

International integration and agricultural productivity in Kazakhstan: a Fourier ARDL approach

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Abstract

Purpose – This study investigates the effects of Kazakhstan’s membership in international economic organizations such as the Organization of Turkic States (OTS), Eurasian Economic Union (EAEU) and Shanghai Cooperation Organization (SCO) on agricultural total factor productivity (AGTFP) during the period 1992–2022. It aims to understand how institutional integration, trade openness and environmental factors influence agricultural productivity in a transitioning economy.

Design/methodology/approach – The analysis employs the fractional frequency Fourier ARDL (FFF-ARDL) method, which allows for modeling potential unknown nonlinear structural breaks. Annual data on AGTFP, agricultural GDP, foreign trade ratio and agricultural carbon emissions are analyzed. Dummy variables are used to capture Kazakhstan’s membership in each international organization and comparative models are estimated.

Findings – The results reveal that EAEU membership has a positive and significant impact on AGTFP, while OTS membership shows a negative effect and SCO membership has no significant effect. Agricultural carbon emissions positively influence productivity in the long run but have a short-run limiting effect. Foreign trade openness limits long-run productivity, reflecting structural dependencies.

Research limitations/implications – The study is limited to Kazakhstan and focuses on sector-level productivity; cross-country comparisons could provide further insights.

Originality/value – This study offers a novel empirical investigation into the long-term effects of international institutional integration on agricultural productivity using advanced econometric modeling. By isolating the impacts of multiple international organizations, it contributes to the understanding of how trade and institutional dynamics shape agricultural performance in developing economies.

Keywords Agricultural total factor productivity, International integration, Frequency Fourier ARDL, Kazakhstan

Paper type Research article

1. Introduction

Agricultural productivity plays a critical role in economic growth, poverty reduction, and food security, which are among the cornerstones of sustainable development and directly affect the long-term prosperity of countries (Ali and Mujahid, 2025). Particularly in developing economies, the agricultural sector remains essential for employment, food availability, and export earnings (Kumar, 2024). However, the accumulation of traditional factors of production alone is insufficient to sustain productivity growth. In recent decades, international economic cooperation, technology transfer, trade integration, and investment flows have become increasingly decisive in shaping agricultural performance (Fuglie, 2004).

Kazakhstan, as a post-Soviet transition economy, has undertaken extensive economic and institutional reforms to enhance agricultural productivity after gaining independence. During the early transition period, collective farms were privatized, and the ownership structure of agricultural land was radically transformed (Spoor, 1999). Although privatization encouraged individual entrepreneurship in farming, market imperfections—especially in land and credit



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access—limited efficiency gains. The recognition of private property rights in 2003 and the liberalization of land exchange rules further stimulated sectoral modernization (Kvartiuk and Petrick, 2021). Subsequent investment inflows, technology transfer, and institutional restructuring strengthened market mechanisms and facilitated Kazakhstan's gradual integration into global agricultural systems (Kurmanova *et al.*, 2021).

International economic organizations have also played an influential role in reshaping Kazakhstan's agricultural development by promoting production efficiency, trade liberalization, and food security. Membership in the Organization of Turkic States (OTS), the Eurasian Economic Union (EAEU), and the Shanghai Cooperation Organization (SCO) has provided institutional platforms for trade coordination, investment cooperation, and regional policy alignment (Schubert, 2017a, b; Gussarova *et al.*, 2017). These frameworks contributed to improving connectivity, logistics, and cross-border integration—particularly through the EAEU's customs union and SCO's infrastructure-oriented initiatives (Zalessky, 2024; Schubert, 2017a, b). Such integration efforts have expanded Kazakhstan's trade with neighboring countries, including Russia and China, and facilitated the inflow of investment capital (Gussarova *et al.*, 2017; Amonboev, 2023).

Each organization contributes to regional agricultural development through distinct mechanisms. The OTS promotes cooperation in areas such as sustainable water management, organic farming, and smart agricultural systems, while seeking to enhance productivity and food trade among member countries via shared investment platforms (Musabay Baki, 2022). The EAEU, through common production policies and the reduction of trade barriers, promotes regional food security and sustainable agricultural modernization among major producers such as Russia, Kazakhstan, and Belarus (Aslanli, 2023; Lines *et al.*, 2017). The SCO, on the other hand, focuses on facilitating trade in high-quality agricultural goods, developing logistics infrastructure, and supporting digital agriculture and e-commerce to improve agricultural competitiveness (Zhang *et al.*, 2022). Collectively, these organizations seek to strengthen agricultural trade, ensure food supply stability, and promote sectoral modernization through regional collaboration.

Despite the growing importance of such regional frameworks, there remains a limited number of empirical studies explicitly examining agricultural total factor productivity (TFP) in Kazakhstan and similar transition economies within the OTS, EAEU, and SCO contexts. TFP serves as a comprehensive indicator of production efficiency, capturing the joint influence of technological progress, input utilization, and institutional quality on agricultural output (Färe *et al.*, 1994). Understanding its determinants within evolving institutional structures is thus crucial for formulating effective policy strategies.

This study aims to analyze the long-term impact of Kazakhstan's membership in the OTS, EAEU, and SCO on agricultural TFP over the period 1992–2022. Unlike previous works that have mainly examined output, input quantities, or trade flows, this study focuses on productivity dynamics to reveal how institutional integration shapes long-run sectoral efficiency. The research adopts the Fractional Frequency Fourier ARDL (FFF-ARDL) approach, which flexibly models gradual and nonlinear structural shifts without the need to specify break dates, allowing for a more realistic representation of transitional economies. While the Fourier ARDL framework offers methodological innovation, the analysis is context-specific and does not claim universal generalizability. Instead, it provides new evidence on how international organizational membership interacts with trade openness and institutional alignment to influence agricultural productivity in a developing, reform-driven economy such as Kazakhstan.

2. Theoretical framework

Agricultural productivity is a multidimensional process shaped by the interaction of economic growth, international trade, and institutional structures. Within this process, regional economic integration develops mechanisms to enhance agricultural production, reduce trade barriers,

and promote technological progress. Regional economic organizations can therefore increase agricultural productivity by coordinating trade policies, investment strategies, and institutional reforms among member countries.

According to the new growth theory, the diffusion of knowledge and technology leads to sustainable economic growth and long-term productivity gains (Romer, 1986). Regional integration can accelerate this process by stimulating knowledge spillovers, facilitating technology adoption, and mobilizing capital investments. Modern inputs, technological progress, and capital accumulation in agriculture play a decisive role in determining total factor productivity (TFP). Accordingly, the EAEU shapes its agricultural policies to strengthen coordination among member countries and aims to support food security through joint projects (Aslanlı, 2023).

