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Global logistics efficiency after COVID-19: a cross-country analysis using the logistics performance index*

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ABSTRACT

This study analyses the World Bank's Logistics Performance Index (LPI) to quantify changes in logistics performance before and after COVID-19, using a slack-based measurement (SBM) model of data envelopment analysis (DEA) and the Malmquist Index (MI), which indicates efficiency changes over time. The LPI analysis shows performance gains, but challenges in timeliness and international shipments. The SBM-DEA model indicates efficiency improvements mainly through technological advancements. After the pandemic, the decline in efficiency in customs operations and international shipments signals a need for streamlined procedures and cost reductions. The analysis also shows that the post-pandemic recovery varied by region. This study contributes to the theory by showing how dynamic capabilities and institutional resilience influence logistics adaptability and widen global performance gaps. Informed by the resource-based view and dynamic capabilities theory, it advises policymakers to enhance logistics infrastructure, modernise customs, and reduce costs to tackle post-pandemic challenges in underperforming regions.

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1. Introduction

The COVID-19 pandemic has had a deep impact on the global logistics industry (Kara et al. 2024; Mavi et al. 2022; Rinaldi and Bottani 2023). Government-imposed restrictions around the globe, including lockdowns, travel bans, and social distancing measures, disrupted supply chains (SCs) and created unprecedented challenges (Golgeci et al. 2023). From factory closures to disrupted transportation systems and labour shortages, the efficiency of global logistics operations was significantly compromised. This disruption caused delays in production, shipping, and delivery, resulting in longer lead times and SC bottlenecks (Rinaldi and Bottani 2023). Additionally, the surge in demand for essential goods, medical supplies, and e-commerce deliveries strained the logistics sector, revealing vulnerabilities in the global logistics system and underscoring the need for improved flexibility, resilience, and digitalisation (Golgeci et al. 2023).

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To handle these challenges, firms were forced to reevaluate their SC strategies, explore alternative sourcing options, and diversify their supplier networks to lessen their risks. Despite the substantial obstacles presented by the pandemic, it has also spurred innovation and hastened the adoption of new technologies in the logistics industry. Automation, digitalisation, artificial intelligence (AI), and data analytics are becoming increasingly vital tools for optimising routes, managing inventory, and enhancing overall efficiency (Klumpp and Ruiner 2022; Loske and Klumpp 2021).

However, although the immediate disruptions caused by the pandemic have been widely studied (Kara et al. 2024; Mavi et al. 2022; Rinaldi and Bottani 2023), a critical research gap persists: there is a lack of systematic, cross-country analyses that quantify the longer-term effects of the pandemic on logistics efficiency using a robust, comparative, and dynamic approach. Existing studies largely focus on short-term shocks or single-year data, often overlooking the way in which logistics performance indicators evolve over time. This limitation impedes a deeper understanding of how the pandemic has reshaped global logistics structures and long-term efficiencies. Secondly, while the importance of the Logistics Performance Index (LPI) for global logistics and international trade is increasingly recognised (Martí, Puertas, and García 2014), existing studies often focus on single-year LPI scores (Rezaei, van Roekel, and Tavasszy 2018), neglecting the evolving nature of logistics efficiency and the variety of impacts that occur over time. Moreover, while the literature highlights the importance of key factors like infrastructure, customs, and international shipments in logistics performance (Çemberci, Civelek, and Canbolat 2015; Liu et al. 2018; Sumantri and Lau 2011), there is limited research on how the pandemic has impacted these specific components and what strategies are needed to improve them in the future.

This study seeks to fill these critical gaps. First, it offers a dynamic, multi-year evaluation of logistics performance before and after the pandemic, which provides a broader temporal view. Second, it identifies specific logistical weaknesses and improvements by focusing both on overall LPI scores and on individual dimensions (e.g. customs, infrastructure, and timeliness). In doing so, the study contributes valuable empirical evidence to the literature on global supply chain management, and informs resilience-building strategies for the logistics sector.

To assess the impact of the pandemic on logistics performance, this study relies on the LPI developed by the World Bank. In particular, it benchmarks countries' logistics performance using data envelopment analysis (DEA), and seeks to quantify the impact of the pandemic and to identify areas for improvement. The LPI provides a quantitative metric to evaluate countries' logistics performance, and encompasses customs regulations, transportation infrastructure, international shipments, logistics competence, tracking and tracing, and timeliness (World Bank 2023a). It offers a robust structure for analysing and benchmarking the logistics performance of individual countries (Arvis et al. 2016; Martí, Puertas, and García 2014).

The research uses LPI data from two distinct timeframes: 2012–2018 and 2023. The 2012–2018 period represents the pre-pandemic baseline, when global logistics were operating under relatively stable conditions, unaffected by the COVID-19 disruptions that ensued. In contrast, the 2023 LPI captures the situation after the major waves of the pandemic had passed, providing an opportunity to assess how logistics systems adapted or regressed after the crisis. This time gap effectively isolates the impact of the pandemic on logistics efficiency, and offers a clear before-and-after comparison of performance trends.

As Charnes, Cooper, and Rhodes (1978) suggested, DEA is a notable mathematical programming approach for assessing the comparative efficiency of organisational entities. It has been used to measure efficiency for many different entities, such as airports, universities, bank branches, and retail shops (Apaydin, Bayraktar, and Hossary 2018; Bayraktar, Tatoglu, and Zaim 2013; Michali et al. 2021; Sarrico and Dyson 2000). Relying on the LPI reports from the World Bank for 2018 and earlier, as well as those for 2023, the Malmquist Index (MI) measures changes in efficiency over time, using the slack-based measurement (SBM) approach. Through peer-to-peer benchmarking with the SBM model, the study evaluates countries' logistics governance skills and identifies areas for improvement in LPI indicators both before and after the pandemic. Ultimately, this research highlights the aspects that must be attended to in order to enhance logistics performance efficiency in the post-pandemic era. Thus, this study contributes both theoretically and practically by offering one of the earliest cross-country dynamic analyses of post-pandemic logistics efficiency, applying advanced efficiency measurement techniques (DEA, MI, and SBM), and delivering actionable insights for global logistics performance and policy improvement.

