



The dynamic relationship between industrialization, urbanization, CO₂ emissions, and transportation modes in Korea: empirical evidence from maritime and air transport

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Abstract

This study investigates the causal relationship between logistics efficiency and factors affecting the logistics environment, such as industrialization, urbanization, and CO₂ emissions. With the expectation that logistics efficiency will contribute to economic growth and enhance country competitiveness in the near future, it is necessary to confirm the impact of each factor on different transportation modes, such as maritime and air transport. To this end, this study identifies causal relationships between the factors affecting the logistics environment and specific modes of transportation using data from 2010 to 2018. We employed the panel unit root test, panel co-integration test, fully modified OLS (FMOLS), panel dynamic OLS (DOLS), and panel VECM Granger causality tests for the estimations. The results revealed that factors affecting the logistics environment have different effects depending on the modes of transportation. For maritime transportation, long-run bidirectional causal associations were found between port volume, total exports, industrialization, and urbanization. This implies that export promotion and the resulting economic and social environment changes can increase port throughput; this increase can, in turn, develop and improve economic growth and factors affecting the logistics environment. In contrast, for air transport, we detected a long-run, unidirectional causal relationship among these variables and air volume changes with growing exports, urbanization, and industrialization. Thus, this study suggests a theoretical framework for analyzing the causal relationship between the factors affecting the logistics environment and each mode of transportation, providing insights for policymakers to promote logistics efficiency.

Keywords Logistics efficiency · Transportation mode · Industrialization · Urbanization · CO₂ · Panel VECM · Granger causality

Introduction

In a rapidly changing global environment such as industrialization, urbanization, and economic growth, logistics efficiency has been recognized as a significant global issue. The role of logistics efficiency in enabling international trade involves the implementation of profit-maximizing activities, from freight transport to payment systems. Logistics is induced by economic activities, and efficient logistics is recognized as an enabler of economic growth (Müller et al. 2015). A changing environment is accelerating demand in the transport sector (Nasreen et al. 2020) and leading to the flow of freight by transportation in trade (Brancaccio et al. 2020; Tavasszy 2020). Moreover, transportation efficiency and competitiveness have been globally highlighted (Liljestränd et al. 2015) where transportation is approaching capacity (Müller et al., 2012) amid a fierce debate over global warming. Recently, the COVID-19 pandemic highlighted the significance of transportation, as overall trade and production stalled due to limited passenger and freight movement.

In this regard, complex logistics supply chains are constantly evolving and facing various uncertainties (Giuffrida et al. 2021). In particular, the uncertainty inherent in a logistics supply chain can affect logistics performance (Russell et al. 2020; Wang, 2018). Therefore, previous studies have suggested solutions through a systematic review of uncertainties related to logistics and transportation (Grecco and Moura 2022; Nocera et al. 2018; Nocera and Cavallaro 2017; Shafique et al. 2021). As a result, logistics has come to play an increasingly central role due to the changes in demand, industries, and concerns about sustainability (Jaramillo et al. 2018). From this point of view, logistics involves the problem of the selection of the mode of transport (Hausman et al. 2013) and suggest that transportation modes constitute an important mechanism for increasing logistics efficiency. This is because logistics efficiency can be increased through the efficient operation and transition of several transportation modes including seaports, airports, railways, and roads.

However, the logistics and transportation industries face several challenges while improving logistics efficiency with regard to the surrounding factors affecting the logistics environment. Changes in means of transportation, such as maritime and air transport, is fundamental for economic development, as they are an essential factor in the development and cost of logistics and trade (Abbasi and Nilsson 2016). Furthermore, transportation efficiency in these sectors can integrate regional economic supply chains by improving transportation connectivity and management (Song and van Geenhuizen 2014). However, intensive use of fossil fuels has detrimental effects on the environment (Neves and Marques 2021; Rashidi and Cullinane 2019). In particular, the transportation sector is a mainly segment fossil fuel consumption, which is accelerating anthropogenic climate change by emitting air pollutants such as nitrogen dioxide (NO₂) and carbon dioxide (CO₂) (Shafique et al. 2021; Zhang et al. 2018). As a result, growing global concerns over environmental issues have led policymakers and scholars to confront the impact of environmental pollution, determinants, and sustainable logistics activities (Chandran and Tang 2013; Liu et al. 2018; Sun et al. 2014). For instance, transportation plays a essential role in climate change mitigation. Namely, logistics is attracting global attention for economic, social, and environmental reasons as it affects the protection of national economic activities and environmental sustainability (Lee and Wu 2014). Urbanization through international trade, which is the cornerstone of economic growth, industrialization through various industrial developments, and their consequent carbon emissions, represent a dynamic relationship between logistics and transpor-

tation, an essential element of the supply chain. Therefore, it is necessary to observe the dynamic relationship between the factors affecting the logistics environment and transportation modes at the macro level and examine the economic and environmental indicators of industrialization, urbanization, and CO₂ emissions.

These challenges can be solved by enhancing related competitiveness through interactions and causal relationships among logistics environment subjects. Specifically, countries tend to adopt efficient utilization systems for transportation modes to enhance their logistics competitiveness. Additionally, a change in policy that identifies and reflects the unique characteristics of various environmental structures is required to increase the efficiency of transportation modes at the national level (Önsel Ekici et al. 2016). To this end, policymakers need to understand the logistics industry as a whole to improve the sustainability and efficiency of transportation networks and services (Yetkiner and Beyzatlar 2020), and to build an integrated transportation infrastructure through the efficient operation of transportation modes and related activities (Yavas and Ozkan-Ozen 2020).

Therefore, this paper analyzes the causal relationships between the factors affecting the logistics environment and transportation modes. Transportation performance is fundamentally linked to the economy (Chang et al. 2020) and few studies have examined this perspective involving modes of transport and logistics environment structure. Therefore, based on previous studies, these relationships are analyzed by reflecting on the research on transportation modes and logistics environment structure (industrialization, urbanization, and CO₂ emissions).

