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THE ROLE OF THE BELT AND ROAD INITIATIVE IN ADVANCING SUSTAINABLE AGRICULTURE AND FOOD SECURITY IN PAKISTAN

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ABSTRACT: *This study examines the impact of Chinese foreign direct investment and infrastructure development on sustainable food security in Pakistan's agricultural sector. Using annual data from 1985 to 2022, it applies Vector Autoregressive and dynamic ARDL models to explore both short- and long-run relationships among key variables such as infrastructure, governance, exchange rates, and trade. Unit root tests confirm the data's stationarity after first differencing. ARDL bounds testing reveals strong long-term links, showing that a 1% rise in Chinese FDI and infrastructure improves food availability by approximately 0.13%–0.21% and 0.16%–0.24%, respectively. Governance and exchange rate stability are also found to significantly enhance food security outcomes. The error correction terms suggest a gradual return to equilibrium, with adjustments occurring at a rate of 9%–27% annually. Overall, the findings underscore that foreign investment and infrastructure development are key drivers of food availability, offering valuable policy insights for advancing food security and achieving sustainable development goals.*

KEYWORDS: FDI, Food Security, BRI, Sustainable Infrastructure Development, Institutional Quality.

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INTRODUCTION

By 2030, food security is aimed to be achieved globally, yet many nations still struggle with hunger, poverty, and a shortage of basic supplies. The United Nations has emphasized the significance of food security in attaining the Sustainable Development Goals (SDGs). To secure food security, Goal 2 of the SDGs seeks to advance sustainable agriculture, encourage collaboration in agricultural investment, and ensure food security (Assembly, 2015). By 2030, the first two (SDGs) of the United Nations are to be achieved (UN, 2015). The COVID-19 pandemic has had a substantial influence on the advancement of these objectives; estimates suggest that, in 2030, 670 million people will go hungry, the same number as in 2015, the year the SDGs were introduced (FAO et al., 2022). Women and children make up most of the underprivileged inhabitants in rural areas that rely on agriculture for their subsistence (World Bank, 2020). Poverty aggravates food insecurity in rural regions, and studies show that the COVID-19 epidemic has exacerbated household food security (Emediegwu and Nnadozie, 2022; Sassi and Trital, 2022).

The numbers of SDGs are particularly relevant for Pakistan's sustainable way of life and food security (Akram and Khalid et al., 2021). Among those the following SDGs are particularly relevant.

Figure 1: UNO SDG2 to be achieved by 2030

Source: *Authors constructed*

Figure 1, "MOVEMENT PROGRESS AWAY Zero Hunger 2," highlights the global efforts and advancements in addressing hunger and promoting food security.

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SDG 1: No Poverty: This goal aims to eliminate poverty in all its manifestations, including extreme poverty and hunger. Reducing poverty and ensuring access to nutritious foods are necessary steps towards achieving food security and sustainable livelihoods in Pakistan.

Goal 2: Zero Hunger: The goal of its objective is to eradicate hunger, improve nutrition and food security, and advance sustainable agriculture. This entails boosting agricultural output in Pakistan, developing food distribution networks, encouraging sustainable farming methods, and guaranteeing that everyone may get their hands on healthy meals.

SDG 3: Good Health and Well-Being: Promoting good health and well-being requires guaranteeing access to nourishing food. To achieve this, Pakistan must make significant efforts to enhance healthcare services, reduce malnutrition, and encourage a healthy diet.

SDG 8: Decent Work and Economic Growth: Having access to opportunities for both decent work and economic growth is essential for sustainable livelihoods. To achieve this, Pakistan must take steps to support small-scale farmers and businesses, generate jobs, and encourage inclusive economic growth.

SDG 12: Responsible Consumption and Production: Ensuring food security and sustainable livelihoods requires promoting sustainable patterns of consumption and production. In Pakistan, efforts to eliminate food waste, improve sustainable farming practices, and minimize environmental degradation are critical to accomplishing this goal.

SDG 13 - Climate Action: Climate change presents significant risks to both food security and livelihoods, especially in agrarian societies like Pakistan. Mitigation of climate change, adaptation, and climate-resilient agriculture are all critical to Pakistan's long-term growth.

SDG 15: Protecting and restoring ecosystems especially agricultural land is vital for long-term food security and sustainable livelihoods. In Pakistan, combating deforestation, adopting sustainable land management practices, and preserving biodiversity are essential steps. Achieving these goals requires an integrated approach that addresses interconnected social, economic, and environmental challenges. Collaborative efforts among the government, civil society, private sector, and international partners are crucial to advancing sustainable development and meeting the SDGs (Tariq and Zaman et al., 2022).

Pakistan faces significant challenges in ensuring food security, including food insecurity, hunger, and poverty, despite its significant agricultural sector. Several factors contribute to these issues, including population expansion, climate change, water scarcity, poor infrastructure and socioeconomic inequalities (Hussain et al., 2021).

The objective of the national food security policy is to enhance food security, increase agricultural productivity, and promote sustainable agricultural practices. Implemented initiatives include the Benazir Income Support Programme and the Ehsaas Programme Provide social safety nets and cash transfers to vulnerable populations to alleviate poverty and food insecurity. Invest in irrigation infrastructure, water conservation measures, and drought-tolerant crop varieties to make agriculture more resilient to climate change and water scarcity. 4,444 nutrition programs targeting the health of mothers and children, including the National Nutrition Program and Vitamin Supplementation Program (Malik and Irshad, 2023).

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The World Bank forecasts growing benefits of foreign direct investment (FDI) for GDP, trade, and employment in Belt and Road Initiative (BRI) nations, particularly agricultural economies facing food security challenges due to insufficient investment. Implementing advanced agricultural technologies including precision farming, genetically modified crops, drip irrigation, and mechanization can increase productivity, reduce costs, and enhance climate resilience. To fully realize these advantages, BRI countries should foster favorable investment environments, provide incentives for technology adoption, and reinforce agricultural research and advisory services (Fatima and Javid, 2022).

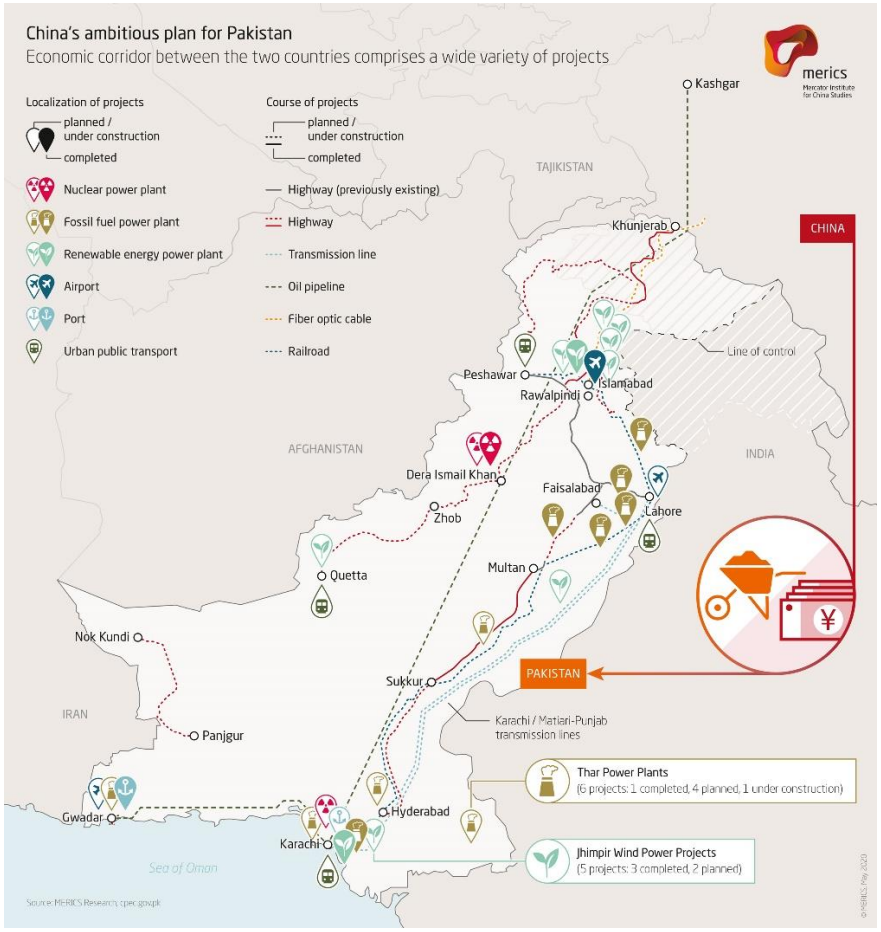

Figure 2: CEPEC projects under umbrella of BRI in Pakistan.