SCO policies also emphasize trade facilitation and institutional mechanisms to support agricultural exchange among member countries, thereby expanding agricultural markets and strengthening integration into regional food systems (Zhang *et al.*, 2022). Similarly, policies implemented by the OTS focus on reducing trade barriers, promoting agricultural competitiveness, and enhancing technology transfer (Bedelbayeva *et al.*, 2021). These initiatives facilitate agricultural modernization and the diffusion of innovation across member states. Moreover, the SCO develops policies to increase production efficiency and optimize energy use, aligning agricultural practices with regional energy strategies to enhance productivity through sustainable resource utilization (Zhang *et al.*, 2022).

In the process of regional economic integration, human capital constitutes a key channel of productivity improvement. Schultz (1961) emphasized that human capital investment is a fundamental driver of economic growth, as knowledge spillovers accelerate technology adoption and enhance production efficiency. In economies with higher education levels, the uptake of modern agricultural technologies occurs faster, fostering the transition from labor-intensive to capital- and knowledge-intensive production. Regional organizations that promote agricultural trade and policy harmonization can, in this sense, function as platforms for human capital development and the dissemination of best practices (Zhang *et al.*, 2022).

From a broader institutional perspective, recent political economic theories highlight that productivity and technological transformation are deeply embedded in institutions governing economic exchange. Acemoglu and Robinson (2016, 2019) argue that inclusive economic and political institutions, which secure property rights, ensure rule-based governance, and encourage innovation, create the foundation for sustainable productivity growth. Conversely, extractive institutions, designed to preserve elite rents and concentrate power, hinder technological diffusion and limit efficiency improvements. Their theory underscores that the persistence of underdevelopment stems from “vicious circles” of extractive political and economic institutions, while inclusive systems create “virtuous circles” that reinforce growth through innovation and participation. In the context of Kazakhstan and similar transition economies, integration into regional organizations such as the EAEU and OTS can be interpreted as a gradual movement toward more inclusive institutional arrangements, expanding access to markets, investment, and technology. However, if institutional reforms remain partial or captured by rent-seeking structures, as Acemoglu and Robinson (2016, 2019) caution, the benefits of integration may be unevenly distributed, constraining total factor productivity gains.

In this context, the determinants of Kazakhstan’s agricultural TFP and the effects of international economic organization membership can be analyzed through three main theoretical frameworks: growth theories, international trade theories, and agricultural transformation models. From a growth economics perspective, the Solow-Swan model posits that TFP reflects capital accumulation, labor dynamics, and technological progress (Solow, 1956). The subsequent contributions of Barro and Sala-i-Martin (1995) emphasize the complementary roles of human capital, energy intensity, and trade openness in determining productivity growth.

The impact of regional economic cooperation on agricultural productivity can also be evaluated through Balassa’s (1961) theory of economic integration, which argues that

integration fosters growth by facilitating trade flows and investment among member countries. Meanwhile, [Hayami and Ruttan's \(1971\)](#) theory of agricultural transformation explains how modernization, technological change, and institutional reform drive productivity improvements through physical and organizational innovations. From the institutional economics perspective, [North \(1990\)](#) underlines that institutional change—particularly through formalized economic cooperation—reduces uncertainty, strengthens property rights, and promotes sustainable growth. Within this framework, Kazakhstan's engagement in organizations like the EAEU and SCO can be understood as institutional mechanisms that enhance market coordination and investor confidence ([Bedelbayeva et al., 2021](#)).

Overall, the theoretical framework suggests that agricultural productivity emerges from the joint evolution of economic growth, regional integration, and institutional inclusiveness. Regional organizations (EAEU, SCO, OTS) can enhance agricultural efficiency through trade integration, technology transfer, and investment flows, while human capital accumulation and inclusive institutions, as emphasized by Acemoglu and Robinson, sustain these gains by aligning political incentives with productivity-oriented development.

3. Literature review

3.1 Total Factor Productivity (TFP) methodology and global context

Research on agricultural productivity has extensively focused on measuring Total Factor Productivity (TFP) and assessing global patterns of technological and structural transformation. Early cross-country studies revealed considerable disparities in TFP growth, particularly between developed and developing countries. [Coelli and Rao \(2005\)](#) employed Malmquist index analyses to show that while developed countries exhibited steady gains in agricultural productivity during the 1980s and 1990s, many developing countries experienced stagnation or regress. Similarly, [Fulginiti and Perrin \(1997\)](#) documented TFP declines in 14 of 18 low-income countries between 1961 and 1985, highlighting persistent inefficiencies and the need for systemic reform. Building on these findings, [Fuglie \(2012\)](#) reported a global transition from input-led to productivity-led growth, noting that many emerging economies improved performance through institutional reforms, technology diffusion, and improved governance frameworks.

Seminal theoretical works such as [Hayami and Ruttan \(1971\)](#) emphasized that technological and institutional innovation underpin agricultural transformation. [Alston et al. \(1998\)](#) and [Evenson et al. \(1997\)](#) advanced the methodological refinement of TFP estimation by incorporating both technical change and efficiency effects. [Fuglie \(2012\)](#) expanded this framework by introducing “technology capital,” referring to investments in R&D, extension services, and human capital as drivers of sustainable productivity growth. In transitional and resource-based economies like Kazakhstan, modernization trajectories are path-dependent and heavily shaped by institutional readiness. In the Turkish context, [Atiyas and Bakış \(2013\)](#) identified labor mobility and inter-sectoral structural change as pivotal forces behind TFP improvement during the 2000s, linking productivity dynamics to macroeconomic restructuring and policy stability.

Country-specific studies further confirm that reforms in infrastructure, property rights, and innovation systems are key determinants of agricultural productivity. [Evenson et al. \(1997\)](#) and [Fan et al. \(2000\)](#) demonstrated that public investment in agricultural research and rural infrastructure raised productivity and reduced poverty in Indonesia and India, respectively. Similarly, [Fan and Zhang \(2002\)](#) highlighted how institutional reforms in China's rural sector accelerated TFP growth through improved incentive mechanisms. Yet, [Sheng et al. \(2020\)](#) found that although China's agricultural output grew rapidly between 1978 and 2016, TFP expansion decelerated after 2009 due to non-technological constraints such as land fragmentation and policy rigidities. More recently, [Seitov \(2023\)](#) provided evidence from Russia that cost management, institutional adaptation, and managerial efficiency are critical for regional productivity performance. Collectively, these studies reveal a gradual evolution of

the TFP literature—from purely quantitative measurement toward an institutional and policy-oriented understanding of productivity change.