This paper addresses three important gaps in the literature. First, this is the first study to focus on broadening the understanding of factors affecting the logistics environment and analyzing detailed factors that affect transportation modes. It provides a theoretical framework for analyzing such factors, and its results can provide policymakers with insights into the promotion of logistics efficiency. In particular, Korea has various international ports in the region for international trade (Adhikari et al. 2019), and a road and rail transportation system in which cargo is distributed throughout Korea. In terms of geographical location, maritime and air transport are the two sole means of international trade. In addition, maritime transport has the largest transport capacity and is held as the most preferred mode of transportation in international trade; air transport, the second most preferred, can be an alternative to maritime transport in some industries (Mohamad Taghvaei et al. 2019; Yoon et al. 2020). Therefore, the scope of transportation modes in this paper is restricted to maritime and air. Second, the relationship between the factors affecting the logistics environment and transportation modes is analyzed as short- and long-run causal relationships. To this end, the dynamic relationship between factors affecting the logistics environment, consisting of industrialization, urbanization, and CO₂, and each transportation mode, such as maritime and air transport, are analyzed using a panel vector error correction model (VECM) model. Panel data not only provide an increased sample size but also have a high degree of freedom, so the prediction accuracy is higher than that of time series and cross-sectional data. (Kasman and Duman 2015; Lee and Chang 2008; Mahadevan and Asafu-Adjaye 2007; Sadorsky 2012). For this reason, this study adopts panel VECM, an ideal econometric analysis tool that understands the nexus and examines the path of causation (Mujtaba et al. 2021). In particular, this methodology is suitable for analyzing dynamic interactions (Jacobs et al. 2019). Finally, the research sample focuses on Korea to establish a strategy to improve logistics efficiency, reflecting the regional context. Korea has an international trade-oriented

economy (Ha et al. 2019) and experiences export-led growth, and is considered to have a considerable logistics and transportation industry (Jun et al. 2018). In addition, Korea's role in linking Asian trade and transportation is growing at a time when the importance of multimodal transportation for logistics efficiency is increasing (Wang and Yeo 2018). An empirical understanding of this is necessary because export-dependence problems are on the rise due to the diversification of export markets and changes in Korea's global supply chains. Therefore, this study aims to provide theoretical and policy implications for logistics efficiency by analyzing the relationship between changes in the logistics environment and transportation methods through a reflection on the characteristics of logistics sectors.

The remainder of this paper is organized as follows. [Literature review](#) section presents the literature review and explains the variables examined in this study. The methodology is described in [Methodology](#) section. Data sources and descriptive statistics are reported in [Data and descriptive statistics](#) section, and the results of the analysis are discussed in [Results](#) section. Finally, concluding remarks are presented in [Conclusions](#) section.

Literature review

Numerous studies in the logistics industry have focused on analyzing competitiveness through efficiency analysis. Indeed, with the rapid development of the global economy due to increasing economic and social activities, globalization has emerged as an international phenomenon (Shahbaz et al. 2015) that has integrated and expanded the scope of the supply chain and logistics across borders (Mirzaei and Parsa 2019). For this reason, the logistics industry is increasingly transforming due to the changes associated with globalization (Ahmed et al. 2021; Deng 2013) and the dependence of delivery of products or services on physical logistics support, such as material handling, loading/unloading, packaging, labeling, warehousing, and transportation (Kuştepli et al. 2012; Martel et al. 2016).

More explicitly, logistics efficiency can facilitate trade flows because it can lower lead time and cost, allowing for systematic operation and management in global supply chains (Wang et al. 2021a, b). In other words, Logistics efficiency accelerates international trade, leading to economic growth. (Fugate and Mentzer 2010). In the context of trade logistics, logistics efficiency is measured through logistics performance (Song and Lee 2022) as an important determinant of international trade and national competitiveness (Anderson and Villa 2015; Roy et al. 2018). Logistics performance reflects international trade, which is the result of the effectiveness and efficiency of logistics activities (Fugate et al. 2010). In addition, it can also promote trade flows because the volume and characteristics of these trade flows are determined by transportation performance, such as costs and transport modes (Behar and Venables 2011; Lafkihi et al. 2019). Among them, the maritime, road, and air transportation modes play an important role in enhancing national competitiveness as essential indicators of logistics competitiveness.

The primary issues addressed in the literature regarding transport mode choices are utility and cost efficiency, while topics such as environmental sustainability and intermodal transport have only recently begun to gain attention (Bask and Rajahonka 2017). Specifically, studies have shifted their focus from traditional considerations of cost, efficiency, flexibility, and lead time to the development of global warming, environmental impact of energy efficiency, social responsibility, business ethics, and sustainability of environmental

management (Bebbington and Thomson 2013; Lee and Wu 2014). Especially, urbanization is an essential factor in economic growth and is crucial to the success of industrialization. This is because urbanization accelerates infrastructure construction and increases manufacturing and service production efficiency in urbanized areas (Liu and Bae 2018; Shang et al. 2018). This development of urbanization and industrialization causes an increase in the transportation industry along with fuel combustion and affects global climate change due to an increase in carbon emissions in the long run (Shafique et al. 2021; Wang et al. 2019). Conversely, logistics activities can promote urbanization, industrialization, and economic development, and cause environmental degradation (Khan et al. 2019a, b; Kuo et al. 2019; Shahbaz et al. 2015). Namely, Industrialization and urbanization are vital processes in economic and social modernization (Li and Lin 2015), which require energy consumption and have a significant long-term impact on CO₂ emissions (El Ouahrani et al. 2011; Li et al. 2015; Lv et al. 2019; Sun et al. 2014; Xie et al. 2017; Zang et al. 2017). However, countries are particularly reluctant to reduce CO₂ emissions, since it might adversely impact economic development (Khan et al. 2019a, b). The energy consumption of the logistics industry, which drives the flow of trade, is also at the core of its operations: the more the energy consumption, the greater the negative impact on social and environmental sustainability (Khan et al. 2019a, b). In contrast, industrialization has a positive impact on energy intensity, while trade openness, technological innovation, and economic growth have negative impacts (Pan et al. 2019). Ultimately, the development of logistics and transportation, including roads, railways, airports, and seaports, has a positive effect on social and economic growth, which promotes industrial added value and trade patterns (Ahmed et al. 2021), but has a negative effect on the environment because of the increased consumption of energy resources (Li et al. 2019; Pan et al. 2019; Sadorsky 2012; Zhang et al. 2017). Therefore, the impact of social, economic, and environmental changes on logistics and transportation should be considered, as international trade, energy, and the economy have causal relationships (Khan and Qianli 2017; Lee and Farzipoor Saen 2012; Nasreen and Anwar 2014; Song et al. 2020).

In this regard, with the growing importance of sustainable economic development and environmental conservation (Armeanu et al. 2021), their mutual influence within the logistics industry, including transportation, has become an important issue. When considering the sustainability of the transportation sector, the sensitivity of the economic, social, and environmental contexts in which transportation is located should be considered. Therefore, several studies on the nexus between economics, society, and energy can be found in the fields of logistics and transportation (Grant et al., 2017). However, the relationship between logistics performance and environmental sustainability with regard to transportation modes has been discussed from different perspectives. Research has recently focused on CO₂ emissions (Seuring and Müller 2008) to examine the dynamic relationship between carbon emissions, economic growth, industrialization, trade opening, and foreign direct investment (Pan et al. 2019). However, few studies have investigated the factors affecting the logistics environment in the context of transportation modes to improve performance. Table 1 presents summaries of prior literature employing variables for industrialization, urbanization, CO₂, and transportation.

