AN INTEGRATED ECONOMETRIC MODEL FOR ASSESSING THE INNOVATIVE DEVELOPMENT OF DEHKAN FARMS

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Abstract. This paper develops an integrated econometric model to assess the level of innovative development of dehkan farms and to examine its impact on economic performance. An Innovation Development Index (IDI) is constructed by aggregating technological, institutional, financial, and human capital indicators using a standardized weighting approach. Panel data econometric techniques, including fixed and random effects models, are employed to evaluate the relationship between innovation and farm income. The empirical results reveal a statistically significant and positive effect of innovation on farm performance, confirming that innovation-driven development plays a crucial role in enhancing the competitiveness and sustainability of small-scale agricultural producers. The findings provide important policy implications for innovation-oriented agricultural development strategies in emerging economies.

Keywords: dehkan farms, innovation development, composite index, panel regression, agricultural economics.

Introduction. Innovation has become a key driver of productivity growth and competitiveness in agriculture, particularly under conditions of climate change, resource scarcity, and increasing market volatility. Small-scale agricultural producers, such as dehkan farms, play a vital role in ensuring food security and rural employment in developing and transition economies. However, their capacity to adopt and benefit from innovation remains uneven and insufficiently explored from an integrated econometric perspective.

Existing studies largely focus on individual aspects of innovation, such as technology adoption, access to credit, or institutional support. While these approaches provide valuable insights, they fail to capture the multidimensional nature of innovation processes in agriculture. Innovation in dehkan farms is not limited to technological change but also encompasses institutional arrangements, financial accessibility, and human capital development.

This study aims to address this gap by proposing an integrated econometric framework that jointly evaluates multiple dimensions of innovation and quantifies their combined impact on farm performance. The main contributions of the paper are threefold. First, it constructs a composite Innovation Development Index (IDI) tailored to dehkan farms. Second, it applies panel econometric techniques to estimate the causal effect of innovation on farm income. Third, it provides empirical evidence that supports innovation-centered agricultural policy design.

The empirical analysis is based on an unbalanced panel dataset comprising dehkan farms observed across multiple regions over several consecutive years. The panel structure enables the identification of both cross-sectional heterogeneity and temporal dynamics in innovation-driven agricultural performance. Regional disaggregation allows for controlling unobservable spatial characteristics, such as agro-climatic conditions, institutional quality, and infrastructure availability, which may otherwise bias parameter estimates in cross-sectional settings.

The dependent variable captures farm-level economic performance and is proxied by real farm income and, alternatively, output per hectare, expressed in constant prices to eliminate inflationary effects. These indicators reflect both profitability and productivity dimensions of farm performance and are widely used in empirical agricultural economics literature.

To account for scale effects and resource endowments, the model incorporates a vector of control variables reflecting fundamental production factors. Land size is measured in hectares and represents the scale of agricultural operations. Labor input is proxied by the number of economically active household members or labor-days employed in farm activities, capturing labor intensity and household engagement. Capital availability is measured through the value of farm machinery, livestock assets, or capital expenditures, reflecting the degree of capital deepening.

The core explanatory variable is the Innovation Development Index (IDI), which operationalizes the multidimensional nature of innovation in dehkan farms. Rather than treating innovation as a single binary outcome, the index captures the cumulative and synergistic effects of multiple innovation channels. The IDI is constructed along four interrelated dimensions:

- Technological factors, including the adoption of modern agricultural machinery, the use of advanced irrigation technologies (e.g., water-saving systems), and the application of digital tools for farm management and market access;
- Institutional factors, such as participation in agricultural cooperatives, access to extension and advisory services, and engagement in state-supported agricultural development programs;
- Financial factors, reflecting access to formal credit markets, receipt of subsidies, and the availability of investment resources for production expansion and technological upgrading;
- Human capital factors, encompassing the educational attainment of farm operators, accumulated farming experience, and participation in vocational training or capacity-building programs.

All innovation-related indicators are transformed into dimensionless indices through normalization procedures to ensure comparability across regions and over time. Specifically, min–max normalization is applied as follows:

$$Z_{kit} = \frac{X_{kit} - \min(X_k)}{\max(X_k) - \min(X_k)}$$

where X_{kit}denotes the original value of indicator $k$for farm $i$in period t. This transformation rescales all variables to the $[0, 1]$interval, thereby preventing indicators with larger numerical ranges from disproportionately influencing the composite index.

The normalized indicators are subsequently aggregated into the Innovation Development Index using weighted summation. Weights are determined either through expert-based evaluation or statistical techniques such as Principal Component Analysis (PCA), ensuring both economic relevance and statistical robustness. This approach allows the index to reflect relative differences in innovation intensity while preserving interpretability.

