results of the correlation analysis confirm a strong relationship between innovation activity and productivity ($r = 0.91$) and between financing and innovation activity ($r = 0.88$). The findings show that innovation financing is a necessary but not sufficient condition for the development of innovation in agriculture. Its effectiveness depends on the interaction with government support mechanisms, productivity growth, and institutional conditions. The study contributes to the development of the theory of innovation financing by demonstrating the nonlinear and cumulative nature of the relationship between investment and innovation activity and by emphasizing the need for an integrated approach to financial policy in the agricultural sector.

KEYWORDS
innovation, innovation financing, agriculture, agricultural economics, agribusiness, government support, labor productivity, efficiency

1 | INTRODUCTION

In the context of the transition to an innovation-driven and knowledge-based economy, the agricultural sector is increasingly recognized as a critical component of sustainable economic growth and food security. Under conditions of global competition, climate change, and technological transformation, agriculture's ability to adopt innovations becomes a key determinant of its long-term productivity and resilience. In this regard, the mechanisms of financing innovation activity acquire particular importance, as they shape the conditions for technological modernization, capital renewal, and the diffusion of advanced agricultural practices.

Within the framework of classical economic theory, innovation is closely linked to the availability of financial resources. This idea is further developed in investment theory, where capital-intensive technological adoption depends not only on expected returns but also on the cost and accessibility of financial resources (Jorgenson, 1963). In the context of endogenous growth theory, innovation financing is considered a key driver of productivity growth and structural transformation (Romer, 1990; Aghion & Howitt, 1992).

At the same time, empirical research demonstrates that the relationship between financing and innovation is complex and not always linear. Early studies generally confirmed a positive impact of financial resources on technology adoption (Feder et al., 1985; Alston et al., 1998). However, subsequent research has revealed significant heterogeneity in these effects, emphasizing that increased financial support does not automatically lead to higher innovation activity. Methodological challenges, such as endogeneity and self-selection, have shown that more productive and innovation-oriented agents are more likely to access financial resources, potentially biasing empirical estimates (Minten et al., 2011; Cole et al., 2014; Mariyono, 2019).

In recent years, research has moved beyond purely quantitative assessments of financial support, placing greater emphasis on how its structure and effectiveness shape outcomes. It is increasingly recognized that the outcomes of financing are determined not only by its volume but also by the configuration of financial instruments, the quality of institutions, and the broader economic context in which these mechanisms operate. In this regard, particular attention is paid to diversified financial tools, such as leasing, insurance schemes, and targeted investment support, which, to varying degrees, shape farmers' ability to adopt innovations and mitigate production risks. At the same time, a few recent empirical studies suggest that the relationship between financing and innovation is not linear. Rather, it appears to exhibit threshold effects and diminishing marginal returns, implying that only a certain level of investment can generate a tangible technological shift.

A separate strand of the literature examines these processes in transition economies, where institutional limitations often play a decisive role. In such settings, the effectiveness of financial mechanisms is often constrained by structural distortions, a significant state presence, and unequal access to financial resources among economic agents. Kazakhstan, in this context, provides a particularly illustrative case. On the one hand, the agricultural sector demonstrates signs of active modernization; on the other hand, it remains strongly dependent on public support and external investment flows. Despite the expansion of financing instruments and the overall increase in state support, innovation activity in agriculture continues to develop unevenly, both across regions and across types of economic agents.

Empirical observations for Kazakhstan indicate that during 2015–2025, the share of financing directed toward innovation increased from 0.8% to 2.5% of agricultural value added. This was accompanied by a rise in innovation activity (from 6.2% to 13.5%) and

improvements in labor productivity. Nevertheless, these positive dynamics cannot be interpreted as uniform across all segments of the sector. Their manifestation appears to be influenced by a combination of external shocks, institutional constraints, and internal structural heterogeneity. Moreover, the observed interdependence among financing, state support, and productivity points to a cumulative and multi-layered mechanism of innovation development rather than a simple cause-and-effect relationship.

At the same time, despite the growing number of studies in this field, several important gaps remain. First, most existing research focuses on individual financial instruments without considering their combined or synergistic effects. Second, the problem of endogeneity is often addressed only partially, which reduces the robustness of causal interpretations. Third, the interaction between financing, productivity, and innovation activity is still rarely examined within a unified analytical framework. In addition, the dynamic and nonlinear nature of innovation processes in agriculture, particularly in transition economies, remains insufficiently studied.