Logistics performance is widely recognized not only for economic growth through international trade but also for environmental sustainability (Liu et al. 2018; Mariano et al. 2017; Meersman and Nazemzadeh 2017; Tienhaara 2014; Wang et al. 2020). However, sustainable logistics development requires activities that reduce the negative effects of environmental

Table 1 Summary of prior literature on industrialization, urbanization, CO₂ emissions and transportation

Authors	Countries	Period	Methodology	Dependent factor	Explanatory factor
(Lin and Zhu 2017)	China	1970–2015	ARDL, VECM Granger causality	CO ₂	Energy intensity, Per capita real GDP, Industrialization, Urbanization, Renewable energy
(Rahman and Vu 2020)	Australia Canada	1960–2015	ARDL, VECM Granger causality	CO ₂	Renewable energy use, Economic growth, Trade, Urbanization
(X. Liu et al. 2021a, b)	Five North-east Asian countries	1995–2014	FMOLS, DOLS, Homogeneous penal Granger causality	CO ₂	Real Output, Non-renewable, Renewable Energy, Urbanization
(Chen et al. 2018)	185 countries	1998–2014	Panel Granger causality, Impulse response	Particulate matter (PM _{2.5})	Energy consumption structure, Energy intensity, Economic growth, Urbanization
(Saidi et al. 2020)	46 developing countries	2000–2016	GMM	GDP	Transport infrastructure, Logistics infrastructure, Real trade openness, Energy consumption, Urbanization, Financial development, Capital stock, Inflation
(Wang and Su 2019)	China	1990–2015	Granger causality	DE(CO ₂ /GDP)	Economic growth, Industrialization, Urbanization, Energy consumption structure, Technical progress
(Ajmi and Inglesi-Lotz 2020)	26 OECD countries	1980–2013	FMOLS, DOLS, Granger causality	GDP	Biomass energy consumption, Capitalization, Trade openness
(Azam et al. 2021)	10 newly industrialized countries	1990–2015	FMOLS, VECM Granger Causality	GDP	Renewable electricity consumption, Non-renewable electricity consumption, Gross capital formation, Labor force, Trade openness
(Wang et al. 2018a, b)	China, India	1980–2014	Decoupling analysis, Impulse response	DE(CO ₂ /GDP)	Industrialization, Urbanization, GDP, Carbon emissions intensity
(Mahmood et al. 2020)	Saudi Arabia	1968–2014	ARDL	CO ₂	Industrialization, Urbanization
(Wang et al. 2021a, b)	China	2000–2017	VAR, VECM	EXIM, Exports, Imports, National GDP, GDP per capital	Air freight, Air passengers, Seaport vessel traffic, Seaport cargo handling, Capacity, Road, Railway, Truck, Workers, Infrastructure
(Ahmed et al. 2021)	Pakistan	1972–2017	ARDL, FMOLS, DOLS, FEVDM, Impulse response	Industrial value added	Labor force employed, Capital, Ports, Roads, Railways, Airports
(Salman et al. 2019)	Indonesia, South Korea, Thailand	1990–2016	FMOLS, DOLS, Panel Granger causality	GDP	CO ₂ , Energy consumption, Trade openness, Institutional quality

Table 1 (continued)

Authors	Countries	Period	Methodology	Dependent factor	Explanatory factor
(Wang et al. 2021a, b)	46 developing countries	1980–2014	FMOLS, DOLS, Granger causality	CO ₂	GDP, Renewable energy, Non-renewable energy, Urban population, Export product quality
(Kayani et al. 2020)	Top ten CO ₂ emitter countries	1990–2016	Panel VECM, FMOLS	CO ₂	Financial development, Urban population, Renewable energy consumption, Globalization
(Li et al. 2017)	China	1985–2013	ARDL, VECM	CO ₂	Railway, Road, Airline, Waterway operational mileage per capita
(Shafique et al. 2020)	Hong Kong, Singapore, South Korea	1995–2017	FMOLS, Granger causality	Freight transport by air	GDP, CO ₂ , Energy consumption, Urbanization
(Nasreen et al. 2018)	63 developing countries	1990–2016	GMM	Economic growth	Energy consumption, Freight transport, capital stock, Labor force, Foreign direct investment,
(Wang et al. 2018a, b)	170 countries	1980–2011	Granger causality	CO ₂	Energy consumption, GDP, Urban population
(Adams et al. 2020)	19 SSA countries	1980–2011	IV-GMM	CO ₂	GDP, Electricity consumption, Population, Foreign direct investment, Agriculture, Institutions, Urbanization, Transport energy
(Nasreen et al. 2020)	18 Asian countries	1980–2017	Granger causality	Environmental quality	Real oil prices, Economic growth, Transport energy consumption, Energy prices

losses, while increasing the positive effects of economic and social gains (Abbasi and Nilsson 2016; Lee and Wu 2014). Therefore, it is necessary to analyze the causal relationship between the factors affecting the logistics environment and transportation modes, including the aforementioned external environmental variables, to improve logistics performance. This is because the economic impact of transportation can vary significantly owing to differences in market size and cost by means of transportation, which enables efficient operation and management of transportation (Song and van Geenhuizen 2014; Wang et al. 2021a, b). A comprehensive review of the literature emphasizes that research on transportation modes is increasingly needed (Macharis and Bontekoning 2004; Maparu and Mazumder 2020), with policymakers and scholars alike focusing on identifying the determinants and directions that affect these variables.

Thus, this study attempts to compare the causal relationship between the five variables of trade volume (exports and imports), urbanization, industrialization, and CO₂ by means of transportation. The logistics and transportation industries are closely related to major global changes such as industrialization, urbanization, and sustainable economic development. However, the relationship between transportation modes and the factors affecting the logistics environment remains inconclusive. The causal relationship between logistics and CO₂

has been examined previously, but the contribution of this study is its estimation of the relationship between industrialization and urbanization concurrently with these relationships from the perspective of transportation modes. In addition, since few studies have examined the relationship between the factors affecting the logistics environment in Korea, this study contributes to the literature by filling this gap. The empirical results of prior studies are sometimes inconsistent because of their use of different datasets and alternative econometric methodologies, as well as because of individual country characteristics (Li et al. 2019; Nasreen et al. 2020). Therefore, this study attempts to analyze the relationship between factors affecting the logistics environment and transportation modes in Korea by investigating the relationship between volume and industrial factors by transportation mode. This study makes an important contribution to the comparative analysis of the nexus with the logistics environment of each transportation mode (port and air transport) in Korea.

To this end, this study explores the relationship between industrialization, urbanization, CO₂ emissions, and transportation modes using panel data from 2010 to 2018. A panel VECM test is used for the analysis, which is suitable for identifying long-term relationships and the direction of causality between selected variables. In other words, this study examines the long- and short-term causal relationship between international trade and factors affecting the logistics environment through industrialization, urbanization, CO₂ emissions, and transport modes such as ports and airports. In particular, transportation accounts for the majority proportion of logistics, and transportation operation and management are essential to improve logistics efficiency. This is because it can promote international trade and increase national competitiveness through logistics efficiency. Therefore, this study aims to present the direction of a macro perspective for improving logistics efficiency by analyzing the association with the logistics environmental factors that affect the volume of international trade by transportation modes. In addition, based on the above analysis, this study explores the causal relationship between factors affecting the logistics environment and transportation modes from an international perspective and proposes an integrated approach to balance sustainable development and economic growth for policymakers and governments.