Source: Authors constructed

Figure 2, illustrates the China-Pakistan Economic Corridor (CPEC) projects, which are a key component of the Belt and Road Initiative (BRI) in Pakistan. However, it is important to ensure that foreign direct investment is consistent with national development priorities and that technology adoption is inclusive, environmentally sustainable and socially just (Ministry of National Food Security and Research, 2018). China has become a major investor in Pakistan's infrastructure, agriculture, and energy sectors through projects such as the (CPEC). Under CPEC, China has invested in the development of transportation networks, energy projects, and industrial zones that can contribute to economic growth, job creation, poverty alleviation, and ultimately improve livelihoods (Ahmed and Laiq, 2022). China's expertise in agricultural technology, irrigation, and crop cultivation could help Pakistan increase productivity, improve

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resilience to climate change, and promote sustainable agricultural practices (Mustafa and Arif et al., 2021). China is contributing to improving Pakistan's sustainable livelihoods and food security by leveraging its economic cooperation, investments, and expertise. (Ahmed, I.& Shabbir, G.2019). The Belt and Road Initiative its objective is to enhance the economic well-being of nations and promote regional collaboration, foster cultural exchange, and contribute to global peace and development.

Based on SOFI 2023, the population of undernourished individuals rose from 29.8 million in 2006 to 42.8 million in 2022. Pakistan is facing a significant issue with food insecurity. This study aims to investigate the potential positive impact of China's foreign direct investment (FDI) and infrastructure development on the food security system in Pakistan

LITERATURE REVIEW

Samdrup et al. (2023) a meta-analysis of 24 studied reveals economic growth and foreign direct investment have a direct positive association. However, the impact varies across sectors and is complex. In poor nations, a meta-regression study reveals insufficient data to support either a detrimental or positive impact on food security.

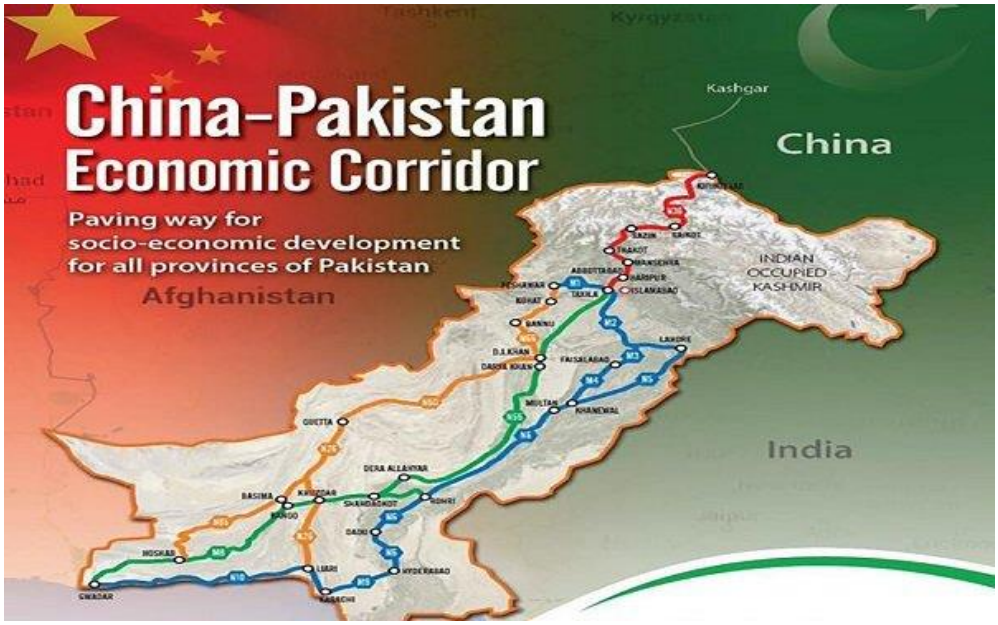

Figure 3: CPEC for sustainable development in Pakistan

Source: *Authors constructed*

Figure 3, Represent the China-Pakistan Economic Corridor paves the way for socio-economic development across all provinces of Pakistan and beyond, including Afghanistan.

Similarly, Abdulsalam et al. (2021) examined the impact of Chinese investment on the economies of 25 Asian and North African countries participating in the Belt and Road (B&R) initiative between 2007 and 2016. The analysis employed the Johansen Fisher and Panel

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cointegration test, the panel dynamics ordinary least squares (SDOLS) model, and the Toda and Yamamoto technique to establish causality.

Baig et al. (2023) The pandemic COVID-19 has accelerated stakeholder-driven approaches to sustainability, with food security becoming a critical challenge especially in developing regions like South Asia. For Pakistan, initiatives such as the China-Pakistan Economic Corridor (CPEC) present a multi-layered socio-economic pathway to address food insecurity amid ongoing crises. This study employs a three-phase stakeholder analysis identification, social network inquiry, and prioritized communication to assess solutions. Stakeholders stress the importance of integrated, ministry-aligned reporting to create synergies and ensure inclusive policy-making. The findings highlight the need for coordinated, sustainable strategies to strengthen food security in Pakistan's post-pandemic recovery.

Martín and Fernández (2022) Pakistan's food security issues include low production and accessibility. To address these, government policies should encourage Chinese investment in agriculture, promoting advanced technologies and practices. CPEC infrastructure development can enhance agricultural growth and market enhancement. However, non-agricultural FDI can worsen food insecurity, necessitating tailored policy interventions.

Khan et al. (2023) analyzed the influence of global quality on sector-specific foreign direct investment (FDI) in Pakistan, utilizing data spanning from 1986 to 2019. Research has shown that in developing countries such as Pakistan, more robust institutional quality, which promotes significant technical progress through foreign direct investment (FDI), leads to an improvement in the overall economic performance.

Li and Abbas (2023) investigated the direct impact of Chinese infrastructure investment, specifically in CPEC projects, on the food supply in Pakistan. The study used empirical analysis to determine how infrastructure development influences agricultural production and distribution, ultimately influencing food access in the country.

Zhang and Raza (2024) investigated the mediating effect of institutional quality in the correlation between China's OFDI, infrastructure development, and food security in Pakistan. It is anticipated to investigate how institutional elements such as governance structures and regulatory frameworks influence the efficacy of Chinese investments in enhancing food supply and security.

Wu and Khan (2024) research provided a complete examination of China's OFDI in Pakistan, focusing on the implications for food supplies. It evaluated the interaction of infrastructural development and institutional quality when estimating the impact of Chinese investments on agricultural productivity and food security in Pakistan.

Lin and Azam (2022) analyzed China's outbound FDI in Pakistan's agriculture sector and investigated its implications for food availability. They addressed investment trends, technology transfer, and overall influence on food security and agricultural production.

Siddiqui and Jin (2023) comparative analyzed the importance of institutional quality on agricultural development in Pakistan, with an emphasis on investments from China and domestic sources. They evaluated how governance structures and regulatory frameworks affect the efficacy of investments in increasing food availability.

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Research has the potential to investigate how improvements in transport, energy and industrial infrastructure impact agricultural production, marketing and distribution systems, and how these impact food security outcomes. Institutional quality, including governance structures, regulatory frameworks, and political environments, can have a significant impact on food availability by influencing investment decisions, market functioning, and resource allocation in the agricultural sector. Strengthening institutional quality, transparency and accountability is essential to foster sustainable agricultural development and ensure equal access to food resources (Nazir and Malik, 2018). Studies highlight the importance of institutional quality for Pakistan's economic development and governance outcomes. However, there is limited literature that specifically examines the relationship between domestic institutional quality, investment in CPEC, and food availability.