3.2 *Environmental sustainability and productivity*

An emerging strand in the literature highlights the intricate trade-offs between productivity growth and environmental sustainability. Historically, productivity gains have often come at significant ecological cost, including soil degradation, biodiversity loss, and greenhouse gas emissions (Tilman *et al.*, 2011). This tension has led to the rise of the “sustainable intensification” paradigm, which seeks to reconcile higher yields with lower environmental footprints. Such a framework is particularly relevant for transition economies like Kazakhstan, where semi-arid conditions and outdated farming methods create ecological vulnerability.

Melfou *et al.* (2007) underscored that traditional TFP indicators fail to capture externalities and advocated broader frameworks such as “total resource productivity” and “social TFP.” Fuglie (2004) found that the stagnation of Indonesia’s agricultural TFP during the 1990s was partly due to the absence of environmentally conscious policy measures. Coelli and Rao (2005) and the OECD (2021) subsequently introduced the “green TFP” concept, incorporating environmental externalities into productivity analysis. These approaches are crucial for understanding long-run sustainability in Central Asia, where land salinization, irrigation inefficiency, and overexploitation of natural resources are persistent challenges. Furthermore, climate-induced volatility has expanded the scope of the literature to include resilience-enhancing innovations—such as conservation tillage, drought-tolerant crop varieties, and smart irrigation technologies—that link environmental stewardship to productivity gains. Overall, integrating environmental performance into productivity frameworks not only enriches methodological rigor but also enhances the policy relevance of agricultural efficiency studies.

3.3 *Agricultural trade and regional integration*

Trade liberalization and regional integration have been extensively examined as channels of productivity enhancement. Theoretically, openness to trade fosters efficiency by reallocating resources toward sectors with comparative advantage, stimulating competition, and encouraging technology transfer (Martin and Mitra, 2001; Mundlak and Larson, 1992). Anderson and Martin (2006) empirically confirmed that multilateral trade reforms significantly boosted global agricultural productivity, particularly in developing economies. Building on this, Anderson *et al.* (2013) provided a detailed analysis of how agricultural trade distortions and protectionist policies impede productivity growth, showing that countries reducing tariff and subsidy asymmetries experienced stronger long-term productivity convergence. His findings emphasize that removing trade distortions not only improves allocative efficiency but also enhances dynamic gains through technology diffusion and market expansion—insights directly relevant for economies transitioning from planned to market-based agricultural systems.

In developing and middle-income contexts, Valdés and Foster (2010) demonstrated that agricultural growth has disproportionately pro-poor effects, magnifying welfare outcomes beyond its GDP contribution. However, they and other scholars warn that liberalization without institutional support can exacerbate inequality and volatility. In post-Soviet economies, Lerman and Sedik (2009) showed that land privatization and international trade integration reversed Kazakhstan’s production decline but noted that long-term success depends on institutional quality and access to inputs. These findings align with Anderson *et al.* (2013), who argued that integration benefits are maximized when accompanied by credible domestic reforms that align with global standards.

Kazakhstan’s membership in the EAEU, SCO, and OTS presents a distinctive empirical case of multi-layered regional integration. While these organizations provide opportunities for market access, infrastructural cooperation, and technology spillovers, their productivity

impacts hinge on institutional effectiveness and trade facilitation depth. As emphasized by Anderson and Martin (2006), gains from integration are more pronounced when harmonization extends beyond tariff reduction to include standards, logistics, and investment coordination. In Kazakhstan’s case, this requires bridging domestic structural constraints—such as limited credit availability, logistics bottlenecks, and uneven adoption of agricultural technologies—to translate trade openness into tangible productivity gains. Consequently, this study’s focus contributes to bridging the empirical gap by evaluating how institutionalized integration within the EAEU, SCO, and OTS frameworks interacts with Kazakhstan’s agricultural productivity dynamics.

4. Data

The data used in this study include annual observations for Kazakhstan for the period 1992–2022. The variables selected to analyze the determinants of agricultural productivity are obtained from reliable and internationally recognized data sources. Agricultural TFP data that reflects the technological dimension of agricultural growth is obtained from the “International Agricultural Productivity” dataset provided by the United States Department of Agriculture (USDA) Economic Research Service. This variable expresses the increase in agricultural output relative to total inputs used and measures the evolution of technical changes in production and resource utilization efficiency over time. The agricultural gross domestic product (agricultural GDP) variable represents the percentage change in total GDP obtained from the World Bank’s World Development Indicators database. This variable reflects the relative size of the agricultural sector in the national economy and its dynamic structure over time. The agricultural carbon emissions variable, which the World Bank provides, shows the carbon dioxide equivalent greenhouse gas emissions from the agricultural sector and is important for assessing the environmental dimension of the production structure in the sector. Another variable included in the study, the share of foreign trade volume in gross domestic product, which is taken from the World Bank database, reflects the openness of Kazakhstan’s economy to foreign trade and the intensity of international trade activities and shows the extent to which the country is integrated into the global economic system.

The independent variables are important for analyzing the economic and environmental pressures on Kazakhstan’s agricultural sector and structural transformation dynamics. Agricultural GDP reflects the macroeconomic weight of the sector, while carbon emissions indirectly represent the level of mechanization in production and environmental costs. On the other hand, the foreign trade ratio plays a critical role in measuring access to information, technology and inputs through import and export channels and the effects of global market pressures on the agricultural sector. The model also analyzes the effects of organizational integration on agricultural productivity by using dummy variables representing Kazakhstan’s membership dates in international economic organizations. Accordingly, dummy variables representing the relevant years were included in the model to assess the potential structural effects of the membership of the OTS, EAEU, and SCO on agricultural productivity.

Table 1, which presents descriptive statistics, reveals the general distributional characteristics of the four main variables used in the study. These variables are defined as

Table 1. Descriptive statistics

	AGTFP	AGDP	TRADE	AGCAR
Mean	83.812	7.7035	79.289	0.147
Max	131.592	23.342	149.337	0.426
Min	55.500	4.288	53.049	0.039
Std. Dev.	21.947	4.375	19.380	0.089
Obs.	31	31	31	31

agricultural total factor productivity (AGTFP), agricultural gross domestic product as a share of total GDP (AGDP), foreign trade as a share of GDP (TRADE), and agricultural carbon emissions (AGCAR). The table reveals that the variables show a remarkable variability during the analysis period. AGTFP has experienced both upturns and downturns over time, indicating that the production structure and the level of technology utilization in the sector have fluctuated over the years. The share of agriculture in total GDP has also not been stable over this period, indicating that the relative weight of the agricultural sector in Kazakhstan's economy has changed over time. The ratio of foreign trade to GDP shows significant fluctuations in the country's level of integration into the global economic system. The observed differences in agricultural carbon emissions reflect structural transformations in production techniques, level of mechanization, and input use. The wide range of values and standard deviations observed among the variables indicate that Kazakhstan's agricultural economy has been shaped by various endogenous and exogenous dynamics over time, making it meaningful to analyze the relationship between these dynamics and international cooperation organizations with the Fourier ARDL model.