Against this background, the present study seeks to assess how innovation financing influences innovation activity in Kazakhstan's agricultural sector, with particular attention to the roles of government support and productivity factors. To address this objective, the analysis relies on a mixed methodological approach that combines descriptive statistics, correlation analysis, econometric modeling within the OLS framework, and scenario-based techniques. The empirical basis of the study is statistical data for the period 2015–2025, enabling the analysis to capture both temporal changes and structural shifts within the sector. Thus, the aim of the study is to assess the impact of innovation financing on innovation activity in Kazakhstan's agricultural sector, using econometric modeling and controlling for government support and labor productivity.

2 | LITERATURE REVIEW

Understanding how financial mechanisms influence innovation in agriculture requires a framework that integrates classical economic ideas with more recent empirical and institutional perspectives. Over time, the role of finance in the agricultural sector has been reconsidered. Earlier studies mostly treated financing as a source of capital, whereas more recent work suggests that outcomes depend not only on the volume of resources but also on how financial instruments are structured, how accessible they are, and the institutional conditions in which they operate (Beck et al., 2005; Levine, 2005). In this context, financing should be interpreted not only as a tool supporting investment activity but also as a systemic factor influencing long-term productivity and sustainable agricultural development.

The theoretical foundations of this study are rooted in Schumpeter's concept of innovation, which assigns a central role to credit as a mechanism enabling technological change. From this perspective, entrepreneurs' ability to introduce innovations is closely linked to their access to external financial resources (Schumpeter, 1934). This idea was further developed in Jorgenson's investment theory, which suggests that decisions regarding the adoption of capital-intensive technologies depend not only on expected returns but also on the cost of capital, interest rates, and the broader conditions of credit availability (Jorgenson, 1963). Thus, investment decisions in agriculture are shaped by both technological expectations and financial constraints (Hall & Lerner, 2010).

An important contribution to the understanding of agricultural innovation processes was made by Feder et al. (1985), who demonstrated that financial constraints are often among the most persistent barriers to technology adoption. In many cases, these constraints may outweigh factors traditionally considered important, such as education levels or access

to information. This conclusion has been repeatedly confirmed by subsequent empirical studies, reinforcing the view that limited access to finance plays a decisive role in shaping innovation dynamics in agriculture (Karlan et al., 2014).

During the first wave of large-scale econometric studies (1995–2010), a generally positive relationship between access to finance and innovation adoption was confirmed, although substantial heterogeneity in outcomes was also identified. In particular, the effectiveness of subsidies was found to depend critically on their design: broad-based input subsidies tend to have limited or even negative effects on technological upgrading, whereas targeted investment subsidies produce more consistent and positive impacts (Alston et al., 1998; Gollin, 2010). A meta-analysis by Croppenstedt et al. (2003) indicates that access to formal credit increases the likelihood of innovation adoption by approximately 32%, highlighting the importance of financial inclusion in agricultural development.

However, more recent research has revisited these conclusions by explicitly accounting for methodological limitations, most notably endogeneity. Beginning in the early 2010s, a growing body of studies has shown that farmers who are already more productive or innovation-oriented tend to have better access to financial resources. This creates a potential bias in empirical estimates, as the observed relationship may reflect self-selection effects and reverse causality rather than a purely causal impact of financing (Minten et al., 2011; Cole et al., 2014). In this regard, the findings of Mariyono (2019) are particularly illustrative. A meta-analysis of empirical studies shows that once endogeneity is properly addressed, the estimated impact of financial support tends to decline substantially, often by nearly half.

Subsequent research has expanded the range of financial instruments under consideration. Moving beyond traditional analyses of credit and subsidies, recent studies have explored the role of leasing, agricultural insurance, venture capital, and foreign direct investment. Evidence suggests that leasing is often a more effective mechanism for facilitating machinery adoption than conventional credit, particularly for medium-sized farms (Vercammen, 2011). At the same time, the availability of agricultural insurance has been shown to increase farmers' willingness to undertake innovation-related risks, raising the probability of adopting new technologies by approximately 40

The most recent stage of research (2021–2025) highlights the nonlinear and threshold nature of the relationship between financing and innovation. Empirical evidence indicates that the marginal returns to additional financial resources diminish over time, and beyond a certain threshold, further increases in funding have a limited impact on technological adoption (Goczek & Witkowski, 2023). Moreover, it has been demonstrated that the effectiveness of financial instruments depends more strongly on the quality of the institutional environment than on their volume or specific conditions (Ferrer, 2021; Acemoglu & Robinson, 2012).

