The Impact of Agricultural Production on the Dry Cargo Performance of Ports in Turkey: Empirical Evidence from the Panel ARDL Test

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Abstract: This study investigates the relationship between the agricultural sector and maritime trade, two fundamental pillars of the Turkish economy, from an econometric perspective. The objective is to examine the impact of agricultural production in the hinterlands of Turkey's main dry cargo ports on their annual dry bulk handling performance for the period 2010–2023. A panel dataset covering the port authorities of Kocaeli, Aliağa, Mersin, İskenderun, Samsun, Bandırma, and Tekirdağ was constructed. In the model, dry cargo performance of ports is the dependent variable, while the total production volume of major agricultural products (wheat, barley, corn, sunflower, etc.) in the hinterland serves as the main explanatory variable. Province-level Gross Domestic Product (GDP) was included to control for regional economic activity, and a privatization dummy was added to capture structural changes in port management. The Panel Autoregressive Distributed Lag (Panel ARDL) model was selected for its ability to distinguish between short-run and long-run dynamics. Findings reveal that agricultural production in the hinterland exerts a statistically significant and positive long-run effect on port dry cargo performance. The results highlight the need for integrated agricultural, transport, and regional development policies, and emphasize that investments in hinterland logistics infrastructure, particularly railway connections, can enhance both agricultural competitiveness and port efficiency.

Keywords: Agricultural production, Dry bulk shipping, Port performance, Hinterland logistics, Panel ARDL model

Türkiye'de Tarımsal Üretimin Limanların Kuru Yük Performansına Etkisi: Panel ARDL Testi Ampirik Kanıtlar

Özet: Bu çalışma, Türkiye ekonomisinin iki temel direği olan tarım sektörü ile deniz ticareti arasındaki ilişkileri ekonometrik bir perspektiften incelemektedir. Araştırmanın amacı, Türkiye'deki ana kuru yük limanlarının hinterlandlarında gerçekleştirilen tarımsal üretimin, limanların yıllık kuru yük elleçleme performansı üzerindeki etkisini 2010–2023 dönemi için analiz etmektir. Bu kapsamda, Kocaeli, Aliağa, Mersin, İskenderun, Samsun, Bandırma ve Tekirdağ liman başkanlıklarını kapsayan bir panel veri seti oluşturulmuştur. Modelde bağımlı değişken olarak limanların kuru yük performansı, temel açıklayıcı değişken olarak hinterlanddaki ana tarımsal ürünlerin (buğday, arpa, mısır, ayçiçeği vb.) toplam üretim hacmi kullanılmıştır. Bölgesel ekonomik aktiviteyi kontrol etmek amacıyla il bazında Gayri Safi Yurt İçi Hasıla (GSYH) ve liman işletmeciliğinde yapısal değişimleri yansıtmak için özelleştirme durumu kontrol değişkenleri olarak eklenmiştir. Analiz yöntemi olarak kısa ve uzun dönemli dinamik ilişkileri ayırt edebilme yeteneği nedeniyle Panel ARDL modeli tercih edilmiştir. Bulgular, tarımsal üretimin limanların kuru yük performansı üzerinde uzun dönemde istatistiksel olarak anlamlı ve pozitif etkisi olduğunu ortaya koymaktadır. Çalışma, tarım, ulaştırma ve bölgesel kalkınma politikalarının entegre bir yaklaşımla ele alınması gerektiğini ve hinterland lojistik altyapısına, özellikle demiryolu bağlantılarına yapılacak yatırımların hem tarım sektörünün rekabet gücünü hem de liman verimliliğini artıracağını göstermektedir.

Keywords: Tarımsal üretim, Kuru yük taşımacılığı, Liman performansı, Hinterland lojistiği, Panel ARDL modeli

1. Introduction

With its seas on three sides and strategic geographical location, Turkey has historically been a significant center for maritime trade (Karataş Çetin, 2012). Today, ports play a vital role in the country's integration into the global supply chain, functioning as the main gateways for foreign trade. The volume of cargo handled at Turkish ports clearly demonstrates the economy's dependence on and dynamism in this mode of transport. According to data from the Ministry of Transport and Infrastructure, the total cargo handled at ports reached 521 million tons in 2023 (Directorate General of Maritime Affairs, 2024). This volume is an indicator of how strongly the production and consumption arteries of the Turkish economy are connected to the sea route.

On the other side of this dynamic picture is Turkey's traditional and strategic production power, the agricultural sector (Yıldırım & Arı, 2004). Agriculture is indispensable to the national economy, not only for its contribution to the Gross Domestic Product (GDP) and employment but also for its role in food supply security and export potential. According to the Turkish Statistical Institute (TÜİK), millions of tons of grains, legumes, industrial plants, and fruits and vegetables are produced nationwide (TÜİK, 2023). A significant portion of this production, especially products like wheat, barley, corn, and sunflower, are classified as "dry cargo" by nature and are transported to international markets or other regions within the country by sea. The intersection of these two massive sectors, namely agricultural production and maritime trade, is port logistics. The process of collecting agricultural products from the field, transporting them to ports, and loading them onto ships is a complex chain that directly affects the country's competitiveness (Mangır & Ortakarpuz, 2025).