The Figure 1 below illustrates the evolution of Kazakhstan's agricultural total factor productivity over the period 1992–2022. The trend reveals a series of structural shifts, with visible fluctuations during the early transition years followed by a sustained upward trajectory in the post-2000 period. These non-linear and gradual changes in productivity dynamics underscore the appropriateness of the Fractional Frequency Fourier ARDL (FFF-ARDL) methodology, which enables the modeling of smooth and unknown structural breaks without the need for predefined break dates. The observed pattern justifies the use of Fourier terms to account for persistent regime shifts associated with institutional transformations and international economic integration.

5. Methodology

In this study, the Fractional Frequency Fourier ARDL (FFF-ARDL) method was applied to analyze the long-term effects of Kazakhstan's membership in international economic

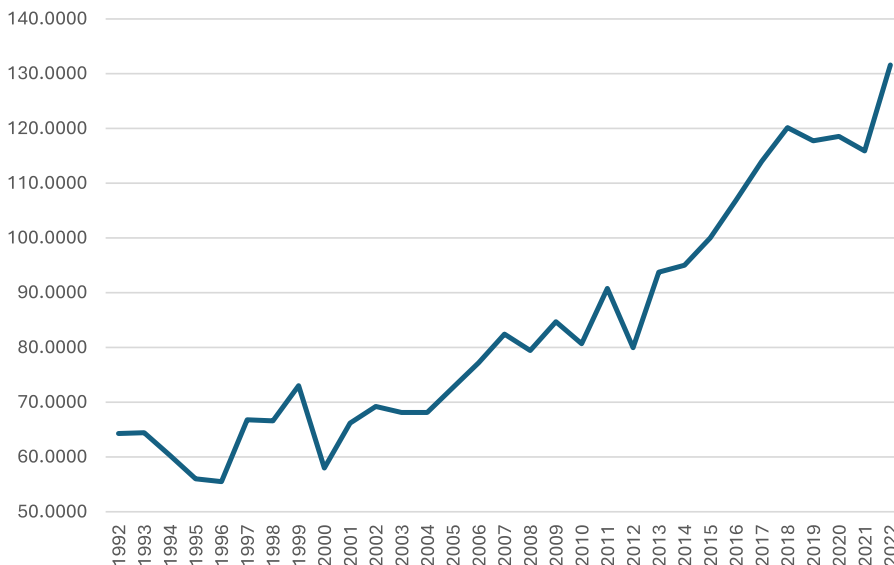


Figure 1. Agricultural total factor productivity in Kazakhstan (1992–2022)

organizations (Eurasian Economic Union, Organization of Turkic States, and Shanghai Cooperation Organization) on agricultural total factor productivity. The ARDL cointegration test approach (Pesaran *et al.*, 2001) was chosen because it offers the flexibility to use series with different levels of integration; indeed, this model can accommodate mixed integration orders without requiring variables to be I(0) or I(1) (McNown *et al.*, 2018). The cointegration analysis using the ARDL model tests whether there is a long-term relationship between the series through the joint significance of the lagged level terms. The bounds test proposed by Pesaran *et al.* (2001) is based on comparing the F-statistic obtained from the estimated model with pre-tabulated critical values (Telatar and Adimli, 2024). When the calculated F-statistic exceeds the upper critical value, a cointegration (long-term) relationship between the series is accepted; when the statistic falls below the lower critical value, the absence of cointegration is concluded. If the F-statistic falls between the two critical values, the test result is reported as indecisive.

In this study, three different unit root tests are applied to determine the stationarity properties of time series. In this context, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, which are among the traditional approaches, as well as the Zivot-Andrews unit root test, which considers structural breaks, are used. The ADF test controls for autocorrelation through lagged differences, while the PP test applies nonparametric corrections for autocorrelation and heteroskedasticity. Combining both tests provides more reliable results, especially in small samples. However, since the ADF and PP tests do not model potential structural breaks, the Zivot-Andrews test is preferred to overcome this limitation. The test allows for a more realistic test of whether the series is stationary by endogenously identifying a single possible structural break point in the series (Becker *et al.*, 2006).

After determining the stationarity of the series, the FFF-ARDL method was applied to test the relationships between the variables. While maintaining the flexibility of the traditional ARDL approach, the Fourier ARDL model provides a more comprehensive framework as it can model an unknown number of smooth structural breaks that may exist in time series through sine and cosine components (Bozoklu and Yilanci, 2020). Fourier ARDL models provide significant advantages over traditional cointegration tests in that they do not require *a priori* knowledge of the dates of structural breaks and can explain nonlinear trends (Fangjhy *et al.*, 2022).

The general structure of the model is expressed as follows:

$$y_t = \alpha_0 + \sum_{i=1}^p \alpha_i y_{t-i} + \sum_{j=0}^q \beta_j x_{t-j} + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t$$

In this equation, y_t is the dependent variable, x_t is the independent variable, γ_1 and γ_2 are the coefficients of Fourier terms, k is the frequency, T is the number of observations, and ε_t is error term. Thanks to the Fourier transform, structural breaks can be integrated into the model in a fluctuating and continuous manner without being fixed to specific date intervals.

The specific Fourier ARDL model used in this study is constructed as follows:

$$AGTFP_t = \alpha_0 + \sum_{i=1}^p \alpha_i AGTFP_{t-i} + \sum_{j=0}^{q_1} \beta_j AGDP_{t-j} + \sum_{j=0}^{q_2} \phi_j TRADE_{t-j} + \sum_{j=0}^{q_3} \theta_j AGCAR_{t-j} + \delta_1 D1_t + \delta_2 D2_t + \delta_3 D3_t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t$$

where $D1$, $D2$, and $D3$ are dummy variables representing Kazakhstan's membership in SCO, OTS, and EAEU, respectively.

In this study, to decompose the potential effects of Kazakhstan's membership processes in three different international economic organizations on AGTFP, the dummy variables included in the model are considered separately. The variable D1 represents membership in the SCO (2001), D2 represents the OTS process (2009), and D3 represents membership in the EAEU (2015). When used together with Fourier terms, both known structural breaks (with dummy variables) and unknown, persistent trend changes (with Fourier terms) are simultaneously integrated into the model.