METHODOLOGY

Conceptual Framework

This study used an advanced empirical model to study the dynamics of China's outward FDI, infrastructure development, and institutional quality of food availability in Pakistan. (This framework examines China's FDI and infrastructure investments in Pakistan's agricultural sector enhance food security by improving productivity and market access. It highlights the role of foreign investment in promoting sustainable agricultural development.)

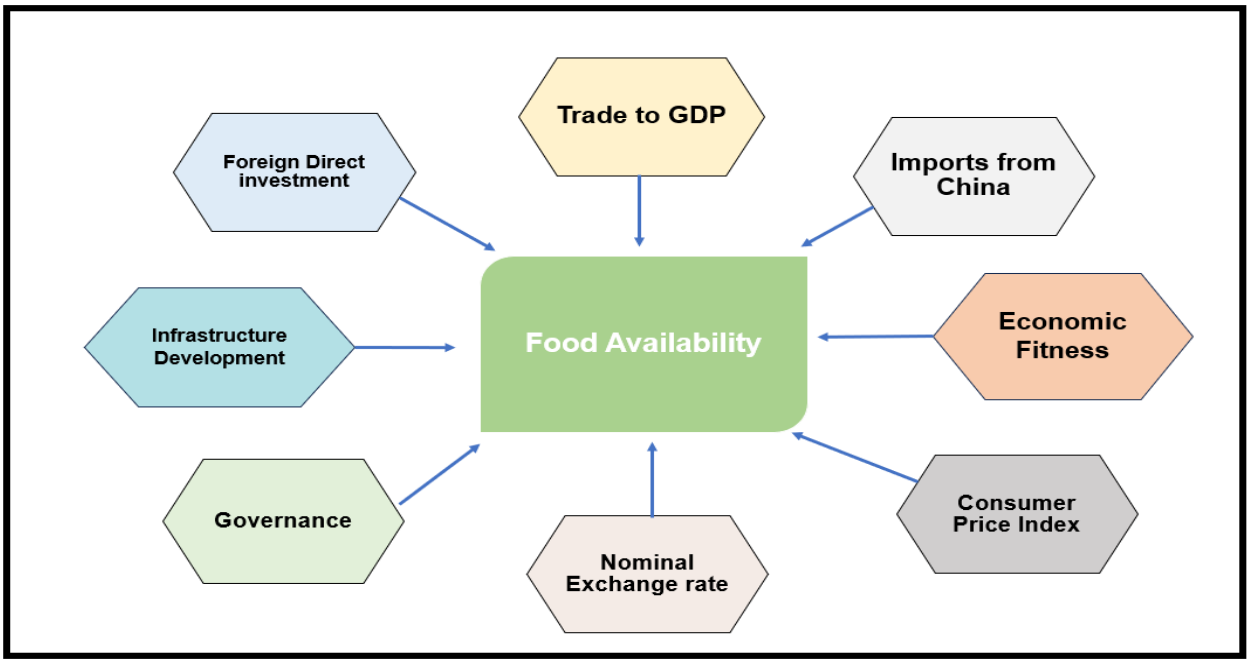

Figure 4: Conceptual framework

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In today's dynamic and interconnected world, economic fitness is critical to success. It refers to the ability of individuals, corporations, and governments to adapt, innovate, and compete effectively in the global economy. Productivity, creativity, adaptability, resilience, and sustainability are critical factors in determining economic fitness. Entities that prioritize these criteria can not only thrive in the face of adversity but also capitalize on possibilities for growth and development. Figure 4, presents the underlying factors that contribute to economic fitness, highlighting the interconnected elements that drive sustainable growth and adaptability in a competitive environment. Economic health helps stakeholders navigate volatility and design a road for long-term prosperity by cultivating a culture of continual improvement and strategic foresight.

The Consumer Price Index (CPI) is a significant economic metric that monitors fluctuations in the mean prices of a composite of commodities and services bought by households. It is a critical instrument for determining inflation and cost-of-living adjustments. The CPI, which includes categories such as food, housing, transportation, and healthcare, provides insight into how price changes affect consumers' purchasing power over time.

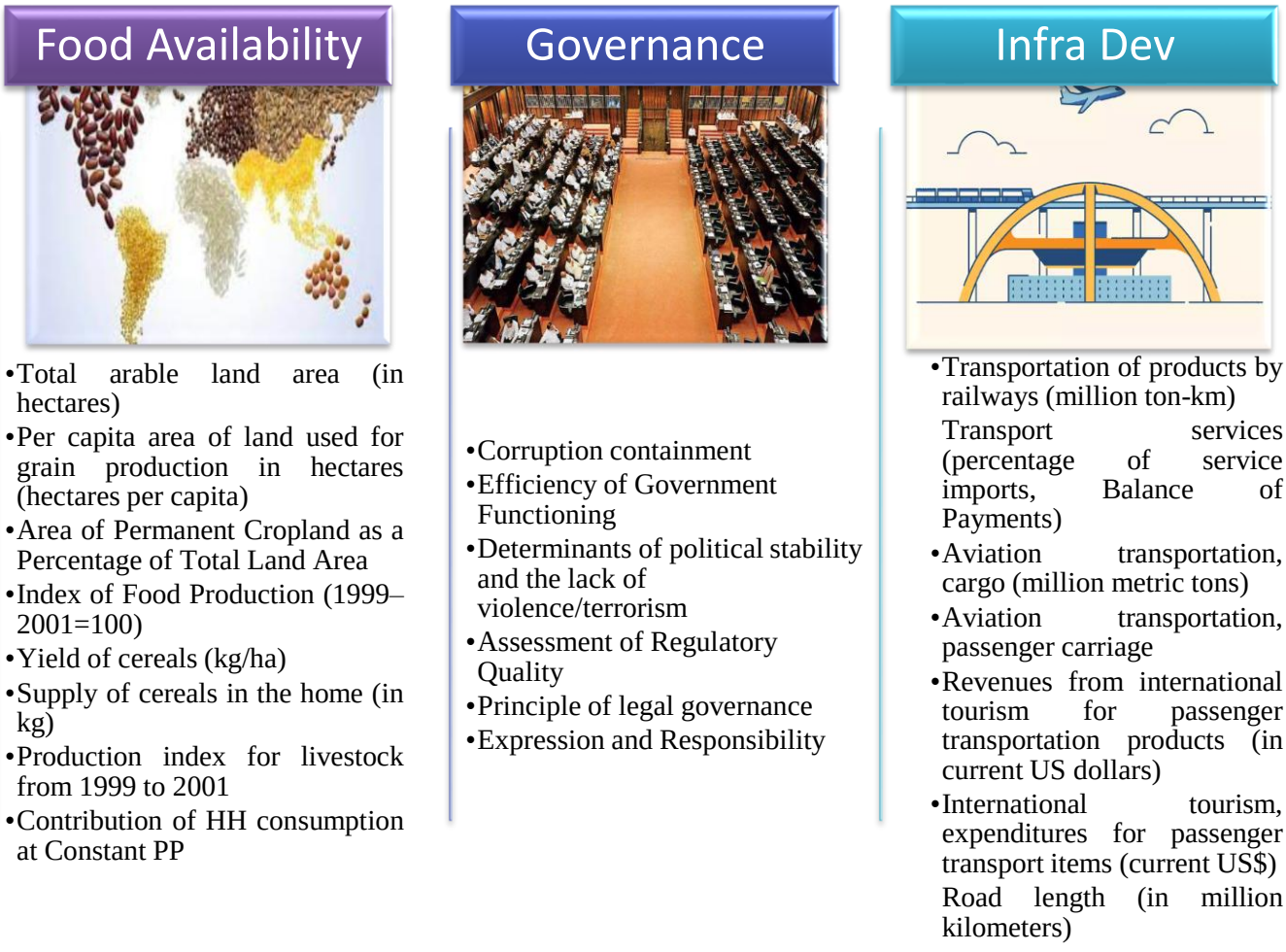

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Figure 5: Indicators of Sustainable Development: Food Availability, Governance, and Infrastructure"

To estimate the effect of China's Outward Foreign Direct Investment (OFDI), infrastructure development, and institutional quality on food availability in Pakistan, this study used time series data from 1985 to 2022. Figure 5, presents the selected indicators used to measure Food Availability, Governance, and Infrastructure Development, providing a comprehensive view of the variables involved in the analysis.