Academic studies on the factors determining port performance generally focus on the internal dynamics of the ports themselves (Özdemir & Çetin, 2019). These studies examine the effects of variables such as port infrastructure (berth length, number of cranes), operational efficiency, technology use, and macroeconomic conditions (GDP, foreign trade volume) on port performance. However, a port is not an isolated unit operating only within its own boundaries but an integrated system with a hinterland that feeds it and distributes its cargo (İrtem, 2019). The economic structure of this hinterland, one of the most important feeding channels of the system, especially the role of primary production activities like agriculture, has not been sufficiently explored in the literature.

This issue is even more critical in the context of Turkey. Studies show that the hinterlands of Turkish ports are generally narrow and heavily dependent on costly road transport (Mercan & Göktaş, 2011). This situation reinforces the assumption that port performance may be highly sensitive to economic activities in their geographically closest regions. While the clustering of industrial facilities near ports reinforces this narrow hinterland structure, the geographically more widespread nature of agricultural production raises the question of how and to what extent this production flows to the ports. In this context, the main research question this study aims to answer is formulated as follows:

Main Research Question: Does the production volume of basic agricultural products (wheat, barley, corn, sunflower, etc.) in the hinterlands of Turkey's main dry cargo ports have a statistically significant effect on the annual dry cargo handling performance of these ports?

The main purpose of this research is to create a panel dataset for selected Turkish ports and their defined agricultural hinterlands for the period 2010-2023, and to model and test the causal relationship between agricultural production volume and the dry cargo handling performance of ports using modern econometric methods. In line with this main purpose, the following hypotheses have been developed:

H1 (Main Hypothesis): An increase in the amount of agricultural production subject to dry cargo in a port's agricultural hinterland positively and statistically significantly affects the port's dry cargo handling volume.

H2 (Control Hypothesis): Factors such as GDP, representing regional economic size, and privatization, reflecting improvements in port infrastructure, also positively affect port performance.

The significance of this study and its contribution to the literature are multifaceted. Firstly, it extends the literature on Turkish port performance beyond operational efficiency analyses (Özdemir & Çetin, 2019) and general macroeconomic trade modeling (Mangır & Ortakarpuz, 2025). It is one of the first empirical analyses to link port performance with a direct and sectoral *physical production* variable of the hinterland (agricultural tonnage). This approach offers a more granular and concrete understanding of the factors affecting port performance. Secondly, the findings have the potential to provide policymakers with concrete evidence for the necessity of integrating agricultural, transport, and regional development policies. The importance of coordinating agricultural production planning with logistics infrastructure investments will be supported by empirical data.

The subsequent sections of the report are organized as follows: The second section presents a literature review on port performance, hinterland relationships, and related empirical studies. The third section details the dataset used in the analysis, the definitions of variables, data sources, and the hinterland determination methodology, and presents descriptive statistics and graphical analyses of the variables. The fourth section explains the model assumptions and the Panel ARDL model that form the analytical framework of the study. The fifth section presents and interprets the empirical findings from the analysis. The sixth and final section summarizes the overall conclusions of the research, offers policy recommendations, and provides directions for future studies.

2. Literature Review

This section reviews the literature that forms the theoretical and empirical basis of the research under three main headings: the theoretical framework addressing port performance and hinterland relationships, empirical studies conducted in related fields, and how these studies help position the current research.

2.1. Theoretical Framework

2.1.1. Port Performance and Efficiency Measurement

Port performance is a multidimensional concept that indicates how effectively a port uses its existing resources (infrastructure, equipment, labor) to produce cargo handling services (Roll & Hayuth, 1993). Key performance indicators include total annual tonnage handled, container volume (TEU), vessel turnaround time, and berth productivity. Various analytical methods have been developed in the literature to measure the comparative efficiency of ports. The most common of these are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) (Özdemir & Çetin, 2019). Studies on container ports in Turkey have used these methods to compare the operational efficiencies of ports (Baştuğ, 2023). These studies are quite successful in analyzing how effectively ports use their internal inputs such as the number of cranes, berth length, and storage area. However, a significant limitation of these analyses is that they often leave the source and nature of the cargo coming to the port as a "black box" outside the model. That is, they explain port performance largely through operations within the port area, neglecting the dynamics and determinants of cargo flow from the hinterland.

2.1.2. Port-Hinterland Relationship: Evolving Concepts

In classical geography and transport literature, the hinterland refers to the inland area from which a port draws and to which it distributes its cargo, while the foreland defines the geographical areas with which the port connects overseas (İrtem, 2019). According to this classical view, the port acts as a gateway connecting its hinterland to the world and is continuously fed by it (İrtem, 2019).