This study stands out from various angles. The LPI report for 2023 was released recently, and our study is among the first to evaluate these developments in the logistics field following the pandemic. To the best of our knowledge, this study represents one of the initial efforts to employ DEA methodologies and the MI extensively in assessing logistics efficiency within the LPI dataset, providing a dynamic evaluation of logistics performance before and after the pandemic. While many existing studies consider single-year LPI scores for logistics efficiency, this study captures the dynamically changing impact of logistics dimensions on performance using the MI. Similarly, the use of the SBM model within DEA to track efficiency changes offers a more nuanced understanding of how logistics performance has shifted as a result of the pandemic. Finally, the findings from this cross-country comparison provide timely and invaluable guidance to policymakers in shaping logistics priorities.

The remainder of the paper is organised as follows. The next section offers background information on logistics and examines studies on the interplay between logistics and the LPI, efficiency, and the pandemic. Section 3 outlines the data and research methodology employed to investigate the impact of the pandemic on logistics. Following the results and discussion section (Section 4), the study concludes in Section 5 with a concise summary, policy insights, limitations, and recommendations for future research.

2. Background and literature review

A national economy is significantly influenced by the effectiveness with which the country's industries handle and execute logistics activities. Strong performance in these logistics functions enhances the nation's competitiveness, economic growth, and overall prosperity (Sumantri and Lau 2011). A competitive advantage in logistics operations may help a country expand its market and increase its business growth and global trade (Ekici, Kabak, and Ülengin 2016). Chang and Lai (2017) state that a notable improvement in international logistics has appeared as governments have upgraded their logistics infrastructure to strengthen their competitive advantage. Chang, Lu, and Lai (2022) also explain the crucial role of regulations, technology, and integration as the drivers of competitive advantage for international logistics. Infrastructure facilitates the transportation of goods and requires an effective and timely exchange of information (Wong and Tang 2018). Improved technology enables the tracking and tracing of the flow of materials. Integration refers to collaboration within the whole logistics system. Avoiding redundant or inconsistent regulations is critical if the logistics industry is to save money and time and have a competitive advantage in the market (Chang, Lu, and Lai 2022).

A country's economic situation, income level, and geographical location influences its logistics performance. Developed countries with high incomes and EU members have generally higher LPI scores (Martí, Martín, and Puertas 2017). Logistics performance significantly impacts global economic growth (Coto-Millán et al. 2013), and there is a strong association between these two measures (Luz et al. 2016; McKinnon et al. 2017). Thus, it is evident that enhancing economic development and regional integration is essential for improving logistics performance, and that this in turn fuels broader global economic growth.

Recent studies have focused on understanding the complex relationship between logistics performance and environmental sustainability. Liu et al. (2018) underlined the significance of the link between the assessed logistics performance and environmental degradation in Asian countries. Furthermore, Rashidi and Cullinane (2019) measured the sustainability of operational logistics performance in OECD countries, and found a statistically insignificant association between sustainability and LPI. Conversely, by establishing an environmental logistics performance index

(ELPI), Lu et al. (2019) assessed and compared the effectiveness of eco-friendly transportation and logistics practices through a DEA approach. Their findings illustrated a strong association between the ELPI and the LPI.

In today's global economy, international trade is one of the crucial factors for economic prosperity. Global competition forces countries to enhance their efficiency on a global scale. Logistics networks facilitate international trade (Arvis et al. 2016). Martí, Puertas, and García (2014) underscored the critical role of LPI indicators, particularly for developing nations in Africa, South America, and Eastern Europe. Excellency in logistics operations enhances competitiveness by ensuring the smooth, robust, and cost-effective movement of goods and services. Conversely, effective logistics operations produce a seamless flow of goods, services, and information from origin to consumer. These operations are critical in meeting customers' expectations and bolstering profitability. Consequently, organisations increasingly prioritise their logistics operations to accelerate delivery, optimise inventory management, refine procurement strategies, and enhance information exchange across their SCs.

2.1. Theoretical underpinnings of logistics performance

Building on seminal works in logistics performance and global supply chain management, our study draws primarily on the resource-based view (RBV), its extension to dynamic capabilities theory (DCT), and institutional theory to frame our analysis.

RBV suggests that a firm's – or, in this context, a country's – sustainable competitive advantage comes from its unique resources and capabilities (Barney 1991). In analysing logistics performance through the LPI, we conceptualise critical logistics assets, such as advanced infrastructure, efficient customs operations, and reliable international shipping systems, as strategic resources under the RBV lens. Deficiencies in infrastructure and customs clearance, identified through declining LPI scores, reflect resource gaps that hinder countries' logistics competitiveness in the global economy.

Similarly, DCT (Teece, Pisano, and Shuen 1997) supports our investigation into how logistics systems have adapted to the disruptions caused by the COVID-19 pandemic. Improvements that are observed in logistics competence, quality, and tracking systems after the pandemic illustrate the exercise of dynamic capabilities. Countries that swiftly adopt technological innovations and optimise their logistics operations demonstrate superior dynamic capabilities, enabling them to enhance service reliability and efficiency under turbulent conditions.

Moreover, institutional theory offers another vital perspective on logistics performance. The regulatory frameworks, governance structures, and policy environments that shape national logistics systems are crucial in determining operational outcomes (North 1990). A post-pandemic decline in customs efficiency and international shipment performance points to institutional rigidities and governance shortcomings. Under institutional theory, the inability of some nations to reform or streamline their logistics regulatory processes during the pandemic underscores how institutional contexts can either constrain or facilitate dynamic resource deployment and adaptation.

Collectively, these theories provide an integrated analytical foundation: RBV explains the significance of logistics resources; DCT clarifies how countries adapt and innovate logistics operations under stress; and institutional theory reveals the critical enabling or constraining role of formal rules and governance structures. Through this theoretical triangulation, we critically interpret our results, showing that logistics performance improvements or deteriorations after the pandemic are not isolated phenomena but are deeply rooted in the dynamic interplay between resources, capabilities, and institutional contexts.

2.2. Logistics and the LPI

Comparing and contrasting national logistics systems may help us to judge their relative performance and benchmark their strengths and weaknesses, allowing us to identify areas for further improvement, such as infrastructure, services, policies, and regulations (Ekici, Kabak, and Ülengin 2016). Since 2007 the World Bank has released the LPI, which assesses and ranks the logistics performance of different countries. This index was published in 2010, 2012, 2014, 2016, 2018, and, most recently, in 2023. The latest report evaluates the LPI for 139 countries. The LPI provides a comprehensive assessment of logistics costs, infrastructure quality for land and sea transportation, and customs procedures at the country level.

