The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0144-3585.htm

Role of climate change in altering global agricultural trade dynamics: an empirical analysis

Journal of Economic Studies

765

Received 15 December 2024
Revised 8 May 2025
Accepted 12 May 2025

Zubair Tanveer
Department of Economics and Quantitative Methods, University of Management and Technology, Lahore, Pakistan and National Tariff Commission, Islamabad, Pakistan
Rukhsana Kalim
Department of Economics and Quantitative Methods, University of Management and Technology, Lahore, Pakistan, and
Noman Arshad
Department of Business Analytics, Business School, Sunway University, Petaling Jaya, Malaysia

Abstract

Purpose – The study investigates the impacts of climate change on global agricultural trade. It aims to analyze how temperature and precipitation, along with proposed macroeconomic factors such as agricultural productivity, tariff rate, exchange rate, price and technological innovations influence the worldwide trade balance of agricultural products.

Design/methodology/approach – The research employs the Panel Quantile ARDL model using a two-step ECM with a pooled means group (PMG) specification technique. Data spanning 23 years (2000–2022) from 166 countries is analyzed, incorporating climatic variables (temperature and precipitation) and economic factors to determine their effects on agricultural trade.

Findings – The study reveals that the average annual temperature significantly affects global agricultural trade, with a positive impact on exports up to a certain threshold, beyond which the relationship becomes detrimental. This indicates a nonlinear, inverted U-shaped relationship, where regions with moderate temperature increases can benefit, but excessive warming harms trade performance. Agricultural total factor productivity and technological innovations consistently enhance agricultural exports, with a stronger impact observed in countries with higher export-to-import ratios. On the other hand, factors like higher tariff rates and unfavorable relative world prices hinder trade competitiveness, especially in net-exporting regions. Precipitation levels alone were found to have an insignificant effect, suggesting that temperature is a more critical climatic variable influencing agricultural trade dynamics.

Practical implications – Policymakers should promote precision agriculture, boost productivity and adjust trade policies to strengthen export performance and food security. Given that climate and economic shocks affect net-exporting and net-importing regions differently, tailored strategies are essential to ensure trade resilience and climate equity.

Originality/value – This research uniquely applies a global-level quantitative analysis to agricultural trade and climate change, introducing a quadratic relationship between climatic variables and trade dynamics. It addresses gaps in existing literature by using extensive, real-world data rather than projections.

Keywords Climate change, Trade patterns, Comparative advantage, Agriculture products, Panel quantile ARDL model

Paper type Research paper

1. Introduction

Climate change, driven by greenhouse gas emissions and characterized by frequent extreme temperatures, glacial melting, volatile spells of precipitations and droughts, considerably affects sectoral and regional production and consumption worldwide (Dellink *et al.*, 2017). Climate change directly disrupts trade patterns and specialization through distribution chains and transportation routes and indirectly by altering the productivity of factors of production and tastes (Dellink *et al.*, 2017; Schenker and Stephan, 2014). The World Trade Organization

Journal of Economic Studies
Vol. 53 No. 4, 2026
pp. 765-788

e-ISSN: 1758-7387
p-ISSN: 0144-3585
DOI 10.1108/JES-12-2024-0829

(WTO) emphasizes that climate change substantially threatens future growth and prosperity, reshaping countries' economic and trade prospects. Many nations stand to see their comparative advantages change, with agriculture and certain manufacturing sectors being particularly vulnerable to climate impacts (WTO, 2022a, b).

The world is facing a pressing food insecurity problem as the Global Report on Food Crisis 2024 (FSIN, 2024) revealed that around 282 million people experienced acute food insecurity in 59 countries/territories during 2023. Among them, one-fourth are affected by weather extremes alone. Moreover, evidence shows that household food insecurity is directly and indirectly affected by climate change (Alam *et al.*, 2016). In this scenario, agricultural output and trade play an important role in alleviating the negative consequences of climate change and redistributing food among those who lack or have a shortage of it (FAO, 2018; WTO, 2022a).

The rise in global temperatures, contributing to a decline in agriculture and light manufacturing (Jones and Olken, 2010), is expected to disproportionately affect nations that heavily rely on agriculture exports (IPCC, 2022; Jägermeyr *et al.*, 2021). However, some nations may still have the potential to improve their agricultural productivity and emerge as leading exporters (FAO, 2018). In contrast, warmer countries might increasingly shift toward developing less climate-sensitive sectors such as manufacturing and services, thereby altering their comparative advantages (Conte *et al.*, 2020; Nath, 2022). This shift is especially likely as evidence shows that a 1 °C rise in temperature can reduce the annual export growth of developing countries by 2.0–5.7% points (Jones and Olken, 2010).

Agriculture sector contributes about 4% to the global GDP (FAO, 2021), and trade of agricultural products accounts for around 8% of total merchandise trade worldwide (see Figure 1), which is very crucial to tackle the food insecurity problem of the world under the prediction of a growing population to almost 10 billion by 2050 (UNDESA, 2022). Climate change has a direct impact on agriculture productivity (Farooq *et al.*, 2023; Ortiz-Bobea *et al.*, 2021; Ray *et al.*, 2019; Rosenzweig *et al.*, 1994), resultantly influences trade patterns and comparative advantages (WTO, 2022a, 2023). Moreover, trade redistributes surplus food to deficit regions, supporting food security and climate change challenges (Bozzola *et al.*, 2023; FAO, 2018), allowing a country facing a reduction in agricultural production to import crops with reduction in yield and export other crops with stable production owing to climatic conditions (Costinot *et al.*, 2016).

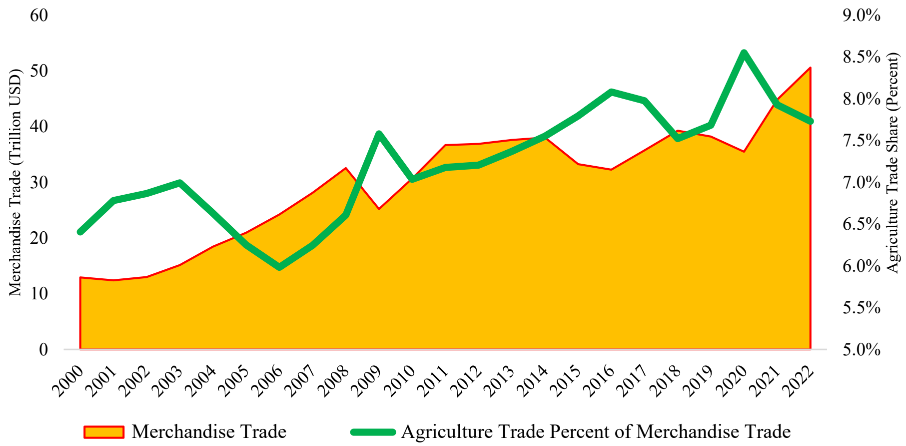

Figure 1. Agriculture trade share in total merchandise trade. Source: FAOSTAT

Moreover, evidence reveals that countries in warmer climates, closer to the equator, have been profoundly affected by climate change, resulting in agricultural production declines (IPCC, 2019; Sun *et al.*, 2019). Most of them are developing economies (IPCC, 2019) with limited adaptive capacity (Reilly and Hohmann, 1993), insufficient infrastructure (WTO, 2022a), limited technological access, and weaker institutions (Acemoglu *et al.*, 2002). Projections from various studies strongly suggest that warmer countries may face adverse shocks, whereas colder countries could potentially experience increased agricultural productivity due to climate change (FAO, 2018; Farooq *et al.*, 2023; IPCC, 2019; WTO, 2022a).

Documented rationally, differences in climatic conditions are the source of comparative advantage of the nations (Bozzola *et al.*, 2023; Lamonaca *et al.*, 2024). Climatic-induced changes in temperature and precipitation may damage the agricultural production of one country, reducing its exports while favoring another nation by enabling it to grow more agricultural products and reduce its imports. Put differently, warmer countries that are net exporters of farm products may suffer severely from global warming, while colder countries that are net importers of agricultural products may benefit from global warming and reduce their agrarian imports by increasing production. This will have multiple dynamics, influencing trade patterns, consumer preferences, exchange rate variations, sectoral shifts, and more. This phenomenon is discussed and recently empirically analyzed by Lamonaca *et al.* (2024).

There is limited research on the influence of climate change on trade (Dellink *et al.*, 2017). Most of the literature has explored trade as a tool or mechanism for adapting international standards to improve environmental quality, where a number of researchers found that trade had improved environmental quality (Ali *et al.*, 2021; Blyde and Ramirez, 2022; Ibrahiem and Hanafy, 2021; Rahman and Vu, 2021) while some others opposed it (Al-Mulali and Ozturk, 2015; Al-Mulali and Sheau-Ting, 2014; Yang and Li, 2019; Zhou *et al.*, 2020). However, studies regarding the investigation of the impacts of climate change on trade mainly deal with climate change-induced disruptions in supply chains and transportation networks, which can lead to delays, escalated costs, and potential shifts in trade patterns (Dellink *et al.*, 2017, 2019; Hummels, 2007).

Some studies like Juliá and Duchin (2007), Reilly and Hohmann (1993) have investigated how climate change affects international trade in agricultural products and found that trade can adapt to changes in comparative advantage and satisfy global demand in various climate scenarios. Additionally, Dellink *et al.* (2017) conducted a comprehensive analysis combining qualitative and quantitative analyses to assess the direct and indirect impacts of climate change on agriculture trade. These analyses projected a slight decrease in agricultural trade, but countries with relatively larger and diverse markets would demonstrate greater resilience. Moreover, recent literature Bozzola *et al.* (2023), Lamonaca *et al.* (2024) examined how long-term climate conditions influence agri-food exports and the trade patterns of 20 partner countries and concluded that higher marginal temperatures and rainfall levels benefit countries' exports. The authors found that the greater the disparities in climate characteristics between trading partners, the higher the value of bilateral exports. These effects vary between developing and developed countries.