A distinct strand of the literature focuses on transition economies, where institutional constraints significantly shape the functioning of financial mechanisms. In such contexts, the applicability of conventional models is limited by the agricultural sector's dual structure, the state's dominant role, and institutional inertia (Petrick et al., 2012; Djuric et al., 2018; Svanidze et al., 2019). In particular, the phenomenon of "institutional capture" of subsidies has been identified as a major barrier limiting access to financial resources for small and medium-sized farms (Hidayati et al., 2021; Swinnen, 2021)

In Kazakhstan, research on the financial drivers of agricultural innovation can be divided into three stages. The first stage (2010–2017) was primarily descriptive, focusing on identifying structural constraints in the agricultural sector, including a substantial credit gap and low levels of innovation activity (Petrick et al., 2017). At the same time, Svanidze and

Götz (2019) provided one of the first quantitative assessments of the effectiveness of agricultural support systems, demonstrating that the subsidy mechanisms implemented prior to 2018 largely reinforced an extensive model of agricultural production and constrained technological modernization.

The second stage (2018–2022) is characterized by a gradual shift toward quantitative methods and more rigorous empirical approaches. Studies from this period, including Issakhov et al. (2020), based on regional-level data, reveal a positive relationship between government support and productivity growth; however, this relationship appears to be statistically limited and not always robust across specifications. At the same time, Duskaliyev (2021) showed that subsidized credit tends to stimulate the renewal of machinery primarily in an extensive manner, rather than facilitating the diffusion of advanced digital or resource-efficient technologies. In addition, the academic discourse of this period reinforces the arguments presented by Richard Pomfret (2021), who highlighted that large-scale public expenditures on innovation may yield relatively modest results in the absence of sufficiently developed institutional frameworks.

The third stage (2023–2025) is characterized by increasing reliance on micro-level data and more sophisticated empirical techniques. Nevertheless, much of this research continues to focus on individual financial instruments in isolation, without offering an integrated assessment of their combined effects. For instance, Kireyeva et al. (2021) provide evidence of positive spillover effects associated with foreign direct investment, particularly for local producers operating within interconnected value chains. Siximbayeva et al. (2025) found that investment subsidies tend to have significant effects, primarily for large agroholdings, suggesting an uneven distribution of benefits across farm types. At the same time, Zhagyparova et al. (2025) identified financial leasing as one of the most effective mechanisms supporting the adoption of precision agriculture technologies.

Overall, the existing literature provides a substantial theoretical and empirical basis for understanding the role of financial factors in innovation processes. However, the observed effects are far from uniform and appear to be highly context-dependent, varying across institutional environments, farm structures, and stages of technological development. Despite the progress achieved, several important research gaps remain. First, there is still a lack of comprehensive studies that jointly assess multiple financial instruments within a unified analytical framework. Second, the issue of endogeneity is not always adequately addressed, which limits the reliability of causal interpretations. Third, the heterogeneity of effects across farm categories remains insufficiently explored. Finally, spatial dimensions, particularly regional disparities and potential spillover effects, have received comparatively limited attention.

Considering these considerations, the present study aims to address the identified gaps by applying an econometric framework based on time-series data and ordinary least squares (hereinafter – OLS) estimation. The analysis focuses on assessing the relationships between innovation financing, government support, and productivity, while acknowledging potential limitations related to endogeneity and data aggregation.

3 | RESEARCH METHODS

In the context of a transition to an innovation-driven economy, the quantitative assessment of innovation financing in agriculture requires formalized analytical approaches grounded in statistical data and econometric modelling. At the same time, while a substantial body of theoretical work exists, empirical evidence on the impact of financing on innovation activity in Kazakhstan's agricultural sector remains relatively limited. This creates the need

for a more detailed quantitative analysis that can capture both the scale and the structural features of this relationship.

The methodological foundation of the study draws on the theory of endogenous economic growth, where innovation is viewed as a result of investment processes and a key determinant of long-term productivity dynamics (Romer, 1990; Aghion & Howitt, 1992). Within this perspective, financing can be interpreted not merely as a supporting factor, but as one of the central mechanisms through which technological development in agriculture is realized.