Using a survey methodology, the LPI measures six indicators of country-level logistics activities: *customs*, *infrastructure*, *international shipments*, *logistics competence and quality*, *tracking and tracing*, and *timeliness*. These are not independent and some may be antecedents to others (Arvis et al. 2016; Martí, Puertas, and García 2014). RBV highlights the foundational importance of customs, infrastructure, and international shipments as core logistics resources that underpin national competitiveness. DCT, in contrast, highlights the more adaptive capabilities reflected in logistics competence and quality, tracking, and timeliness, which enable countries to respond effectively to disruptions. Institutional theory underscores the importance of formal rules and regulatory environments, particularly those influencing customs and international trade operations, that either facilitate or impede logistics performance.

In this study, the interplay between DCT and institutional contexts is especially important: countries' ability to reconfigure logistics resources dynamically is often contingent upon the flexibility and supportiveness of their institutional environments. Thus, our theoretical integration allows us to explain better why some nations demonstrated resilience and improvement in the LPI dimensions after COVID-19, while others experienced persistent declines tied to structural and governance inefficiencies. We now define and discuss the focal concepts in our study.

Customs refers to border management clearance efficiency in the context of the LPI (Arvis et al. 2023). It emphasises the speed, simplicity, and predictability of customs procedures (Rezaei, van Roekel, and Tavasszy 2018). From an RBV perspective, efficient customs procedures are a strategic resource that underpins a country's competitive advantage in global trade. They enable smoother border operations, reducing delays and costs and allowing customs formalities to be completed on time without interfering with product flows or diminishing the effectiveness of customs control. Improper or inflexible customs processes negatively affect economic competitiveness (Adomavičiūtė 2016). Thus, efficient customs procedures are critical to creating differentiation, cost reduction, and competitive advantage.

Infrastructure facilitates the transportation of goods and entails an effective and timely exchange of information in transport networks for importing and exporting goods, telecommunications networks to expedite information exchanges, import duty handling systems, and many other services (Wong and Tang 2018). Infrastructure serves as a tangible resource within the RBV framework, forming the backbone of a nation's logistics system by facilitating movement and connectivity. Well-developed railways, ports, airports, roads, and telecommunication services create a perfect logistics environment. However, the physical infrastructure of many developing countries is unsatisfactory (Wong and Tang 2018). The aim of the LPI is to assess the quality of trade- and transport-related infrastructure (Arvis et al. 2023).

International shipments gauges the ease of arranging shipments at competitive prices (Arvis et al. 2023). RBV implies that robust international shipping capabilities, supported by good-quality infrastructure and streamlined customs processes, may enhance a country's competitive edge. The capacity of a country to offer competitive prices depends upon its logistics costs, and, in developing countries, these costs are the most significant for reducing trade costs (Çemberci, Civelek, and Canbolat 2015). These costs are generally related to tariffs and fees. A country with a competitive advantage in logistics costs may have easy access to new markets, promote commerce, and increase its potential for international trade.

Tracking and tracing refers to the capability to track and trace consignments in logistics networks (Arvis et al. 2023). A tracking and tracing system links information systems and material flow using certain technologies such as RFID, GPS, QR code, and WSN (Shamsuzzoha et al.

2013). DCT suggests that integrating and continuously improving these systems is essential for enabling quick responses to SC disruptions, and that this reflects a nation's dynamic ability in adaptation and innovation. Thus, countries gain a great deal from such systems, learning about delivery problems and delays in the logistics network ahead of time. Tracking and tracing the flow of materials can enable any irregular or unexpected events to be identified and addressed before they become serious, which minimises the damage (Çelebi 2019; Shamsuzzoha et al. 2013). A tracking and tracing system may increase competitive advantage and customer satisfaction and decrease the cost incurred as a result of coordination problems (Çemberci, Civelek, and Canbolat 2015).

Timeliness is assessed by the frequency with which shipments reach consignees within the scheduled or expected delivery time (Arvis et al. 2023). It measures the punctuality of shipment delivery times (Martí, Puertas, and García 2014). From a DCT perspective, timeliness is enhanced through agile processes and the capacity to adapt logistics operations in response to real-time information and emerging challenges. Failing to meet delivery deadlines is intolerable, so timeliness is a critical factor for competition. It is also one of the determinants of trade volumes because time and logistics costs are directly correlated with shipment size (Çelebi 2019).

Logistics competence and quality are driven by the quality of logistics operations such as customs administration and transportation channels, and by inspection institutions' quality and standards (Arvis et al. 2023; Çemberci, Civelek, and Canbolat 2015). The DCT perspective emphasises that continuous learning, process enhancement, and innovation in logistics practices are essential for sustaining high competence and quality, especially in the face of disruptions like the COVID-19 pandemic. More expensive and time-consuming trade processes cause trading markets to be less competitive (Korinek and Sourdin 2011). Thus, good logistics performance necessitates the continuous improvement of service reliability, responsiveness, supportability, performance specifications, commercial standards, and resource enrichment through ongoing investment in logistics operations (Çelebi 2019).

The World Bank calculates the country-level LPI scores by taking a weighted average of the scores for the indicators for each country. Yu and Rakshit (2025) investigated the weights used in the LPI calculations to determine the relative importance of the LPI indicators, and offered a tool to guide policymakers. Interestingly, their proposal and the one established by the World Bank produce a similar country ranking. However, they found that service delivery performance was more critical for LPI than policy regulations, and that the most significant indicator was timeliness.

2.3. Efficiency of logistics operations across the globe

Efficient logistics operations are essential for timely deliveries, cost reductions, and customer satisfaction. Logistics efficiency entails optimising transportation, warehousing, and inventory activities to minimise costs and maximise service levels. As globalisation intensifies, efficient logistics systems become even more crucial to support international trade and economic development (Golgeci, Yildiz, and Andersson 2020). Various factors, including infrastructure, technology and innovation, the regulatory environment, and human capital, influence logistics efficiency globally (Lakshmanan 2011). First, high-quality infrastructure, including roads, ports, and railways, is fundamental for efficient logistics operations (Lakshmanan 2011). Second, adopting advanced technologies, such as automation, AI, and data analytics, significantly enhances logistics efficiency by improving route optimisation, inventory management, and real-time tracking, reducing costs and increasing reliability (McKinnon et al. 2017). Third, efficient customs procedures and regulatory frameworks facilitate smooth logistics operations, while bureaucratic hurdles and complex regulations can delay shipments and increase costs (Liu et al. 2018; Martí, Puertas, and García 2014). Furthermore, it is argued that a skilled workforce and effective management practices are crucial for efficient logistics operations (Murphy and Poist 2007).