Methodology

This study explores the relationship between export volume, import volume, urbanization, industrialization, and CO₂ emissions by transportation modes using panel VECM (Johansen 1991).

The most commonly used methods for estimating panel data are pooled OLS, random- and fixed-effects (Manwa et al. 2019). However, these models can be inconsistent in the presence of endogeneity issue such as missing variables associated with the model from equation or unclear magnitude and causal direction between variables (Randrianarisoa and Gillen 2022). Thus, to control the endogeneity problem, it is used GMM method, which is the widely used estimation method in multiple-way linkages between certain variables (Omri 2013). The Panel VECM model also has the power to solve the problems of endogeneity, but has the advantage of identifying short- and long-term relationships and the relationship direction of variables (Kayani et al. 2020). That is, Panel VECM is useful for analyzing both the short- and long-run relationships, and it estimates and analyzes the rate

at which the dependent variables changed by other variables return to equilibrium (Antonakakis et al. 2017). In this context, this paper attempts to analyze the association between variables using panel VECM.

The general empirical model of equations adopted in this study is expressed as follows:

$$Maritime_{it} = \int (ex_{it}, im_{it}, ind_{it}, urb_{it}, co2_{it}) \tag{1}$$

$$Air_{it} = \int (ex_{it}, im_{it}, ind_{it}, urb_{it}, co2_{it})$$

where $Maritime_{it}$ is the Korean trade volume by maritime transport, air_{it} is the Korean trade volume by air transport, ex_{it} , im_{it} are the total export and import volumes of Korea, ind_{it} is industrialization, urb_{it} is urbanization, and CO_2 is CO_2 emissions from fuel combustion.

To reduce the variation among the variables, all variables are transformed into logarithmic form, and the expression applied to Eq. (1) can be described as follows:

$$\ln Maritme_{it} = \delta + \alpha_1 \ln ex_{it} + \alpha_2 \ln im_{it} + \alpha_3 \ln ind_{it} + \alpha_4 \ln urb_{it} + \alpha_5 \ln co2_{it} + \epsilon_{it} \tag{2}$$

$$\ln Air_{it} = \delta + \alpha_1 \ln ex_{it} + \alpha_2 \ln im_{it} + \alpha_3 \ln ind_{it} + \alpha_4 \ln urb_{it} + \alpha_5 \ln co2_{it} + \epsilon_{it}$$

where δ represents the intercept or constant term and $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are the partial slope parameters to be estimated. This implies that each variable represents the effect of elasticity on the dependent variable. ϵ_t is the error term—a stochastic term that captures what is not observed in the fitted model. Moreover, subscript i indicates the countries in the panel data and t indicates time (from 2010 to 2018).

Four steps are required to investigate the dynamic causal relationship between maritime and air transport, industrialization, urbanization, and CO_2 . First, the characteristics of the selected variables are identified using descriptive statistics. Second, panel unit root tests are performed to investigate the stationarity of the panel datasets. Third, panel cointegration tests are conducted to examine the long-term relationship between the selected variables. Fourth, the coefficients of long-term relationships are calculated using fully modified ordinary least squares (FMOLS) and panel dynamic ordinary least squares (DOLS). Finally, a panel VECM Granger causality test is performed to estimate the causal relationships between the selected variables (Fig. 1).

Panel unit root test

Before beginning the analysis, a unit root test on the selected variables is performed to verify the stability of the time-series data. If the variables are non-stationary and non-cointegrated, the regression results may be spurious. Thus, we conduct a panel unit root test with Levin-Lin-Chu (LLC; (Levin et al. 2002), Im-Pesaran Shin (IPS) W-statistics (Im et al. 2003), Fisher augmented Dickey-Fuller (Dickey and Fuller 1979) and Fisher Phillips-Perron (PP) tests (PHILLIPS and PERRON 1988). The null hypothesis indicates that there is a unit root in the panel data for each series, but the alternative hypothesis has no unit roots.

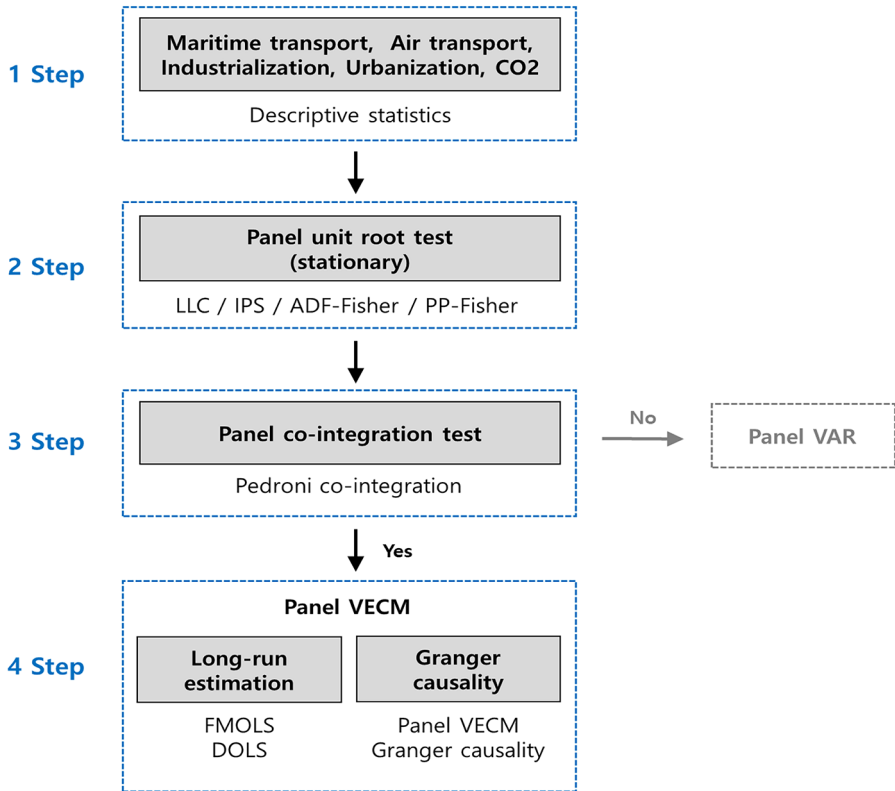


Fig. 1 Flow diagram of the methodology approach

Panel Co-integration test

The panel co-integration test is used to identify whether long-term relationships exist between variables. For standard general least squares techniques, it is important to check whether the series is stationary because non-stationary time series can lead to invalid statistical inferences.

Therefore, this study uses the Pedroni co-integration test based on the residual-based strategy of Engel and Granger (Engle and Granger 1987). The test presents two statistical groups: within-dimension and between-dimension. The first includes the panel v -statistic, panel ρ -statistic, panel PP-statistic, and panel ADF-statistic, while the second includes the group rho-statistic, group PP-statistic, and group ADF-statistic. The null hypothesis for this co-integration is that there is no co-integration, while the alternative hypothesis indicates that the time series shows co-integration.