The present study empirically investigates the impact of climate change on the trade of agricultural products at the global level. This analysis makes several contributions that distinguish it from existing literature. First, it covers the trade of all agrarian products listed in FAOSTAT, offering a comprehensive commodity-level perspective that has not been examined in previous studies. Second, to the best of our knowledge, a global-scale empirical analysis on this topic is lacking. Our study addresses this gap by utilizing a panel dataset of 166 countries over a 23-year period (2000–2022). Third, while existing studies often rely on projected climate scenarios, this research uses observed historical data from 2000 to 2022, providing an evidence-based analysis of real-world climate–trade dynamics. Fourth, the study introduces a non-linear specification by incorporating squared terms of temperature and precipitation, capturing the possibility of threshold effects where moderate climate changes may enhance agricultural trade, but extreme changes may hinder it. This concept aligns with recent approaches such as Bozzola *et al.* (2023), Lamonaca *et al.* (2024), though our study applies it across a much broader global context. Finally, the study adopts a panel quantile ARDL modeling framework, which enables the estimation of both short-run and long-run effects and captures heterogeneous impacts across different levels of agricultural trade balance, offering a richer understanding of the distributional effects of climate change.

The conceptual foundation of this study rests on the connection of climate economics and international trade theory, particularly focusing on the determinants of agricultural trade balances under climate variability. According to neoclassical trade theory, relative prices, tariffs, and exchange rates influence trade flows by affecting countries' comparative advantages (Berkum and Maiji, 1998; Costinot, 2009; Krugman *et al*., 2018; Ricardo, 1817; Salvatore, 2019). In agriculture, however, these market-based determinants are increasingly mediated by climatic factors, such as temperature and precipitation, which directly influence production potential and indirectly alter trade performance through changes in yields, costs, and supply stability (Dell *et al*., 2012; Hertel *et al*., 2010; Lamonaca *et al*., 2024).

This study conceptualizes the agricultural trade balance (export-to-import ratio) as the outcome of a combination of climatic variables (average temperature, precipitation, and their squared terms to capture nonlinear effects) and economic drivers (export-import price ratio, tariffs, and exchange rates). The theoretical justification stems from the Ricardian framework, which postulates that productivity differences, driven here by climatic suitability, form the basis of trade (Costinot *et al*., 2016). Moreover, the structure recognizes that the impact of these variables may differ across the distribution of countries based on their trade balance status (e.g. net exporters vs. net importers), justifying the use of a quantile regression approach (Koenker and Bassett, 1978; Koenker and Xiao, 2006). The ARDL structure allows for distinguishing short-run shocks from long-run equilibrium relationships, capturing both the immediate and persistent effects of climatic and economic shocks on trade (Pesaran *et al*., 1999).

2. Literature review

The relationship between climate change and international trade, particularly concerning primary goods, bears significant consequences (FAO, 2018, 2022; WTO, 2022a). Climate-driven disruptions can disrupt the production and distribution of primary goods, leading to shift trade pattern (Conte *et al*., 2020; Nath, 2022; WTO, 2022b). Recognizing the destructive effects of climate change on crucial trade infrastructure underscores the urgency of developing adaptable strategies to ensure the resilience of primary goods trade in the face of these challenges. Studies like Bozzola *et al.* (2023), Dellink *et al.* (2017, 2019), FAO (2022) stated that the literature focuses mainly on the trade consequences of climate change mitigation policies or the effects of trade policies on greenhouse gas emissions. Dedicated analyses that look at the long-term impacts of climate change on international trade are still very scarce.

However, some studies discussed the direct impacts of climate change on trade through disruption of supply chains and transportation networks, which could lead to delays, escalated costs, and potential shifting trade patterns (Dellink *et al*., 2017; Hummels, 2007). The consensus among researchers is that the transportation infrastructure is crucial to global trade and is adversely affected by climatic conditions. This proposition is underlined by Burkett *et al*. (2014), documenting a risk to all forms of transportation, including air, land, and sea, to global warming. Although some research suggests that Arctic shipping and associated supply chains may gain, the consensus points to adverse outcomes (Hansen *et al*., 2016; Liu and Kronbak, 2010).

To calculate economic loss or gain in the form of consumer surplus, producer surplus, and government payments, Reilly *et al*. (1994) looked at the impact of climate change on agriculture through trade and concluded that different climatic scenarios depicted varying implications across various regions. Furthermore, Juliá and Duchin (2007) evaluated the economic adjustment mechanism through trade in response to the effects of climate change on agriculture and found that trade encounters the global food requirement even in the face of changing weather patterns.

Furthermore, Calzadilla *et al*. (2013) used a global computable general equilibrium model including water resources (GTAP-W) to assess climate change impacts on global agriculture. A joint analysis of climate variables (precipitation, temperature, river flow and CO_2 fertilization) affecting agricultural production shows that global food production declined by around 0.5% in the 2020s and around 2.3% in the 2050s. Only the most adversely affected regions experience a deterioration in their terms of trade and a decline in welfare. Other areas less affected by climate change may experience welfare gains because their relative competitive position improves. Macedo *et al*. (2020) incorporated climate variability and non-tariff measures into a gravity model of Port wine exports, showing that rising temperatures and climate anomalies in importing countries negatively affect trade flows. Their findings highlight the growing importance of climatic factors alongside traditional economic variables in shaping international trade.

Many studies have looked at how climate and environmental issues affect trade such as Cagatay and Mihci (2006) showed that trade openness can have both good and bad effects on the environment, and they stressed the need to include environmental factors when studying trade. Santeramo (2022) explained how environmental rules, like technical trade measures, can sometimes act as hidden trade barriers. Koska *et al*. (2021) further demonstrated that tariffs and commodity taxes can serve as strategic environmental tools when consumption of imported goods generates pollution, highlighting the role of asymmetries in countries' pollution disutility. In another study, Santeramo *et al*. (2024) warned that climate policies might lead to protectionism if not properly managed under global trade agreements. Later, Santeramo *et al*. (2025) discussed how these technical measures, if not fair, can increase trade inequalities.

Dellink *et al*. (2017) estimated the effects of climate change on international trade and how trade can mitigate the costs of climate change. The study examined direct impacts on infrastructure and transport routes and indirect impacts resulting from changes in resources and production. Direct effects are analyzed qualitatively through a literature review, while the OECD's ENV-Linkages model, a dynamic computable general equilibrium model, was used to assess the indirect impacts on agricultural trade. The authors projected climate change-induced yield shocks resulting in significant losses in agricultural productivity. Moreover, trade of agricultural commodities was projected to decline slightly, mainly due to reduced yields and demand for other commodities, resulting in a 3% decrease in food product trade compared to the overall trade decline of 0.6%. Moreover, the authors highlighted those countries with larger domestic markets and diversified trade patterns would be better positioned to withstand climate shocks.

Bozzola *et al*. (2023) and Lamonaca *et al*. (2024) examined the long-run impacts of climate change on agri-food exports in a sample of 20 developing and developed countries. The authors used a 30-year moving average of climate variables for structural effects of climate change. They found that higher temperatures and rainfall positively impact agri-food exports and estimated the quadratic relationship between climate change and the export of agri-food. Moreover, the gravity model results revealed that greater climatic differences between trading partners lead to higher bilateral export values. Additionally, it highlighted that developed and developing countries respond differently to climate change. The literature highlights the vulnerability of trade patterns and infrastructure to climate-induced disruptions, underscoring the need for adaptive strategies. While the existing research provides limited insights into the impact of climate change on the trade dynamics of agricultural products, a gap remains in comprehensive, long-term analyses which the present study is trying to fill. Recently, Liang *et al*. (2025) found mixed effects of CO_2 emissions on bilateral export in selected Asian countries. The authors documented that CO_2 emissions might increase exports by altering production pattern but reduced trade through environmental degradation.

3. Data description

The details of the variables used for analysis are given in Table 1, briefly explaining the names, short descriptions, and sources. The study period is from 2000 to 2022, subject to the availability of trade data taken from FAOSTAT. Moreover, the World Bank's Climate Change Knowledge Portal (CCKP) is a source of climatic variables like average annual temperature and precipitation. Similarly, variables like exchange rate, tariff rate, export and import price, and technological innovations are extracted from World Development Indicators (WDI) from 2000 to 2022, and worldwide data of index of agriculture total factor productivity is taken from the United States Department of Agriculture (USDA) for the study period. These data sources are publicly available, provide reliable data, and are widely recognized for their accuracy and comprehensiveness in the respective fields.

The correlation matrix for the study variables is depicted in Table 2. The export-to-import ratio of agricultural products is positively associated with temperature [1], precipitation, and exchange rate and negatively associated with agricultural TFP, tariff rate, prices of traded goods, and technological innovations. Moreover, temperature and precipitation are directly associated with the export-to-import ratio of agricultural products and indirectly associated

Table 1. Details of the variables

Variable	Symbol	Description	Source	Time
Export-to-import ratio	EIR	Export to import ratio of agriculture products	FAOSTAT	2000 to 2022
Temperature	TEMP	Average mean temperature over the aggregation period (unit °C)	CCKP	2000 to 2022
Precipitation	PREC	Aggregated accumulated precipitation (unit mm)	CCKP	2000 to 2022
Agriculture TFP	ADTFP	Index of agricultural total factor productivity, 2015 = 100	USDA	2000 to 2022
Exchange rate	EXRT	Official exchange rate (LCU per US$, period average)	WDI	2000 to 2022
Tariff rate	TFRT	Simple mean applied tariff is the unweighted average of effectively applied rates for all products subject to tariffs calculated for all traded primary goods	WDI	2000 to 2022
Ratio of export to import price	PRICE	Ratio of export unit value index (2015 = 100) and import unit value index (2015 = 100)	WDI	2000 to 2022
Technological innovations	PTNT	Residential and non-residential patent applications	WDI	2000 to 2022

Source(s): Authors' own work

Table 2. Correlation matrix of the variables used for the analysis

	EIR	TEMP	PREC	AGTFP	EXRT	TFRT	PRICE	PTNT
EIR	1							
TEMP	0.006	1						
PREC	0.050	0.283	1					
AGTFP	−0.040	0.133	−0.021	1				
EXRT	0.020	0.137	0.053	−0.034	1			
TFRT	−0.105	0.252	0.027	0.021	0.015	1		
PRICE	−0.105	−0.001	0.035	−0.003	−0.022	−0.064	1	
PTNT	−0.033	−0.159	−0.034	0.000	−0.026	−0.032	0.008	1

Source(s): Authors' own work

with technological innovations. Since there are no strong or perfect correlations between any pair of the variables in the dataset, it may be concluded that multicollinearity is not a serious concern. Strengthening further, a Table A2 depicting the Variance Inflation Factor (VIF) of the study variables is given at Appendix 1 which confirms that there are no multicollinearity concerns, and these variables can be appropriately included without any econometric issues.