Efficiency analysis has been used in several areas of logistics operations. The efficiency of different modes of transportation, such as air (Kotegawa et al. 2014), road freight (Cedillo-Campos et al. 2019; Qu et al. 2019), rail (Mandic, Jovanovic, and Bugarinovic 2014), and intermodal transport (Heinold and Meisel 2018; Yan et al. 2020), has been investigated using DEA models. Using DEA and the MI, Acar and Torgalöz (2022) analysed changes in the foreign trade logistics efficiencies of OECD member countries between 2007 and 2018.

The extant literature frequently uses LPI scores to evaluate logistics efficiencies. Yu and Hsiao (2016) employed a DEA model with assurance regions to analyse LPI scores, proposing potential paths to enhance the utilisation of countries' resources to boost their logistics efficiencies. Martí, Martín, and Puertas (2017) assessed countries' logistics performance using DEA and the LPI data set, finding that logistics performance depends on the country's geographical location and income level. Sternad, Skrucany, and Jereb (2018) evaluated the 2016 LPI dataset for some selected EU countries through a DEA model, and found that many EU countries ranked highly by the LPI were, in fact, not logistically efficient. Using the 2018 LPI data and DEA, Ulkhaq (2023) found that Germany was the most logistically efficient performer, while Niger ranked as the least efficient. Using the same dataset with a novel DEA approach, Bayraktar et al. (2024) uncovered significant disparities across country performance groups, such as low-, medium-, and high-performing groups, particularly in relation to the adoption of technological advancements.

Our use of DEA and the MI is firmly anchored in the broader literature on performance measurement and efficiency analysis. Previous studies have demonstrated that DEA is a robust non-parametric technique for evaluating the relative efficiency of decision-making units (Charnes, Cooper, and Rhodes 1978). By utilising both SBM and MI scores, this study not only assesses static efficiency but also captures temporal changes, thereby providing insights into the dynamic evolution of logistics performance. This method aligns with performance management theories that prioritise continuous improvement and benchmarking (Kaplan and Norton 1996). Furthermore, by implementing these methodologies in a cross-country context, the study enriches the theoretical discourse on how efficiency metrics can guide strategic logistics and supply chain management decisions at the regional level.

2.4. Logistics and the COVID-19 pandemic

The COVID-19 pandemic has profoundly impacted global logistics, exposing vulnerabilities and catalysing significant changes across the SC landscape (Golgeci et al. 2023). Inflexible logistics infrastructures, sloppy customs regulations, poor-quality logistical services, and inadequate interconnections rendered logistics networks susceptible to uncertainties, resulting in unforeseeable transactional distractions. Restrictions on movement and transportation led to reduced availability of freight services, increased shipping costs, and extended transit times. Air freight, in particular, faced severe capacity constraints due to the grounding of passenger flights, which typically carry a significant portion of global cargo (Mavi et al. 2022). Similarly, the pandemic disrupted warehousing operations by causing labour shortages and necessitating the implementation of health and safety protocols. This led to inefficiencies in inventory management and increased costs for storage and handling. Furthermore, the efficiency of customs procedures was adversely affected, with greater bureaucratic hurdles and delays in processing shipments. This highlighted the need for streamlined customs procedures to enhance the efficiency of international logistics (Adomavičiūtė 2016). Significant disruptions like the global COVID-19 pandemic, incidents in key water routes like the Suez Canal, and ongoing global conflicts have considerably increased the need to rethink the management, structure, and strategy of logistical networks (Golgeci et al. 2023).

The logistics sector faced numerous challenges as a result of COVID-19, such as a significant decrease in demand, disturbances in the logistics infrastructure, rising operational expenses, and an increasing number of businesses going bankrupt (Sumbal et al. 2023). International shipments were strongly affected, since many countries closed their borders to prevent the spread of the virus.

In addition to reducing the volume of goods transported by road and air in Europe, the pandemic altered the structure of that sector to incorporate more cabotage transit (Kutsenko et al. 2022). In addition, to ensure the flow of goods and because of the restrictions on international shipments, outsourcing logistics functions to third parties gained importance (Rinaldi and Bottani 2023). These difficulties led to large-scale discussions on transportation volumes, freight capacities, SC network design, the selection of transportation modes, localising manufacturing, and food logistics (Vilko and Hallikas 2023). Establishing critical corridors and gateways was considered to be a crucial strategy for the post-pandemic recovery. Some businesses began planning to reconstruct their supply networks with greater decentralisation by using regional logistics centres (Mavi et al. 2022).

On the other hand, the disruptions caused by border closures, limited human resources, and supply shortages prompted firms to innovate and reconfigure their businesses to meet customer demand better. Moreover, the pandemic has accelerated innovation and digitalisation efforts in the logistics sector. Technologies such as blockchain, the Internet of Things (IoT), AI, and big data facilitate the tracking of commodities during shipping and at ports, decrease bureaucratic inefficiencies, and reduce disputes in the transportation of commodities (Zondervan, Tolentino-Zondervan, and Moeke 2022). Similarly, the pandemic introduced contactless deliveries in which there is no physical contact between the driver, the consumer, and the store or warehouse staff (Sumbal et al. 2023). All these new developments have improved the ability of the logistics sector to track and trace the flow of materials, leading to significant advances in the implementation of information and communication technology in logistics. Hence, the pandemic enhanced communication and collaboration among logistics partners and developed their infrastructure.

Another beneficial outcome of COVID-19 was the accelerated adoption of e-commerce in the markets. During the pandemic, changing shopping habits and purchasing behaviours affected consumer satisfaction and impacted logistics competence and quality (Kara et al. 2024). Although the restrictions and disruptions no longer exist, people still prefer online shopping channels. Therefore, firms sought innovations in e-commerce to compete with their rivals.

Crises often have a worse effect on small and medium-sized enterprises in the logistics sector, as they lack the necessary survival resources. In addition, their management structures, available budgets, and operational scales make them vulnerable to innovation and digitalisation in the post-pandemic era (Zondervan, Tolentino-Zondervan, and Moeke 2022). Similarly, developing countries lack the technology required to overcome the problems arising from the pandemic, while developed and emerging countries have a better chance of adaptation because of their wealth and know-how.

3. Research methodology

3.1. Data and sample

The LPI developed by the World Bank assesses countries' trade logistics performance in more than 160 countries, which vary from year to year, and points out potential improvement areas. Its theoretical background and methodology are accessible at www.lpi.worldbank.org. The index includes qualitative and quantitative questions answered by international logistics operators over the different areas of logistics applications (Beysenbaev and Dus 2020).