In the analysis, each dummy variable is included independently in the model, and thus, three separate Fourier ARDL models are estimated. This approach allows for a comparative analysis of the effects of different international cooperations on the agricultural sector and provides a more reliable assessment of the effects of changing institutional structure on agricultural productivity over time. This approach also provides a more holistic and disaggregated analysis framework to identify the structural character of policy effects specific to particular periods.

Several diagnostic tests are necessary to assess the validity and reliability of the model estimates. Although the serial correlation test (Breusch-Godfrey) detects any interdependence among the error terms, the test for changing variance (Breusch-Pagan-Godfrey) checks whether the error terms in the estimated model are constant in variance. The Jarque-Bera test provides an important assessment of the validity of parametric tests by measuring the conformity of error terms to normal distribution. The Ramsey RESET test checks for the accuracy of the model's functional form; it produces significant results, especially in the presence of omitted variables or misspecified relationships. All these tests allow us to determine whether the estimation results are statistically trustworthy by determining whether the econometric model infringes on its basic assumptions. Contrary results indicate autocorrelation, heteroskedasticity, non-normality, or model structural deficiencies, leading to biased or inconsistent forecasts.

Apart from that, CUSUM (Cumulative Sum of Recursive Residuals) and CUSUM of Squares tests are employed to test the structural stability of the model over time. These tests, initially designed by [Brown et al. \(1975\)](#), test whether the regression coefficients change over time and the overall structural stability of the model. While the CUSUM test evaluates the dynamic aspects of the model behavior over time, the CUSUM of Squares test is designed to check for abrupt changes in the variance structure of the model. In both tests, the computed statistical values must not exceed the 5% significance level. If these limits are breached, then it is concluded that the model suffers from structural breaks in certain periods or that the estimated coefficients become unstable in the long run. Such a result would invalidate the model and potentially weaken the credibility of policy conclusions. Therefore, diagnostic and structural stability tests are crucial tools in the overall evaluation of econometric research.

Within the above framework, the basic hypothesis tested in our study can be expressed as follows:

- H0.* There is no long-term relationship, i.e. cointegration, between the variables (Kazakhstan's membership in the relevant organizations and agricultural TFP do not move together in the long term).
- H1.* There is a long-term cointegration relationship between the variables (there is a stable long-term equilibrium relationship between the membership variables and agricultural TFP).

An important feature of the Fractional Frequency Fourier ARDL (FFF-ARDL) approach is its ability to flexibly capture structural breaks in time series without the need for exogenously defined dummy variables. By incorporating trigonometric terms derived from Fourier transforms, the model allows for the representation of both gradual and cyclical structural shifts rather than discrete one-time breaks. This flexibility is particularly valuable when the timing, frequency, or number of breaks is unknown or when structural change occurs

continuously over time. In other words, the Fourier approach models regime transitions as smooth trend variations, enhancing the robustness of long-run estimations without requiring the prior identification of specific break dates (Tsong *et al.*, 2016). The Fourier-ARDL framework developed by Solarin (2019) and further refined by Pata and Aydin (2020) has proven to be an effective cointegration method in cases characterized by multiple or uncertain breaks (Pata *et al.*, 2023). Consistently, Yilanci *et al.* (2020) demonstrated that the inclusion of Fourier terms within the ARDL setting improves the model’s sensitivity to structural shifts, allowing for the detection of long-term relationships even under complex data-generating processes. Likewise, Syed *et al.* (2023) confirmed the methodological validity of the Fourier-enriched ARDL model by successfully identifying stable long-run linkages between climate policy uncertainty and clean energy consumption despite the presence of multiple structural breaks.

In the present study, this feature is particularly relevant because Kazakhstan’s agricultural sector has undergone gradual institutional and trade-related transformations through its membership in multiple regional organizations. Using Fourier terms allows the analysis to accommodate these overlapping integration processes without imposing abrupt dummy-based regime changes. Moreover, the inclusion of lagged variables for all explanatory factors functions as a robustness check against potential endogeneity concerns, ensuring that causality runs from integration dynamics and structural factors toward productivity rather than the reverse. While the FFF-ARDL method provides a powerful tool for identifying stable long-run equilibria under such transitional conditions, it is important to note that its results remain context-specific. The model captures smooth institutional and policy-driven shifts in Kazakhstan’s agricultural system but does not assume immediate or uniform productivity responses across all integration phases—a limitation that reflects the gradual nature of institutional adaptation in transition economies.

6. Empirical results

The results of the unit root tests shown in Table 2 provide important findings regarding the stationarity of the variables used in the study. The combined use of different tests has enabled a more reliable assessment of the behavior of the series over time with both conventional and structural break analyses.

According to the ADF, Phillips-Perron, and Zivot-Andrews unit root tests, AGTFP and AGCAR are non-stationary at level but become stationary after first differencing, indicating that both variables are integrated of order one. The Zivot-Andrews test further confirms these findings by identifying the presence of structural breaks in both series, suggesting that they have been subject to abrupt or nonlinear changes over time. In contrast, AGDP and TRADE are found to be stationary at level, based on both conventional tests and the Zivot-Andrews procedure, implying a relatively stable trend in these variables. Overall, the mixed order of integration among the series does not pose a limitation for the Fourier ARDL method; on the contrary, it highlights the suitability of this approach in capturing both short- and long-term dynamics under structural change.

Table 2. Unit root tests

	ADF I(0)	I(1)	Philips-Perron I(0)	I(1)	Zivot-Andrews I(0)	I(1)
AGTFP	-2.182	-8.446***	-2.557	-22.470***	-3.688	-13.824***
AGDP	-4.145**	-5.169***	-6.527***	-11.327***	-6.126***	-8.833***
TRADE	-4.929***	-8.722***	-3.836***	-9.787***	-8.417***	-11.384***
AGCAR	-3.015	-8.328***	-3.015	-17.942***	-4.438*	-14.297***

Note(s): ***, **, and * show the significance at the 1%, 5%, and 10% levels, respectively

The F-statistics presented in Table 3, when evaluated against the critical values suggested by Pesaran *et al.* (2001), indicate the rejection of the null hypothesis of no long-run relationship among the variables. Accordingly, all three models confirm the existence of a statistically significant and stable cointegration relationship. This finding validates the suitability of the FFF-ARDL model and confirms the long-term relevance of the structural relationships analyzed in the study.

In this study, the determinants of Kazakhstan's AGTFP are analyzed through the FFF-ARDL, and the results are compiled in Table 4. In this context, three different models were estimated and analyzed with only one international economic integration variable in each model. Thus, the effects of these organizational collaborations were evaluated separately from each other. Model 1 considers the membership of the SCO in 2001, Model 2 considers the OTS in 2009, and Model 3 considers the membership of the EAEU in 2015.

