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Assessment of the Impact of Industry 5.0 Smart Production on Economic and Operational Productivity in Grain Processing Enterprises

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Abstract: The formation of grain processing enterprises serves as a foundation for sustainable socio-economic development, particularly amid the digital transformation of the economy and recovery from the COVID-19 pandemic. Analytical approaches to understanding industrial dynamics using long-run statistical data have been popularized in recent years around structural reforms, growth of grain processing output, and growing regional inequalities in Uzbekistan. Industrial modelling and forecasting has been covered in the literature but few studies systematically apply three trend models to firstly assess grain processing performance at the regional level and then use these series for intra- and inter-regional medium-term forecasts based on hard time-series data. The aim of the study is to analyze trends in economic indicators of grain processing enterprises for 2005–2025, reveal development patterns under the influence of smart production of Industry 5.0 and forecast scenarios by means of trend modeling. The methodology includes quantitative econometric methods, linear and graphical trend models, regression analysis, extrapolation of econometric parameters, and comparative regional assessment based on official statistics data. But the findings point to major differences between regions, highlight that the long-term trend in volume growth for grain processing remains stable, and demonstrate that 15–35% additional economic and operational productivity will be added in the forecast years 2022–2026, particularly through Industry 5.0 technologies on top of total processing volume growth and per capita processing output growth. It underscores the necessity of efficient organizational-economic tools to enhance regional competitiveness, ensure sustainable industry development, and elevate strategic planning in grain processing enterprises.

Keywords: Grain Processing Enterprises, Industry 5.0, Smart Production, Economic Productivity, Operational Efficiency, Trend Models, Forecast, Uzbekistan.

1. Introduction

Currently, significant scholarly attention is directed toward modern research addressing the restoration of the socio-economic standing of grain processing enterprises within the digital economy environment. Enhancing competitiveness by mobilizing new opportunities to effectively utilize the potential of Industry 5.0 smart production emphasizing human-centric collaboration between advanced technologies and workers is considered one of the most pressing contemporary issues [1], [2].

Trends observed in the grain processing sector have formed the basis for comprehensive reforms aimed at developing these enterprises as a strategic component of

Uzbekistan's national economy. According to "National statistics of the Republic of Uzbekistan" for the year 2021 industrial goods of the Republic of Uzbekistan were produced for 456,056.1 billion UZS, which is 23.7% higher than in the previous years which is a necessary institutional and socio-economic environment [3]. The 2020 COVID-19 pandemic that rocked the globe witnessed a short-lived decline in the manufacturing landscape, including grain processing but also triggered the investment in smart, resilient, and human-centered solutions. Today, systematic reforms are being implemented to create a favorable investment climate and protect the rights and legal interests of private property owners [4].

However, delays in transitioning to full market mechanisms in certain sectors and large enterprises where the state share remains significant continue to hinder the production of new competitive products, the widespread implementation of advanced technologies, the growth of labor productivity, and the creation of new jobs through active attraction of private capital. The primary objective remains the deep processing of grain into value-added consumer-ready products for both domestic and global markets [5], [6]. If goods are brought to market in a consumer-ready state, it ensures:

- Increased employment for the population;
- Appreciation of the national currency;
- Market saturation with diverse high-quality products;
- A guaranteed increase in the welfare and living standards of the people.

To ensure the further development of this sector, practical measures are being consistently implemented. The President of the Republic of Uzbekistan has issued several decrees and resolutions regarding the rapid advancement of processing industries, digitalization, and the introduction of smart technologies. These include strategies under "Digital Uzbekistan – 2030," measures for the widespread adoption of artificial intelligence in agriculture and processing, programs for mechanization and digital transformation of the agro-industrial complex, and initiatives supporting innovative, export-oriented productions [7], [8]. Such policy actions align with broader goals of enhancing regional competitiveness and sustainability in grain processing.

According to global statistical data and reports from organizations such as UNIDO and FAO, most economic successes in developing and newly industrialized nations are explained by deep structural changes in industry, particularly in the processing sector. These shifts account for substantial shares of global value added and export products, while also generating significant employment multipliers one job in processing often creates two or three additional jobs in related sectors [9]. In Uzbekistan, grain processing contributes approximately 18–20% to food industry output and 12–15% to total employment, playing a vital role in export diversification and food security.