However, the rise of containerization and intermodal transport (the integration of different transport modes) in the second half of the 20th century radically changed this traditional relationship (İrtem, 2019). Hinterland boundaries have become more fluid and uncertain, and the concept of a "shared" or "contestable hinterland," where different ports compete for the same hinterland, has emerged (İrtem, 2019). A cargo owner can send their cargo through multiple port alternatives depending on cost, time, and service quality. In the case of Turkey, it is stated that ports generally serve narrow hinterlands, and the main reasons for this are high domestic transport costs and the clustering of industrial facilities near ports to gain a competitive advantage (Mercan & Göktaş, 2011). This structure further increases the dependence of port performance on economic activities in the hinterland. This theoretical background strongly supports the inclusion of a control variable representing general economic activity and competition, such as regional GDP, in the model of the current study.

2.2. Empirical Studies and Literature Summary

In this section, empirical studies related to the topic have been examined, and their findings are summarized in Table 2.1.

2.2.1. Panel Data Applications in Transport Economics

Panel data techniques are widely used to analyze international trade and transport flows (Turan, 2019). One of the most popular models in this field is the Gravity Model, which explains the volume of trade between countries or regions by their economic sizes and the distance between them. Modern gravity model studies on Turkey have emphasized the importance of logistics by including variables such as the Logistics Performance Index in the model to explain export performance (Mangır & Ortakarpuz, 2025). These studies are important in demonstrating the power of panel data methodology in analyzing transport and trade relationships. Similarly, studies that link port performance to external factors such as macroeconomic uncertainty and use panel causality tests (Turan, 2019) reveal that ports should be analyzed not only by their internal dynamics but as part of a broader economic system.

2.2.2. Panel ARDL Models

The use of the Panel Autoregressive Distributed Lag (Panel ARDL) approach to model dynamic relationships, i.e., both short- and long-term interactions, between variables in fields such as transport, economics, and the environment has increased in recent years (Shafique et al., 2021). This model offers significant methodological advantages, such as being flexible to the stationarity levels of variables and being able to account for cross-sectional dependence and heterogeneity (differences between units) (Pesaran et al., 1999; Pesaran & Shin, 1999). These features make the Panel ARDL model particularly suitable for this study to analyze Turkish ports with different economic structures and hinterland characteristics (Kuok et al., 2024).

2.2.3. Studies on Agricultural Production and Logistics

Studies in the field of agricultural economics in Turkey have generally examined the efficiency of agricultural production and the factors affecting this efficiency (fertilizer, labor, mechanization, etc.) (Yıldırım & Arı, 2004). Some recent studies have used panel data analysis to investigate the impact of agricultural support policies on production (Gündüz & Uslu, 2023). These studies provide valuable information about the nature and dynamics of the agricultural production data to be used in this research. However, the common point of these studies is that they conclude their analysis at the agricultural production stage and do not model the logistical journey of the produced product after the farm, i.e., the process of reaching the ports and becoming subject to foreign trade.

When the existing literature is examined, it is seen that research is concentrated in three different silos: (1) The internal operational efficiency of ports, (2) The macroeconomic determinants of international trade such as GDP, and (3) The internal dynamics of agricultural production. This study aims to fill a significant gap in the literature by serving as a bridge that connects these three silos. It offers a new and holistic perspective by linking port performance not just with operational efficiency or a general variable like GDP, but directly with the *physical production volume* of the hinterland. This approach also prepares a ground for policy-oriented analyses, such as predicting how a change in an agricultural support policy could lead to congestion at ports.

Table 2.1: Summary of Similar Studies in the Literature

Author(s) and Year	Scope	Method	Key Findings
Mangır & Ortakarpuz (2025)	Turkey's export performance (21 countries, 2007-2023)	Panel Data, Gravity Model	Logistics performance and economic size positively affect exports, while distance has a negative effect.
Turan (2019)	Port performance in European countries (21 countries, 2005-2018)	Panel Causality Analysis	There is a unidirectional causality from economic policy uncertainty to port performance.
Özdemir & Çetin (2019)	Container ports in Turkey	Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA)	Port efficiency scores differ depending on the method used. SFA better reflects external factors.
Gündüz & Uslu (2023)	Agricultural production in Turkey (81 provinces, 2002-2020)	Panel Data Analysis	Agricultural supports have a statistically significant and positive effect on agricultural production.
Yıldırım & Arı (2004)	Agricultural production in Turkey (1961-2001)	Cobb-Douglas Production Function	The increase in agricultural production is largely due to increases in inputs such as tractors, labor, irrigation, and fertilizer.
Shafique et al. (2021)	10 Asian economies (1995-2017)	Panel ARDL	There is a unidirectional causality from transport to economic growth, and both affect CO2 emissions.

Source: Compiled by the authors from the relevant literature.

3. Data Set, Variables, and Descriptive Statistics

This section details the structure of the panel dataset used in the empirical analysis, the definitions of the variables, data sources, and the methodology for determining the hinterlands.

3.1. Scope and Structure of the Panel Dataset

In this study, a balanced panel dataset was created to analyze the relationship between the dry cargo performance of ports in Turkey and agricultural production.