Data Description and Data Source

- **Foreign direct Investment (FDI):** is a significant economic driver, involving investments in foreign businesses or assets, thereby transferring capital, technology, and managerial expertise to the host country. China's FDI in Pakistan, focusing on infrastructure, energy, and agriculture, aligns with Pakistan's economic development and strategic interests, fostering long-term collaboration and regional connectivity under CPEC.

- **Infrastructure development index:** The IDI is a quantitative measure used to evaluate and compare infrastructure development in a specific geographic area, aggregating various components into a single index value.

- **Governance Index:** The Governance Index is a quantitative measure that evaluates and compares the quality and effectiveness of governance across different entities, aggregating various governance dimensions into a single index value.

- **Nominal Exchange Rate:** An important economic indicator, the nominal exchange rate measures the value of one country's currency with another's currency by showing the price at which one country's currency can be exchanged for another country's currency on the foreign exchange market.

- **Consumer price index:** The Consumer Price Index (CPI) is a fundamental economic indicator specifically designed to quantify fluctuations in the price level of a collection of consumer goods and services across a certain period. It reflects the cost of living and is commonly used to assess inflation within an economy.

- **Economic Fitness:** Economic Fitness is a quantitative measure that evaluates a country's productivity complexity and potential for future growth, derived from the Economic Complexity Index (ECI) and other metrics that analyze the economy's structure based on export diversity and sophistication.

- **Imports from China:** Total value or quantity of goods and services that Pakistan purchases from China over a specific period. It is a key economic indicator that reflects trade relationships, economic dependency, and the influence of Chinese products on the domestic market.

- **Trade to GDP:** The trade-to-GDP ratio is a variable that quantifies the significance of trade (both imports and exports) in a country's economy and its openness to international trade. It is frequently expressed as a percentage and is determined by dividing the sum of exports and imports by the country's GDP.

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Table 1: Data Description and Source

Abbreviation	Explanation	Source
Dependent Variable		
FA (Food Availability)	Food Availability in terms of physical accessibility to food goods, affordability, and nutritional value.	Index Author Calculation
Independent Variables		
FDI	Foreign Direct Investment	SBP
Inf_Dev	Infrastructure development index	Index Author Calculation
ER	Nominal Exchange Rate	SBP
CPI	Consumer price index	SBP
Imp_China	Imports from China (million US $)	SBP
Control Variables		
Trade	Trade to GDP (ratio)	WDI
Gov	Governance Index	WGI
EF	Economic Fitness	WB

Note: World Development Indicators (WDI), State Bank of Pakistan (SBP)

Econometric Technique

- **Unit Root Test:** Before applying the econometric models, the stationarity of variables is checked. This is very important to make the non-stationary data stationary to get the practical results of the study.

- **Stationarity Test:** In time series analysis, the stationary test is crucial for preventing the occurrence of a unit root bias. Furthermore, it is essential to make advantage of a suitable estimation methodology the econometric models that elucidate the long-term correlation between dependent and independent variables. If all variables are integrated at the level, ordinary least squares (OLS) regression is employed for estimate. When certain variables are integrated at the same level as others are integrated at the first difference, the Autoregressive Distributed Lag (ARDL) method is used for the estimate.

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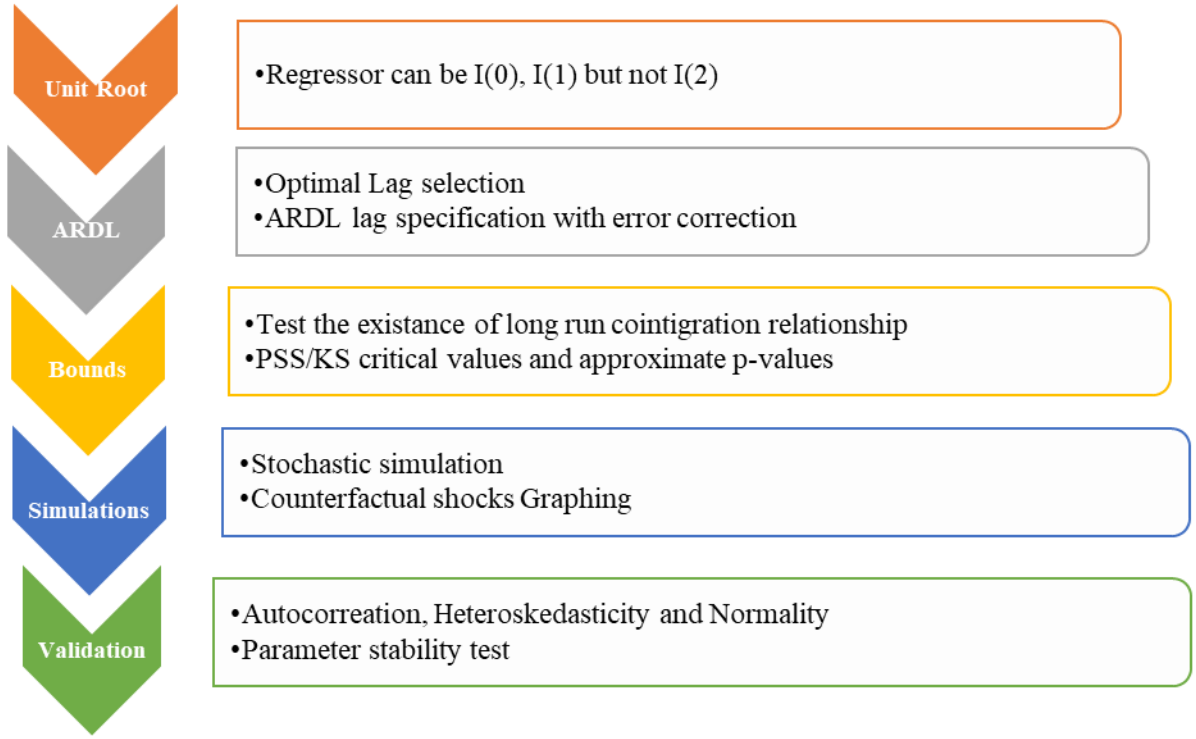

Source: *Authors constructed*

Figure 6: Dynamic Simulations of Empirical Model

To conduct an empirical investigation on the short- and long-run dynamics of food availability with some control variables, the following three econometric models are specified. Figure 6, 'Dynamic Simulations of Empirical Model' provides a visual representation of these dynamics, illustrating the impact of selected variables on food availability over time.

- **Model Specification:**

The factors β_1–β_6 measure how responsive or malleable AF4 is to variations in its corresponding independent variables. These variables are projected to affect AF4 both in their current form and through their lagged and differenced values. They represent important economic indicators such as FDI, inflation, governance quality, and currency rates. The subscript i designates individual cross-sections, which correspond to various nations or regions, and the time interval (from 1985 to 2022).

$$\Delta FA_t = \alpha + \sum_{i=1}^{m}\beta_{1i}\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{4i}\ln CPI_{t-i} + \sum_{i=1}^{m}\beta_{5i}\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{6i}\ln FA_{t-i} + \sum_{i=1}^{m}\beta_{7i}\Delta\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{8i}\Delta\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{9i}\Delta\ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{10i}\Delta\ln CPI_{t-i} + \sum_{i=1}^{m}\beta_{11i}\Delta\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{12i}\Delta\ln FA_{t-i} + \varepsilon_t \quad \text{(i)}$$

Where β1, β2, β3, β4, β5, and β6 reflect the responsiveness of AFA to changes in Foreign Direct Investment from China, inflation, governance quality, exchange rates, adjusted capital flows, and financial assets, respectively. The coefficient β7 indicates the rate at which deviations from the long-term connection between variables are adjusted. The error term εit represents the unobserved variables that impact AFA.