Table 3 represents summary statistics of the study variables. It is revealed that all variables except agricultural TFP and price ratio have substantially different mean and median values with relatively large standard deviation values. Moreover, skewness and kurtosis values suggest that distributions of most variables are not normal, containing significant outliers and variability. Besides, estimated values of the Jarque-Bera test reject the null hypothesis of normal distribution for all variables, indicating the presence of outliers and probable non-linear relationships within the dataset.

4. Methodology

The study aims to estimate the impact of climate change on the trade of agricultural products. For an adequate econometric model and considering the extent of dataset spanning from 2000 to 2022 for 166 countries, unit root analysis is performed through various tests such as Levin, Lin and Chu (LLC), Pesaran and Shin (PS) W-stat, Augmented Dickey-Fuller (ADF), and Phillips-Perron (PP) (Levin *et al*., 2002) as applied in prior studies (Hanif *et al*., 2023; Iqbal *et al*., 2023). Additionally, cointegration tests for the dataset are also performed to identify the long run relationship among the variables. Based on descriptive statistics like kurtosis, skewness, and Jarque-Bera, VIF outcomes, as well as the outcomes of unit root analysis and cointegration test, and to achieve the study objectives, the panel quantile ARDL (PQARDL) using two step ECM with pooled means group (PMG) specification technique is found to be appropriate econometric model for empirical analysis. The PMG specification estimates long run homogenous while short run heterogenous coefficients (Blackburne and Frank, 2007).

The quantile regression model (QR) has been increasingly using for empirical investigations (Alqaralleh and Hatemi-J, 2024; Amoh *et al*., 2024; Isayev *et al*., 2024; Kebede and Tawiah, 2023; Ledhem and Mekidiche, 2022) and being a median-based regression, has several advantages over mean-based regression such as robustness to outliers and no need for normal error term distribution (Agung, 2021; Koenker and Bassett, 1978). Moreover, using linear programming methods, QR provides a more comprehensive view of the distribution of dependent variable (Agung, 2021; Davino *et al*., 2014). Furthermore, quantile regressions are robust to heteroscedasticity, as they do not assume constant variance of the error term across observations, ensuring consistent estimation even under heteroscedastic conditions (Koenker and Xiao, 2004, 2006). Similarly, the ARDL structure,

Table 3. Descriptive statistics of the variables used for the analysis

Statistics	EIR	TEMP	PREC	AGTFP	EXRT	TFRT	PRICE	PTNT
Mean	1.01	18.87	917.48	97.23	1,801,699	10.99	1.02	12000.41
Median	0.63	22.23	701.05	97.37	15.35	8.54	1.00	53.00
Standard deviation	1.63	8.43	860.51	18.47	11,000,000	7.83	0.19	81174.80
Range	22.17	46.38	4761.13	219.40	67,200,000	99.40	2.04	159,000
Skewness	6.89	−0.81	1.13	1.31	61	2.55	1.03	12.18
Kurtosis	71.45	2.75	3.95	9.21	3,731	17.79	7.26	186.77
Jarque-Bera	771,417	439.83	972.69	7318.24	2,160,000	27,884	3397.57	556,000
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Observations	3798.0	3885.00	3885.00	3862.00	3733.00	2734.0	3645.00	3885.0

Source(s): Authors' own work

particularly when used in panel settings, addresses potential endogeneity by incorporating lagged explanatory variables, which serve as internal instruments, reducing simultaneity and reverse causality biases (Chen *et al.*, 2023; Pesaran *et al.*, 1999; Sam *et al.*, 2019). This specification captures both short-run fluctuations and long-run relationships across quantiles, and it aligns with the autoregressive frameworks discussed by Santeramo (2022). Besides these, by explicitly including lagged dependent and independent variables, the model accounts for dynamic persistence and is thus robust to autocorrelation in the error term, enhancing efficiency and reliability of coefficient estimates (Cho *et al.*, 2015). Therefore, the PQARDL model is robust to endogeneity, heteroscedasticity, autocorrelation, and outliers (Ebi and Bowen, 2016; Galvao, 2011; Zheng *et al.*, 2024).

Apart from this, we conducted additional robustness checks to confirm the reliability of our results. These include the use of variance inflation factor (VIF) diagnostics to assess multicollinearity, alternative lag specifications, and the application of Wald tests to verify the joint significance of key coefficients across quantiles. The consistency of the results across these diagnostics reinforces the robustness and validity of our empirical findings. These features make the PQARDL model a powerful and reliable tool for uncovering complex, non-linear, and distributional effects of climatic and economic variables on agricultural trade balance. Empirically several studies have used this technique such as Arshed (2023), Arshed *et al*. (2023), Iqbal *et al*. (2023), Jahanger *et al*. (2022), Kakar *et al*. (2024), Sohail and Arshed (2022), Ul-Durar *et al*. (2023, 2024, 2025), Wang *et al*. (2024).

The selected econometric model given in Equations (1) and (2) offers a quantile-wise estimation of the export-to-import ratio in response to the chosen regressors. The following econometric models are used for estimation:

$$\begin{aligned}\mathrm{EIRAG}_{it\tau} = {} & \alpha_{0\tau} + \alpha_{1\tau}TEMP_{it} + \alpha_{2\tau}TEMP_{it}^2 + \alpha_{3\tau}PREC_{it} + \alpha_{4\tau}PREC_{it}^2 + \alpha_{5\tau}AGTFP_{it} \\ & + \alpha_{6\tau}EXRT_{it} + \alpha_{7\tau}TFRT_{it} + \alpha_{8\tau}PRICE_{it} + \alpha_{9\tau}PTNT_{it} + \varepsilon_{it} \qquad (1)\end{aligned}$$

$$\begin{aligned}\Delta\mathrm{EIRAG}_{it\tau} = {} & \alpha_{0\tau} + \alpha_{1\tau}\Delta TEMP_{it} + \alpha_{2\tau}\Delta TEMP_{it}^2 + \alpha_{3\tau}\Delta PREC_{it} + \alpha_{4\tau}\Delta PREC_{it}^2 \\ & + \alpha_{5\tau}\Delta AGTFP_{it} + \alpha_{6\tau}\Delta EXRT_{it} + \alpha_{7\tau}\Delta TFRT_{it} + \alpha_{8\tau}\Delta PRICE_{it} \\ & + \alpha_{9\tau}\Delta PTNT_{it} + \delta_\tau \mathrm{ECM}_{it-1} + \mu_{it} \qquad (2)\end{aligned}$$

The above equations show the econometric model used for the estimation. The dependent variable is the export-to-import ratio of agricultural products (EIRAG), and core independent variables include temperature (TEMP) and precipitation (PREC) as proxies for climate change used by various researchers (Bozzola *et al.*, 2023; Calzadilla *et al.*, 2013; Janssens *et al.*, 2020) along with some control variables like agricultural total factor productivity (AGTFP), exchange rate (EXRT), tariff rate (TFRT), ratio of export unit value to import unit value (PRICE) and technological innovations (PTNT). Moreover, the econometric model also uses squares of temperature and precipitation to check the quadratic relationships of climate change with the trade of agricultural products. The purpose of polynomial terms is to check whether the degree of the impact of climatic conditions changes with changes in climatic variables and to find to which extent temperature and precipitation play a positive/negative role. This phenomenon is not rigorously investigated in the literature, nevertheless, recently (Bozzola *et al.*, 2023) estimated it for agri-food trade using moving average temperature values and Liang *et al.* (2025) examined the effects of CO_2 emissions on bilateral export in selected Asian countries.

5. Results

The outcomes of unit root analysis performed using the Levin, Lin and Chu test, Pesaran and Shin test, ADF – Fisher test, and PP – Fisher tests are given in Table 4. Most variables are

Table 4. Outcomes of unit root analysis and panel cointegration test

Variables	Levin, Lin and Chu	Pesaran and Shin W-stat	ADF – Fisher Chi-square	PP – Fisher Chi-square
Export to import ratio of agriculture products	−14.370	−12.007	734.57	771.385
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Agriculture TFP	−7.579	−6.515	470.412	654.668
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Temperature	−24.307	−22.814	1278.55	1380.79
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Temperature square	−25.616	−23.141	1305.38	1383.99
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Precipitation	−29.526	−38.709	2146.51	3462.93
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Precipitation square	−31.788	−38.689	2144.91	3569.60
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Innovation	−4.823	−10.397	577.559	872.875
I(0)	(0.000)	(0.000)	(0.000)	(0.000)
Exchange rate	3.9564	29.591	199.981	333.236
I(0)	(1.000)	(1.000)	(1.000)	(0.119)
Exchange rate	−7592.21	−2790.87	3500.90	3514.13
I(1)	(0.000)	(0.000)	(0.000)	(0.000)
Tariff rate	13.216	−10.517	664.892	703.343
I(0)	(1.000)	(0.000)	(0.000)	(0.000)
Tariff rate	−58.647	−49.025	2252.42	3091.45
I(1)	(0.000)	(0.000)	(0.000)	(0.000)
Price ratio	−8.229	−3.1424	399.068	418.84
I(0)	(0.000)	(0.000)	(0.008)	(0.001)
Kao panel cointegration test				
ADF	*t*-statistic		Probability	
	−3.352		0.0004	

Source(s): Authors' own work

stationary at the level; however, exchange rate and tariff rate are non-stationary at level, and they become stationary after taking the first difference, which provides evidence for ARDL applications. Additionally, the calculated value of Kao Panel Cointegration Test provides strong evidence for long run equilibrium relationship among the variables. Blackburne and Frank (2007) stated that if the variables are non-stationary and cointegrated then error correction mechanism (ECM) can be formulated.