Panel FMLOS and DOLS estimates

If a co-integration relationship is found between the selected variables, the next step is to estimate the long-run parameters. The panel co-integration tests estimate whether a long-

term relationship exists, but they cannot explore long-run elasticity estimates. Thus, it is necessary to analyze the long-run equilibrium relationship between the variables through FMLOS and DOLS analyses. These methods can control for the serial correlation of long-term execution and endogeneity problems and are consistently estimated from the selected samples.

Panel VECM Granger causality

The next step is to analyze Granger causality, for which we use the VECM proposed by (Engle and Granger 1987). If the time-series data of the model are all cointegrated, the empirical framework of the VECM Granger causal function can be utilized to investigate the short-term and long-term causal directional connections between each variable.

In short-term causality, the dependent variable represents weak Granger causality in response to only a short-term impact on the stochastic environment, and the long-term cause implies that the independent variable responds to the deviation from the long-term equilibrium. Therefore, to determine the directional causal relationship between the selected variables, long-run causal relationships are analyzed using the residuals of the variables, and short-run causal relationships are performed on dynamic VECMs.

The VECM equation (formula) is described as follows:

$$\begin{bmatrix} \Delta \ln Maritime \\ \Delta \ln ex_{it} \\ \Delta \ln im_{it} \\ \Delta \ln ind_{it} \\ \Delta \ln urb_{it} \\ \Delta \ln co2_{it} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} + \begin{bmatrix} b_{11,1} & \dots & b_{16,1} \\ b_{21,1} & \dots & b_{26,1} \\ b_{31,1} & \dots & b_{36,1} \\ b_{41,1} & \dots & b_{46,1} \\ b_{51,1} & \dots & b_{56,1} \\ b_{61,1} & \dots & b_{66,1} \end{bmatrix} \begin{bmatrix} \Delta \ln port_{it-1} \\ \Delta \ln ex_{it-1} \\ \Delta \ln im_{it-1} \\ \Delta \ln ind_{it-1} \\ \Delta \ln urb_{it-1} \\ \Delta \ln co2_{it-1} \end{bmatrix} + \dots + \begin{bmatrix} b_{11,k} & \dots & b_{16,k} \\ b_{21,k} & \dots & b_{26,k} \\ b_{31,k} & \dots & b_{36,k} \\ b_{41,k} & \dots & b_{46,k} \\ b_{51,k} & \dots & b_{56,k} \\ b_{61,k} & \dots & b_{66,k} \end{bmatrix} \begin{bmatrix} \Delta \ln port_{it-k} \\ \Delta \ln ex_{it-k} \\ \Delta \ln im_{it-k} \\ \Delta \ln ind_{it-k} \\ \Delta \ln urb_{it-k} \\ \Delta \ln co2_{it-k} \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix}$$

$$\begin{bmatrix} \Delta \ln Air_{it} \\ \Delta \ln ex_{it} \\ \Delta \ln im_{it} \\ \Delta \ln ind_{it} \\ \Delta \ln urb_{it} \\ \Delta \ln co2_{it} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} + \begin{bmatrix} b_{11,1} & \dots & b_{16,1} \\ b_{21,1} & \dots & b_{26,1} \\ b_{31,1} & \dots & b_{36,1} \\ b_{41,1} & \dots & b_{46,1} \\ b_{51,1} & \dots & b_{56,1} \\ b_{61,1} & \dots & b_{66,1} \end{bmatrix} \begin{bmatrix} \Delta \ln air_{it-1} \\ \Delta \ln ex_{it-1} \\ \Delta \ln im_{it-1} \\ \Delta \ln ind_{it-1} \\ \Delta \ln urb_{it-1} \\ \Delta \ln co2_{it-1} \end{bmatrix} + \dots + \begin{bmatrix} b_{11,k} & \dots & b_{16,k} \\ b_{21,k} & \dots & b_{26,k} \\ b_{31,k} & \dots & b_{36,k} \\ b_{41,k} & \dots & b_{46,k} \\ b_{51,k} & \dots & b_{56,k} \\ b_{61,k} & \dots & b_{66,k} \end{bmatrix} \begin{bmatrix} \Delta \ln air_{it-k} \\ \Delta \ln ex_{it-k} \\ \Delta \ln im_{it-k} \\ \Delta \ln ind_{it-k} \\ \Delta \ln urb_{it-k} \\ \Delta \ln co2_{it-k} \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix}$$

where Δ stands for the first difference operator; σ is a residual term; ECT represents the long-run dynamics, which is the error correction term; and the ECT coefficient measures the nature of a long-run relationship running from the selected variables. Established long-running causal relationships among the selected variables were identified using ECT_{t-1} . c denotes the coefficient of ECT_{t-1} ; if c has a negative sign and is statistically significant, it indicates the existence of long-run causality among the selected variables. To estimate short -and long-run causality relationships, the former uses F-statistics, and the latter uses t-statistics.

Data and descriptive statistics

To analyze the panel data, we first present their descriptive statistics and then perform a panel unit root test and co-integration test, followed by FMOLS and DOLM analyses. Finally, we analyze the VECM Granger causality estimated using panel VECM. Table 1 presents the descriptive statistics of the panel data between 2010 and 2018. This study selects the remaining 99 countries that extracted flaws in the panel data based on countries with import

Table 2 Definitions and source of variables

Variables	Symbol	Description (Definitions)	Source
Maritime	LNMARITIME	Maritime Trade Volume (KRW)	KITA
Air	LNAIR	Air Trade Volume (KRW)	KITA
Export	LNEX	Total Export volume (KRW)	KITA
Import	LNIM	Total Import volume (KRW)	KITA
Urbanization	LNIND	Urban population (% of total population)	World Bank
Industrialization	LNURB	Industrial value added (% of GDP)	World Bank
CO ₂ emissions	LNCO2	CO ₂ emissions from fuel combustion	IEA

Table 3 Summary statistics of the Panel data

Variables	Obs	Mean	Std.Dev	Min	Max
LNMARITIME	891	13.79116	2.18304	6.97073	18.94023
LNAIR	891	11.46980	2.61716	5.58350	18.42128
LNEX	891	13.38263	2.12892	7.55747	18.90388
LNIM	891	13.42341	3.30259	-	25.35146
LNIND	891	4.108878	0.16634	3.52771	4.69086
LNURB	891	4.987001	0.14090	4.58346	5.203655
LNCO2	891	6.587969	0.42707	6.31405	9.22365

and export transactions with Korea. The volume of two modes of transportation, maritime and air transport are selected as a dependent variable, and industrialization (industrial value added (% of GDP)), urbanization (urban population (% of total population)), and CO₂ emissions (CO₂ emissions from fuel combustion) as independent variables. In particular, this study considers that various factors have an uncertain and complex effect on CO₂ emissions by utilizing the total CO₂ emissions from fuel combustion (Xie et al. 2021). Data are collected from the Korea International Trade Association (KITA), World Bank, and International Energy Agency (IEA). The definitions and sources of the variables used in this study are listed in Table 2, and the summarized statistics are presented in Table 3.