The error correction coefficient is negatively signed in all three models, statistically significant at the 1% level, and above 1 in absolute value. This indicates that the model has long-run relationships and that when the system experiences imbalances, it quickly compensates for these imbalances in the following period. This strong and significant error correction term confirms that the Fourier ARDL model produces valid and consistent results.

Regarding the long-run coefficients, only the AGCAR variable was found to be positive and significant in Model 1. TRADE is estimated significantly negative while AGDP is insignificant in this model. In Model 2, both AGDP and TRADE variables have significant and negative coefficients. The AGCAR variable is also positive and statistically significant. In Model 3, while the AGCAR variable remains significant, the TRADE variable is negative and significant, and the AGDP variable is borderline significant. This suggests that long-run relationships can be sensitive to international integration and that the AGCAR variable, in particular, stands out as a strong determinant in the long run in all models.

When the short-run coefficients are analyzed, TRADE is found to be negative and statistically significant only in Model 1 and Model 2. This finding suggests that trade openness may have a limiting effect on agricultural productivity in the short run; however, this effect is not consistent in all models, suggesting that this relationship is sensitive to model structure or periodic fluctuations. The level effect and lagged differences of AGCAR variable are found to be negative and significant in all models. These results suggest that agricultural carbon emissions produce a fluctuating and suppressive effect on agricultural productivity in the short run. Although the short-run coefficients of variable AGDP are positive, they are not statistically significant in any of the three models. This suggests that the short-term growth contribution of the agricultural sector does not have a direct and measurable effect on AGTFP, and therefore this variable does not play a determining role in short-term dynamics.

The dummy variables included in the models separately produce significant findings on the effect of Kazakhstan's membership in international economic organizations on AGTFP. In Model 2, the OTS membership variable's coefficient is negative and statistically significant. This indicates that this cooperation can harm agricultural productivity due to the process of constraining or harmonization. On the other hand, the EAEU membership variable in Model 3

Table 3. Bound test results

<i>k</i>	<i>F</i> -statistics			Significance level	Critical values	
	Model 1	Model 2	Model 3		Lower bound	Upper bound
3	12.636	10.437	12.393	1%	4.29	5.61
				5%	3.23	4.35

Note(s): *k* is the number of independent variables; Critical values are obtained from Table CI(iv) at Pesaran *et al.* (2001)

Table 4. Fractional frequency Fourier ARDL

	Model 1		Model 2		Model 3	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>ECT</i>	-1.241***	0.159	-1.163***	0.164	-1.362***	0.177
Long-Run						
AGDP	0.577	0.751	-1.287**	0.496	-0.605*	0.343
AGCAR	213.678***	13.935	203.600***	15.892	186.252***	17.870
TRADE	-0.429***	0.075	-0.588***	0.089	-0.321***	0.049
Short-Run						
Δ AGDP	1.982	0.642	1.029	0.741	0.951	0.173
Δ AGCAR	3.378	12.198	-3.252	13.890	0.872	13.723
Δ AGCAR ₋₁	-244.783***	34.423	-221.016***	35.478	-245.032***	34.901
Δ AGCAR ₋₂	-135.496***	27.745	-111.174***	28.092	-130.641***	27.272
Δ TRADE	-0.141*	0.069	-0.317***	0.075	-0.116	0.068
sin	4.108***	1.114	6.673***	0.875	5.420***	1.188
cos	7.481***	1.028	0.696	1.377	4.499***	0.812
SCO	6.623	1.797				
OTS			-9.743**	1.832		
EAEU					7.341***	1.742
constant	98.797***	12.245	133.030***	18.325	116.856***	14.771
Observations	28		28		28	
R-squared	0.99		0.988		0.989	
Optimum k	3.80		4.0		3.89	

Note(s): ***, **, and * show the significance at the 1%, 5%, and 10% levels, respectively. To test for potential endogeneity, the model was also re-estimated using lag-augmented ARDL specifications with alternative lag structures for each independent variable. The results were largely consistent with those presented here, and no systematic evidence of endogeneity was detected. Due to space and interpretation concerns, these results are not reported in detail but are available upon request

had a positive and significant coefficient, suggesting that membership in this group positively affects productivity. In contrast, in Model 1, the SCO membership variable was insignificant and, therefore, cannot be assumed to impact agricultural TFP significantly. These differential effects must be evaluated in the context of variables such as the structural depth of the organizations, sectoral policy priorities, and the level of implementation of agricultural cooperation.

Finally, the coefficients of the sin and cos terms of the Fourier components are statistically significant in most of the models. The sine component is significant in all three models, while the cosine component is significant in Model 1 and Model 3, but not in Model 2. This finding suggests that Kazakhstan’s agricultural productivity over time is affected not only by artificially defined sudden break points, but also by non-specific, fluctuating and nonlinear structural transformations. These transformations are more pronounced in some models (especially those including SCO and EAEU) and weaker in others. The integration of the Fourier transform in this analysis is both methodologically and theoretically justified by the fact that structural breaks can be of unknown shape and number.

Table 5 presents the diagnostic test results for all three models estimated in the study. The Breusch-Godfrey LM test statistics indicate no evidence of serial correlation, as the *p*-values for all models exceed the 5% significance level. Likewise, the Breusch-Pagan-Godfrey test results confirm the absence of heteroscedasticity, supporting the homoscedasticity assumption. The Jarque-Bera test outcomes suggest that the residuals are normally distributed across all models. Furthermore, the Ramsey RESET test results indicate that the functional form of the models is correctly specified, with no signs of omitted variable bias. In addition to these diagnostic tests, Figure A1 in the Appendix presents the CUSUM and CUSUM of Squares stability tests. For each model, the test statistics remain within the 5%

Table 5. Diagnostic tests

Tests	Model 1	Model 2	Model 3
Serial Correlation LM (Breusch-Godfrey)	0.1028	0.1048	0.1209
Heteroscedasticity (Breusch-Pagan-Godfrey)	0.3066	0.7348	0.3753
Jarque-Bera Normality Test	0.7817	0.5907	0.862
Ramsey Reset Test	0.5083	0.3828	0.9345

significance boundaries, confirming the structural stability of the estimated coefficients. Collectively, these findings validate the statistical adequacy, consistency, and robustness of the empirical models employed in the analysis.

7. Discussion

The empirical results of this study reveal that Kazakhstan's integration into international economic organizations exerts heterogeneous effects on agricultural total factor productivity (AGTFP), depending on the institutional maturity, policy coherence, and sectoral prioritization of each framework. These findings are consistent with the predictions of growth theory, trade liberalization models, and institutional economics, which jointly emphasize that productivity gains arise not only from openness but also from institutional inclusiveness, technology diffusion capacity, and the ability to internalize sectoral externalities.