LPI evaluates countries' logistics performance using six indicators: *international shipments*, *tracking and tracing*, and *timeliness* as SC/logistics performance outcomes and *customs*, *infrastructure*, and *logistics competence* as SC policy arrangement inputs (Arvis et al. 2016). Like Martí, Martín, and Puertas (2017) and Arvis et al. (2016), we consider the same indicators as outputs and inputs in our DEA models. In selecting our input and output variables, we aim to capture the key elements influencing logistics efficiency and performance.

The World Bank released seven different LPI reports between 2007 and 2023. To characterise the before-pandemic era, this study uses aggregated LPI scores covering four years of data between 2012 and 2018, with the most recent index, reported in 2023, representing the after-pandemic era. The disparities between these two timeframes on LPI constructs are our base for investigating the impact of the pandemic on countries' logistics applications.

The study evaluates 136 countries for which complete LPI data is available across all reporting years included in the analysis. These countries are distributed across seven regions classified by the World Bank (World Bank 2023b): East Asia & Pacific (EAP), Europe & Central Asia (ECA), Latin America & Caribbean (LAC), Middle East & North Africa (MENA), North America (NA), South Asia (SA), and Sub-Saharan Africa (SSA). We selected all available samples from the LPI dataset for several key reasons. First, the LPI is a widely recognised and comprehensive measure that captures the logistics performance of countries across various dimensions, including customs procedures, infrastructure quality, international shipments, logistics quality and competence, tracking and tracing, and timeliness (Beysenbaev and Dus 2020). We aimed to leverage the breadth of this index to ensure that our analysis covered diverse logistics environments spread across the seven regions globally. Second, using all available LPI data allowed us to conduct a more robust analysis to avoid biases that could arise from a selected dataset, thereby allowing our analysis accurately to reflect global trends and variations in logistics performance. Lastly, the comprehensive use of the LPI dataset aligns with our research objective of conducting a thorough and comparative analysis of logistics performance on a global scale, providing a holistic view of global logistics performance.

3.2. Data envelopment analysis

DEA is a linear programming model that benchmarks similar organisational units having multiple inputs and outputs specified in different scales. Its capability to handle multiple outputs as performance indicators and to denote performance with a single metric creates a real advantage over many other methods. DEA does not assume any objective function form, and derives the weights from the data (Cooper, Seiford, and Tone 2007). While comparing multiple units, it points out the sources of inefficiency for each of the inputs and outputs (Bayraktar et al. 2024). This study considers the countries to be the decision-making units (DMUs) and the input and output indicators of the LPI to be the inputs and outputs of the DEA model.

Different DEA models address different needs of researchers. Input-oriented DEA models investigate possible reductions in inputs while keeping output levels constant. In contrast, output-oriented DEA models focus on increasing outputs while maintaining input levels. Non-oriented DEA merges input and output-oriented models, allowing flexibility in evaluating efficiency, with outputs being maximised and inputs minimised simultaneously (Cooper, Seiford, and Tone 2007). Return to scale in DEA models assesses the proportional change in output when there is a change in inputs. If the proportional change is the same for both inputs and outputs, then the return to scale is constant; otherwise, it is variable. Under the variable return to scale (VRS) assumption, a DMU may not be perfectly scalable but might experience increasing or decreasing returns to scale. VRS models are a suitable choice if different DMUs operate at different scales. They are flexible enough to handle varying scale efficiencies across DMUs and they reflect the diversity in scale efficiency more realistically.

In DEA, the distances may be measured using radial or non-radial models. Radial models assume a proportional change in the variables and include the CCR (Charnes–Cooper–Rhodes) and the BCC (Banker–Charnes–Cooper) models. Non-radial models such as SBM deal directly with slacks and ignore the radial characteristics of the variables (Cooper, Seiford, and Tone 2007). The choice between using a radial or a non-radial DEA model depends on the underlying assumptions regarding returns to scale and the necessary level of flexibility to accurately evaluate the efficiency of DMUs. Non-radial models may be suitable when the study wants to identify the variables that lead to efficiency improvements, and to assess efficiency across varying scale efficiencies. Radial models are effective when a straightforward and easy-to-interpret efficiency assessment is required.

3.2.1. CCR model

The CCR model proposed by Charnes, Cooper, and Rhodes (1978) defines the efficiency of a DMU as the ratio of the outputs to the inputs, and it takes a value less than or equal to 1. This model assumes a constant return to scale (CRS) with the radial measurement of the variables (Cook and Zhu 2005). The CCR score is therefore the result of the proportional maximum input (output) reduction (expansion) rate common to all inputs (outputs) (Tone 2001). For n DMUs, m inputs (x_{ij}), and s outputs (y_{rj}), a fractional programming non-oriented CCR model may be stated as follows:

$$\max_{v,u} \theta = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{1}$$

Subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1, 2, \ldots, n \tag{2}$$

$$v_i, u_r \geq 0 \qquad \text{For all } i, r \tag{3}$$

In the formulation above, the efficiency score of DMU o (θ_o) is the ratio of weighted outputs ($\Sigma u_r y_{ro}$) to weighted inputs ($\Sigma v_i\, x_{io}$) under the restriction that the efficiency scores of the remaining DMUs are no more than 1. In the model, the weights of the inputs (v_i) and outputs (u_r) are selected so that θ_o* is the maximum possible efficiency score for o. If θ_o* = 1 and there is at least one optimum pair with v_i* > 0 and u_r* > 0, DMU o is CCR efficient (Cooper, Seiford, and Tone 2007). For the optimum weights v_i* and u_r*, the values of v_i* x_{io} and u_r*y_{ro} denote the relative contribution of each term to the efficiency.