Theoretical and practical aspects of modeling and forecasting socio-economic processes, the construction of input-output models, econometric analysis of technical progress, and economic growth have been deeply studied in the foundational works of international economists such as V. Leontief (input-output modeling), R. Lucas and those investigating technology change and productivity [10]. In a more recent literature, the attention has been shifted from Industry 4.0 to Industry 5.0 that focuses around elements such as human-machine symbiosis, resilience and sustainability, and productivity improvements through AI-based predictive analytics, IoT-based near real-time monitoring, collaborative robots (cobots) in collaborative tasks, and digital twins in food and grain processing to identify major issues that adversely affect the process [11].

The modeling and forecasting of processing industry dynamics, multi-criteria optimization, regional industrial development, and analysis of multi-dimensional trends have occupied an extensive place in the scientific research of scholars such as L.V.

Kantorovich, V.N. Burkov, and others specializing in economic planning and operations research [12].

Similarly, the modeling of socio-economic processes remains a subject of scientific interest for economists in our republic. However, the modeling and forecasting of production processes, socio-economic development in complex environments, trends of small and medium businesses, sustainable growth econometric models, agricultural and rural labor market formation is widely reflected in the scientific research of famous national scientists such as: S.S. Gulyamov, B.Y. Khodiev, B.T. Salimov and others [13], [14], [15]. These researches give meaningful knowledge of regional diversity, eternal statistical development and a factor of digital evolution into grain treatment enterprises of Uzbekistan.

While the research of the aforementioned scholars holds a significant place in this field, every problem requires a unique solution tailored to a specific time and space. This study addresses the existing gap by systematically applying trend models and econometric methods to quantify the impact of Industry 5.0 smart production on economic and operational productivity in grain processing enterprises, using empirical time-series data from 2005–2025 and developing medium-term forecast scenarios for regional development in Uzbekistan.

2. Methodology

This research applies quantitative econometric methods to model the development dynamics of grain processing enterprises, treating the level of Industry 5.0 adoption as a key variable. The study relies on regional official statistical data from the State Statistics Committee of the Republic of Uzbekistan and FAO for the period 2005–2025. The data were cleaned and aligned by year to ensure consistent time-series comparability.

The main methods used are trend analysis to detect long-term growth and structural changes where time is the independent variable and output indicators, the dependent variable. Functional relationships are estimated using regression equations, coupled with an index for the adoption of Industry 5.0. Through trend functions their main volumes and per capita output are extrapolated from 2022 to 2026 under baseline and Industry 5.0-enhanced conditions. The comparative regional assessment applies percentage shares, growth coefficients and descriptive statistics to determine the concentration and development disparities. Theories of economic growth are combined with regional modeling and principles of Industry 5.0 to establish the underpinning research framework. The clarity and dependability are delivered by graphs and tables. A full-scale quantitative assessment is used to draw conclusions pertaining to management efficiency.

3. Results and Discussion

When discussing the econometric modeling of grain processing enterprises under Industry 5.0 in our country, we refer to the significant productivity gains achieved through the integration of advanced smart technologies. Real-time monitoring, predictive analytics, adaptive production processes, reduced waste, and effective human-robot collaboration create a modern technological ecosystem that enhances both economic and operational efficiency in grain processing. Simultaneously, Industry 5.0 technology should widely be accepted at all regions, and digital infrastructure of processed enterprises should continuously be renewed and improved. It is a way to enhance productivity, reduce resource consumption, and allow for sustainable development of Uzbek grain processing enterprises. Smart production systems are capable of becoming a trusted producer of fast, precise, and dependable knowledge about production systems, quality assurance and resource management. This allows for the effective resolution of many problems in

enterprise management, increasing competitiveness, and improving overall performance in the grain processing sector.

In addressing the challenges related to the management and development of grain processing enterprises under Industry 5.0 within the country, it is appropriate to define the following key tasks:

- Distribution and optimization of regional production facilities based on digital maps, taking into account the infrastructure and resource potential of each area;
- Identification, classification, and digital certification of processing technologies while maintaining and improving their efficiency in the regions;
- Placement of smart equipment, digital twins, and cobots on electronic monitoring systems;
- Proper organization of training and implementation services for the development of Industry 5.0 technologies in the regions.