Results

Unit root test

As this study utilizes panel time-series data, it is necessary to confirm whether the data were stationary. To this end, a common unit root test is performed on selected variables such as maritime and air transport, industrialization, urbanization, and CO₂ emissions. Table 4 presents the panel unit root test results for all the variables. The null hypothesis of the panel unit root test is that there is a unit root, which indicates that the variable is non-stationary.

Table 4 Panel unit root test

Level	LNMRITIME	LNNAIR	LNEX	LNIM	LNIND	LNURB	LNCO2
LLC	-17.49770***	-9.03555***	-13.92950***	-142.80300***	-21.95290***	3.43671	-7.6321***
IPS	-6.80808***	-2.58302***	-4.11320***	-52.75930***	-1.94534**	15.45170	1.7241
ADF-Fisher	404.85900***	283.17900***	316.24100***	989.43300***	216.21900	345.78300***	132.9300
PP-Fisher	378.89200***	268.99900***	317.42500***	539.95300***	209.74600	389.48500***	146.3960
First Difference							
LLC	-32.12810***	-29.25360***	-28.31420***	-136.98000***	-38.19380***	-15.28220***	-23.5519***
IPS	-12.62680***	-11.01750***	-11.55620***	-67.98400***	-11.38910***	-12.61050***	-10.6236***
ADF-Fisher	557.65800***	518.60200***	523.65700***	1436.53000***	487.54000***	617.98200***	509.7340***
PP-Fisher	725.41500***	641.04100***	696.87800***	1502.19000***	617.61000***	831.76000***	594.5720***

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Conversely, the alternative hypothesis is that there is no unit root, which indicates that the variable is stationary.

The results of the panel unit root test indicate that not all variables showed stationarity at all levels, but after taking the first difference, all variables showed stationarity at the 1% level. This indicates that all the variables reject the null hypothesis and adopt the alternative hypothesis that the panel data have no unit root at the first difference.

Panel Co-integration test

Since the trade volumes for maritime and air transport, industrialization, urbanization, and CO₂ emissions are found to be stationary at the first difference, the Pedroni cointegration test, which provides seven different test statistics, is applied to investigate the long-run relationships. Table 5 presents the results of the panel residual cointegration tests. For both the maritime and air transport models, four out of seven statistics represent a co-integration effect between the time-series data. Therefore, these variables reject the null hypothesis that there is no cointegration and accepted the alternative hypothesis at the 1% level. In other words, the co-integration equation results reveal that a long-term relationship exists between explanatory variables such as industrialization, urbanization, and CO₂ emissions and the dependent indicators of maritime and air transport.

Panel FMOLS and DOLS estimate results

If the model shows co-integration, the next step is to estimate the associated long-run co-integration parameters by employing both fully modified OLS (FMOLS) and dynamic OLS (DOLS) processes. The estimated results for FMOLS and DOLS are presented in 6 and 7, respectively

Table 6 presents the FMOLS and DOLS results for the maritime transport model. The results indicate that exports and imports have long-run positive effects on maritime transport at significance levels of 1% and 5%, respectively. From the FMOLS approach, the effect of increasing exports and imports is positive and significant, implying that a 1% increase in these variables contributes 0.7052% and 0.0116% of maritime transport, respectively. The DOLS approach also has a positive and significant effect on increasing exports and imports, implying that a 1% increase in these variables contributes to 0.7102% and 0.0120% of the maritime transport, respectively.

Table 7 presents the FMOLS and DOLS results for air transport. From the FMOLS approach, the results indicate that exports and CO₂ emissions have a long-run positive effect on air transportation volume at significance levels of 1% and 5%, respectively. The effect of exports and CO₂ emissions on air transport is positive and significant, implying that a 1% increase in these variables contributes to 0.4044% and 0.9753% of air transport, respectively. For the DOLS approach, the effect of exports is positive and significant at the 1% level, implying that a 1% increase in exports use contributes to 0.3874% of air transport.

Information on the causal association between the variables is not available using the FMOLS and DOLS. Thus, the results of the short-term and long-term causal relationships can be identified through the panel VECM.

Table 5 Panel co-integration test

	Maritime transport Model		Air transport Model	
	Statistics	Weighted Statistics	Statistics	Weighted Statistics
Alternative hypothesis: common AR coefs. (within-dimension)				
Panel v-statistic	-7.02396	-8.76755	-6.89035	-8.60399
Panel rho-statistic	10.16827	10.14482	9.95782	10.77735
Panel PP-statistic	-22.86063***	-22.57208***	-20.11929***	-19.88619***
Panel ADF-statistic	-11.94394***	-11.18948***	-11.17346***	-8.74660***
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-statistic	14.55756		15.62659	
Group PP-statistic	-31.50426***		-26.85688***	
Group ADF-statistic	-12.12093***		-8.25600***	

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Table 6 Panel FMOLS and DOLS estimates: Maritime transport model

	FMOLS				DOLS			
	Coefficient	Std. Error	t-Statistic	Prob.	Coefficient	Std. Error	t-Statistic	Prob.
LNEX	0.70522	0.01978	35.66061	0.00000	0.71015	0.03401	20.88190	0.00000
LNIM	0.01158	0.00302	3.82945	0.00010	0.01203	0.00470	2.55831	0.01070
LNIND	0.38169	0.52419	0.72816	0.46670	0.28502	0.69724	0.40878	0.68280
LNURB	-0.29786	0.48113	-0.61908	0.53600	-0.22096	0.91616	-0.24118	0.80950
LNCO2	0.60219	0.30960	1.94509	0.05210	0.59377	0.50788	1.16913	0.24270

Table 7 Panel FMOLS and DOLS estimates: Air transport model

	FMOLS				DOLS			
	Coefficient	Std. Error	t-Statistic	Prob.	Coefficient	Std. Error	t-Statistic	Prob.
LNEX	0.40438	0.03947	10.24438	0.00000	0.38739	0.04812	8.04982	0.00000
LNIM	-0.00037	0.00329	-0.11218	0.91070	-0.00056	0.00529	-0.10549	0.91600
LNIND	-0.59168	0.48863	-1.21088	0.22630	-0.17594	0.85369	-0.20609	0.83680
LNURB	0.30201	0.68754	0.43926	0.66060	0.64677	1.12756	0.57360	0.56640
LNCO2	0.97525	0.42889	2.27388	0.02320	0.49152	0.57371	0.85674	0.39180

Panel Granger causality

Following the results of the co-integration test on trade, industrialization, urbanization, and CO₂ emissions, we subsequently analyze the short-run and long-run causality relationships between the variables through the panel VECM Granger causality models. The results are presented in Table 8. The F-statistics and associated p-values identify short-run causality, whereas t-statistics and associated p-values represent long-run causal relationships.