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$$\Delta FA_t = \sum_{i=1}^{m}\beta_{1i}\Delta \ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\Delta \ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\Delta \ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{4i}\Delta \ln ER_{t-i} + \sum_{i=1}^{m}\beta_{5i}\Delta CPI_{t-i} + \sum_{i=1}^{m}\beta_{6i}\Delta \ln FA_{t-i} + \beta_{7i}ECM_{t-1} + \varepsilon_t$$

(ii)

The equation captures the relationship between food security in Pakistan's agriculture sector and key factors, highlighting the role of China's FDI. It examines the long-term effects of FDI, infrastructure, exchange rates, economic conditions, and Chinese imports on food availability using lagged variables. Each coefficient (β1, β2, etc.) reflects the strength of influence, with FDI (β1), infrastructure (β2), and economic stability (β4) positively impacting food security, while exchange rates (β3) and imports (β5) are also considered.

$$\Delta FA_t = \alpha + \sum_{i=1}^{m}\beta_{1i}\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{4i}\ln EF_{t-i} + \sum_{i=1}^{m}\beta_{5i}\ln \mathrm{Im}p\_China_{t-i} + \sum_{i=1}^{m}\beta_{6i}\ln FA_{t-i} +$$
$$\sum_{i=1}^{m}\beta_{7i}\Delta\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{8i}\Delta\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{9i}\Delta\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{10i}\Delta\ln EF_{t-i} + \sum_{i=1}^{m}\beta_{11i}\Delta\ln \mathrm{Im}p\_China_{t-i} + \sum_{i=1}^{m}\beta_{12i}\Delta\ln FA_{t-i} + \varepsilon_t$$

(iii)

The equation shows how China's FDI, infrastructure, and economic factors influence food security in Pakistan. The dependent variable (ΔFA) measures food availability as a proxy for food security. A positive coefficient for Chinese FDI (β1) suggests that higher investment boosts agricultural output. Infrastructure (β2), such as roads and irrigation, also improves food access. Exchange rate changes (β3) affect trade costs, while economic factors (β4) support investment and stability. Chinese imports (β5) may enhance food security through agricultural goods or technology. The Error Correction Mechanism adjusts short-term imbalances, with lagged food availability (FAt–1) capturing long-term effects. Overall, the model highlights how FDI and macroeconomic factors shape sustainable food security in Pakistan.

$$\Delta FA_t = \sum_{i=1}^{m}\beta_{1i}\Delta\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\Delta\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\Delta\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{4i}\Delta\ln EF_{t-i} + \sum_{i=1}^{m}\beta_{5i}\Delta\,\mathrm{Im}p\_China_{t-i} +$$
$$\sum_{i=1}^{m}\beta_{6i}\Delta FA_{t-i} + \beta_{7i}ECM_{t-1} + \varepsilon_t$$

(iv)

The model examines how China's FDI, infrastructure, and economic factors affect food security in Pakistan. Food availability (AFA) is the key variable, with FDI (β1) and infrastructure (β2) expected to boost agricultural output. Governance (β3), exchange rates (β4), and trade openness (β5) also influence food access and market efficiency. Lagged food availability (FAt-1) and the Error Correction Mechanism capture long-term trends. Overall, the model highlights how investment and policy factors shape sustainable food security.

$$\Delta FA_t = \alpha + \sum_{i=1}^{m}\beta_{1i}\ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{4i}\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{5i}\ln Trade_{t-i} + \sum_{i=1}^{m}\beta_{6i}\ln FA_{t-i} + \sum_{i=1}^{m}\beta_{7i}\Delta\ln FDI\_China_{t-i} +$$
$$\sum_{i=1}^{m}\beta_{8i}\Delta\ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{9i}\Delta\ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{10i}\Delta\ln ER_{t-i} + \sum_{i=1}^{m}\beta_{11i}\Delta\ln Trade_{t-i} + \sum_{i=1}^{m}\beta_{12i}\Delta\ln FA_{t-i} + \varepsilon_t$$

(v)

The model captures how China's FDI, infrastructure, governance, exchange rates, and trade openness influence food security in Pakistan. ΔFAt reflects changes in food availability, with lagged variables showing delayed effects. Coefficients (β1i to β5i) measure each factor's impact, highlighting the role of past investments and policies. The Error Correction Mechanism adjusts short-term changes toward long-term balance. This framework aids policymakers in enhancing food security through targeted economic strategies.

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$$\Delta FA_t = \sum_{i=1}^{m}\beta_{1i}\Delta \ln FDI\_China_{t-i} + \sum_{i=1}^{m}\beta_{2i}\Delta \ln Inf\_Dev_{t-i} + \sum_{i=1}^{m}\beta_{3i}\Delta \ln Gov_{t-i} + \sum_{i=1}^{m}\beta_{4i}\Delta \ln ER_{t-i} + \sum_{i=1}^{m}\beta_{5i}\Delta Trade_{t-i} + \sum_{i=1}^{m}\beta_{6i}\Delta \ln FA_{t-i} + \beta_{7i}ECM_{t-1} + \varepsilon_t$$

(vi)

This study uses the ARDL approach to examine the impact of China's FDI, infrastructure, governance, and institutional quality on food availability in Pakistan. The Error Correction Model (ECM) captures short-run dynamics, while the CUSUM test checks model stability. Diagnostic tests address issues like heteroscedasticity and serial correlation. The ECM term reflects adjustment speed to long-term equilibrium. The Toda-Yamamoto causality test further explores long-term directional relationships.

$$Y_t = y_{1t}, ..., y_{kt}, ..., y_{Kt}$$

For k = 1, . . . K. subsequently including the p lags of K endogenous variables:

$$Y_t = Ay_{t-1} + ... + A_p y_{t-p} + CD + \mu_t$$

Here, Ai is the K×K coefficient matrices for lags *i*=1…, p, and μ is the white noise error term. Matrix CCC contains deterministic regressors (e.g., trend, constant, seasonal dummies) with appropriate dimensions. This study employs an augmented VAR model with lag order 1.

Table 2 VAR model

$$\begin{pmatrix} FA_t \\ FDI\_China_t \\ Inf\_Dev_t \\ Gov_t \\ ER_t \\ CPI_t \\ EF \\ Trade \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \\ \alpha_8 \end{pmatrix} + \begin{pmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \\ \beta_{31} & \beta_{32} \\ \beta_{41} & \beta_{42} \\ \beta_{51} & \beta_{52} \\ \beta_{61} & \beta_{62} \\ \beta_{71} & \beta_{72} \\ \beta_{81} & \beta_{82} \end{pmatrix} \begin{pmatrix} FA_{t-1} \\ Inf\_Dev_t \\ FDI\_China_{t-1} \\ GOV_{t-1} \\ ER_{t-1} \\ CPI_{t-1} \\ EF_{t-1} \\ Trade_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{FA,t} \\ \varepsilon_{FDI\_China,t} \\ \varepsilon_{Inf\_Dev,t} \\ \varepsilon_{Gov,t} \\ \varepsilon_{Er,t} \\ \varepsilon_{CPI,t} \\ \varepsilon_{EF,t} \\ \varepsilon_{Trade,t} \end{pmatrix}$$

OUTCOME OF RESULTS

The findings in Table 3 show that all variables have statistical significance except for the GOV (governance) variable. The table indicates that all variables exhibit unit root issues at the level except for GOV (governance). The second section of Table 3 shows that, except for GOV (Governance), at the first difference, all variables are considered to be stationary. Based on the results, it seems appropriate to utilize the (ARDL) model due to the varied order of integration. Examining the stationarity of variables at the level and the first difference, both without and with Trend, involves the Unit Root Test, which includes the Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. lnFA (food availability), lnFDI_China (Foreign direct investment from China), and other variables are included. Here's a thorough analysis:

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Many variables exhibit non-stationarity as their test statistics do not exceed the thresholds at which a unit root null hypothesis is rejected, suggesting they are not stationary at that level. After differencing, all variables become stationary with significant test statistics (*p<0.10), indicating that differencing once removes the unit root, making them stationary. When the p-values of these tests fall below a specific threshold (e.g., 0.05 or 0.10), it suggests evidence that contradicts the null hypothesis of a unit root, suggesting that stationarity is the case.