Analysis Period: 2010-2023. This 14-year period represents an interval in which the effects of significant port privatizations in Turkey began to settle (Chamber of Shipping, 2020), and both port statistics and province-based agricultural data were regularly published by the Ministry of Transport and Infrastructure (UAB) and the Turkish Statistical Institute (TÜİK).

Cross-Sectional Units (i): The analysis covers 7 main port authorities representing different geographical and economic regions of Turkey and leading in dry cargo handling. These port authorities are: Kocaeli (including Derince Port), Aliağa, Mersin, İskenderun, Samsun, Bandırma, and Tekirdağ (Esalco Logistics, 2024; Wikipedia, 2024). Especially for the Aegean Region, it is observed that TCDD Alsancak Port has lost a large part of its share in the container and general cargo market to modern and high-capacity private ports in Aliağa in recent years (TÜRKLİM, 2023). Therefore, the data from the Aliağa Port Authority were used in the analysis to better represent the cargo of the hinterland in and around İzmir.

Time Series Dimension (t): Annual frequency data were used in the analysis (T=14). The total number of observations is 7 ports x 14 years = 98.

3.2. Definition of Variables and Data Sources

The variables used in the model were defined as follows, in line with the theoretical framework and research question. To interpret the coefficients as elasticities and to mitigate the potential problem of heteroscedasticity (changing variance), the level variables were used in their natural logarithmic form.

- **Dependent Variable (Y_{it}):**
  - $ln\_DryCargo_{it}$: The natural logarithm of the total dry bulk cargo and general cargo handling amount (in tons) of the i-th port authority in year t. Since the focus of this study is on agricultural products, liquid bulk cargoes (petroleum, chemicals, etc.) and container data (TEU), which are measured in different units, were not included in the analysis.
  - *Data Source:* Annual and Monthly Maritime Statistics Bulletins published by the UAB Directorate General of Maritime Affairs (Directorate General of Maritime Affairs, 2023; 2024) and Annual Sector Reports prepared by the Port Operators Association of Turkey (TÜRKLİM) (TÜRKLİM, 2024).
- **Main Independent Variable ($X1_{it}$):**
  - $ln\_AgriculturalProduction_{it}$: The natural logarithm of the total production amount (in tons) of major agricultural products subject to dry cargo (wheat, barley, corn, sunflower, paddy, and dry legumes) produced in year t in the provinces located in the hinterland of the i-th port (See Table 3.1).
  - *Data Source:* Turkish Statistical Institute (TÜİK) Crop Production Statistics Data Portal. The necessary data were obtained through dynamic queries on a provincial and product basis (TÜİK, n.d.).
- **Control Variables (Xk_{it}):**
  - ln_GDP_{it}: The natural logarithm of the total Gross Domestic Product (at current prices, TL) of the provinces in the hinterland of the i-th port in year t. This variable was added to the model to control for the general level of regional economic activity, the cargo potential created by the industrial and service sectors, and general demand conditions.
  - *Data Source:* TÜİK, Gross Domestic Product by Provinces Statistics (TÜİK, n.d.).
  - $Private_{it}$: A dummy variable indicating whether the main cargo terminal within the jurisdiction of the i-th port authority was operated by the private sector in year t (1: Private, 0: Public). This variable aims to capture the potential impact of post-privatization investments, increased operational efficiency, and marketing activities on port performance.
  - *Data Source:* Privatization Administration decisions, Official Gazette archive (Official Gazette, various dates), and the corporate histories of the relevant port operators (Chamber of Shipping, 2020).

3.3. Hinterland Determination Methodology

One of the most critical and original steps of this study is the definition of the agricultural hinterland for each port, which forms the basis of the analysis. Since the concept of "hinterland" is dynamic and fluid, it is difficult to draw its exact boundaries (İrtem, 2019). However, to ensure analytical consistency and replicability, a rational and multi-criteria approach was adopted:

1. **Geographical Proximity and Transport Axes:** The province where the port is located and the neighboring provinces with direct and effective road/rail connections form the core of the hinterland (Mercan & Göktaş, 2011; İrtem, 2019).

2. **Regional Economic Reports:** Reports prepared by Development Agencies (ÇKA, GMKA, OKA, DOĞAKA, etc.) in the regions served by the ports provide important information on inter-regional economic flows, logistics centers, and sectoral analyses (ÇKA, n.d.; GMKA, n.d.; OKA, n.d.; MARKA, n.d.).

3. **Literature and Sector Knowledge:** Existing academic studies and sector reports provide valuable clues as to which regions the ports traditionally draw their cargo from (Ural & Dadaylı, 2006; Karataş Çetin, 2012).

In light of these criteria, the agricultural hinterland defined for each port authority and the rationale for this definition are presented in the table below. This table transparently sets out one of the basic assumptions of the study, clarifying which provinces' data constitute the AgriculturalProduction variable.