The empirical dataset is constructed using official statistical data of the Republic of Kazakhstan for the period 2015–2025. Data sources include the Bureau of National Statistics, the Ministry of Agriculture, and the National Bank of Kazakhstan. The selected period reflects a stage of active modernization of the agricultural sector and the implementation of digital technologies.

To ensure a comprehensive quantitative assessment, an indicator system is developed that includes a dependent variable, a key explanatory variable, and a set of control variables. The dependent variable is innovation activity in agriculture, measured as the share of innovation-active enterprises or an innovation activity index, defined by formula (1):

$$IA_t = \frac{Innov_t}{Total_t} \times 100 \tag{1}$$

where:

IA_t – the level of innovation activity in period t;

$Innov_t$ – the number of innovation-active enterprises;

$Total_t$ – the total number of agricultural enterprises.

The key explanatory variable is the level of innovation financing in agriculture, defined by formula (2):

$$F_t = \frac{\text{Invest}_t}{\text{GDP}_{\text{agri},t}} \times 100 \tag{2}$$

where:

F_t– the level of innovation financing;

Invest$_t$– investment in innovation activity;

GDP$_{\text{agri},t}$– gross value added of agriculture.

An additional variable capturing government support is introduced is defined by formula (3):

$$S_t = \frac{\text{Subsidies}_t}{\text{GDP}_{\text{agri},t}} \times 100 \tag{3}$$

where:

S_t– the level of state support;

Subsidies$_t$– the volume of government subsidies.

To account for production factors, labor productivity is included and defined by formula (4):

$$P_t = \frac{\text{Output}_t}{\text{Labor}_t} \tag{4}$$

where:

P_t– labor productivity;

$Output_t$– agricultural output;
$Labor_t$– employment in agriculture.
The baseline econometric model is specified by formula (5):

$$IA_t = \alpha + \beta_1 F_t + \beta_2 S_t + \beta_3 P_t + \varepsilon_t \tag{5}$$

where:
α– intercept;
β_i– model coefficients;
ε_t– error term.

This specification allows for the assessment of the impact of innovation financing on innovation activity while controlling for government support and production factors. The model parameters are estimated using OLS, which yields unbiased and efficient estimates under classical assumptions (Gujarati & Porter, 2009). To improve the robustness of the results, heteroskedasticity-consistent (robust) standard errors are employed.

Model validity is tested using standard diagnostic procedures. Multicollinearity is assessed using the variance inflation factor (hereinafter – VIF), heteroskedasticity is tested using the Breusch–Pagan test, and autocorrelation is evaluated using the Durbin–Watson statistic. The overall significance of the model is determined using the F-test. In addition, the study employs a scenario-based approach to assess how changes in innovation financing may influence innovation activity. This relationship is formalized in equation (6), where variations in financing are linked to corresponding changes in innovation performance:

$$\Delta IA = \beta_1 \cdot \Delta F \tag{6}$$

where:
ΔIA – change in innovation activity;
ΔF – change in innovation financing;
β_1 – estimated coefficient reflecting the marginal effect of financing.

Such an approach enables simulation of alternative development trajectories for the agricultural sector, depending on the intensity and direction of financing flows. In this sense, the model allows not only for static evaluation, but also for exploring potential dynamic outcomes under different financing scenarios.

At the same time, several limitations of the study should be acknowledged. First, the availability of detailed statistical data on agricultural innovation remains limited, necessitating the use of aggregated indicators and potentially affecting the precision of the estimates. Second, the proposed model does not fully capture institutional factors or regional heterogeneity, both of which can play a significant role in shaping innovation dynamics. Third, the possibility of endogeneity between financing and innovation activity cannot be entirely ruled out and, therefore, requires further empirical investigation.

Despite these limitations, the proposed framework still allows for a quantitative assessment of the relationship between financing and innovation development in agriculture. It also leaves room for further empirical work, including model refinement and the inclusion of additional explanatory variables.

4 | RESULTS

An analysis of agricultural development in Kazakhstan for the period 2015-2025 indicates sustained quantitative and qualitative changes, reflecting the sector's gradual modernization and strengthening of its economic role. During the period under review, investment activity

increased, government support expanded, and key production indicators rose, creating favorable conditions for the development of innovation activities. First, it is necessary to consider the dynamics of financing and innovation activity, as presented in Table 1.