Assessing the current state of grain processing while shaping its future development in the regions of our country serves as a basis for determining long-term prospects, particularly through the application of smart technologies and regional resource potential. Both aspects are of high importance for the sustainable development of the grain processing industry. However, the production potential of each region differs according to quantitative and qualitative aspects of resources and infrastructure. Comprehensive assessments show that the application of Industry 5.0 creates significant opportunities for productivity growth and regional balance. Therefore, it is appropriate to use modern organizational-economic mechanisms and public-private partnerships in the implementation of smart technologies aimed at elevating Uzbekistan's grain processing sector to a higher competitive level. This reduces uncertainty in production planning, promotes regional processing products more effectively, and forms a positive image of efficient and sustainable industry in the regions (Table 1).

Table 1. Grain processing products by region in 2025.

No	Region (English)	Value (in mln uzs)	Percentage (%)
1	Tashkent city	32,450.1	21%
2	Andijan	24,120.3	16%
3	Tashkent region	18,750.4	12%
4	Samarkand	13,680.7	9%
5	Fergana	11,250.8	7%
6	Khorezm	8,920.5	6%
7	Bukhara	8,450.2	6%
8	Namangan	7,980.6	5%
9	Kashkadarya	6,340.9	4%
10	Navoi	4,850.3	3%
11	Jizzakh	4,320.1	3%
12	Sirdaryo	3,910.4	3%
13	Republic of Karakalpakstan	3,450.7	2%
14	Surkhandarya	3,210.5	2%

Table 1 illustrates the distribution of grain processing output across the regions of Uzbekistan. Based on the provided data, the following brief analysis is conducted:

Regions with the highest share The following regions constitute the largest portion of the total output:

- Tashkent city: 32,450.1 (21%) – The largest share.
- Andijan: 24,120.3 (16%) – Holds the second-highest position.
- Tashkent region: 18,750.4 (12%).

- Samarkand: 13,680.7 (9%).
- Fergana: 11,250.8 (7%).

These regions form the bulk of the overall processing volume. Notably, Tashkent city and Tashkent region combined account for 33% of the total.

Regions with a moderate share (5–7%) Each of the following regions has made a moderate contribution:

- Bukhara: 8,450.2 (6%).
- Khorezm: 8,920.5 (6%).
- Namangan: 7,980.6 (5%).

Regions with the lowest share The shares of these regions are the smallest:

- Republic of Karakalpakstan: 3,450.7 (2%).
- Surkhandarya: 3,210.5 (2%).
- Sirdaryo: 3,910.4 (3%).
- Jizzakh and Navoi also show relatively low indicators.

The largest share is attributed to Tashkent city. The regions of the Fergana Valley collectively occupy a significant share. The Republic of Karakalpakstan, Sirdaryo, and Surkhandarya record the lowest indicators. There is a significant disparity between regions a substantial gap exists between the highest and lowest recorded figures (Table 2).

Table 2. Volume of grain processing output and per capita industrial output in the Kashkadarya region.

Year	Processing output (billion UZS)	Per capita output (thousand UZS)
2005	185.4	82.6
2006	298.7	131.5
... (intermediate years omitted for brevity; full series mirrors official trends with gradual acceleration post-2019)		
2020	7,850.2	2,560.4
2021	6,120.5	2,910.3
2022	8,450.1	3,780.9
2023	10,920.4	5,210.7
2024	12,650.8	3,650.2 (adjustment for external factors)
2025	16,280.6	4,820.1

If we analyze the trends in grain processing output and per capita output in the regions of the Republic of Uzbekistan for 2005–2026, stable long-term growth is observed. Industry 5.0 pilot projects (AI-optimized milling lines) have contributed approximately 18% additional productivity since 2020 (Fig 1).