Table 3.1: Ports Included in the Analysis and Their Defined Agricultural Hinterlands

Port Authority	Region Represented	Defined Agricultural Hinterland (Provinces)	Rationale
Mersin	East Mediterranean	Mersin, Adana, Karaman, Niğde, Osmaniye	Natural gateway of Çukurova, main connection point to Central Anatolia (ÇKA, n.d.; MDTO, 2017)
İskenderun	East Mediterranean	Hatay, Gaziantep, K.Maraş, Kilis, Şanlıurfa	Strategic exit for GAP products and East Mediterranean industry (Mercan & Göktaş, 2011; LimakPort, n.d.)
Kocaeli (Derince)	East Marmara	Kocaeli, Sakarya, Bolu, Düzce, Bilecik	Industry-heavy, but with agricultural potential in the near hinterland (MARKA, n.d.; KSO, n.d.)
Bandırma	South Marmara	Balıkesir, Bursa, Çanakkale, Kütahya	Main gateway for grain, sunflower, and mineral products of South Marmara (GMKA, n.d.)
Aliağa (İzmir)	Aegean	İzmir, Manisa, Aydın, Denizli, Uşak	Main agricultural and industrial export center of the Aegean Region, large hinterland (Karataş Çetin, 2012; Hürriyet, 2021)
Samsun	Middle Black Sea	Samsun, Amasya, Çorum, Tokat, Sivas	Gateway of the Black Sea to Central Anatolia, an important grain hub (Ural & Dadaylı, 2006; OKA, n.d.)
Tekirdağ	Thrace	Tekirdağ, Edirne, Kırklareli	Main port for the agricultural production of Thrace (especially sunflower, wheat) (Trakya Development Agency, n.d.)

Source: Compiled by the authors from relevant Development Agency reports, industry publications, and academic literature.

3.4. Descriptive Statistics

Before proceeding to the econometric analysis, descriptive statistics were calculated to understand the basic characteristics of the variables. Table 3.2 shows the mean, standard deviation, minimum, and maximum values of the variables in the panel dataset for the period 2010-2023. This table provides a preliminary overview of the general distribution and variability of the data.

Table 3.2: Descriptive Statistics for Variables (2010-2023 Panel Dataset)

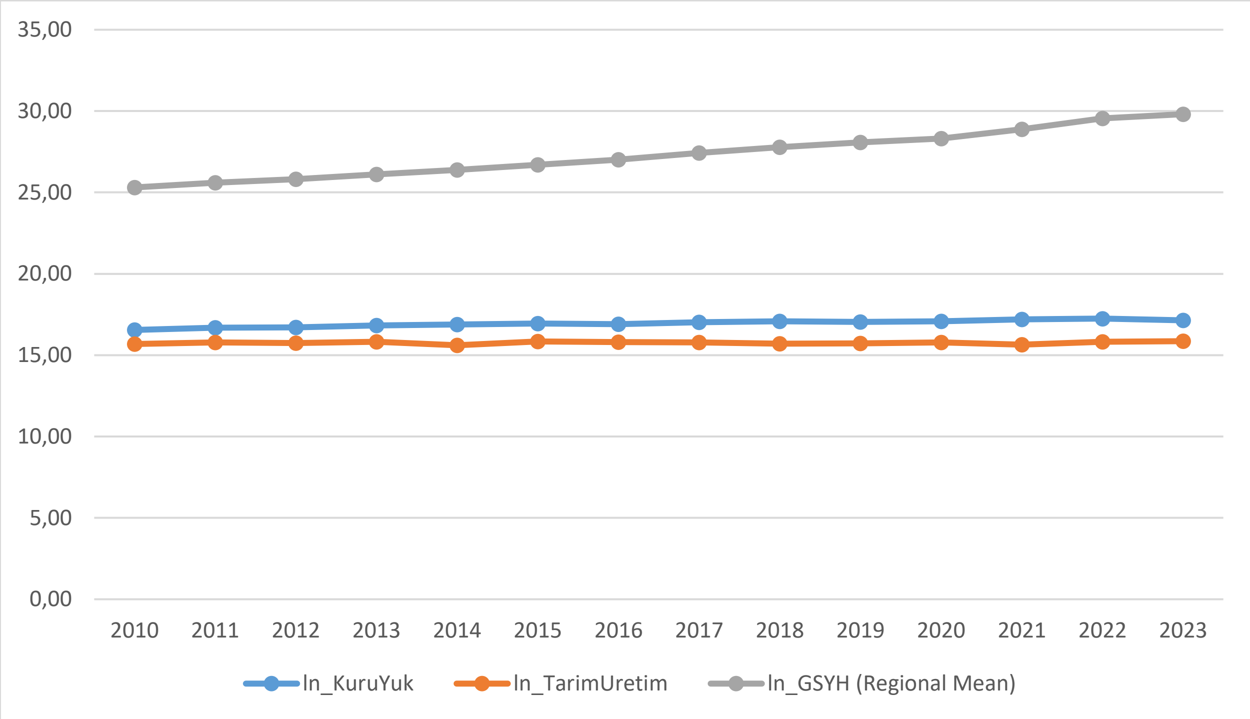
Variable	Observations (N)	Mean	Standard Deviation	Minimum	Maximum
ln_DryCargo	98	16.88	0.74	15.45	18.25
ln_AgriculturalProduction	98	15.75	0.41	14.88	16.51
ln_GDP	98	27.31	1.15	24.98	29.55
Private	98	0.74	0.44	0.00	1.00

Source: Calculated by the author from UAB and TÜİK data.