The analysis shows short-run, single-directional causal relationships from maritime transport to total exports, industrialization, and CO₂ emissions based on significant F-statistics. Considering the short-run causality, we find a relationship between bidirectional causality between maritime transport and exports, maritime transport and CO₂ emissions, exports and CO₂ emissions, and urbanization and CO₂ emissions, while we detect a short-run, unidirectional causal relationship from maritime transport and exports to industrialization, industrialization to CO₂ emissions, and CO₂ emissions to imports. In addition, we identify a short-run, unidirectional causal relationship between from imports to exports, and maritime transport. These results are not surprising because CO₂ emissions can be an indicator of industrial growth due to economic and industrial expansion activities (Li et al. 2017). In the case of maritime transport, total exports, industrialization, and urbanization, the ETC_{t-1} results are negative and significant at the 1% level, indicating that they have a long-run, bidirectional causal relationship. In addition, a long-run, unidirectional causal relationship is found from maritime transport, exports, urbanization, and industrialization to imports and CO₂ emissions, respectively.

Table 9 summarizes the panel Granger causality results for air transport. Considering the short-run causality, we find bidirectional causality between air transport and industrialization, urbanization and CO₂ emissions, and air transport and imports, as well as a short-run, unidirectional causal relationship from air transport to exports, and from urbanization to CO₂ emissions. In addition, we identify a short-run, unidirectional causal relationship between exports and imports and from CO₂ emissions to industrialization. In the case of exports, industrialization, and urbanization, the ETC_{t-1} results are negative and significant at the 1% level, indicating that they have a long-run, bidirectional causal relationship. In addition, we find a long-run unidirectional causal relationship between exports, urbanization, and industrialization for each variable (e.g., air transport, imports, and CO₂ emissions).

The results of Granger causality movements are summarized in Fig. 2.

This study fills an important gap in the literature on logistics efficiency based on the factors affecting the logistics environment and transportation modes. For maritime transport, a bidirectional causal relationship between maritime transport, exports, and CO₂ emissions is determined, indicating that maritime transport increases CO₂ emissions through exports. In contrast, a bidirectional causal relationship between imports and industrialization for air transport is identified. The results indicate that air transport is more affected by imports and industrialization than by exports and CO₂ emissions, which have a greater effect on maritime transport.

Based on these results, stakeholders should consider the trade value between the transportation sectors and seek strategic measures accordingly. Specifically, the effects of urbanization, industrialization, and CO₂ emission reduction may depend on the connectivity of each transportation mode. Therefore, it is necessary to establish a sustainable innovation model for logistics by improving efficiency through multimodal transportation.

Table 8 Panel Granger causality analysis: Maritime transport model

	Short-run						Long-run
	D(LNMARITIME)	D(LNEX)	D(LNIM)	D(LNIND)	D(LNURB)	D(LNCO2)	ETC _{t-1}
D(LNMARITIME)	-	11.85948***	73.75604***	3.17524	1.34635	85.53036***	-0.04583***
D(LNEX)	65.95371***	-	32.29894***	1.64833	3.55316	50.14875***	-0.04541***
D(LNIM)	4.25036	2.07464	-	3.92235	4.71025*	450.69150***	0.02128
D(LNIND)	10.16280***	16.08607***	2.64978	-	0.57858	1.20961	-0.00361***
D(LNURB)	0.40437	0.04124	1.56134	2.47741	-	12.35020***	-0.00005***
D(LNCO2)	6.19748***	7.08791**	1.20729	4.63760 *	31.62644***	-	-0.00025

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Conclusions

The main objective of this study was to examine the dynamic relationships between the factors affecting the logistics environment and transportation modes (i.e., maritime and air transport). This study identified causal relationships between industrialization, urbanization, CO₂ emissions, and transportation modes, such as maritime and air transport, using data from 2010 to 2018. Panel unit root tests, panel co-integration tests, panel FMOLS, and panel VECM Granger causality methods were used to estimate the direction of causality between variables.

The empirical results revealed that maritime and air transport have different causal relationships with factors affecting the logistics environment. To explore the long-run impact of the determinants of freight transportation volume, we applied the panel FMOLS and panel DOLS estimation techniques. The panel FMOLS and panel DOLS estimates for maritime transport show a positive impact on exports and imports. For air transport, the panel FMOLS estimates have a positive impact on exports and imports, while the panel DOLS estimates have a positive impact on exports only. The panel Granger causal results illustrate that, with regard to maritime transport, short-run, bidirectional causal relationships exist between maritime transport and exports, maritime transport and CO₂, exports and CO₂, and urbanization and CO₂. For air transport, short-run bidirectional causal relationships were identified between air transport and industrialization, urbanization and CO₂, and air transport and imports. In addition, in the case of maritime transport, long-run bidirectional causal associations were found for maritime transport, total exports, industrialization, and urbanization. This implies that export promotion and the resulting economic and social environmental changes can increase maritime transport, while this increase can bolster economic growth and factors related to the logistics environment. In conclusion, maritime transportation in Korea has a more significant impact on economic growth than air transportation, which is consistent with previous studies (Hong et al. 2011).

The key point of this study is the need to focus on the logistics environment structure to facilitate international trade for economic growth. Logistics efficiency (i.e., high levels of logistics services and transport infrastructure) is an important indicator of a country's economic growth and reduced fossil fuel consumption (Khan et al. 2019a, b). To this end, it is necessary to estimate the effects of the dynamic relationship between industrialization, urbanization, and the environment on transportation modes and establish a specific strategy for them. The sustainable development of logistics seeks activities that generate economic and social benefits while reducing negative impact; however, in the long term, these activities face difficulties and barriers (Abbasi and Nilsson 2016). Therefore, the importance of efficient transportation systems and policies is emphasized, as they are crucial in determining the flow of international trade and can lead to economic growth through international trade (Wessel 2019). In addition, the factors affecting the logistics environment have different impacts on different transport modes based on the products they carry; for example, maritime transport tends to transport heavy and inexpensive products, while air transportation modes carry light and high-value products. In the case of Korea, maritime transportation has become an important part of the economy, and handles more than 99% of imports and exports (Lee et al. 2020). However, the shipping and shipbuilding industries are facing new challenges due to stricter emission regulations, so it is urgent to prepare countermeasures such as conversion of LNG fuel and development of green port and so on. On the