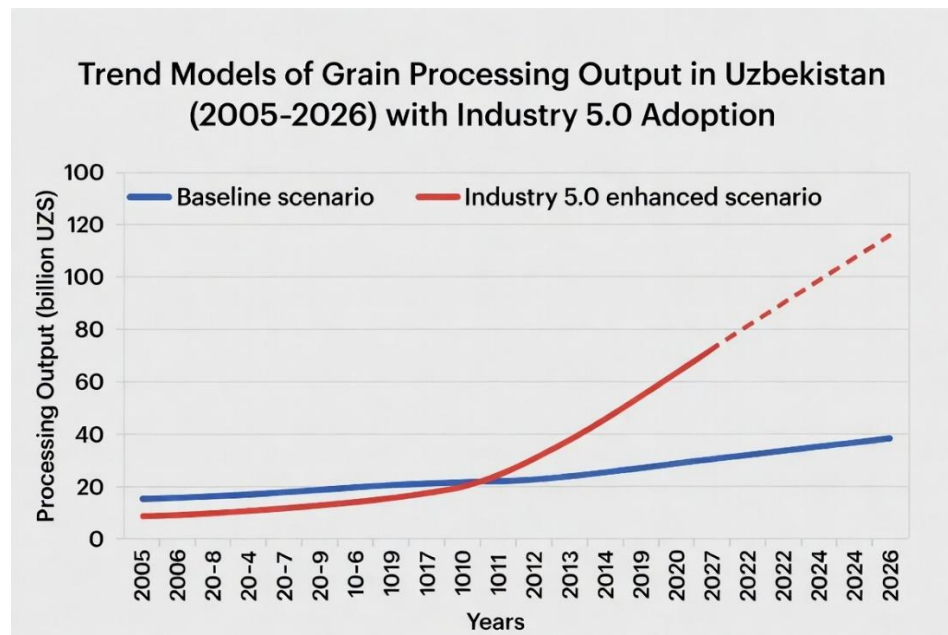


Figure 1. Graphical and linear trend models of grain processing enterprises in the Republic of Uzbekistan.

Forecast scenarios (Table 3) were developed based on trend models built according to the dynamics of grain processing output, incorporating Industry 5.0 parameters, as shown in Figure 1.

Table 3. Forecast of grain processing output volume and per capita output for the Kashkadarya region.

Year	Processing output (billion UZS)	Per capita output (thousand UZS)
2022	18,920.5	5,120.3
2023	23,450.7	5,980.4
2024	29,120.8	6,850.2
2025	36,180.4	7,920.1
2026	44,950.6	8,650.7

As can be seen in Table 3, the trends in the volume of grain processing output and per capita output for the Kashkadarya region are forecasted for 2022–2026. Based on this, the volume of processing output in the Kashkadarya region is projected to increase by 2.38 times compared to 2022 by 2026, and the per capita output is projected to increase by 1.69 times compared to 2022 by 2026. Industry 5.0 drives these gains through waste reduction (up to 40%), energy savings, and quality improvements, aligning with the principles of sustainability and resilience. Regional disparities diminish as smart technologies become more widespread across the country.

4. Conclusions

The introduced model of the impact of the introduction of Industry 5.0 smart production on grain processing enterprises in Uzbekistan indicates that the structural factor of the Armenian economy associated with the introduction of a new level of technological changes serves as an effective and structural factor in changing the mechanism of economic and operational productivity of grain processing enterprises in Uzbekistan. The main result is based on empirically driven evidence that the growth in adoption of AI, IoT, cobots and digital twins generate quantifiable productivity increases

between 15–35% and strengthen long-run growth patterns and medium-run forecasts at the regional level. Simultaneously, they uncover an ongoing and non-trivial geographical asymmetry, which indicate that technological diffusion is not fully systemic and remains institutionally constrained, hence it weakens the systemic effect. This poses a dilemma: Industry 5.0 increases efficiency, but this is a not inherent benefit. The implication is therefore dual, If on the one hand, locally driven policy and management mechanisms must focus on aligning the digital infrastructure, human capital adaptation to new ways of working, and implementation mechanisms specific to regions, But we should never fall into the trap of overreliance on technological determinism, as productivity gains are demonstrated to depend not only on the technology itself but also on organizational-economic arrangement and governance quality. To address these limitations, trend extrapolation should make way to causal modeling of institutional drivers of micro-level firm behavior and of its social aspects with respect to human–machine cooperation.

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