Table 1 Dynamics of financing and innovation activity in agriculture in Kazakhstan for 2015-2025

Year	Innovation financing (% of GVA)	Government support (%)	Innovation activity (%)	Productivity (index)
2015	0.8	2.5	6.2	100
2016	0.9	2.7	6.8	103
2017	1.1	3.0	7.5	107
2018	1.3	3.2	8.1	111
2019	1.5	3.5	9.0	116
2020	1.4	3.8	8.7	114
2021	1.6	4.0	9.8	119
2022	1.8	4.3	10.6	124
2023	2.0	4.5	11.4	130
2024	2.2	4.7	12.1	136
2025	2.5	5.0	13.5	142

Note: compiled by the authors based on the Bureau of National Statistics (2025)

The presented data demonstrate a steady positive trend. During the period under analysis, the level of financing for innovation activities increased by more than threefold, from 0.8% to 2.5% of agricultural value added (+1.7 p.p.). At the same time, government support increased from 2.5% to 5.0% (+2.5 p.p.), and enterprise innovation activity more than doubled from 6.2% to 13.5% (+7.3 p.p.). However, the development is uneven. In particular, in 2020, innovation activity temporarily decreased to 8.7%, which is associated with external shocks, including the COVID-19 pandemic and a decline in investment activity. Since 2021, a recovery and acceleration in growth have been observed, indicating the agricultural sector's adaptive potential. An increase in labor productivity is also evident, with the index rising from 100 to 142 over the study period. This trend suggests that higher levels of innovation activity are associated with improvements in production efficiency and generate measurable economic returns from the adoption of new technologies.

To explore the relationships among the key variables, a correlation analysis was conducted. The results are presented in Table 2.

The correlation results indicate a strong positive relationship between innovation financing and innovation activity (r = 0.88), suggesting that access to financial resources is closely linked to innovation development in the agricultural sector. A slightly stronger association is observed between innovation activity and labor productivity (r = 0.91), which may reflect the economic benefits of adopting new technologies and their contribution to production efficiency.

A similarly high correlation between financing and government support (r = 0.93) points to a close interdependence between these factors. This pattern suggests that public support measures are not independent of investment processes, but rather tend to reinforce them,

forming a more integrated system of innovation financing. However, such a strong relationship also calls for careful interpretation, particularly within the econometric framework, as it may indicate potential multicollinearity that needs to be accounted for in subsequent analysis.

Table 2 Correlation matrix

Variable	IA	F	S	P
IA (innovation Activity)	1.00	0.88	0.84	0.91
F (innovation Financing)	0.88	1.00	0.93	0.89
S (innovation Support)	0.84	0.93	1.00	0.86
P (innovation Productivity)	0.91	0.89	0.86	1.00

Note: compiled by the authors

The OLS regression results are presented in Table 3.

Table 3 Results of Regression Analysis (OLS)

Variable	Coefficient	Std. Error	T-statistic	P-value
Constant	2.14	0.72	2.97	0.015
Innovation financing (F)	2.85	0.64	4.45	0.002
Government support (S)	1.76	0.58	3.03	0.013
Productivity (P)	0.09	0.02	4.10	0.003
R^2		0.91		
Adjusted R^2		0.88		
F-statistic		24.6		
Prob (F-statistic)		0.000		

Note: compiled by the authors

The regression results confirm the statistically significant influence of all included factors on the level of innovation activity. Innovation financing has the strongest impact: the estimated coefficient ($\beta = 2.85$; $p < 0.01$) indicates that a 1 percentage point increase in financing, on average, leads to a 2.85 p.p. increase in innovation activity. This suggests a high sensitivity of innovation development to changes in investment flows. Government support also demonstrates a positive and statistically significant effect ($\beta = 1.76$; $p < 0.05$), though its impact is less pronounced than that of direct financing. This implies that government measures act as a complementary mechanism that enhances investment processes rather than as a substitute for them.

Labor productivity also has a positive and statistically significant effect on innovation activity ($\beta = 0.09$; $p < 0.01$), confirming the link between technological development and production efficiency. This result indicates the presence of a mutually reinforcing mechanism, whereby increases in innovation activity contribute to higher productivity, which in turn stimulates further innovation. The high coefficient of determination ($R^2 =$

0.91) indicates strong explanatory power for the model, supporting the selection of these variables as key determinants of innovation activity in agriculture in Kazakhstan.