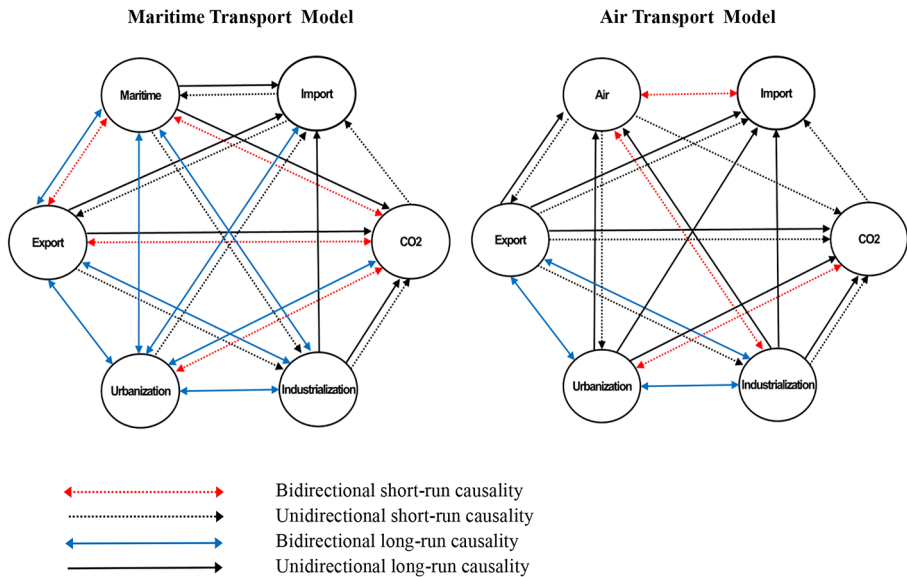


Fig. 2 Granger causality relationship flows

Table 9 Panel Granger causality analysis: Air transport model

	Short-run						Long-run
	D(LNAIR)	D(LNEX)	D(LNIM)	D(LNIND)	D(LNURB)	D(LNCO2)	ETC _{t-1}
D(LNAIR)	-	1.31989	11.30250 ***	29.57501 ***	3.15443	1.87674	-0.00135
D(LNEX)	10.75762 ***	-	0.05420	0.18548	1.81362	0.13329	-0.00691 ***
D(LNIM)	6.13109 **	5.53122 *	-	3.95611	2.42020	330.3803 ***	0.01580
D(LNIND)	48.20208 ***	17.03299 ***	2.22591	-	2.41550	0.00529	-0.00061 ***
D(LNURB)	1.13016	0.12979	3.43204	1.38370	-	12.41430 ***	-0.00001 ***
D(LNCO2)	4.70646 *	9.34031 ***	3.89838	5.72753 *	35.64743 ***	-	0.00016

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively

other hand, the growth of air transportation is steadily increasing with the proportion of high-value products of exports and imports, such as semiconductors, information technology (IT) products, and medicinal and pharmaceutical products. Additionally, air transport is expected to further increase in the future as the transportation method is shifting from maritime transport to air transport owing to logistics uncertainty caused by COVID-19. It is worth increasing the competitiveness of air transport by providing customized service strategies for value-added products, such as medical care, fresh products, and cold chains (Li 2020). In this respect, it appears that there is some specialization in transport modes for trade with specific products or regions (Llano et al. 2017).

The theoretical contributions of this study are summarized as follows. First, we applied the panel VECM model to determine the causal relationship between logistics environment factors and mode-specific transportation, such as maritime and air transport, focusing on Korea. The role of global logistics is critical in supply chain management to support economic, social, and environmental outcomes (Khan et al. 2019a, b). Thus, the analysis was conducted using a panel VECM method, which is useful for estimating the direction of short-term and long-term causal relationships. Second, the long- and short-term causal relationships between transportation modes and each variable were identified by utilizing structural variables of the logistics environment, such as industrialization, urbanization, and CO₂ emissions. In other words, this study explored the influence of logistics efficiency on the factors affecting the logistics environment from a macro perspective. These results can provide a foundation for strengthening global competitiveness through an integrated and sustainable perspective on the relevance of transportation and the factors affecting the logistics environment. Specifically, it is possible to suggest a direction for enhancing Korea's logistics competitiveness, such as subsidies, infrastructure development, and detailed strategies in the government-led logistics plan, and to provide an integrated perspective for policymakers and the government to balance sustainable development and economic growth.

The policy implications of this study are as follows. First, the results of this study expand the literature on the logistics industry in Korea. The level of logistics efficiency depends on various factors, such as socioeconomic conditions, urbanization and industrialization levels, resource support, and national development policies. Thus, situations specific to each country should be considered when establishing policies to improve logistics efficiency (Lv et al. 2019). Korea has achieved economic growth centered on international trade through export-led growth policies, and is one of the countries highly dependent on the logistics and transportation industries. It also has the geographical advantage of connecting international trade and transportation in Asia in the global logistics environment (Song and Lee 2022). However, it is necessary to prepare countermeasures because these industries are sensitive to changes in the logistics environment, such as industrialization, urbanization, and CO₂ emissions due to high export dependence. In addition, the realization of sustainable logistics values and the establishment of efficient logistics systems are both theoretically and practically important, and can be improved through multimodal transportation such as the selection of transportation modes. (Liu et al. 2018). Therefore, the results of this study can provide directions and guidelines for future plans to enhance logistics competitiveness in Korea. Second, the government should promote economic growth through energy-efficient technologies and reduce CO₂ emissions by promoting the use of renewable energy (Rahman and Vu 2020). Environmental policies to reduce renewable energy and CO₂ emissions can inevitably increase the consumption of renewable energy and the green supply chain, thereby enhancing international trade and accelerating economic growth (Geng et al. 2017; Ghazouani et al. 2020). Accordingly, most countries must apply new energy technologies across the transportation and green energy sectors to intensify their industrial and international trade capabilities (Wang et al. 2020). Therefore, it can be an effective measure for the government to increase multimodal transport system and provide subsidies for the development and application of new energy technologies to reduce CO₂ emissions to the environment (Jiang et al. 2020; Zhang et al. 2018). Third, even after controlling for various variables, the type of government has a positive impact on transport infrastructure investment, which can improve its efficiency. Transport infrastructure development plays an essential role from a

holistic perspective, including on the economy in the hinterland and CO₂ emissions, which is important for establishing an environmentally friendly and efficient transport system (Liu et al. 2021a, b). Moreover, with the growth of the global economy, logistics management capabilities have become important and there is a growing need for government intervention to promote sustainable logistics. Therefore, while infrastructure investment can have a positive impact on the economy (Song and van Geenhuizen 2014), good governance should be established by adopting strategic policies rather than merely increasing the transportation infrastructure (Kyriacou et al. 2019). In addition, it is possible to review investment in public and/or private plans to improve logistics efficiency, including economic, social, and environmental issues, by establishing a logistics plan that reflects the characteristics and needs of the region (Ramos de Oliveira et al. 2022).

Based on this study, in future research, we aim to conduct comparative studies between Korea and other countries, and estimate the connectivity of transportation modes to enhance logistics efficiency. This approach highlights the impact of economic growth and global competitiveness as well as logistics connections that change as the logistics environment changes. Furthermore, we plan to conduct additional research to support governments and stakeholders by establishing a forecast change model for logistics networks using transportation that transforms along with these changes.

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