Among the three organizations analyzed, the Eurasian Economic Union (EAEU) emerges as the only integration framework generating a positive and statistically significant effect on Kazakhstan's AGTFP. This outcome reinforces the arguments of [Romer \(1986\)](#) and [Solow \(1956\)](#), who identified technology and capital accumulation as long-run productivity drivers, and it echoes [North's \(1990\)](#) assertion that coherent institutions strengthen investor confidence and reduce transaction costs. Within the EAEU, the harmonization of technical standards, the customs union, and coordinated agricultural policies appear to have facilitated knowledge spillovers, enhanced logistics networks, and improved input market efficiency. Such institutional mechanisms likely contributed to the diffusion of modern technologies, greater mechanization, and more efficient resource allocation across Kazakhstan's agricultural value chain. Although intermediary variables such as agricultural R&D intensity or FDI inflows could not be included due to data limitations, the significant positive long-run relationship indicates that the EAEU's structured policy environment has acted as an enabling institutional platform for productivity convergence among its members.

In contrast, membership in the Organization of Turkic States (OTS) demonstrates a negative and statistically significant effect on AGTFP. This finding suggests that, at its current stage, the OTS's agricultural cooperation mechanisms remain institutionally underdeveloped and may have imposed transitional adjustment costs without generating immediate efficiency benefits. From an institutional economics perspective, this pattern reflects the cautionary view of [Valdés and Foster \(2010\)](#), who argue that early-stage integration efforts can create harmonization frictions if domestic readiness and policy alignment are insufficient. The OTS's heterogeneous membership structure, varying levels of technological capacity, and limited coordination of agricultural standards likely constrained the effectiveness of collective initiatives. However, this result should be interpreted as a reflection of *transitional inefficiency* rather than structural failure, indicating that the productivity effects of the OTS may materialize gradually as policy coordination deepens and investment mechanisms mature.

For the Shanghai Cooperation Organization (SCO), the estimated coefficients are statistically insignificant, consistent with the organization's limited agricultural focus. As [Zhang et al. \(2022\)](#) and [Bedelbayeva et al. \(2021\)](#) note, integration effects depend on sectoral

prioritization and the existence of dedicated implementation mechanisms. Since the SCO primarily emphasizes security cooperation, energy connectivity, and transport infrastructure, its indirect contributions to agricultural productivity—through logistics and financing spillovers—remain minimal. The absence of a coherent agricultural investment framework or monitoring mechanism within the SCO likely explains the statistically neutral impact on AGTFP.

The control variables provide further insight into the structural nature of Kazakhstan's agricultural transformation. Agricultural carbon emissions (AGCAR) display a dual dynamic: positive and significant long-run coefficients but negative short-run effects. This pattern implies that mechanization and modern input use—proxied by AGCAR—enhance efficiency over time but create short-term adjustment pressures and environmental trade-offs. These findings are consistent with the “sustainable intensification” literature (Tilman *et al.*, 2011; Fuglie, 2004), which argues that technological adoption must be complemented by ecological adaptation. In light of Hayami and Ruttan's (1971) agricultural transformation framework, the results indicate that Kazakhstan's institutional and environmental infrastructure may not yet be fully capable of internalizing the short-term costs associated with mechanization. The positive long-run elasticity of AGCAR, however, signals potential for “green TFP” growth, where productivity improvements and environmental performance gradually converge through clean technology adoption.

The AGDP variable, representing the share of agriculture in total GDP, exhibits negative and significant long-run effects in two of the three models. This result suggests that a higher agricultural share in GDP does not necessarily indicate modernization but may reflect the persistence of extensive, low-efficiency production systems. Similar dynamics have been discussed by Barro and Sala-i-Martin (1995) and Seitov (2023), who associate such patterns with transitional structural dualism, where sectoral expansion coexists with weak technological upgrading.

Interestingly, trade openness (TRADE) produces a consistently negative long-run impact on AGTFP across all specifications, challenging the conventional assumption of trade-led productivity growth. This counterintuitive outcome likely reflects structural dependencies within Kazakhstan's agricultural trade, particularly its reliance on imported machinery, fertilizers, and seeds, as well as limited diversification in export composition—dominated by wheat, flour, and livestock products. In line with Balassa's (1961) economic integration theory, these findings imply that trade liberalization, absent sufficient domestic value-chain development, may exacerbate external dependence rather than stimulate technological diffusion. To realize the productivity potential of openness, Kazakhstan must strengthen its institutional capacity for quality certification, export competitiveness, and logistics integration, aligning trade policies with the broader goals of agricultural modernization.

Finally, the statistical significance of the Fourier sine and cosine terms confirms the presence of nonlinear and persistent structural transformations in Kazakhstan's agricultural productivity trajectory. This validates the suitability of the Fractional Frequency Fourier ARDL approach in modeling gradual institutional transitions and unobserved shocks. The smooth cyclical patterns captured by Fourier terms illustrate that Kazakhstan's productivity evolution reflects incremental policy adaptation rather than abrupt regime changes, underscoring the importance of adopting flexible econometric frameworks to analyze complex transition dynamics.

8. Conclusion

This study provides empirical evidence that international economic integration affects agricultural productivity in Kazakhstan through distinct institutional channels rather than uniformly across all frameworks. Among the three regional organizations examined, only EAEU membership exerts a positive and statistically significant long-run effect on agricultural total factor productivity (AGTFP), suggesting that structured institutional coherence and

harmonized policy environments are essential for transforming integration into tangible productivity gains. The OTS exhibits a negative but transitional influence, reflecting the adjustment frictions of emerging cooperation mechanisms, while the SCO remains statistically insignificant due to its limited agricultural focus.

These differentiated outcomes underscore that integration-driven productivity improvements depend not solely on trade openness but on institutional quality, sectoral alignment, and policy implementation capacity. The findings also highlight the dual nature of carbon-intensive mechanization—supporting long-term productivity while imposing short-term environmental costs—and the paradoxical effect of trade openness in a structurally dependent agricultural economy. Overall, the study enriches the empirical literature by demonstrating that in transition economies, institutional inclusiveness and integration depth are more critical to productivity growth than the mere existence of regional memberships.

8.1 Policy implications

The policy implications derived from this study emphasize pragmatic and phased strategies to strengthen the productivity benefits of integration while mitigating transition costs.

For the EAEU, Kazakhstan should advance from formal compliance to proactive institutional engagement. This can be achieved by co-financing joint agricultural R&D centers focused on sustainable inputs, climate-resilient crop varieties, and digital mechanization technologies suited to Central Asian conditions. Streamlined sanitary and phytosanitary (SPS) certification procedures and harmonized quality standards would further facilitate integration into regional agricultural value chains. In addition, Kazakhstan should increase its participation in EAEU rural infrastructure funds and promote targeted logistics investments that address post-harvest inefficiencies. Cross-border extension programs and shared knowledge platforms can enhance human capital and reduce technological fragmentation, thereby consolidating the EAEU's role as a functional productivity-enhancing mechanism.