Table 3: Results of Unit Root Test

Variables	**At Level**				**At First Difference**			
	Dickey-Fuller (ADF)		**Phillips–Perron (PP)**		**Dickey-Fuller (ADF)**		**Phillips–Perron (PP)**	
	without Trend	with Trend	without Trend	with Trend	without Trend	with Trend	without Trend	with Trend
lnFA	**-1.42**	**-1.39**	**-1.42**	**-2.19**	**-4.36***	**-4.33***	**-5.66***	**-5.70***
	0.15	0.17	0.44	0.13	0.00	0.01	0.00	0.00
lnFDI_China	**-0.99**	**-4.06***	**-1.09**	**-4.18***	**-6.71***	**-6.49***	**-7.19***	**-6.87***
	0.75	0.01	0.71	0.01	0.00	0.00	0.00	0.00
lnInf_Dev	**-2.36**	**-2.34**	**-2.60**	**-2.59**	**-5.96***	**-5.88***	**-5.89***	**-5.96***
	0.16	0.41	0.10	0.29	0.00	0.00	0.00	0.00
lnGov	**-3.62***	**-4.49***	**-3.67***	**-3.94****	----	----	----	----
	0.01	0.00	0.01	0.02	----	----	----	----
lnER	**-2.27**	**-2.54**	**-2.27**	**-2.54**	**-7.24***	**-7.31***	**-7.48***	**-9.10***
	0.19	0.31	0.19	0.31	0.00	0.00	0.00	0.00
lnCPI	**-2.47**	**-3.72***	**-1.78**	**-2.63**	**-4.37***	**-4.32***	**-4.09***	**-4.02***
	0.13	0.03	0.38	0.27	0.00	0.01	0.00	0.02
lnEF	**-2.42**	**-3.38**	**-2.40**	**-3.48**	**-6.40***	**-6.31***	**-10.40***	**-9.84***
	0.14	0.07	0.15	0.05	0.00	0.00	0.00	0.00
lnImp_China	**2.77**	**0.72**	**2.62**	**0.86**	**-4.07***	**-7.15***	**-6.65***	**-7.16***
	1.00	1.00	1.00	1.00	0.01	0.00	0.00	0.00
lnTrade	**-0.67**	**-4.21***	**0.20**	**-2.13**	**-5.38***	**-4.15***	**-4.13***	**-4.15***
	0.84	0.01	0.97	0.51	0.00	0.01	0.00	0.01

*Note: **legend**: * p<0.10; ** p<0.05; *** p<0.01*

Table 4: Results of the dynamic ARDL Model

Long Run and short-run error correction Coefficients			
Dependent	**FA**		
Variables	**Model 1**	**Model 2**	**Model 3**
Selected Model	(4, 4, 3, 4, 1, 4)	(4, 4, 4, 4, 2, 0, 3)	(3, 4, 4, 2, 2, 3, 2)
lnFDI_China	**0.13**	**0.21**	**0.16**
	2.97*	1.69*	1.97**
lnInf_Dev	**0.17**	**0.24**	**0.16**
	2.39**	2.41***	1.68*
lnGov	**0.31**	----	**0.18**
	1.98**		0.31
lnER	**0.14**	**0.06**	**0.02**
	1.67*	1.98**	2.51**

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lnCPI	**0.39**		----
	3.06***		
lnEF	----	**0.14**	----
		2.27**	
lnImp_China	----	**0.19**	----
		1.71*	
lnTrade	----	----	**0.41**
			2.17**
Constant	**8.68**	**12.11**	**18.27**
	5.49***	7.23***	5.38***
Trend	**0.91**	**0.44**	**0.45**
	5.74***	0.75	2.1**
ECMt-1	**-0.27**	**-0.09**	**-0.12**
	-4.65***	-2.72***	-5.9***
legend: * p<0.10; ** p<0.05; *** p<0.01			

Source: *Author Calculations*

Table 4 shows long- and short-term results coefficient values of the co-integrated correlation between food insecurity availability, China's outward FDI in Pakistan, infrastructure development, governance, economic fitness, inflation, nominal exchange rate, trade openness, and imports from China to Pakistan. Because of data constraints, the study developed three long-short-run co-integrated models to analyze the relationship between food availability, China's outward FDI in Pakistan, and other control variables. Based on the empirical findings, models 1, 2, and 3 indicate that a 1 per cent rise in China's outward FDI in Pakistan results in a 0.13, 0.21, and 0.16 per cent increase in food availability, respectively. According to the data, there is a clear link between infrastructure development and food availability. According to the findings, an increase in infrastructure development results in a 0.17%, 0.24%, and 0.16% increase in food availability for models 1, 2, and 3, respectively. The data indicates that governance also contributes to an increase in food availability. A 1% rise in the governance index results in a 0.31% increase in food availability.

The coefficient value of ECM donates the speed of adjustment in the short run. The empirical results from models 1, 2, and 3 in Table 4 indicate adjustments of 0.31%, 0.24%, and 0.16% occurring within one year. Subsequently, the t-statistics values show the significance of the ECM coefficient values at the 1%, 5%, and 10% significance levels.

Bound Test

At the 1% level of statistical significance, the F-statistics for three (ARDL) models are found to be statistically significant, according to the conclusions of the Bounds Test for cointegration's findings. It would appear from this that the null hypothesis, which states that there are no long-term links between the variables in any model, is rejected. These findings indicate a sustainable equilibrium between the accessibility of food and the variables taken into account.

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Table 5: Results of Bounds Test

ARDL Bounds Test and model validity test						
Null Hypothesis: No long-run relationships exist						
	ARDL_1		**ARDL_2**		**ARDL_3**	
Test Statistic	Value	K	Value	K	Value	K
F-statistic	5.49***	5	5.61***	6	10.91***	6
Critical Value Bounds						
Significance	**I0 Bound**	**I1 Bound**	**I0 Bound**	**I1 Bound**	**I0 Bound**	**I1 Bound**
10%	2.75	3.79	2.53	3.59	2.53	3.59
5%	3.12	4.25	2.87	4	2.87	4
2.50%	3.49	4.67	3.19	4.38	3.19	4.38
1%	3.93	5.23	3.6	4.9	3.6	4.9

Source: *Author Calculations, Note:* ***legend****: * p<0.10; ** p<0.05; *** p<0.01*

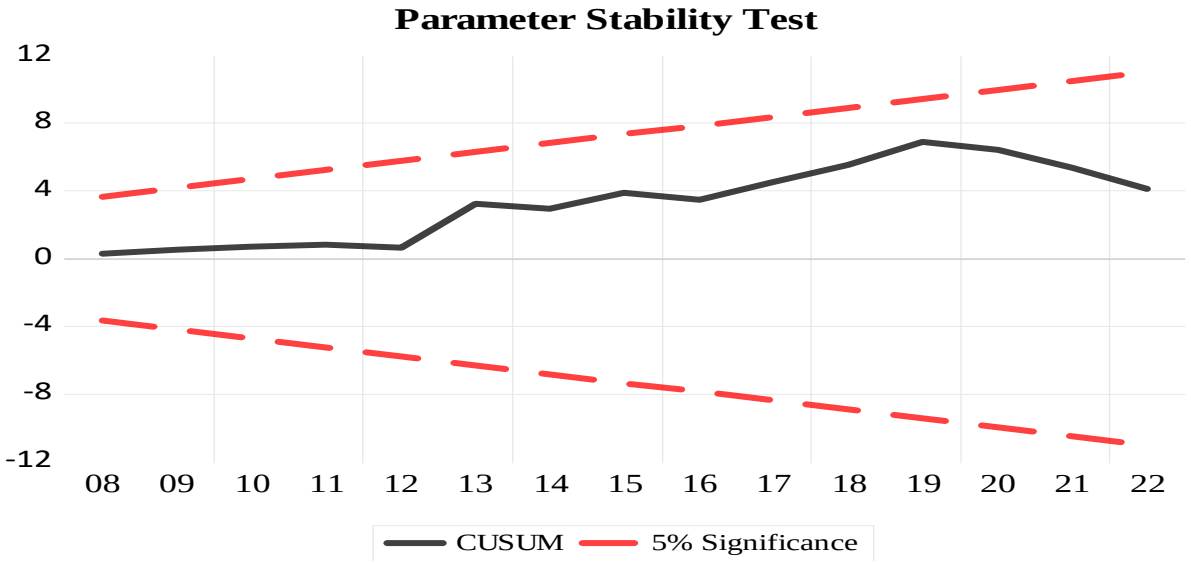

Figure 7: (Source: Author Calculations)