5.1 Results of quantile regression model and discussion

The results of the econometric model used for empirical analysis in Equations (1) and (2) are presented in Table 5. The dependent variables, export-to-import ratio of agricultural products, are distributed in percentiles/quantiles to examine their responsiveness to changes in climatic conditions depicted by the level of temperature and precipitation and some macroeconomic variables given in econometric model. The estimated coefficients of average annual temperature are positive and statistically significant across all quantiles. It is pertinent to note that the magnitude of the estimated coefficient of yearly average temperature is increasing along with higher percentiles of export-to-import ratio, showing that temperature has a more positive influence in the region having higher levels of exports of agriculture products. These results suggest that *ceteris paribus* global warming is beneficial for exporting agricultural products, with relatively substantial positive effects on regions with higher exports. Among sample countries, 35% of countries have an average export-to-import ratio [2] greater than

Table 5. Results of panel quantile regression. Dependent variable export to import ratio of agriculture products

Quantiles	10Q	20Q	30Q	40Q	50Q	60Q	70Q	80Q	90Q
Temperature	0.0174***	0.0318***	0.0367***	0.0357***	0.0377***	0.0425***	0.0439***	0.0594***	0.1069***
	(0.0048)	(0.0051)	(0.0054)	(0.0060)	(0.0081)	(0.0111)	(0.0075)	(0.0091)	(0.0194)
Temperature square	−0.0009***	−0.0012***	−0.0013***	−0.0012***	−0.0012***	−0.0011**	−0.0006	−0.0004	−0.0005
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0008)
Precipitation	−0.0001*	0.0000	0.0001	0.0001	0.0000	0.0002	0.0002*	0.0002	0.0003
	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0003)
Precipitation square	0.0000	0.0000	0.0000	0.0000	0.0000*	0.0000	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Agriculture TFP	0.0031***	0.002***	0.0034***	0.0039***	0.004***	0.0061***	0.0072***	0.0072***	0.0060
	(0.0006)	(0.0006)	(0.0006)	(0.0007)	(0.0010)	(0.0021)	(0.0017)	(0.0021)	(0.0041)
Exchange rate	0.0000	0.0000**	0.0000***	0.0000***	0.0000***	0.0000	0.0000	0.0000*	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0002)
Tariff Rate	−0.008***	−0.009***	−0.011***	−0.012***	−0.011***	−0.009***	−0.018***	−0.026***	−0.0287***
	(0.0028)	(0.0019)	(0.0017)	(0.0019)	(0.0030)	(0.0034)	(0.0049)	(0.0064)	(0.0051)
Price	−0.0428	−0.0981*	−0.268***	−0.276***	−0.298***	−0.511***	−0.564***	−0.6841**	−1.3352***
	(0.0422)	(0.0568)	(0.0606)	(0.0793)	(0.1015)	(0.1565)	(0.1740)	(0.2826)	(0.4101)
Technological innovation	0.0168***	0.0370***	0.0512***	0.0591***	0.0735***	0.0886***	0.1078***	0.1523***	0.2806***
	(0.0044)	(0.0061)	(0.0061)	(0.0068)	(0.0089)	(0.0153)	(0.0144)	(0.0216)	(0.0440)
ECM	−0.125***	−0.072***	−0.053***	−0.029*	−0.013***	−0.001	0.0105	*0.0347***	*0.0667****
	(0.0149)	(0.0033)	(0.0099)	(0.0166)	(0.0035)	(0.0102)	(0.0070)	(0.0149)	(0.0035)

Note(s): ***, **, * represents 1, 5, and 10% level of significance, respectively. Standard errors of the estimated coefficients are given in parentheses
Source(s): Authors' own work

one, depicting net-exporters of agricultural products, and among them, around 60% have a higher value of the mean of average annual temperature for the study period [3] (see Table A1 in Appendix 1) showing that they are relatively warmer. Moreover, around one-fourth of these net exporters are classified as developed and three-fourth as developing countries [4]. This phenomenon is supported by the evidence provided by Bozzola *et al*. (2023), Gouel and Laborde (2021), stating that a warming climate may suit developing countries and export despite climatic loss, which is shifting to the consumer in the form of higher international prices.

The positive impact of average annual temperature on export-to-import ratio of agriculture products varies with temperature levels. The estimated coefficients of the quadratic terms confirm a non-linear relationship with EIRAGR, indicating that the effect of temperature changes in magnitude and direction at different levels of temperature, highlighting the importance of considering non-linear models. From the 10th to the 60th percentiles, these coefficients are negative at a highly statistically significant level. These values advocate an inverted U-shape relationship between trade balance of agriculture products and temperature level across the first six quantiles and their thresholds are given in Figure 2. Nevertheless, the regions with higher agricultural exports do not have statistically significant nonlinear relationships. This may be due to their higher productivity level owing to precision and climate-smart farming practices, exports of processed agriculture commodities, and re-exporting products with value addition which are not directly affected by the temperature level. Besides, these regions may have established and diversified trade markets along with multiple trade agreements which support their exports.

Our findings are opposite to what the temperature threshold estimated by Bozzola *et al*. (2023) where authors estimated a negative coefficient for temperature normal and a positive coefficient for the square of temperature normal, depicting that the value of agri-food exports displays a convex response to temperature normal with cut-off point at 5 to 6 Celsius. Nevertheless, the threshold levels/cut-off points in our case are different for each quantile. Regions with lower export-to-import ratios of agricultural products (net-importers) have a narrow optimal temperature range for enhancing agricultural exports. However, as the export-to-import ratio increases, the temperature threshold also increases gradually, which implies that these regions have room to expand their production and exports, as pointed out by FAO (2018), WTO (2022a).

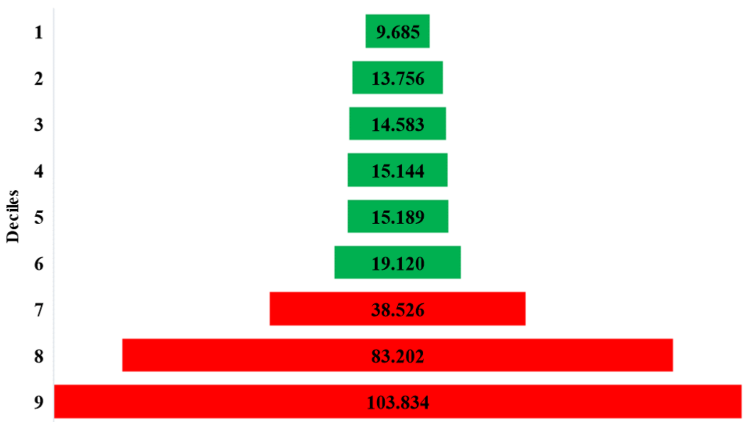

Figure 2. Threshold of temperature (°C) for deciles of export to import ratio of agriculture products. Source: Authors' own work

Contrary to the level of average annual temperature, precipitation and its square term do not have a statistically significant impact on the trade balance of agricultural products across all quantiles, indicating that precipitation alone may not be a strong predictor of agricultural trade performance. Although precipitation significantly affects agricultural production (Tanveer and Kalim, 2024) its impact may not always translate into trade performance. Additionally, its effects may be region-specific and become less visible in a large global dataset, where temperature likely captures most of the climate-related variation in trade. However, the literature provides evidence of the direct impact of rainfall on infrastructure and transport routes, which influence trade costs (Calzadilla *et al*., 2013; Dellink *et al*., 2017). Moreover, Bozzola *et al*. (2023) have estimated inverted U-shaped relationships of rainfall with agri-food exports, with 98.85 mm as a cut-off point.

Agriculture total factor productivity is directly proportional to the EIRAGR across all quantiles. This relation underscores the importance of productivity enhancements in the agrarian sector to improve trade performance. These results are well matched with Cai and Wang (2020), Khurshid *et al*. (2021) where Khurshid *et al*. (2021) identified positive impacts of livestock and crop production on the exports of Pakistan and Cai and Wang (2020) calculated the agricultural total factor productivity index of Hunan Province from 2005 to 2017 and found that 1% increase in agricultural total factor productivity index led agricultural exports to increase by 1.3%. Similarly, Mahadevan and Suardi (2010) emphasize that trade gains are more sustainable in countries with strong productivity growth and supporting macroeconomic fundamentals.

Although the exchange rate positively impacts exports, its magnitude is too small (near zero). These results imply that the exchange rate has a limited impact on EIRAGR, suggesting that currency fluctuations alone do not significantly drive agricultural trade ratios. These findings are supported by Ahmed *et al*. (2017) in Pakistan, and Alege and Osabuohien (2015) found that export and import of agriculture products are inelastic to changes in the exchange rate in Sub-Saharan Africa.

Tariff, a hurdle for international trade and a policy instrument, negatively influences EIRAGR across all quantiles. Similarly, the estimated coefficients of the ratio of export unit value to import unit value are inversely related to the trade balance of agricultural products. This outcome suggests that higher relative export prices reduce competitiveness, particularly for countries with high export-to-import ratios. This phenomenon well supports the outcomes of Beckman and Scott (2021), Hayakawa *et al*. (2018) documented that higher tariff reduces export levels through extensive and intensive margins. Moreover, Beckman and Scott (2021) stated that removing global agricultural tariffs would increase global trade by 11% and enhance consumer welfare by $56.3 billion, along with efficient global agriculture trade.

Moreover, technological innovations play an important role in enhancing exports of agricultural products across all quantiles, and the magnitude of estimated patents is increasing along with higher quantiles of dependent variables. The stronger effect on higher quantiles highlights the critical role of innovation in boosting agricultural trade for countries with better trade performance. These results support the findings of Jiva (2023), Maryna and Yur (2023), Méndez-Zambrano *et al*. (2023), where authors report that technological innovations significantly boost agricultural exports by improving competitiveness, increasing productivity, refining product quality, dropping costs, and enhancing resource use efficiency. Moreover, Jiva (2023), Méndez-Zambrano *et al*. (2023) reported that innovations can boost agribusiness profits by 15% by aiding in soil and water management and the use of agrochemicals.

The term error correction mechanism (ECM) indicates the adjustment speed to long-term equilibrium. The estimated parameters of ECM are negative and significant for the first five quantiles and negative but insignificant for the sixth quantile. Moreover, these coefficients are positive for the 70th to 90th percentiles. Ideally, a negative and statistically significant value is evidence for the adjustment of the model towards long-term equilibrium after a shock. It can be concluded that the lower export-to-import ratio model adjusts quickly towards long-run equilibrium after any shock, whereas the higher export-to-import ratio model slowly or does not converge quickly to its long-run equilibrium.

This may be due to the difference in market dynamics, institutional structure, policy rigidity/flexibility, adaptive capacity, and trade policy between net-importing and net-exporting countries of agricultural products. Understanding these dynamics is crucial for policymakers to tailor their strategies to enhance resilience and capitalize on potential shifts in comparative advantage under climate change. Moreover, this suggests that exporting and importing countries require different trade policies, exporters need long-term stabilization measures, while importers may benefit more from short-term adjustments and climate adaptation strategies.