In the case of the OTS, agricultural cooperation remains largely declarative and policy-oriented rather than operational. To convert strategic commitments into measurable outcomes, OTS should institutionalize a permanent agricultural coordination unit responsible for monitoring, financing, and evaluating joint initiatives. Kazakhstan, as one of the bloc's leading agricultural economies, can drive pilot projects on technology-sharing, joint training, and mutual recognition of machinery and input standards. These initiatives should be sequenced according to members' technological readiness, avoiding the inefficiencies of uniform policy adoption across diverse agricultural systems.

For the SCO, given its current emphasis on energy and security, a realistic pathway involves integrating agriculture into its existing economic cooperation framework rather than creating new bureaucratic layers. Establishing an SCO Agricultural Modernization Council could provide a coordination platform linking agriculture with energy efficiency and transport corridor development. Priority should be given to rural infrastructure, agro-logistics corridors, and agri-tech financing through public-private partnerships. Moreover, embedding environmental sustainability within the SCO's broader agenda would align agricultural productivity gains with the region's climate adaptation objectives.

The positive long-run association between agricultural carbon emissions and productivity suggests that mechanization can coexist with sustainability when guided by "green transition" policies. Kazakhstan should adopt incentive-based mechanisms encouraging precision farming, renewable-energy irrigation systems, and low-emission equipment. Redirecting subsidy schemes toward efficiency and emission reduction—rather than output volume—would align productivity goals with environmental commitments.

Finally, the negative long-run relationship between trade openness and AGTFP highlights structural vulnerabilities within Kazakhstan's agricultural integration. Policymakers should diversify export portfolios toward higher value-added and processed products while simultaneously investing in domestic input industries—particularly seed production,

machinery manufacturing, and fertilizer processing. Strengthening certification, traceability, and logistics infrastructure would enhance competitiveness in both regional and global agri-food markets. In summary, integration must be complemented by inward-looking reforms that enhance sectoral resilience, ensuring that openness translates into sustainable productivity growth.

8.2 Limitations and recommendations for future research

This study is not without limitations. First, although agricultural carbon emissions were used as a sector-specific environmental proxy, broader indicators such as total emissions, soil degradation, or climate vulnerability could not be incorporated due to data gaps. Future research should explore composite environmental indices—such as green TFP or climate risk-adjusted productivity measures—to better capture the interaction between sustainability and efficiency.

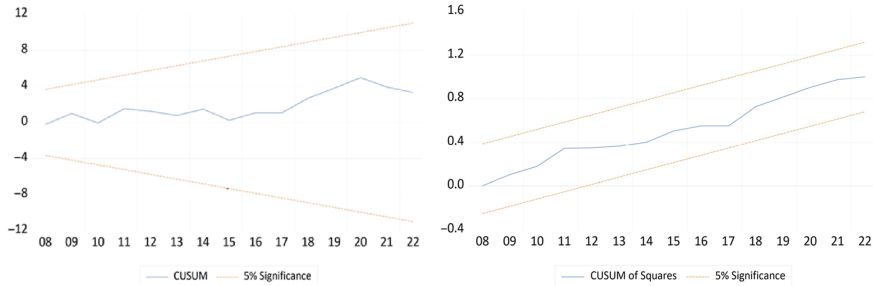
Second, the analysis was conducted at the national level, even though Kazakhstan's agricultural performance exhibits substantial spatial heterogeneity. The absence of consistent regional TFP data constrained subnational modeling. Future studies employing spatial econometric or geographically weighted regression (GWR) approaches could better reveal the geographic asymmetries of integration benefits.

Third, the use of binary dummy variables to represent organizational memberships imposes a simplifying assumption of discrete regime shifts. Although robustness tests with lag structures and alternative model specifications mitigate this concern, they cannot fully capture the varying intensity of institutional integration. Continuous indices or dynamic treatment effect models could provide more nuanced insights into how different degrees of participation influence productivity trajectories.

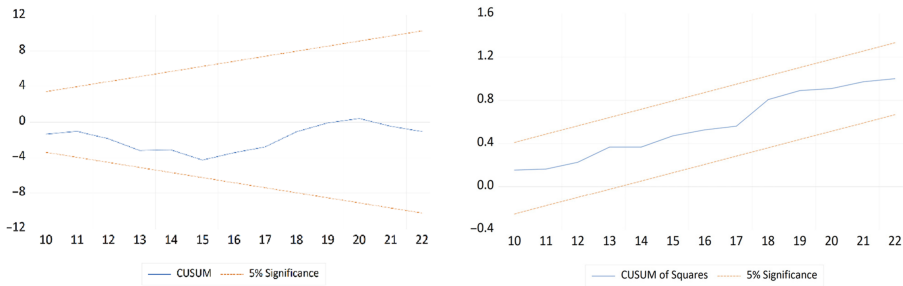
Fourth, the study did not incorporate a counterfactual or synthetic control analysis to estimate productivity outcomes in the absence of integration. Future research could build upon this limitation by simulating non-member trajectories or conducting cross-country comparisons within the EAEU and OTS contexts. Finally, given Kazakhstan's transitional economic structure, caution should be exercised in generalizing these findings to other member states. Comparative case studies considering sectoral composition, institutional maturity, and policy coherence would deepen understanding of how integration mechanisms translate into agricultural productivity across diverse political economies.

Appendix

Model 1



Model 2



Model 3

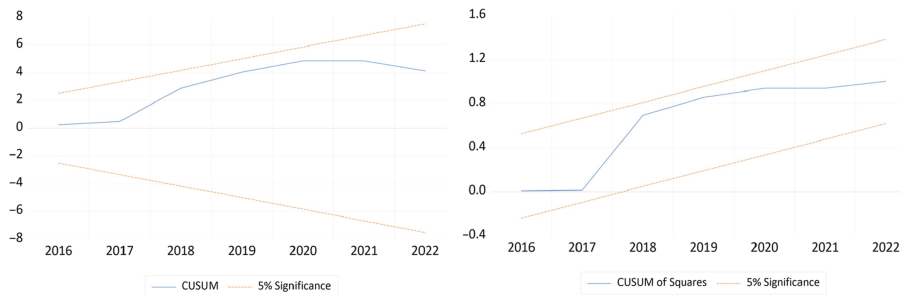


Figure A1. CUSUM and CUSUM of square for three models

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