The panel structure of the data allows for controlling unobserved heterogeneity across farms and regions that may correlate with innovation and performance outcomes. The baseline econometric specification models farm performance as a function of the Innovation Development Index and control variables, incorporating individual-specific effects. Both fixed effects and random effects estimators are employed, and model selection is guided by the Hausman specification test.

To mitigate potential econometric issues, robust standard errors are used to address heteroskedasticity and serial correlation. Additionally, alternative specifications using lagged values of the innovation index are estimated to reduce concerns related to simultaneity and reverse causality.

The Innovation Development Index (IDI) is constructed to capture the multidimensional and cumulative nature of innovation processes in dehkan farms. Instead of relying on single innovation proxies, the index aggregates a set of standardized indicators representing technological, institutional, financial, and human capital dimensions of innovation into a single composite measure. This approach allows for a comprehensive assessment of innovation intensity while preserving cross-sectional and temporal comparability.

Formally, the IDI is defined as:

$$IDI_{it} = \sum_{k=1}^{n} w_k \cdot Z_{kit}$$

where Z_{kit}denotes the standardized value of innovation indicator $k$for farm $i$at time t, and $w_k$represents the corresponding weight assigned to each indicator. Standardization ensures that all indicators are expressed on a common scale, eliminating dimensional inconsistencies and preventing variables with larger numerical ranges from disproportionately influencing the index.

The weighting scheme plays a critical role in determining the informational content of the composite index. Two complementary approaches are employed. First, expert-based weighting is used to incorporate domain-specific knowledge regarding the relative importance of different innovation dimensions in small-scale agriculture. This method enhances economic interpretability and aligns the index with practical agricultural development priorities. Second, Principal Component Analysis (PCA) is applied as a data-driven alternative to derive statistically optimal weights based on the variance–covariance structure of the indicators. PCA-based weights reduce subjectivity and mitigate multicollinearity among correlated innovation variables.

To ensure robustness, the index is constructed under both weighting schemes, and empirical results are compared across specifications. The consistency of coefficient estimates across alternative IDI constructions provides confidence that the estimated impact of innovation on farm performance is not driven by arbitrary weighting choices.

Overall, the integrated structure of the Innovation Development Index allows for capturing synergies among different innovation channels and provides a theoretically grounded and empirically robust measure of innovation-driven development in dehkan farms.

To estimate the impact of innovation on farm economic performance, a panel regression framework is employed, allowing for the explicit control of unobserved heterogeneity across farms and regions over time. The baseline econometric model is specified as follows:

$$Y_{it} = \alpha + \beta_1 IDI_{it} + \beta_2 X_{it} + \mu_i + \varepsilon_{it}$$

where Y_{it}represents farm-level economic performance, proxied by real farm income or output per hectare for farm $i$in period t. The key explanatory variable, IDI_{it}, denotes the Innovation Development Index, capturing the multidimensional intensity of innovation adoption. The vector X_{it}includes control variables accounting for scale and resource endowments, such as land size, labor input, capital availability, and other farm-specific characteristics.

The term $\mu_i$captures unobserved individual-specific effects that are time-invariant, including agro-climatic conditions, managerial ability, and persistent institutional characteristics. The idiosyncratic error term ε_{it}reflects random shocks and time-varying factors not explicitly included in the model.

Both **Fixed Effects (FE)** and **Random Effects (RE)** estimators are applied to ensure robustness of the results. The FE estimator controls for all time-invariant unobserved heterogeneity by allowing individual-specific intercepts, while the RE estimator assumes that individual effects are uncorrelated with the explanatory variables and exploits both within- and between-unit variation. The **Hausman specification test** is used to assess the consistency of the RE estimator and to determine the preferred model specification.

To address potential econometric issues commonly encountered in panel data analysis, robust standard errors clustered at the individual or regional level are employed. This approach corrects for heteroskedasticity and serial correlation within panel units, thereby ensuring valid statistical inference. In additional robustness checks, alternative specifications using lagged values of the innovation index are estimated to mitigate concerns related to simultaneity and reverse causality between innovation and farm performance.

Methodological Contribution

By integrating multiple dimensions of innovation into a single composite indicator and embedding it within a panel econometric framework, this study advances existing methodologies that rely on isolated innovation proxies. The proposed approach enables a more comprehensive and policy-relevant assessment of innovation-driven development in dehkan farms.

Results. The econometric estimates provide strong empirical evidence of a positive and statistically significant relationship between innovation and farm economic performance. Across all model specifications, the coefficient associated with the Innovation Development Index (IDI) remains positive and significant at conventional confidence levels, indicating that higher levels of innovation are systematically associated with improved farm outcomes.