6. Conclusion

Climate change is a global phenomenon influencing production and consumption patterns worldwide (Dellink *et al.*, 2017; WTO, 2022a). On the production side, the agriculture sector is the most affected by climate change (Conte *et al.*, 2020; IPCC, 2022; Nath, 2022), which is responsible for feeding the world's growing population. Any disruption in agricultural sector production may cause severe food shortages in the region. Nevertheless, trade can be a temporary panacea for this problem as it provides food from the food-surplus region to the food-shortage region to fulfill the nutritional needs of the people (Bozzola *et al.*, 2023; FAO, 2018). Naturally, some regions have comparative advantages in producing agricultural products and exports, which others import. However, in the wake of climate change, world policymakers are emphasizing that there may be shifting in global trade patterns in response to global warming (Bozzola *et al.*, 2023; FAO, 2018; IPCC, 2022; WTO, 2022a, b).

It is evident that warmer countries are relatively agricultural, and colder countries are non-agricultural economies. Put differently, relatively warm weather is more favorable for agriculture than colder weather [5]. But due to global warming, the average temperature of the globe is increasing, which may cause warm regions (favorable for agriculture production) to become warmer (not favorable for agriculture production) and colder regions (not favorable for agriculture production) to become relatively warmer (suitable for agriculture production) and resultantly shifting production and trade patterns (Conte *et al.*, 2020; Nath, 2022).

This study provides a comprehensive empirical analysis of how climatic and economic factors influence agricultural trade balances across 166 countries over the period 2000–2022. Using a Panel Quantile ARDL model, we account for both short- and long-run dynamics as well as distributional heterogeneity across countries with varying trade profiles. The results confirm the existence of non-linear effects of temperature on agricultural trade balance. Specifically, moderate climate variations tend to enhance trade by supporting productivity, whereas extreme deviations beyond certain thresholds reduce trade performance, likely due to adverse effects on yields and resource availability.

These findings carry important economic and policy implications. First, they highlight the need for climate-sensitive trade strategies that are responsive to regional thresholds and vulnerabilities. Countries currently benefiting from moderate climate conditions may face trade losses as global warming intensifies, while colder regions may become more competitive. Second, the heterogeneity observed across quantiles suggests that net agricultural importers and exporters are differently affected by climate and macroeconomic shifts. This calls for differentiated policy approaches, including targeted investment in climate-resilient agriculture, improved trade infrastructure, and more flexible pricing and tariff frameworks. Additionally, our findings support the need to formally integrate climate variability into global trade negotiations. This includes conducting climate risk assessments, providing adaptation finance, and offering preferential trade terms to climate-vulnerable economies. Such measures are especially relevant given the uneven impacts of climate on net agricultural exporters and importers identified in this study. Furthermore, economies should establish and diversify trade markets along with multiple trade agreements to sustain their exports. Finally, this study contributes to the evolving discourse on the climate–trade nexus, offering macro-level evidence to support policies that promote climate equity, sustainable trade, and resilience in food systems. As global climate pressures intensify, the integration of environmental and trade policy goals becomes increasingly essential. Our results underscore the urgency of adopting a multidimensional, adaptive, and inclusive approach to agricultural trade policymaking.

The current study provides a preliminary worldwide analysis of the hypothesis that climate change affects agricultural trade patterns. To explore this phenomenon deeper, future studies may focus on different models for net-exporting and net-importing countries. Furthermore, sub-sector evaluations, such as those focusing on crops and animals, may be carried out using various models to reflect the unique dynamics of these segments. Besides, region-specific analyses are also required to determine the distinct regional dynamics associated with trade and climate change. Furthermore, investigating the effects of numerous elements such as trade barriers, institutional quality, market circumstances, climatic scenarios, and other economic variables would provide the more comprehensive understanding required for informed policy actions.

Notes

1. The trend of average temperature and export to import ratio of agriculture products is depicted in Figure A1 in Appendix 2.
2. Average is taken from 2000 to 2022. It is crucial to note that it can be possible that these countries might be net-importer in some years.
3. Similarly, mean of average annual temperature is calculated from 2000 to 2022.
4. World Bank classification by income level is used for the calculation.
5. Trend of AGTFP and TEMP across productivity quantiles are presented in Figure A2 in Appendix 2.

References

Acemoglu, D., Johnson, S. and Robinson, J.A. (2002), "Reversal of fortune: geography and institutions in the making of the modern world income distribution", *The Quarterly Journal of Economics*, Vol. 117 No. 4, pp. 1231-1294, doi: 10.1162/003355302320935025.

Agung, G.N. (2021), *Quantile Regression Applications on Experimental and Cross-Section Data Using EViews*, John Wiley & Sons, Hoboken.

Ahmed, K., Qasim, M. and Chani, M.I. (2017), "Impact of exchange rate on exports in case of Pakistan", *Bulletin of Business and Economics*, Vol. 6 No. 2, pp. 98-102.

Alege, P.O. and Osabuohien, E.S. (2015), "Trade-exchange rate nexus in Sub-Saharan African countries: evidence from panel cointegration analysis", *Foreign Trade Review*, Vol. 50 No. 3, pp. 151-167, doi: 10.1177/0015732515589440.

Al-Mulali, U. and Ozturk, I. (2015), "The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region", *Energy*, Vol. 84, pp. 382-389, doi: 10.1016/j.energy.2015.03.004.

Al-Mulali, U. and Sheau-Ting, L. (2014), "Econometric analysis of trade, exports, imports, energy consumption and CO_2 emission in six regions", *Renewable and Sustainable Energy Reviews*, Vol. 33, pp. 484-498, doi: 10.1016/j.rser.2014.02.010.

Alam, M.M., Talib, B.A., Siwar, C. and Wahid, A.N.M. (2016), "Climate change and food security of the Malaysian east coast poor: a path modeling approach", *Journal of Economic Studies*, Vol. 43 No. 3, pp. 458-474, doi: 10.1108/JES-10-2014-0169.

Ali, S., Dogan, E., Chen, F. and Khan, Z. (2021), "International trade and environmental performance in top ten-emitters countries: the role of eco-innovation and renewable energy consumption", *Sustainable Development*, Vol. 29 No. 2, pp. 378-387, doi: 10.1002/sd.2153.

Alqaralleh, H. and Hatemi-J, A. (2024), "Revisiting the effects of renewable and non-renewable energy consumption on economic growth for eight countries: asymmetric panel quantile approach", *International Journal of Energy Sector Management*, Vol. 18 No. 2, pp. 334-349, doi: 10.1108/IJESM-10-2022-0022.

Amoh, J.K., Abdul-Mumuni, A., Penney, E.K., Muda, P. and Ayarna-Gagakuma, L. (2024), "Corruption and external debt nexus in Sub-Saharan Africa: a panel quantile regression approach", *Journal of Money Laundering Control*, Vol. 27 No. 3, pp. 505-519, doi: 10.1108/JMLC-07-2023-0125.

Arshed, N. (2023), "Intervening long-run fundamentals of fossil energy demand-an effort towards responsible and clean energy consumption", *Environmental Science and Pollution Research International*, Vol. 30 No. 54, pp. 114873-114885, doi: 10.1007/s11356-023-30495-8.

Arshed, N., Hanif, U. and Umar, M. (2023), "International journal of social science archives sustainable environmental management: assessing the interplay of climate change, socio-economic factors and ecosystem vitality at the national level", *International Journal of Social Science Archives*, Vol. 6 No. 3, pp. 1-19, available at: www.ijssa.com

Beckman, J. and Scott, S. (2021), "Feature: macroeconomics and agriculture how the removal of tariffs would impact agricultural trade", United States Department of Agriculture, available at: https://www.ers.usda.gov/publications/pub-details/?pubid=100865

Berkum, S. and Maiji, H. (1998), *A Survey of Trade Theories*, Agricultural Economics Research Institute (LEI-DLO), The Hague.

Blackburne, E.F. and Frank, M.W. (2007), "Estimation of nonstationary heterogeneous panels", *The Stata Journal*, Vol. 7 No. 2, pp. 197-208, doi: 10.1177/1536867x0700700204.

Blyde, J.S. and Ramirez, M.A. (2022), "Exporting and environmental performance: where you export matters", *Journal of International Trade and Economic Development*, Vol. 31 No. 5, pp. 672-691, doi: 10.1080/09638199.2021.2003424.

Bozzola, M., Lamonaca, E. and Santeramo, F.G. (2023), "Impacts of climate change on global agri-food trade", *Ecological Indicators*, Vol. 154, 110680, doi: 10.1016/j.ecolind.2023.110680.

Burkett, A.G., Suarez, M., Bindi, C., Conde, R., Mukerji, M.J., Prather, A. and Yohe, A. (2014), "2014: point of departure", in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, pp. 169-194, available at: https://gyohe.faculty.wesleyan.edu/files/2018/05/165.pdf

Cagatay, S. and Mihci, H. (2006), "Degree of environmental stringency and the impact on trade patterns", *Journal of Economic Studies*, Vol. 33 No. 1, pp. 30-51, doi: 10.1108/01443580610639884.

Cai, Z. and Wang, C. (2020), "Study on the effect of agricultural total factor productivity on the export of agricultural products", *Advances in Intelligent Systems and Computing*, Vol. 1142, pp. 779-786, doi: 10.1007/978-981-15-3588-8_90.

Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A. and Tol, R.S.J. (2013), "Climate change impacts on global agriculture", *Climatic Change*, Vol. 120 Nos 1-2, pp. 357-374, doi: 10.1007/s10584-013-0822-4.

Chen, J., Shin, Y. and Zheng, C. (2023), "Dynamic quantile panel data models with interactive effects dynamic quantile panel data models with interactive effects".

Cho, J.S., Kim, T.H. and Shin, Y. (2015), "Quantile cointegration in the autoregressive distributed-lag modeling framework", *Journal of Econometrics*, Vol. 188 No. 1, pp. 281-300, doi: 10.1016/j.jeconom.2015.05.003.