3.2.2. Slack-based DEA models

Tone (2001) developed a non-radial, slack-based additive model considering possible input decreases and output increases simultaneously. The SBM model focuses on input and output slacks, which provide information regarding the use of resources and serve as criteria for target setting to determine improvement areas (Cooper, Seiford, and Tone 2007). The SBM model efficiency score is unit invariant, meaning that it does not change according to the data units. It also decreases monotonically in each slack of input and output (Tone 2001). A fractional programming non-oriented VRS SBM model is depicted below:

$$Min\ \rho = \frac{1 - \left(\frac{1}{m}\right) \sum_{i=1}^{m} s_i^- / x_{io}}{1 + \left(\frac{1}{s}\right) \sum_{r=1}^{s} s_r^+ / y_{ro}} \tag{4}$$

Subject to

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = x_{io} \qquad for\ i = 1, 2, \ldots, m \tag{5}$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{ro} \qquad for\ r = 1, 2, \ldots, s \tag{6}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{7}$$

$$\lambda_j, s_r^+, s_i^- \geq 0 \qquad for\ all\ i,\ j,\ r \tag{8}$$

The formulation (4–8) above represents a slack-based efficiency score for DMU o, where s_i^- and s_r^+ indicate the input excess and the output shortfall (in brief, the slacks), and λ_j is a non-negative intensity variable utilised to construct an ideal composite DMU. Equation 5 (6) denotes that a DMU's input (output) level is a linear combination of a composite ideal input (output) and the slack. Equation (7) enforces the variable return to scale condition. The DMU o is efficient if $\rho^* = 1$, and equivalently if all slacks are zero ($s_r^{+*} = s_i^{-*} = 0$). The optimum SBM efficiency score for any DMU is not higher than its optimum CCR efficiency score, and a DMU is CCR efficient if and only if it is SBM efficient (Tone 2001).

3.2.3. SBM-Max DEA model

While SBM models deal with the slacks directly, the original SBM model refers to the furthest frontier point within the range for efficiency (Tone 2016). This leads to a very low efficiency score for a DMU, and, even more importantly, the projection may hit a remote point that is inappropriate as a reference on the efficiency frontier. To cure this problem, Tone (2016) developed the SBM-Max model to find the nearly closest reference point on the efficiency frontier, minimising the slacks and maximising the efficiency score. An algorithm with several steps is applied to the SBM-Min solution to reach the efficiency score and the slacks in SBM-Max. Further details of the approach are available in the work by Tone (Tone 2016). The adoption of the non-oriented, VRS SBM-Max model to benchmark multi-output and multi-input country-level logistics efficiencies accurately identifies input excesses and output shortfalls, offering invaluable insights into specific inefficiencies within logistics performance.

3.2.4. Malmquist index

While DEA models measure efficiency in a specific timeframe, the Malmquist Index assesses efficiency changes over two periods. The MI is the product of 'Catch-up' and 'Frontier-shift' terms. The catch-up effect indicates the change in the efficiency level of DMU (x,y) from time t_1 (x^{t_1}, y^{t_1}) to t_2 (x^{t_2}, y^{t_2}), assessing the improvement attained by the DMU.

$$Catch\text{-}Up = \frac{\rho^{t_2}(x^{t_2}, y^{t_2})}{\rho^{t_1}(x^{t_1}, y^{t_1})}$$

However, the frontier-shift effect represents the change in the efficient frontiers ($\rho^{t_1}(x, y)$ and $\rho^{t_2}(x, y)$) around the DMU between t_1 and t_2.

$$Frontier\text{-}Shift = \left[\frac{\rho^{t_1}(x^{t_1}, y^{t_1})}{\rho^{t_2}(x^{t_1}, y^{t_1})} \times \frac{\rho^{t_1}(x^{t_2}, y^{t_2})}{\rho^{t_2}(x^{t_2}, y^{t_2})}\right]^{\frac{1}{2}}$$

The resulting MI is calculated as follows (Cooper, Seiford, and Tone 2007):

$$MI = (\text{Catch-Up})(\text{Frontier-Shift}) = \left[\frac{\rho^{t_1}(x^{t_2}, y^{t_2})}{\rho^{t_1}(x^{t_1}, y^{t_1})} \times \frac{\rho^{t_2}(x^{t_2}, y^{t_2})}{\rho^{t_2}(x^{t_1}, y^{t_1})}\right]^{\frac{1}{2}}$$

The catch-up effect assesses the technical efficiency change. The DMU gets closer to its frontier if the catch-up effect exceeds 1. The frontier-shift effect evaluates the technology change. Values higher than 1 indicate a change in the frontier over two time periods. An MI greater than 1 designates an enhancement in the total factor productivity of a DMU from the period $t_1$to t_2. Similarly, an MI equal to 1 signifies no change, while an MI less than 1 represents a decrease in total factor productivity.

This study employs a non-radial, non-oriented Malmquist Index to assess the impact of the pandemic on logistics applications. Therefore, the SBM and super SBM models are utilised to calculate the MI. Tone (2004) further discusses the calculation of the MI. This study utilises the MI to evaluate

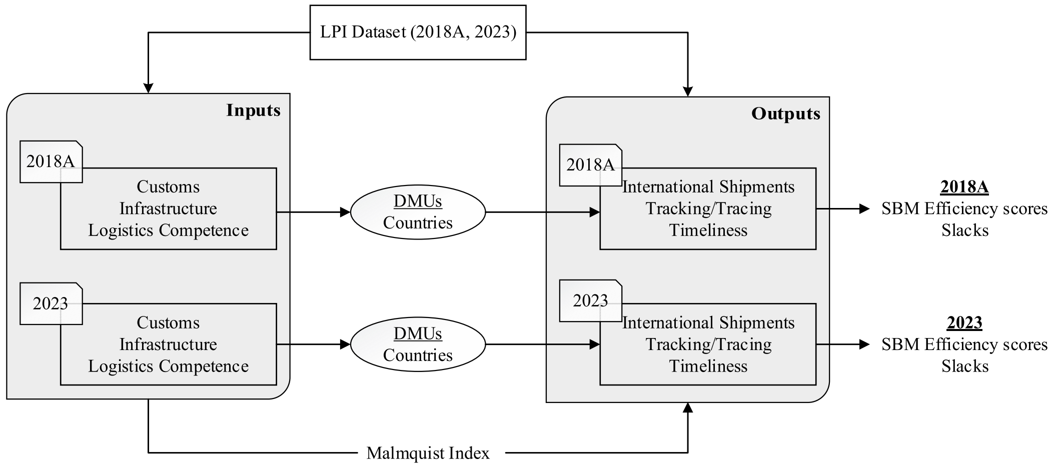

Figure 1. Research model.

Note: 2018A represents the weighted aggregated LPI scores between 2012 and 2018.

dynamic shifts in logistics efficiency over time, distinguishing between enhancements resulting from managerial practices (catch-up) and advancements resulting from technology (frontier-shift).