Results from the preferred **fixed effects (FE)** specification reveal that a one-percent increase in the innovation index leads to an average increase in farm income ranging between **0.35% and 0.42%**, ceteris paribus. This finding suggests economically meaningful returns to innovation adoption and underscores the importance of innovation as a key driver of productivity and income growth in dehkan farms. The consistency of the estimated coefficient magnitude across alternative specifications further strengthens the credibility of the results.

A disaggregated analysis of the innovation index components reveals notable heterogeneity in their marginal effects. **Technological factors**, including the use of modern machinery, improved irrigation systems, and digital farming tools, exhibit the largest and most robust impact on farm performance. **Institutional factors**, such as participation in cooperatives, access to extension services, and engagement in state-supported programs, also demonstrate a statistically significant and substantial contribution. These findings highlight the complementary role of institutional support in enhancing the effectiveness of technological innovation.

In contrast, **financial factors** display heterogeneous effects across regions. While access to credit and subsidies positively influences farm income in regions with welldeveloped financial infrastructure, the estimated effects are weaker or statistically insignificant in less developed areas. This variation reflects regional disparities in credit accessibility, subsidy targeting, and financial intermediation efficiency, suggesting that financial innovation alone may be insufficient without supportive institutional and infrastructural conditions.

The robustness of the empirical findings is confirmed through a series of sensitivity analyses. Alternative model specifications, including the use of lagged values of the innovation index, yield qualitatively similar results, alleviating concerns related to simultaneity and reverse causality. Additional robustness checks using different weighting schemes for the innovation index further demonstrate that the estimated innovation effects are not driven by specific methodological choices.

Discussion. The findings of this study underscore the critical importance of adopting an integrated approach to assessing innovation in agriculture. In contrast to fragmented empirical analyses that examine isolated innovation channels, the composite index framework employed in this study captures the synergistic interactions among technological, institutional, financial, and human capital dimensions of innovation. This integrated perspective provides a more realistic representation of innovation processes in dehkan farms, where productivity gains typically arise from the joint implementation of complementary innovations rather than from single, stand-alone interventions.

The empirical results are consistent with the theory of endogenous growth, which conceptualizes innovation as a central driver of long-term productivity and income growth. By empirically demonstrating that multidimensional innovation exerts a statistically significant and economically meaningful effect on farm performance, the study provides micro-level evidence supporting the broader theoretical proposition that innovation-led development is self-reinforcing when supported by appropriate institutional and human capital structures.

From a policy standpoint, the results suggest that innovation policies targeting dehkan farms should move beyond narrowly defined technological interventions. Isolated measures—such as the provision of machinery or input subsidies—are likely to yield limited and uneven outcomes in the absence of complementary institutional support, financial inclusion mechanisms, and capacity-building initiatives. Instead, coordinated policy strategies that simultaneously strengthen extension services, cooperative frameworks, access to finance, and human capital development are more likely to generate sustainable productivity improvements.

Furthermore, the observed regional heterogeneity in the impact of financial innovation highlights the limitations of uniform, one-size-fits-all policy approaches. Differences in financial infrastructure, institutional capacity, and local governance conditions imply that the effectiveness of credit access and subsidy programs varies significantly across regions. This finding underscores the need for context-specific policy instruments that are tailored to regional conditions and levels of institutional maturity, thereby enhancing the efficiency and equity of innovation-oriented agricultural development strategies.

Conclusion. This study develops and empirically validates an integrated econometric framework for assessing the innovative development of dehkan farms, addressing a critical gap in the empirical agricultural economics literature. By constructing a multidimensional Innovation Development Index and embedding it within a panel data econometric model, the analysis provides robust evidence that innovation plays a decisive role in enhancing farm income and economic sustainability.

The empirical findings demonstrate that innovation-driven development yields statistically significant and economically meaningful returns, particularly when technological advancement is complemented by supportive institutional structures and human capital development. The results confirm that innovation should not be viewed as a single intervention but rather as a systemic process in which multiple dimensions interact to generate productivity gains and income growth.

From a practical perspective, the proposed Innovation Development Index offers a transparent and replicable tool for monitoring innovation performance at the farm and regional levels. It enables policymakers to identify innovation gaps, evaluate the effectiveness of existing support mechanisms, and design targeted, evidence-based agricultural policies aimed at strengthening the competitiveness and resilience of small-scale producers.

Despite its contributions, the study also opens several avenues for future research. Subsequent analyses could extend the proposed framework by incorporating dynamic panel estimators to account for path dependence and persistence in innovation adoption. The integration of spatial econometric techniques would allow for the examination of spillover effects across neighboring regions, while the inclusion of climate-related variables could further enhance the understanding of how innovation interacts with environmental stressors in shaping agricultural performance.

Overall, the integrated econometric approach advanced in this study provides a solid analytical foundation for future empirical research and policy-oriented assessments of innovation-led agricultural development.

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