Conte, B., Desmet, K., Krisztián Nagy, D. and Rossi-Hansberg, E. (2020), "Local sectoral specialization in a warming world", (28163; NBER Working Paper Series), available at: http://www.nber.org/papers/w28163

Costinot, A. (2009), "An elementary theory of comparative advantage", available at: http://www.nber.org/papers/w14645

Costinot, A., Donaldson, D. and Smith, C. (2016), "Evolving comparative advantage and the impact of climate change in agricultural markets", *Source: Journal of Political Economy*, Vol. 124 No. 1, pp. 205-248, doi: 10.2307/26549861.

Davino, C., Furno, M. and Vistocco, D. (2014), *Quantile Regression: Theory and Applications*, John Wiley & Sons.

Dell, M., Jones, B.F. and Olken, B.A. (2012), "Temperature shocks and economic growth: evidence from the last half century", *Journal: Macroeconomics*, Vol. 4 No. 3, pp. 66-95, doi: 10.1257/mac.43.66.

Dellink, R., Hwang, H., Lanzi, E. and Chateau, J. (2017), "International trade consequences of climate change (2017/01)", doi: 10.1787/9f446180-en.

Dellink, R., Lanzi, E. and Chateau, J. (2019), "The sectoral and regional economic consequences of climate change to 2060", *Environmental and Resource Economics*, Vol. 72 No. 2, pp. 309-363, doi: 10.1007/s10640-017-0197-5.

Ebi, K.L. and Bowen, K. (2016), "Extreme events as sources of health vulnerability: drought as an example", *Weather and Climate Extremes*, Vol. 11, pp. 95-102, doi: 10.1016/j.wace.2015.10.001.

FAO (2018), "The state of agricultural commodity markets", 2018 Agricultural Trade, Climate Change and Food Security, available at: http://www.fao.org/3/I9542EN/i9542en.pdf

FAO (2021), "World food and agriculture – statistical yearbook 2021", in *World Food and Agriculture – Statistical Yearbook 2021*, FAO, doi: 10.4060/cb4477en.

FAO (2022), "The global action on green development of special agricultural products: one country one priority Product– action plan 2021–2025", in *The Global Action on Green Development of Special Agricultural Products: One Country One Priority Product*, FAO, doi: 10.4060/cc0608en.

Farooq, A., Farooq, N., Akbar, H., Hassan, Z.U. and Gheewala, S.H. (2023), "A critical review of climate change impact at a global scale on cereal crop production", *Agronomy*, Vol. 13 No. 1, p. 162, doi: 10.3390/agronomy13010162.

FSIN (2024), "Global report on foord crisis: joint analysis for better decisions food security information network", available at: https://www.fsinplatform.org/grfc2024

Galvao, A.F. (2011), "Quantile regression for dynamic panel data with fixed effects", *Journal of Econometrics*, Vol. 164 No. 1, pp. 142-157, doi: 10.1016/j.jeconom.2011.02.016.

Gouel, C. and Laborde, D. (2021), "The crucial role of domestic and international market-mediated adaptation to climate change", *Journal of Environmental Economics and Management*, Vol. 106, 102408, doi: 10.1016/j.jeem.2020.102408.

Hanif, U., Zahid, F. and Arshed, N. (2023), "Emerging Asian economies growth at the crossroads natural resources and institutional quality", *International Journal of Contemporary Issues in Social Sciences*, Vol. 2 No. 3, pp. 608-621, available at: https://ijciss.org/

Hansen, C.O., Groønsedt, P., Graversen, C.L., Hendricksen, C. and Handelshøjskolen i København, H. (2016), "Arctic shipping: commercial opportunities and challenges", Arctic Institute (Washington, DC), available at: https://research.cbs.dk/en/publications/arctic-shipping-commercial-opportunities-and-challenges

Hayakawa, K., Ishikawa, J., Tarui, N., Oana, H., Washizu, M. and Tanaka, S. (2018), "What goes around comes around: export-enhancing effects of import-tariff reductions what goes around comes around: export-enhancing effects of import-tariff reductions", Vol. 8 No. 18, 5811, doi: 10.1038/s41598-018-23832-2, available at: https://www.alphaliner.com/

Hertel, T.W., Burke, M.B. and Lobell, D.B. (2010), "The poverty implications of climate-induced crop yield changes by 2030", *Global Environmental Change*, Vol. 20 No. 4, pp. 577-585, doi: 10.1016/j.gloenvcha.2010.07.001.

Hummels, D. (2007), "Transportation costs and international trade in the second era of globalization", *Journal of Economic Perspectives*, Vol. 21 No. 3, pp. 131-154, doi: 10.1257/jep.21.3.131, available at: http://www.bea.gov

Ibrahiem, D.M. and Hanafy, S.A. (2021), "Do energy security and environmental quality contribute to renewable energy? The role of trade openness and energy use in North African countries", *Renewable Energy*, Vol. 179, pp. 667-678, doi: 10.1016/j.renene.2021.07.019.

IPCC (2019), "Summary for policymakers: climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems", in *Climate Change and Land*, Cambridge University Press, doi: 10.1017/9781009157988.001.

IPCC (2022), "Climate change 2022 mitigation of Climate Change Working Group III contribution to the sixth assessment report of the intergovernmental panel on climate change", available at: www.ipcc.ch

Iqbal, M., Ul-Durar, S., Arshed, N., Shahzad, K. and Ayub, U. (2023), "Connecting higher education and renewable energy to attain sustainability for BRICS countries: a climate Kuznets curve perspective", *International Journal of Emerging Markets*, Vol. 20 No. 5, pp. 2042-2060, doi: 10.1108/IJOEM-04-2023-0555.

Isayev, M., Irani, F. and Attarzadeh, A. (2024), "Asymmetric effects of monetary policy on non-bank financial intermediation (NBFI) assets: a panel quantile regression approach", *Journal of Economic Studies*, Vol. 51 No. 3, pp. 631-648, doi: 10.1108/JES-01-2023-0024.

Jägermeyr, J., Müller, C., Ruane, A.C., Elliott, J., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J.A., Fuchs, K., Guarin, J.R., Heinke, J., Hoogenboom, G., Iizumi, T., Jain, A.K., Kelly, D., Khabarov, N., Lange, S., Lin, T.S., Liu, W., Mialyk, O., Minoli, S., Moyer, E.J., Okada, M., Phillips, M., Porter, C., Rabin, S.S., Scheer, C., Schneider, J.M., Schyns, J.F., Skalsky, R., Smerald, A., Stella, T., Stephens, H., Webber, H., Zabel, F. and Rosenzweig, C. (2021), "Climate impacts on global agriculture emerge earlier in new generation of climate and crop models", *Nature Food*, Vol. 2 No. 11, pp. 873-885, doi: 10.1038/s43016-021-00400-y.

Jahanger, A., Zubair Chishti, M., Chukwuma Onwe, J. and Awan, A. (2022), "How far renewable energy and globalization are useful to mitigate the environment in Mexico? Application of QARDL and spectral causality analysis", *Renewable Energy*, Vol. 201, pp. 514-525, doi: 10.1016/j.renene.2022.10.081.

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., Leclère, D., Ohrel, S., Ragnauth, S., Schmid, E., Valin, H., Van Lipzig, N. and Maertens, M. (2020), "Global hunger and climate change adaptation through international trade", *Nature Climate Change*, Vol. 10 No. 9, pp. 829-835, doi: 10.1038/s41558-020-0847-4.

Jiva (2023), "Top 13 innovations in agriculture/farming in 2023", JIVA, available at: https://www.jiva.ag/blog/top-13-innovations-in-agriculture-farming

Jones, B.F. and Olken, B.A. (2010), "Climate shocks and exports", *American Economic Review*, Vol. 100 No. 2, pp. 454-459, doi: 10.1257/aer.100.2.454.

Juliá, R. and Duchin, F. (2007), "World trade as the adjustment mechanism of agriculture to climate change", *Climatic Change*, Vol. 82 Nos 3-4, pp. 393-409, doi: 10.1007/s10584-006-9181-8.

Kakar, S.K., Wang, J., Arshed, N., Le Hien, T.T. and Abdullahi, N.M. (2024), "Investigating the biodiversity conservation capability of technological innovation and FinTech", *Heliyon*, Vol. 10 No. 23, e40683, doi: 10.1016/j.heliyon.2024.e40683.

Kebede, J.G. and Tawiah, V. (2023), "Financial globalization and income inequality nexus: panel quantile regression approach", *Journal of Economic Studies*, Vol. 50 No. 2, pp. 73-95, doi: 10.1108/JES-04-2021-0179.

Khurshid, W., Qayyum, A. and Shera, M.J. (2021), "Examining the government policies related to enhancement in the productivity of agriculture sector, and role of major crops and livestock for economic development of Pakistan during 2015–16 to 2020-21", *Journal of ISOSS*, Vol. 7 No. 4, pp. 229-240.

Koenker, R. and Bassett, G. (1978), "Regression quantiles", *JSTOR*, Vol. 46 No. 1, p. 33, doi: 10.2307/1913643.

Koenker, R. and Xiao, Z. (2004), "Unit root quantile autoregression inference", *Journal of the American Statistical Association*, Vol. 99 No. 467, pp. 775-787, doi: 10.1198/016214504000001114.

Koenker, R. and Xiao, Z. (2006), "Quantile autoregression", *Journal of the American Statistical Association*, Vol. 101 No. 475, pp. 980-990, available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=fe58f44f5917316b6a664dabf6dab807176d5885

Koska, O.A., Stähler, F. and Yeni, O. (2021), “Trade and commodity taxes as environmental instruments in an open economy”, *Journal of Economic Studies*, Vol. 48 No. 2, pp. 333-353, doi: 10.1108/JES-08-2019-0362.

Krugman, P.R., Obstfeld, M. and Melitz, M. (2018), “International Economics: Theory and Policy”, 11th ed., Pearson Education, available at: www.myeconlab.com

Lamonaca, E., Bozzola, M. and Santeramo, F.G. (2024), “Climate distance and bilateral trade”, *Economics Letters*, Vol. 237, 111624, doi: 10.1016/j.econlet.2024.111624.

Ledhem, M.A. and Mekidiche, M. (2022), “Islamic securities (ṣukūk) and economic growth: new empirical investigation from Southeast Asia using non-parametric analysis of MCMC panel quantile regression”, *Islamic Economic Studies*, Vol. 29 No. 2, pp. 119-138, doi: 10.1108/ies-06-2021-0020.