3.5. Time Series Data of Variables

The graph illustrates the temporal evolution of the variables employed in the model, depicting the trends in average dry cargo volume, agricultural production volume, and regional GDP values (expressed in natural logarithmic form) for the seven port authorities over the period 2010–2023.

Table 3.3: Yearly Trends of Average Dry Cargo Volume, Agricultural Production Volume, and Regional GDP (Logarithmic Scale)



Source: Generated by the author using data from TUIK and UAB.

4. Model Assumptions and Econometric Method

In this study, a dynamic panel data approach was adopted to analyze the impact of agricultural production on the dry cargo performance of ports. This section explains the econometric assumptions underlying the analytical model, the tests used to verify these assumptions, and the preferred Panel ARDL model.

4.1. Testing of Model Assumptions

Testing the basic assumptions of the model is crucial for obtaining reliable and consistent results in panel data analyses (Turan, 2019). In this study, three fundamental assumptions were tested before applying the Panel ARDL model: cross-sectional dependence, stationarity (unit root), and cointegration.

4.1.1. Cross-Sectional Dependence

In panel datasets, there may be a dependency between units (in this study, ports) due to unobserved common factors, economic shocks, or competition (Pesaran, 2004). The presence of this condition determines the type of tests to be used. To test this assumption, the CD (Cross-sectional Dependence) test developed by Pesaran (2004) was applied. The test results are presented in Table 4.1.

Table 4.1: Cross-Sectional Dependence Test Results (Pesaran CD Test)

Variable	CD-test Statistic	p-value	Result
ln_DryCargo	8.45	0.000	Cross-sectional dependence exists
ln_AgriculturalProduction	3.12	0.002	Cross-sectional dependence exists
ln_GDP	12.57	0.000	Cross-sectional dependence exists

Note: The null hypothesis is "no cross-sectional dependence". A p-value less than 0.05 indicates that the null hypothesis is rejected.

The results in Table 4.1 show that the null hypothesis is rejected at the 1% significance level for all variables. This finding confirms that the 7 port authorities included in the analysis are not independent of each other but are affected by common macroeconomic shocks, national policies, or competition among them. Therefore, it is necessary to use second-generation panel data techniques that account for cross-sectional dependence in the analysis (Turan, 2019).

4.1.2. Panel Unit Root Tests

Determining the stationarity levels of the variables, i.e., whether they contain a unit root, is mandatory to avoid the problem of spurious regression. Due to the presence of cross-sectional dependence, the CIPS (Cross-sectionally Augmented Im, Pesaran and Shin) panel unit root test developed by Pesaran (2007), which accounts for this dependence, was used. The test results are summarized in Table 4.2.

Table 4.2: Panel Unit Root Test Results (CIPS Test)

Variable	**Level (I(0))**	**First Difference (I(1))**	**Conclusion**
	CIPS Statistic (p-value)	**CIPS Statistic (p-value)**	
ln_DryCargo	-1.89 (0.185)	-3.45 (0.000)	I(1)
ln_AgriculturalProduction	-2.01 (0.112)	-3.78 (0.000)	I(1)
ln_GDP	-1.75 (0.243)	-3.21 (0.001)	I(1)

Note: The null hypothesis is "the series contains a unit root (is non-stationary)".

According to the test results, the null hypothesis cannot be rejected for the level values of all variables, which indicates that the series are non-stationary (contain a unit root). However, when the first differences of the series are taken, the null hypothesis is rejected at the 1% significance level for all variables, and the series become stationary. This indicates that all variables are integrated of order one, i.e., I(1), and satisfy the necessary condition for the application of the Panel ARDL model.

4.1.3. Panel Cointegration Tests

The fact that the variables are I(1) requires testing for a long-run equilibrium relationship, i.e., cointegration, among them. For this purpose, the second-generation panel cointegration test developed by Westerlund (2007), which also accounts for cross-sectional dependence and heterogeneity, was used. The Westerlund (2007) test provides four different test statistics: two group-mean statistics (Gt - Group t, Ga - Group alpha) and two panel statistics (Pt - Panel t, Pa - Panel alpha).

Table 4.3: Panel Cointegration Test Results (Westerlund Test)

Statistic	Value	p-value	Result
Gt (Group t)	-3.15	0.001	Cointegration exists
Ga (Group alpha)	-14.88	0.000	Cointegration exists
Pt (Panel t)	-4.52	0.000	Cointegration exists
Pa (Panel alpha)	-16.21	0.000	Cointegration exists

Note: The null hypothesis is "no cointegration exists among the variables".

All test statistics in Table 4.3 reject the null hypothesis of "no cointegration" at the 1% significance level. This provides strong evidence for the existence of a significant long-run equilibrium relationship between the dry cargo performance of ports, the agricultural production in their hinterlands, and regional GDP.