3.3. Research model

Figure 1 displays the research model for the study. Among the LPI indicators, *customs*, *infrastructure*, and *logistics competence* are selected as inputs, while *international shipments*, *tracking and tracing*, and *timeliness* are specified as outputs, in line with the literature (Arvis et al. 2016; Martí, Martín, and Puertas 2017). DEA models aim to reduce the inputs and increase the outputs to maximise the efficiency score. The LPI input indicators assess the country's logistics implementation levels, where higher scores are desirable. Therefore, following the recommendation of Martí, Martín, and Puertas (2017), all inputs undergo a monotone-decreasing transformation. New input variables are derived by subtracting the original values from the maximum score of five, indicating the potential for improvement in each input. In the solutions of all the DEA models, these modified inputs are utilised; however, the tables in the following sections present the inputs on their original scale for simplicity. With this adjustment to the input variables, the non-oriented DEA models calculate efficiency scores by minimising the input and maximising the output variables simultaneously during the analysis.

There is no concrete information about the scalability of countries' logistics operations. Assuming that countries may operate on any scale, VRS is selected in the DEA models as necessary. The study focuses on the logistics performance efficiencies of the countries and the sources of inefficiencies, to guide improvements in their operations. Therefore, the non-radial DEA model, DEA-Max, is used directly to address slacks and assess efficiency under varying scale efficiencies.

To avoid any discrimination problem, DEA models should ensure that the number of DMUs (n) selected is relatively large compared to the number of input (m) and output (s) variables, satisfying the condition of $n \geq \text{Max}\{m^*s, 3(m+s)\}$ as suggested by Cooper, Seiford, and Tone (2007).

4. Results and discussion

4.1. Descriptive evaluation

Table 1 summarises the LPI scores, along with the input and output indicators, before and after the pandemic for 136 counties. There were statistically significant differences in the overall LPI scores

Table 1. Summary of regional LPI score statistics: before and after the pandemic.

			Inputs			Outputs			
Regions	The Number of Countries	Mean	Customs	Infrastructure	Logistics Competence and Quality	International Shipments	Tracking and Tracing	Timeliness	LPI
Global	136	Before	2.750	2.820	2.893	2.901	2.957	3.320	2.943
		After	2.809	2.929	3.037	2.934	3.060	3.247	3.008
		Pairwise t-test	−2.790***	−5.083***	−6.836***	−1.336	−4.193***	2.802***	−4.192***
East Asia & Pacific (EAP)	19	Before	3.057	3.126	3.170	3.121	3.221	3.552	3.207
		After	3.110	3.321	3.326	3.147	3.421	3.484	3.300
		Pairwise t-test	−1.228	−4.088***	−3.465***	−0.429	−3.817***	0.850	−2.211**
Europe & Central Asia (ECA)	45	Before	3.058	3.163	3.217	3.157	3.276	3.656	3.256
		After	3.129	3.258	3.378	3.196	3.373	3.551	3.322
		Pairwise t-test	−1.879*	−2.587**	−4.304***	−0.968	−2.049**	2.426**	−2.295**
Latin America & Caribbean (LAC)	23	Before	2.480	2.477	2.608	2.695	2.680	3.042	2.667
		After	2.482	2.548	2.700	2.657	2.739	3.004	2.691
		Pairwise t-test	−0.060	−1.637	−2.928***	0.680	−1.020	0.770	−0.774
Middle East & North Africa (MENA)	17	Before	2.612	2.832	2.794	2.834	2.858	3.257	2.864
		After	2.759	2.971	2.953	2.906	3.041	3.229	2.98
		Pairwise t-test	−2.238**	−1.585	−1.959**	−0.941	−2.794**	0.284	−2.069*
North America (NA)	2	Before	3.730	4.005	3.915	3.495	4.020	4.085	3.865
		After	3.850	4.100	4.050	3.500	4.150	3.950	3.900
		Pairwise t-test$^{\xi}$	-	-	-	-	-	-	-
South Asia (SA)	5	Before	2.388	2.314	2.552	2.554	2.568	2.898	2.552
		After	2.520	2.360	2.700	2.600	2.540	2.960	2.640
		Pairwise t-test$^{\xi\xi}$	−1.187	−0.669	−2.432*	−0.382	0.321	−0.703	−1.255
Sub-Saharan Africa (SSA)	25	Before	2.30	2.282	2.417	2.532	2.498	2.861	2.488
		After	2.312	2.380	2.556	2.596	2.548	2.756	2.536
		Pairwise t-test	−0.196	−1.966*	−2.344**	−0.957	−0.827	1.688	−1.397

***: Two-sided $p < 0.01$, **: Two-sided $p < 0.05$, *: Two-sided $p < 0.1$.
$^{\xi}$: Group size is so small to make a meaningful statistical analysis, $^{\xi\xi}$: Interpret with caution due to the small group size.

of the countries before and after the pandemic, which point to an overall improvement in logistics activities worldwide. The input indicators, namely *customs*, *infrastructure*, and *logistics competence*, also increased significantly after the pandemic.

During COVID-19, streamlining border procedures through digital solutions to minimise physical contact improved *customs* worldwide. Similarly, efforts to modernise facilities to enhance the resilience of global SCs led to increased investment in *infrastructure*. One positive outcome of the COVID-19 pandemic was the increased recognition of logistics operations. Adopting these new technologies and facilities improved operational efficiency, leading to better *logistics competence and quality*.

However, the output indicators of LPI were affected differently by the pandemic. *Tracking and tracing* systems showed significant progress (p-value < 0.01) after the pandemic and supported the overall advances in logistics performance. The COVID-19 pandemic highlighted the necessity for real-time visibility of SC activities across various commodities, including food and vaccine distribution. The surge in online shopping during the lockdown propelled improvements in last-mile delivery and tracking capabilities. However, there was no significant change in international shipments, reflecting countries' ability to offer competitive prices.

Despite the improvements in *customs* and *infrastructure*, ongoing global and local disruptions in SCs counterbalanced these improvements and resulted in there being no significant change in *international shipments*. An interesting finding pertains to the *timeliness* of logistics activities, which has significantly deteriorated since the pandemic. The slow recovery in many industries, unresolved SC disruptions, reduced transportation capacities, difficulties in managing inventories, shifting consumer behaviours, labour shortages, and variations in productivity, along with adaptations to regulatory changes, may explain why the timeliness indicator for logistics has worsened in the post-pandemic era.