Levin, A., Lin, C.-F. and James Chu, C.-S. (2002), “Unit root tests in panel data: asymptotic and Ÿnite-sample properties”, *Journal of Econometrics*, Vol. 108, pp. 1-24, doi: 10.1016/s0304-4076(01)00098-7, available at: www.elsevier.com/locate/econbase

Liang, Q., Shao, L., Hussain, Z., Chao, Y., Liu, H. and Wang, C. (2025), “Climate change, geography and trade agreements: a perspective of Asian bilateral trade”, *PLoS One*, Vol. 20 No. 4, e0320363, doi: 10.1371/journal.pone.0320363.

Liu, M. and Kronbak, J. (2010), “The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe”, *Journal of Transport Geography*, Vol. 18 No. 3, pp. 434-444, doi: 10.1016/j.jtrangeo.2009.08.004.

Macedo, A., Gouveia, S., Rebelo, J., Santos, J. and Fraga, H. (2020), “International trade, non-tariff measures and climate change: insights from Port wine exports”, *Journal of Economic Studies*, Vol. 48 No. 6, pp. 1228-1243, doi: 10.1108/JES-04-2020-0161.

Mahadevan, R. and Suardi, S. (2010), “Dynamic effects of trade and output volatility on the trade-growth nexus: evidence from Singapore”, *Journal of Economic Studies*, Vol. 37 No. 3, pp. 314-326, doi: 10.1108/01443581011061294.

Maryna, A. and Yur, O. (2023), “Innovative technologies in ensuring the international competitiveness of agricultural enterprises: problems of systemic approach in the economy”, *Економ*і*чн*і Н*ауки*, Vol. 3 No. 2, pp. 63-66, doi: 10.32782/2520-2200/2023-2-3.

Méndez-Zambrano, P.V., Tierra Pérez, L.P., Ureta Valdez, R.E. and Flores Orozco, Á.P. (2023), “Technological innovations for agricultural production from an environmental perspective: a review”, *Sustainability*, Vol. 15 No. 22, 16100, doi: 10.3390/su152216100.

Nath, I. (2022), “Climate change, the food problem, and the challenge of adaptation through sectoral reallocation”, *Presented during the 25th Annual Conference on Global Economic Analysis (Virtual Conference)*, available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6495

Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G. and Lobell, D.B. (2021), “Anthropogenic climate change has slowed global agricultural productivity growth”, *Nature Climate Change*, Vol. 11 No. 4, pp. 306-312, doi: 10.1038/s41558-021-01000-1.

Pesaran, M.H., Shin, Y. and Smith, R.P. (1999), “Pooled mean group estimation of dynamic heterogeneous panels”, *Journal of the American Statistical Association*, Vol. 94 No. 446, pp. 621-634, doi: 10.1080/01621459.1999.10474156.

Rahman, M.M. and Vu, X.B. (2021), “Are energy consumption, population density and exports causing environmental damage in China? Autoregressive distributed lag and vector error correction model approaches”, *Sustainability (Switzerland)*, Vol. 13 No. 7, p. 3749, doi: 10.3390/su13073749.

Ray, D.K., West, P.C., Clark, M., Gerber, J.S., Prishchepov, A.V. and Chatterjee, S. (2019), “Climate change has likely already affected global food production”, *PLoS ONE*, Vol. 14 No. 5, pp. 1-18, doi: 10.1371/journal.pone.0217148.

Reilly, J. and Hohmann, N. (1993), “Climate change and agriculture: the role of international trade”, *The American Economic Review*, Vol. 83 No. 2, pp. 306-312, available at: https://www.jstor.org/stable/2117682

Reilly, J., Hohmann, N. and Kane, S. (1994), "Climate change and agricultural trade who benefits, who loses?", *Global Environmental Change*, Vol. 4 No. 1, pp. 24-36, doi: 10.1016/0959-3780(94)90019-1.

Ricardo, D. (1817), *On the Principles of Political Economy and Taxation of Wages (Third)*, John Murray, London.

Rosenzweig, C., Curry, B., Richie, J.T., Jones, J.W., Chou, T.Y., Goldberg, R. and Iglesias, A. (1994), "The effects of potential climate change on simulated grain crops in the United States", in Rosenzweig, C. and Iglesais, A. (Eds), *Implications of Climate Change for International Agriculture: Crop Modeling Study*, EPA 230-B-94-003. U.S. EPA Office of Policy, Planning and Evaluation, Climate Change Division, Adaptation Branch, Vol. 59, pp. 1-24, available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/20005AHS.PDF?Dockey=20005AHS.PDF

Salvatore, D. (2019), *International Economics*, 13th ed., Wiley, Hoboken.

Sam, C.Y., McNown, R. and Goh, S.K. (2019), "An augmented autoregressive distributed lag bounds test for cointegration", *Economic Modelling*, Vol. 80, pp. 130-141, doi: 10.1016/J.ECONMOD.2018.11.001.

Santeramo, F.G. (2022), "Price dynamics, the law of one price, and quantile regressions", *Journal of Agricultural and Resource Economics*, Vol. 47 No. 3, pp. 513-528, doi: 10.22004/ag.econ.311030.

Santeramo, F.G., Ferrari, E. and Toreti, A. (2024), "Achieving climate change and environment goals without protectionist measures: mission (im) possible?", Art. 01, available at: www.iatrcweb.org

Santeramo, F.G., Lamonaca, E. and Emlinger, C. (2025), "Technical measures, environmental protection, and trade", *Review of International Economics*. doi: 10.1111/roie.12793.

Schenker, O. and Stephan, G. (2014), "Give and take: how the funding of adaptation to climate change can improve the donor's terms-of-trade", *Ecological Economics*, Vol. 106, pp. 44-55, doi: 10.1016/j.ecolecon.2014.07.006.

Sohail, H. and Arshed, N. (2022), "Contribution of islamic debt financing in entrepreneurship promoting financial sector transformation under a creative commons attribution-non-commercial", *International Journal of Management Research and Emerging Sciences*, Vol. 12 No. 2, pp. 1-36, doi: 10.56536/ijmres.v12i2.186, available at: http://ijmres.pk/

Sun, Q., Miao, C., Hanel, M., Borthwick, A.G.L., Duan, Q., Ji, D. and Li, H. (2019), "Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming", *Environment International*, Vol. 128, pp. 125-136, doi: 10.1016/j.envint.2019.04.025.

Tanveer, Z. and Kalim, R. (2024), "An empirical analysis of climate transition: a global outlook of agriculture productivity", *Journal of Economic Studies*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/JES-07-2024-0466.

Ul-Durar, S., Arshed, N., Anwar, A., Sharif, A. and Liu, W. (2023), "How does economic complexity affect natural resource extraction in resource rich countries?", *Resources Policy*, Vol. 86, 104214, doi: 10.1016/j.resourpol.2023.104214.

Ul-Durar, S., Arshed, N., De Sisto, M., Nazarian, A. and Sadaf, A. (2024), "Modeling green energy and innovation for ecological risk management using second generation dynamic quantile panel data model", *Journal of Environmental Management*, Vol. 366, 121741, doi: 10.1016/j.jenvman.2024.121741.

Ul-Durar, S., Bakkar, Y., Arshed, N., Naveed, S. and Zhang, B. (2025), "FinTech and economic readiness: institutional navigation amid climate risks", *Research in International Business and Finance*, Vol. 73, 102543, doi: 10.1016/j.ribaf.2024.102543.

UNDESA (2022), "World population prospects 2022 summary of results", available at: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

Wang, Y., Hanif, N., Arshad, N., Hussain, M., Arshad, Z. and Usman, M. (2024), "Synergizing social sustainability and technological innovation for carbon neutrality in OECD economies", *Sustainable Development*, Vol. 32 No. 6, pp. 6614-6628, doi: 10.1002/sd.3038.

WTO (2022a), “The world trade report 2022: climate change and international trade”, World Trade Organization, available at: www.wto.org

WTO (2022b), “Trade and climate change information brief no. 1: overview of trade policies adopted to address climate change”, available at: https://www.wto.org/english/news_e/news21_e/clim_03nov21-1_e.pdf

WTO (2023), “Re-globalization for a secure, inclusive and sustainable future what is the world trade report?”, available at: www.wto.org

Yang, X. and Li, C. (2019), “Industrial environmental efficiency, foreign direct investment and export——evidence from 30 provinces in China”, *Journal of Cleaner Production*, Vol. 212, pp. 1490-1498, doi: 10.1016/j.jclepro.2018.12.156.

Zheng, C., Shin, Y. and Chen, J. (2024), “Dynamic quantile panel data models with interactive effects”, available at: https://papers.ssrn.com/abstract=4910743

Zhou, X., Sun, X., Yang, Y. and Chen, Y. (2020), “FDI inflows, market fragmentation and their impact on industrial environmental efficiency: an empirical study in China”, *Polish Journal of Environmental Studies*, Vol. 29 No. 4, pp. 2969-2980, doi: 10.15244/pjoes/111970.