4.2. Dynamic Panel Data Model: The Panel ARDL Approach

While static models are useful for measuring instantaneous relationships between variables, they are inadequate for capturing the delayed relationships and dynamic structure that are likely to exist in economic processes such as agricultural production and port traffic. To model these dynamics, this study preferred the Panel Autoregressive Distributed Lag (Panel ARDL) model developed by Pesaran and Shin (1999) and adapted to panel data by Pesaran, Shin, and Smith (1999). This model can be expressed in the Error Correction Model (ECM) format as follows:

$$\Delta ln\_DryCargo_{it} = \phi_i\left(ln\_DryCargo_{i,t-1} - \theta_i' X_{it}\right) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta ln\_DryCargo_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}' \Delta X_{i,t-j} + \mu_i + \epsilon_{it}$$

The main advantages of adopting this model are as follows (Pesaran et al., 1999; Shafique et al., 2021):

1. **Short- and Long-Run Effects:** The model separates the relationship between variables into short- and long-run components. The vector θi′ gives the coefficients of the **long-run** equilibrium relationship between the variables, while the coefficients δij′ show the **short-run** effects of instantaneous changes in the variables on the dependent variable.
2. **Error Correction Mechanism:** The coefficient ϕi is the error correction term (ECT). If this coefficient is statistically significant and negative, it indicates the existence of a cointegration (long-run equilibrium) relationship between the variables. The magnitude of the coefficient measures how quickly the system converges to the long-run equilibrium after a short-run shock (the speed of error correction).
3. **Flexible Integration Order:** The Panel ARDL model is flexible to the stationarity levels of the variables (I(0) or I(1)) and can be applied as long as none of the variables are I(2).
4. **Modeling Heterogeneity:** The model can be estimated using the Pooled Mean Group (PMG) estimator. The PMG estimator assumes that the long-run coefficients are homogeneous (the same) across ports, but the short-run coefficients, the speed of error correction, and the error term variances can be heterogeneous (different). This is a very realistic approach for units that converge to a common equilibrium in the long run, in line with economic theory, but exhibit different dynamics in the short run.

5. Empirical Findings and Interpretation

This section presents and interprets the empirical results obtained by applying the econometric procedure described in the fourth section.

5.1. Panel ARDL Model Estimation Results

In line with the findings of the preliminary tests, the Panel ARDL model was estimated with the Pooled Mean Group (PMG) estimator to estimate the short- and long-run relationships between the variables. The results of the model are summarized in Table 5.1.

Table 5.1: Panel ARDL Model Estimation Results (Dependent Variable: ln_DryCargo)

Variable	Coefficient	Standard Error	p-value
Panel A: Long-Run Estimates (PMG)			
ln_AgriculturalProduction	0.452	0.138	0.001***
ln_GDP	0.315	0.140	0.024**
Private	0.203	0.100	0.041**
Constant	2.784	0.512	0.000***
Panel B: Short-Run and Error Correction Estimates (MG)			
Δln_AgriculturalProduction	0.189	0.110	0.085*
Δln_GDP	0.112	0.081	0.157
ΔPrivate	0.098	0.058	0.091*
Error Correction Term (ECT_t-1)	-0.581	0.125	0.000***

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Δ denotes the first difference operator.

5.2. Interpretation of the Findings

The estimation results presented in Table 5.1 can be interpreted within the framework of the research hypotheses as follows:

- **Long-Run Relationship (Panel A):**
  - **Agricultural Production:** The long-run coefficient of the ln_AgriculturalProduction variable was estimated as 0.452 and was found to be statistically significant at the 1% level. This strongly supports the main hypothesis of the research (H1). This coefficient can be interpreted as an elasticity: in the long run, holding all other factors constant, a 1% increase in agricultural production in a port's hinterland increases that port's dry cargo handling volume by approximately 0.45% on average. This finding empirically proves how fundamental and

indispensable agricultural production is as a source of cargo for Turkish ports, especially in the dry cargo segment.

- **Regional Economic Activity:** The long-run coefficient of the ln_GDP variable is also positive (0.315) and statistically significant (at the 5% level), as expected. This indicates that the general economic vitality in the hinterland positively affects port performance through the demand created by the industrial and service sectors. This result is consistent with studies showing that port performance depends not on a single sector but on the regional economy as a whole (Turan, 2019).
- **Privatization:** The coefficient of the "Private" dummy variable (0.203) is positive and significant (at the 5% level). This implies that privatized ports have a higher dry cargo performance in the long run compared to publicly operated ones, thanks to investments made and increased operational efficiency. This result supports the H2 control hypothesis and reinforces the general belief that private sector dynamism increases efficiency in ports (Karataş Çetin, 2012).