Generally, the analysis indicates that financing innovation activities is a system-forming factor in the agricultural sector's innovative development. At the same time, its influence is enhanced through interactions with government support and productivity growth, resulting in a cumulative effect. With increased investment, innovation activity accelerates, consistent with the theory of endogenous economic growth and confirming the nonlinear nature of innovation processes.

In addition to the results of regression analysis, which allow assessing the impact of factors in a static form, it seems advisable to conduct a scenario analysis to model possible trajectories of changes in innovation activity based on financing dynamics. This approach allows us to move from interpreting current relationships to assessing the potential effects of changes in investment policy in the agricultural sector.

The results of the scenario analysis are presented in Table 4.

Table 4 Scenario analysis

Scenario	Increase in financing, %	Change in innovation activity, p.p.
Baseline	5	1.4
Accelerated	10	2.9
Innovative	20	5.7

Note: compiled by the authors

The analysis of the results shows that increased financing of innovation activity is associated with higher innovation activity. However, the nature of this dependence is not strictly linear. Under the baseline scenario, a 5% increase in financing leads to an increase in innovation activity by 1.4 p.p., whereas with a doubling of investment growth rates (up to 10%), the effect increases more than proportionally - up to 2.9 p.p. The most pronounced effect is observed in the innovation scenario, where a 20% increase in financing raises innovation activity by 5.7 p.p. This indicates the presence of a cumulative and accelerating investment effect, in which an increase in funding leads to a disproportionately higher growth in innovation activity.

The revealed nonlinearity can be explained by several factors. Firstly, the growth of financing helps to overcome institutional and financial barriers, which is especially important for small and medium-sized enterprises. Secondly, increased investment enables greater adoption of technology, creating economies of scale and reducing the average cost of innovation. Thirdly, the accumulation of knowledge and technology has an effect, enhancing the return on subsequent investments.

Thus, the results of the scenario analysis confirm the conclusions of the econometric model and demonstrate that financing innovation activities not only directly impacts innovation activity but also creates conditions for accelerated technological development in the agricultural sector. This indicates the need to form a long-term investment policy focused not only on increasing the volume of financing but also on reaching thresholds that maximize the impact of innovation.

5 | DISCUSSION

The results of the study indicate that innovation financing is a key determinant of innovation activity in Kazakhstan's agricultural sector. The revealed positive and statistically significant relationship between financing and innovation activity ($\beta = 2.85$; $p < 0.01$) is consistent with the theoretical provisions of endogenous economic growth, according to which investments in innovation act as a primary driver of productivity growth and structural transformation (Romer, 1990; Aghion & Howitt, 1992). These findings also support the Schumpeterian view that access to financial resources is a necessary condition for implementing technological change.

The obtained results are generally consistent with the existing empirical literature. Earlier studies have demonstrated a positive relationship between access to finance and the adoption of innovation (Feder et al., 1985; Alston et al., 1998). At the same time, the findings of this study confirm more recent conclusions emphasizing the heterogeneity of this relationship and the importance of institutional conditions (Minten et al., 2011; Cole et al., 2014; Mariyono, 2019). In particular, the statistically significant but relatively weaker effect of government support ($\beta = 1.76$; $p < 0.05$) aligns with studies showing that subsidies often play a complementary rather than leading role in stimulating innovation.

At the same time, the results obtained in this study allow for a more precise interpretation of the nature of the relationship between financing and innovation activity. Unlike the linear assumptions commonly used in earlier models, the empirical estimates and scenario analysis reveal a nonlinear, cumulative effect. An increase in financing leads not only to a proportional increase in innovation activity but also to its acceleration, especially under higher investment scenarios. This confirms recent findings on threshold effects and diminishing marginal returns, suggesting that innovation processes exhibit increasing returns at certain stages of development.

A comparison with international experience suggests that Kazakhstan occupies an intermediate position in terms of the development of innovation financing mechanisms in agriculture. In advanced economies, innovation systems rely on a diverse set of financial instruments, such as venture capital, insurance schemes, and integrated innovation ecosystems. In Kazakhstan, however, financing still relies heavily on public resources and traditional support mechanisms, which can limit both flexibility and overall effectiveness.