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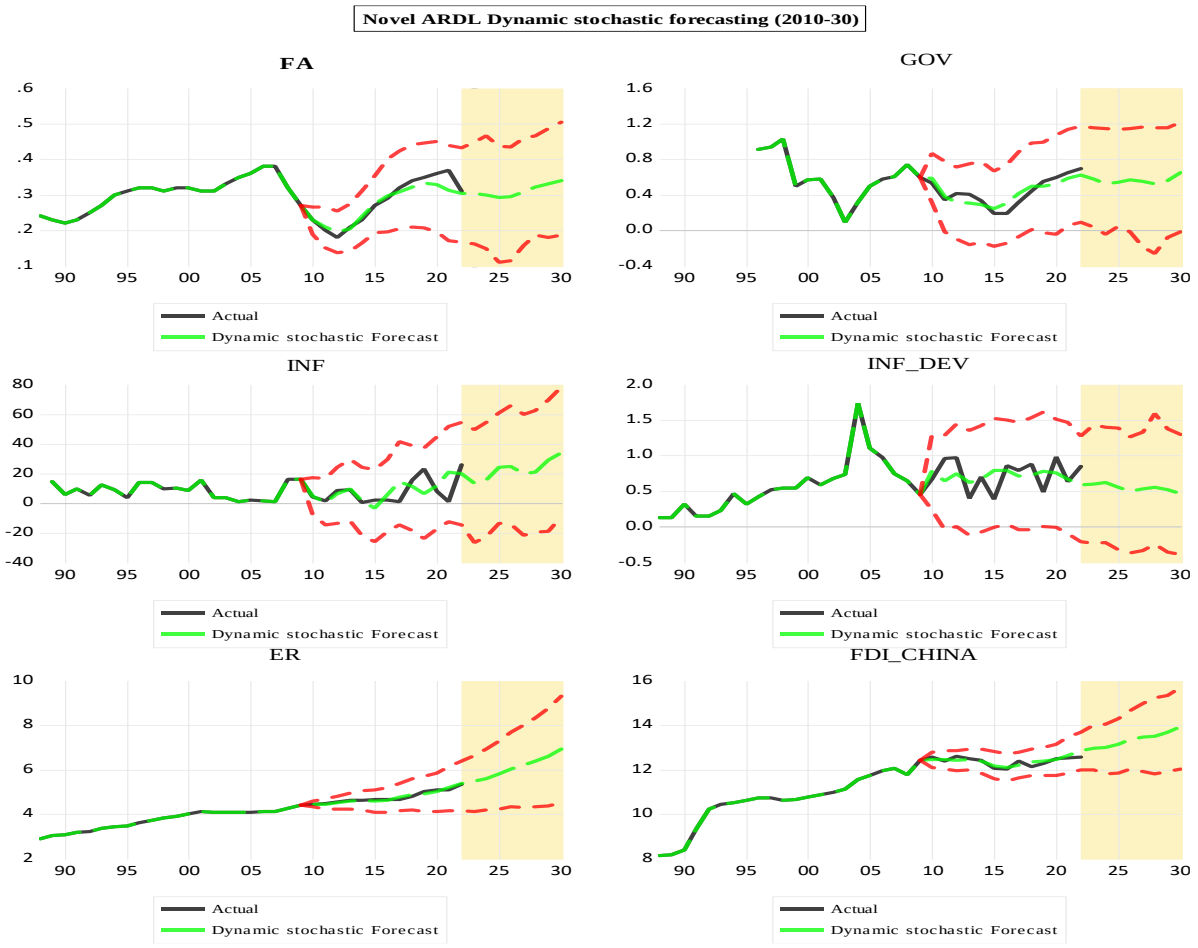

Figure 8: (**Source:** *Author Calculations*)

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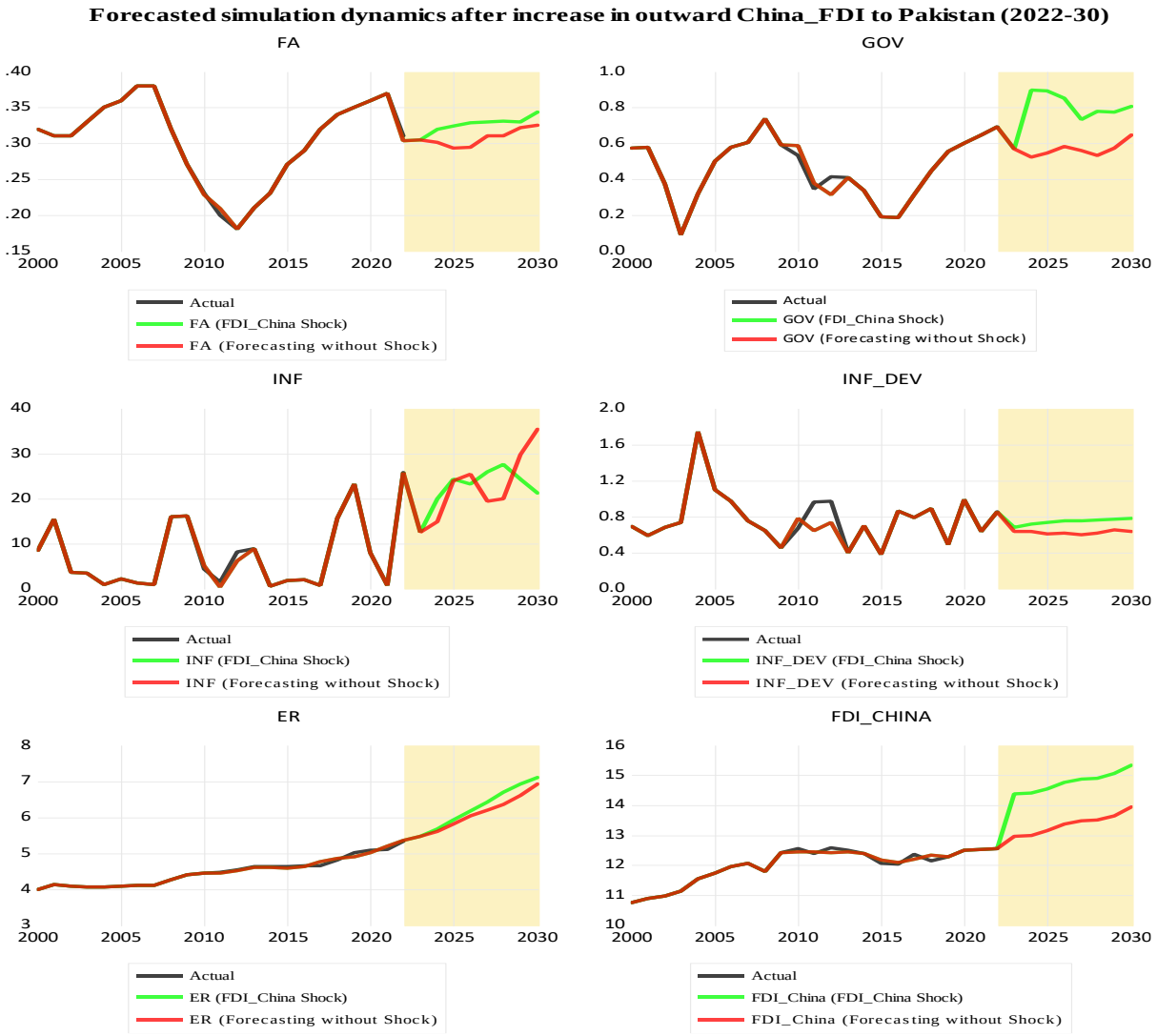

Figure 9: (**Source:** *Author Calculations*)

Figure 9, illustrates an analysis of the influence of China's China-Pakistan Economic Corridor (CPEC) investment in Pakistan, focusing on agriculture and infrastructure, revealing the favorable outcomes of China's outbound investment in Pakistan, spanning from 2015 to 2030. A Critical Analysis of the Influence of Food Availability on the Advancement of the Agricultural Sector after the China-Pakistan Economic Corridor.

Heteroskedasticity and Serial Correlation Tests

The Breusch-Pagan-Godfrey and Breusch-Godfrey LM tests suggest no heteroskedasticity or serial correlation, confirming that the model is valid in terms of constant variance and the lack of autocorrelation in residuals.