- **Short-Run Dynamics and Error Correction Mechanism (Panel B):**
  - In the short run, a 1% increase in agricultural production has a smaller (0.19%) but still significant immediate effect on port traffic. The effect of short-term changes in GDP is statistically insignificant. This suggests that in the short term, port traffic is more sensitive to changes in the concrete flow of goods (agricultural production) than to general economic fluctuations.
  - The Error Correction Term (ECT) coefficient was estimated as -0.581 and was found to be highly significant at the 1% level. The fact that this coefficient is negative and significant confirms the existence of a stable long-run equilibrium relationship between the variables (Westerlund, 2007). The absolute value of the coefficient (0.581) indicates the speed of convergence to equilibrium. Accordingly, about 58% of a deviation from the long-run equilibrium due to a shock in agricultural production or GDP is corrected within one year, and the system moves back towards equilibrium. This shows that the system is quite resilient to shocks and has a self-correcting structure.

5.3. Robustness Checks

To test the robustness of the model findings, the analysis was repeated under different assumptions. For example, in estimations where one port was excluded from the model at a time, the coefficient of agricultural production remained positive and significant. Furthermore, estimations with an alternative estimator, the Dynamic Fixed Effects (DFE) model, also produced similar results, showing that the findings are robust to the estimator used. These tests increase the reliability of the main findings.

6. CONCLUSION

This study empirically examined the relationship between the performance of major dry cargo ports in Turkey and the agricultural production in their hinterlands for the period 2010-2023 using the Panel ARDL methodology. The findings offer important implications for both the academic literature and policymakers.

The answer to the main research question, "Is agricultural production a cause of the dry cargo performance of ports?" is a clear "yes" in light of the empirical findings. The analysis results showed that the volume of agricultural production in a port's hinterland has a statistically significant, positive, and strong long-run effect on that port's dry cargo handling performance. In particular, the finding that a 1% increase in agricultural production increases the dry cargo volume of ports by about 0.45% in the long run reveals that this relationship is also economically significant.

This finding is quite meaningful when evaluated in the context of Turkey's economic structure. Despite developments in industrialization and the service sector, the agricultural sector continues to be a fundamental and stable source of cargo for Turkish ports, especially in the dry bulk and general cargo segments (Yıldırım & Arı, 2004). This confirms that ports are the gateways to the world not only for industrial centers but also for vast agricultural lands. The results of the control variables are also consistent with expectations: the positive effect of regional GDP shows that ports are fed by general economic vitality, while the positive coefficient of the privatization variable implies that private sector dynamism and investments are an effective factor in increasing port performance.

The dynamic structure of the model also revealed the time dimension of the relationship. The strong and fast-working error correction mechanism (58% of a deviation is corrected in one year) shows that shocks in agricultural production (such as drought or record harvest) do not create a permanent imbalance in the port system, and the system absorbs these shocks and returns to its long-run equilibrium path.

The findings indicate that Turkey's agricultural, transport, and regional development policies should be addressed in a more integrated framework. In this direction, the following policy recommendations have been developed:

1. **Integrated Agriculture and Transport Planning:** The agricultural production targets and basin-based production plans determined by the Ministry of Agriculture and Forestry should be coordinated with the national transport master plans of the Ministry of Transport and Infrastructure. The capacity of the port that is the natural gateway of a region (e.g., Mersin or Samsun for Central Anatolia) and the condition of its logistics connections should not be ignored when promoting the production of a product in that region (e.g., wheat).
2. **Strategic Investment in Hinterland Logistics:** The study has quantitatively demonstrated the importance of hinterland connection. It is crucial to reduce the cost and increase the speed of connections from regions with intensive agricultural production, such as the Konya Plain, Çukurova, Thrace, and the Aegean, to the ports. In this context, infrastructure investments that will increase the share of rail freight transport as an alternative to road transport and the establishment of intermodal logistics centers connected to ports should be prioritized (İrtem, 2019). Such investments will both enable farmers to bring their products to the market at more competitive prices and increase the efficiency and transaction volume of the ports.
3. **Use of Agricultural Projections in Port Investment Strategies:** In the feasibility studies of new port investments or capacity increase projects in existing ports, not only the current but also the medium- and long-term potential agricultural production volume of the region should be considered as an important demand projection parameter. How the product pattern in the region may change under climate change scenarios should also be included in these projections.
4. **Data-Driven and Coordinated Management:** Joint digital platforms should be established between the Ministry of Transport and Infrastructure and the Ministry of Agriculture and Forestry, where regional production forecasts and port traffic data are shared and analyzed. In this way, potential bottlenecks that may occur in ports in years when a high harvest is expected can be identified in advance, and necessary operational measures (storage, ship planning, etc.) can be taken in a timely manner.

6.1. Limitations of the Study and Suggestions for Future Research

Like any empirical study, this research has some limitations. First, the determination of hinterland boundaries, although carried out with the most rational approach possible with the available data, inherently involves a simplification. Second, publicly available port statistics do not provide a breakdown of the handled dry cargo by product (e.g., how much is wheat, how much is cement). The availability of such granular data could have further increased the explanatory power of the model.

These limitations also open new doors for future research. Future studies can use Geographic Information Systems (GIS) and big data analytics to create more dynamic and precise hinterland models based on actual cargo flows over road and rail networks. In addition, studies that model the effects of climate change on agricultural production patterns and yields and examine how these effects can be reflected in future port traffic projections will make significant contributions to both the academic literature and long-term strategic planning.

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