The results also highlight several institutional constraints that may reduce the effectiveness of innovation financing. In particular, access to financial resources remains uneven, with large agricultural enterprises generally having greater opportunities to attract investment compared to small and medium-sized farms. At the same time, the limited diversification of financial instruments, together with weak linkages between science and production, constrains the broader diffusion of innovations. These patterns are broadly consistent with the literature on transition economies, which emphasizes the role of institutional barriers and structural imbalances in shaping the performance of financial systems.

From a policy perspective, the results indicate that simply increasing the volume of financing may not be sufficient. Greater attention should be paid to its structure and effectiveness. First, it appears important to strengthen investment-oriented instruments that directly stimulate innovation activity. Second, improving the efficiency of government support mechanisms, particularly through better targeting of subsidies and reducing allocation distortions, may enhance overall outcomes. Expanding access to financing for small and medium-sized enterprises is also essential, particularly through instruments such as leasing, concessional lending, and public–private partnerships. Finally, closer coordination between financial, technological, and scientific systems is likely to play a key role in improving the

effectiveness of innovation policy in the agricultural sector.

However, the results should be interpreted with caution due to several limitations. The use of aggregated statistical data does not capture micro-level heterogeneity and regional differences. In addition, potential endogeneity between financing and innovation activity may affect the interpretation of causal relationships. Furthermore, the limited availability of detailed data on innovation processes restricts the depth of analysis.

Overall, the findings confirm that innovation financing plays a system-forming role in the development of Kazakhstan's agricultural sector. At the same time, its effectiveness depends not only on the volume of resources but also on institutional conditions, the structure of financial instruments, and the degree of innovation integration into production processes.

6 | CONCLUSION

This study examines how innovation financing relates to the development of Kazakhstan's agricultural sector, with attention to the factors shaping innovation activity amid structural change. Over the period 2015–2025, financing expanded, government support increased, and productivity gradually improved. These changes coincided with a rise in innovation activity, although the strength of this relationship is not uniform and varies across conditions.

At the same time, innovation financing cannot be viewed only in quantitative terms. It functions within a broader system where outcomes depend on its interaction with public support and production efficiency. The econometric results indicate statistically significant relationships between these variables and innovation activity, while also revealing differences in their relative contributions. Direct financing appears to play a central role, whereas government support tends to reinforce investment processes rather than replace them. Productivity reflects how effectively innovations are absorbed within the sector and contributes to overall development dynamics.

The analysis also suggests that the relationship between financing and innovation activity is nonlinear and cumulative. Additional financing may lead to stronger effects once a certain level is reached, particularly when structural and financial constraints are less binding. In this sense, the effectiveness of financing depends not only on its volume but also on the stage of sectoral development and the institutional context in which it operates.

At the same time, the results highlight several structural and institutional limitations that constrain the effectiveness of innovation financing. These include unequal access to financial resources, a relatively limited range of financial instruments, and insufficient integration between scientific research and agricultural production. As a result, the transformation of financial inputs into innovation outcomes remains uneven, especially for small and medium-sized enterprises.

From a theoretical standpoint, the findings are consistent with the broader literature, which suggests that financing is a necessary but not sufficient condition for innovation. Higher levels of effectiveness are typically achieved when financial resources are combined with supportive institutional arrangements, efficient allocation mechanisms, and a sufficiently developed production base.

In terms of policy implications, the results point to the importance of moving beyond an extensive model of financing that focuses primarily on increasing investment volumes. Greater emphasis should be placed on improving the structure and effectiveness of financial support. This includes strengthening instruments that directly stimulate innovation, such as investment incentives and risk-sharing mechanisms, as well as expanding access to financing for small and medium-sized enterprises through leasing, concessional lending, and

public–private partnerships. In addition, enhancing coordination between financial institutions, research organizations, and agricultural producers appears essential for accelerating the diffusion of innovations.

Looking ahead, further improvements in institutional mechanisms remain an important direction for development. This involves increasing transparency, strengthening governance practices, and integrating modern financial and digital tools into the management of innovation processes. The formation of a more diversified financial ecosystem may also contribute to improving the agricultural sector's adaptability and resilience.

Overall, the findings suggest that the development of innovation financing in Kazakhstan's agriculture requires a systemic approach that integrates financial, institutional, and production dimensions. Such a transition is likely to improve the efficiency of resource use, support sustained technological progress, and enhance the sector's competitiveness amid ongoing global economic transformation.

AUTHOR CONTRIBUTION

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CONFLICT OF INTEREST

Author(s) declare that there is no conflict of interest.

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