Appendix 1

Table A1. Deciles of arithmetic mean of average export-to-import ratio of the selected countries along with mean value of average annual temperature from 2000 to 2022

Country	Average of TEMP	Average of EIRAGR	Deciles
Argentina	15.158	15.632	Ninth
Brazil	25.562	7.449	Ninth
New Zealand	10.654	5.139	Ninth
Paraguay	23.991	4.880	Ninth
Uruguay	16.848	4.217	Ninth
Malawi	22.699	3.623	Ninth
Australia	22.098	3.267	Ninth
Thailand	26.115	3.037	Ninth
Ukraine	8.720	2.875	Ninth
Ecuador	21.405	2.723	Ninth
Costa Rica	24.850	2.560	Ninth
Zimbabwe	20.467	2.114	Ninth
Chile	9.426	2.037	Ninth
Indonesia	26.003	1.963	Ninth
Guatemala	23.786	1.830	Ninth
Serbia	11.742	1.829	Ninth
Uzbekistan	13.091	1.812	Ninth
Zambia	21.222	1.783	Ninth
Nicaragua	25.934	1.750	Ninth
Kenya	25.202	1.725	Eighth
Hungary	11.815	1.688	Eighth
Moldova	11.229	1.686	Eighth
Denmark	9.145	1.613	Eighth
Malaysia	26.432	1.606	Eighth
Guyana	26.206	1.589	Eighth
Netherlands	10.735	1.576	Eighth
Tanzania	21.402	1.565	Eighth
Myanmar	23.902	1.562	Eighth
Uganda	21.349	1.560	Eighth

(*continued*)

Table A1. Continued

Country	Average of TEMP	Average of EIRAGR	Deciles
Ireland	9.784	1.541	Eighth
Colombia	25.040	1.503	Eighth
India	25.064	1.493	Eighth
Ghana	27.809	1.492	Eighth
Papua New Guinea	24.739	1.437	Eighth
Eswatini	20.753	1.427	Eighth
Belize	25.843	1.423	Eighth
South Africa	16.605	1.414	Eighth
Burkina Faso	29.417	1.373	Eighth
Spain	12.480	1.365	Seventh
Canada	−3.932	1.342	Seventh
Poland	9.061	1.319	Seventh
Bulgaria	11.704	1.317	Seventh
Honduras	24.803	1.311	Seventh
France	11.855	1.288	Seventh
Togo	26.606	1.244	Seventh
Guinea-Bissau	28.101	1.228	Seventh
Türkiye	11.096	1.208	Seventh
Ethiopia	23.512	1.206	Seventh
Cameroon	24.908	1.186	Seventh
Vietnam	24.260	1.184	Seventh
Lithuania	7.604	1.179	Seventh
Sri Lanka	26.178	1.160	Seventh
United States	8.664	1.159	Seventh
Belgium	10.893	1.144	Seventh
Mali	29.332	1.124	Seventh
Madagascar	22.743	1.079	Seventh
Peru	19.711	1.074	Seventh
Belarus	7.715	1.042	Sixth
Fiji	24.800	0.972	Sixth
Mexico	21.438	0.956	Sixth
Austria	7.677	0.942	Sixth
Chad	27.722	0.936	Sixth
Italy	13.452	0.913	Sixth
Turkmenistan	15.825	0.876	Sixth
Kazakhstan	7.399	0.874	Sixth
Burundi	20.560	0.859	Sixth
Germany	9.827	0.823	Sixth
Greece	14.537	0.777	Sixth
Czechia	8.871	0.773	Sixth
Rwanda	19.296	0.772	Sixth
Latvia	7.090	0.768	Sixth
Dominican Republic	24.557	0.751	Sixth
Laos	24.205	0.749	Sixth
Benin	28.211	0.745	Sixth
North Macedonia	11.087	0.727	Sixth
Solomon Islands	25.880	0.725	Fifth
Estonia	6.560	0.702	Fifth
Romania	10.528	0.699	Fifth
Namibia	20.481	0.673	Fifth
Switzerland	4.912	0.668	Fifth
Sudan	26.945	0.653	Fifth
Slovakia	8.137	0.645	Fifth
Tunisia	18.856	0.644	Fifth

(*continued*)

Table A1. Continued

Country	Average of TEMP	Average of EIRAGR	Deciles
Pakistan	21.641	0.617	Fifth
Slovenia	8.457	0.609	Fifth
Mauritius	23.515	0.606	Fifth
Croatia	12.248	0.598	Fifth
Liberia	25.535	0.591	Fifth
Kyrgyzstan	2.970	0.590	Fifth
Portugal	15.994	0.568	Fifth
Philippines	26.336	0.567	Fifth
Syria	17.546	0.566	Fifth
El Salvador	25.334	0.556	Fifth
Tajikistan	3.506	0.551	Fourth
Georgia	9.329	0.545	Fourth
Morocco	18.356	0.524	Fourth
Luxembourg	10.247	0.510	Fourth
Mozambique	24.475	0.501	Fourth
Vanuatu	24.683	0.494	Fourth
Armenia	8.121	0.483	Fourth
Sweden	2.374	0.482	Fourth
Mongolia	1.212	0.481	Fourth
United Kingdom	8.265	0.476	Fourth
China	7.763	0.465	Fourth
Israel	20.224	0.463	Fourth
Trinidad and Tobago	25.490	0.456	Fourth
Azerbaijan	13.271	0.450	Fourth
Cuba	25.872	0.448	Fourth
United Arab Emirates	26.601	0.444	Fourth
Central African Republic	25.602	0.440	Fourth
Iran	18.643	0.438	Fourth
Panama	25.615	0.427	Fourth
Jamaica	25.938	0.420	Third
Russian Federation	−3.521	0.411	Third
Suriname	26.361	0.408	Third
Finland	2.723	0.392	Third
Niger	28.130	0.383	Third
Cambodia	27.427	0.383	Third
Oman	27.819	0.364	Third
Jordan	19.765	0.356	Third
Somalia	26.447	0.345	Third
Cyprus	19.250	0.343	Third
Bhutan	10.532	0.329	Third
Senegal	29.039	0.327	Third
Comoros	23.816	0.322	Third
Egypt	23.347	0.317	Third
Montenegro	10.240	0.290	Third
Nepal	14.322	0.251	Third
Nigeria	27.421	0.237	Third
Botswana	22.150	0.213	Third
Korea Republic	12.348	0.213	Second
Lebanon	15.715	0.211	Second
Bahrain	28.036	0.209	Second
Guinea	26.009	0.199	Second
Malta	19.795	0.195	Second
Afghanistan	13.676	0.188	Second
Iceland	2.111	0.178	Second

(*continued*)

Table A1. Continued

Country	Average of TEMP	Average of EIRAGR	Deciles
Timor-Leste	24.833	0.161	Second
Norway	2.425	0.155	Second
Saudi Arabia	26.183	0.152	Second
Gambia	27.766	0.144	Second
Albania	12.718	0.133	Second
Djibouti	28.633	0.125	Second
Sierra Leone	26.324	0.124	Second
Congo DR	24.424	0.104	Second
Gabon	25.330	0.094	Second
Congo Republic	24.877	0.092	Second
Lesotho	12.492	0.085	Second
Equatorial Guinea	24.776	0.082	First
Yemen	25.610	0.074	First
Korea DPR	7.087	0.069	First
Bangladesh	25.783	0.065	First
Japan	11.925	0.063	First
Kuwait	26.638	0.061	First
Mauritania	28.955	0.055	First
Venezuela	25.806	0.051	First
Haiti	24.963	0.035	First
Algeria	23.753	0.029	First
Qatar	28.354	0.022	First
Iraq	23.220	0.015	First
Eritrea	26.801	0.015	First
New Caledonia	22.784	0.013	First
Brunei Darussalam	26.989	0.012	First
Angola	21.756	0.012	First
Libya	22.917	0.007	First
Cabo Verde	22.611	0.007	First

Source(s): Authors' own work

Table A2. Variance Inflation Factor (VIF) of the study variables

Variable	VIF
Temperature	4.785
Temperature square	4.732
Precipitation	2.913
Precipitation square	2.801
AGTF	0.750
Exchange rate	1.009
Tariff rate	1.141
Price ratio	0.690

Source(s): Authors' own work

Appendix 2

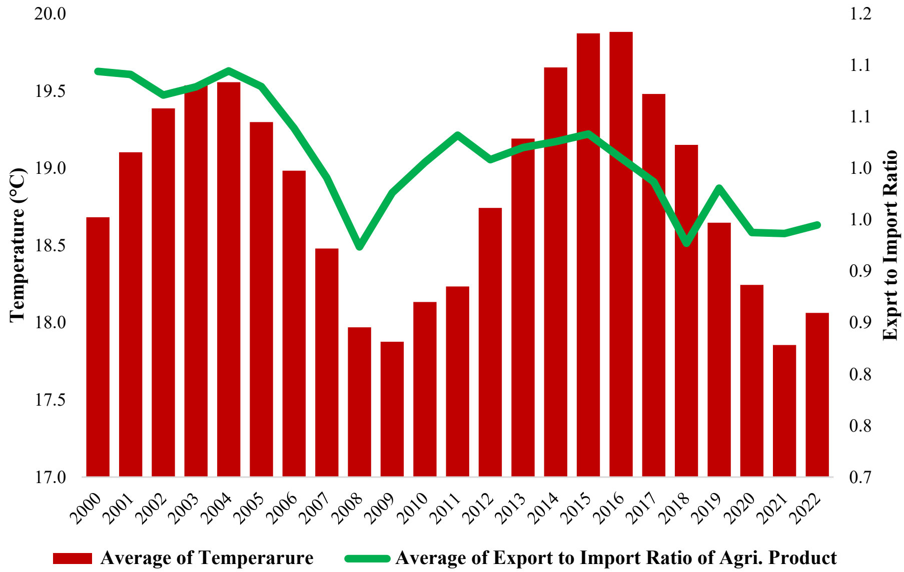

Figure A1. Average temperature and export to import ratio of agriculture products. Source: Climate Change Knowledge Portal (CCKP), World Bank and FAOSTAT

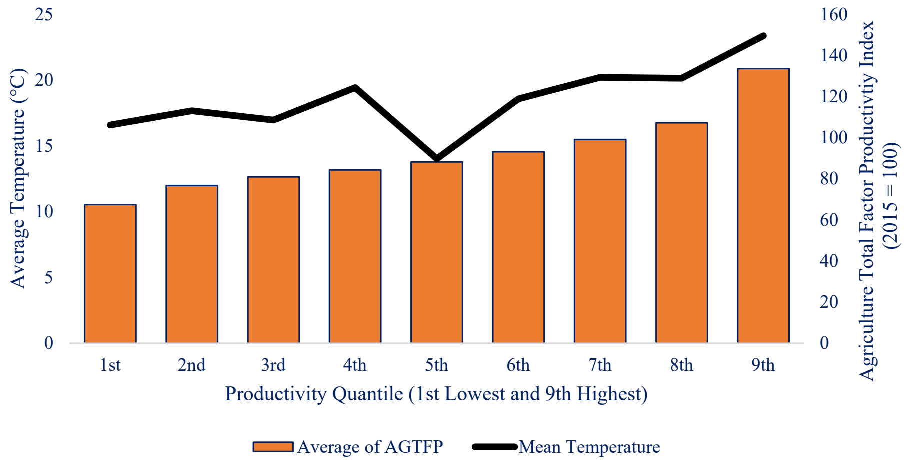

Figure A2. Trend of AGTF and TEMP across productivity quantiles. Source: Authors' own work

Corresponding author
Zubair Tanveer can be contacted at: f2021330003@umt.edu.pk