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Table 6: Heteroskedasticity and Serial Correlation Tests

Heteroskedasticity Test: Breusch-Pagan-Godfrey				**Breusch-Godfrey Serial Correlation LM Test:**			
Null hypothesis: Homoskedasticity				Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	1.267011	Prob. F(11,15)	0.3283	F-statistic	0.403776	Prob. F(2,13)	0.6759

Source: *Author Calculations, Note:* ***legend****: * p<0.10; ** p<0.05; *** p<0.01*

DISCUSSIONS

This study explores the influence of Chinese Foreign Direct Investment (FDI) on food availability in Pakistan, highlighting its positive role in enhancing food security. Results suggest that greater foreign investment, especially in infrastructure and agriculture, supports better access to food. Long-term relationships observed between food availability and variables such as FDI, governance, and economic indicators underscore the importance of aligning economic strategies with food security goals. Model diagnostics confirm the reliability of the ARDL estimations, showing no issues with heteroskedasticity or serial correlation, thus supporting robust and trustworthy results. China's FDI in Pakistan is largely concentrated in sectors like infrastructure, energy, and agriculture. These investments form part of the broader China-Pakistan Economic Corridor (CPEC), a flagship initiative aimed at boosting connectivity and economic development. Key projects include transportation infrastructure (roads, ports, and railways), energy generation (power plants, renewable energy), and agricultural enhancements (irrigation, cold storage). These projects contribute directly to food availability by reducing transport costs, improving supply chains, and increasing agricultural productivity. Institutional quality plays a crucial role in shaping the outcomes of these investments. Strong governance, legal enforcement, and administrative efficiency support effective implementation, while corruption, instability, and policy inconsistency can reduce project success and hinder food access. Strengthening institutions can enhance the sustainability and reach of infrastructure improvements, positively influencing agricultural output and distribution. Food availability depends on factors like market access, pricing, and nutritional quality. China's investment projects—especially those improving logistics and storage—facilitate better integration of markets, reduce post-harvest losses, and help maintain stable food supplies. However, such development must be mindful of possible environmental and social consequences, including ecosystem degradation and displacement of communities. Economic strength and resilience are key to navigating global challenges. Sustainable economic development requires fostering innovation, increasing productivity, and ensuring adaptability. Indicators like the Consumer Price Index (CPI) provide insight into inflation and living costs, influencing broader economic policy and food affordability. To empirically assess the relationship between FDI, infrastructure, and food security, the study applies time series techniques such as the ARDL model. Stationarity tests (ADF and Phillips-Perron) confirm data suitability. Results show that a 1% rise in Chinese FDI leads to a 0.13%–0.21% increase in food availability, while infrastructure development contributes an additional 0.16%–0.24%. Improvements in governance are also strongly associated with better food outcomes. Error correction terms suggest that deviations from equilibrium adjust within a year, underscoring the dynamic nature of these interactions. Chinese investment, particularly under CPEC, affects

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multiple sectors critical to food security. In agriculture, technology transfer such as precision farming, biotechnology, and sustainable practices enhances productivity and resource efficiency. Demonstration centers established by China help train local farmers and introduce modern techniques, contributing to increased yields and improved food availability. Enhanced transport infrastructure reduces delivery times and spoilage, helping ensure fresh produce reaches consumers promptly. Reliable electricity, another focus of Chinese investment, is essential for running cold storage units and processing plants. Energy projects under CPEC, like the Sahiwal coal-fired power plant (1320 MW), have improved energy access and minimized outages affecting agriculture and food logistics. Water management projects, especially those supporting irrigation, have also proven vital in increasing crop productivity, particularly in Pakistan's arid regions. Efficient irrigation systems ensure consistent yields and help stabilize the food supply. However, realizing the full potential of Chinese FDI depends on institutional support and environmental safeguards. Transparency and legal protections are necessary to ensure that investments serve the public interest. A robust legal framework can minimize environmental damage and uphold labor rights while providing investors with a stable and predictable environment. To optimize these investments, local capacity building is essential. This includes training programs, technical expertise, and strong local institutions to manage and maintain projects. Agricultural extension services must be empowered to disseminate new knowledge and practices effectively. The development of Gwadar Port under CPEC has enhanced Pakistan's trade capacity, lowering export costs for agricultural products and improving global market access. This not only stabilizes domestic food prices but also contributes to national food security. Nonetheless, large infrastructure projects may have environmental impacts such as air pollution from coal plants and the displacement of communities. Addressing these challenges through inclusive and sustainable planning is essential to ensuring long-term benefits. Equitable distribution of gains, fair compensation, and proper resettlement policies are necessary for maintaining social harmony and sustainable livelihoods. While Chinese investment brings many benefits, overreliance on a single source of funding increases vulnerability. Diversifying investment partners and strengthening domestic systems are important steps toward sustainable development. Political and security stability are also crucial for ensuring the success and continuity of these projects. In conclusion, Chinese FDI and infrastructure development significantly contribute to improving food security in Pakistan by enhancing agricultural production, logistical efficiency, and access to markets. However, the success of these initiatives hinges on institutional quality, environmental sustainability, and inclusive governance. Policymakers should prioritize attracting more targeted foreign investment while addressing governance and ecological concerns. These findings offer valuable insights for strategic planning to secure long-term food security and sustainable development in Pakistan.

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CONCLUSIONS AND FUTURE PERSPECTIVE

The study highlights the positive impact of Chinese Foreign Direct Investment (FDI) on food availability in Pakistan, revealing that investments in infrastructure, energy, and agriculture under the China-Pakistan Economic Corridor (CPEC) enhance transportation efficiency, market connectivity, and agricultural productivity. These developments reduce transport costs, improve supply chains, and contribute to greater food accessibility. The success of such projects is closely tied to the quality of Pakistan's institutions, as effective governance, regulatory consistency, and legal frameworks are essential for project implementation and sustainability. Conversely, issues like corruption, political instability, and weak enforcement mechanisms can limit the potential benefits of FDI. Econometric analysis using the Autoregressive Distributed Lag (ARDL) model confirms a significant and positive relationship between Chinese FDI, infrastructure development, governance quality, and food availability, supporting the notion that strategic investment and institutional strength are crucial for food security. Chinese investments not only bring capital but also facilitate the modernization of agricultural technologies, such as advanced irrigation systems and precision farming tools, which are vital for boosting productivity and minimizing post-harvest losses. Additionally, these investments expand market access for Pakistani agricultural products, promoting exports and stabilizing domestic food prices.

Future research directions could involve sector-specific analyses to uncover more detailed impacts of Chinese investment on individual agricultural subfields like crop production or fisheries, and could also assess the degree and effects of technology transfer through Chinese projects. Moreover, evaluating the environmental sustainability and social implications, including labor practices and land use, is essential to ensure long-term, equitable development. Investigations into the role and capacity of local institutions, such as provincial governments and district authorities, are also recommended to understand how local governance can support or hinder the realization of FDI benefits. Finally, exploring the long-term sustainability of food systems influenced by these investments especially concerning climate change, water management, and food price volatility would provide a more comprehensive understanding of how foreign investments shape food security outcomes in Pakistan.

List of Abbreviations

ADLR: Augmented Distributed Lag Regression

ADF: Augmented Dickey–Fulle

FDI: Foreign Direct Investment

BRI: Belt & Road Imitative

FD: Food Security

SDGs: Sustainable Development Goals

CPEC: China-Pakistan Economic Corridor

EF: Economic Fitness

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Inf_Dev: Infrastructure development index

ER: Nominal Exchange Rate

CPI: Consumer price index

Gov: Governance Index

EF: Economic Fitness

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We declare that there is no conflict of interest in submission of this research work.

Authors contribution

Hasan Raza Jafri: conceptualization, writing manuscript, data analysis and drawn graphs and images, Shaoyuan Wang: conceptualization supervision, data analysis and revision, Zulfiqar Ali: data analysis, reviewing, editing , Jun Zhang: data analysis, supervision and revision, Muhsin Ali: data analysis, reviewing, editing, Abdorahman Abdillahi Waberi: reviewing, editing, Syed Muhammad Ammar Shah Kakakhel: reviewing, editing, Zeeshan Tariq, reviewing, editing, Ghulam Mustafa: reviewing, editing.

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