Table 1 also displays the regional logistics statistics for the LPI and its indicators. According to World Bank resources (World Bank 2024a), EAP is the fastest-growing and most dynamic region in the world. As illustrated in Table 1, significant improvements have been observed in this region in the *infrastructure*, *logistics competence and quality*, and *tracking and tracing* indicators in the post-pandemic era. Examples of enhancements to the logistics infrastructure in the region include China's Belt and Road Initiative and Vietnam's low-carbon energy investments (World Bank 2024a). Initiatives like the Zhengzhou Urban Rail Line in China, which mitigates 33,960 tons of CO2 emissions annually, along with the National Slum Upgrading Project in Indonesia and the disaster resilience project in the Pacific, are contributing to *logistics efficiency and quality* (World Bank 2024a). Furthermore, digital transformation and the growth of e-commerce in China and Southeast Asia have improved *tracking and tracing* for SC visibility (Asian Development Bank 2022). The regulatory reforms in Malaysia aimed at boosting internet speed and reducing costs have helped to improve digital connectivity, facilitating tracking and tracing. However, in EAP the marginal improvement observed in *customs* is not statistically significant. The region faces challenges such as high debt levels, an aging population, and global trade tensions, which may hinder countries like China and Vietnam from fully realising the benefits of their investments in customs automation (World Bank 2024a). While *timeliness* has shown a tendency to decline, this is not statistically significant for the region. The impact of COVID-19 remains evident in EAP, which is particularly vulnerable to numerous natural disasters and climate risks, having experienced 70% of the world's natural disasters since 2000 (World Bank 2024a).

The logistics performance of ECA is in line with that of the world as a whole. Table 1 indicates that, like the global averages, ECA's *international shipment* performance did not change significantly after the pandemic. Economic stagnation, regional conflicts and catastrophes, and disruption of trade routes because of the war between Russia and Ukraine have strongly influenced *international shipments* not only in ECA but also around the world. While *timeliness* has deteriorated slightly everywhere, ECA is the only region in which this deterioration was statistically significant, as shown in Table 1. Similar drawbacks have also led to delayed shipments and have impacted delivery timelines. Technical expertise in the region, human capital, digital transformation, and innovation capabilities helped ECA achieve a slightly better performance in *customs*, *infrastructure*, and *tracking and tracing* (European Institute for Asian Studies 2024; OECD 2023a). ECA has made significant improvements in *logistics competence and quality* in the post-pandemic era and has the second-best score (coming after NA), as shown in Table 1.

Despite the improvements in EAP, ECA, and NA, the logistics performance of the LAC region lags behind the global averages, as shown in Table 1. Only slight, but still significant, improvements have been made in *logistics competence and quality*, but they remain far below the world averages. Other indicators of the LPI did not change significantly from the pre- to the post-pandemic era. The World Bank's overview of this region states that there has been slow and steady progress in recovering from the pandemic (World Bank 2024b). The same study reports an accelerated digitalisation in the region as a result of the pandemic, although digitalisation remains underexplored in terms of service delivery. This may account for the current logistics performance of the region.

The MENA region, spanning three continents with diverse economic and demographic characteristics, has always contained the most strategic transportation routes and energy corridors globally. The region accounts for approximately 55% of the world's proven oil reserves (OPEC 2023b) and supplies much of the world, primarily Europe and Asia. Key logistics routes for global trade and energy pass through the Straits of Hormuz and the Suez Canal, both located in this region. Consequently, MENA plays a crucial role in overall logistics operations worldwide.

Table 1 shows that the logistics performance of MENA is slightly below the global average, although the region has demonstrated significant improvements in *customs* modernisation, *logistics competence and quality*, and *tracking and tracing* capabilities. The region includes leading logistics development countries such as the UAE and Saudi Arabia, which are early adopters of advanced technologies, as well as countries with limited resources and political instability (World Bank 2025). MENA countries are working hard to modernise roads, enhance port capabilities like those of Jebel Ali Port in the UAE, and develop new economic zones. However, the region struggles with political and economic diversity, which may explain the relatively slow progress in *infrastructure* and the declining *timeliness*. As a crossover region spanning three continents and controlling the main energy passageways, MENA has the potential to become a key logistics hub if it improves its logistics performance and addresses the current challenges.

The NA region is represented in our study by two countries, namely Canada and the US. The averages of the logistics performance indicators for both countries are better than those of any region in the world, as shown in Table 1. All indicators except *timeliness* show progress from the pre-pandemic to the post-pandemic era. This is the result of ongoing investment in modern transportation networks, trade facilitation processes, robust infrastructure, seamless customs operations, and advanced tracking technologies. However, *timeliness* decreased slightly, as depicted in Table 1, potentially due to the slow recovery from the SC disruptions experienced during the pandemic.

The SA region has one of the lowest logistics performance scores globally. While logistics performance indicators, including *timeliness*, generally show slight improvements, *tracking and tracing* slightly decreased, as illustrated in Table 1. However, because of inadequate infrastructure, inefficient customs processes, and a lack of unified regional integration, the logistics performance of the region remains unsatisfactory. Despite some logistics digitalisation initiatives and infrastructure upgrades, such as the Bharatmala road project in India, weaker economies in the region continue to struggle with poor connectivity, red tape, and dependence on informal logistics systems (World Bank 2024c).

Logistics performance indicators in SSA show marginal improvements, but these are not statistically significant. The region has the lowest logistics performance metrics globally and faces substantial challenges due to persistent inefficiencies in border management and SC systems. Efforts to improve *infrastructure*, enhance trade corridors, and increase port capacities through projects supported by the African Continental Free Trade Area have led to increased metrics, but their impact remains marginal (World Bank 2024d). *Timeliness*, as in many other parts of the world, has also slightly deteriorated, highlighting ongoing struggles, unreliable delivery times, and significant dwell times. The regional logistics challenges include insufficient investment, high transportation costs, and a limited adoption of digital solutions (Kuteyi and Winkler 2022).

4.2. Malmquist index

This study employs the MI to evaluate the changes in logistics performance that occurred between the pre-pandemic and the post-pandemic eras. It breaks down efficiency changes into two distinct components: the catch-up effect, which reflects improvements in managerial practices, and the frontier-shift effect, which represents technological advancements. This decomposition aligns closely with DCT, emphasising continuous adaptation and innovation amid environmental disruptions. Consequently, the MI provides a theoretically grounded and empirically robust framework to assess whether enhancements in logistics efficiency are primarily driven by internal operational improvements or by broader technological shifts at the frontier.

To compare the pre- and post-pandemic logistics performance of countries worldwide, the non-oriented, VRS MI values are calculated in Table 2. Consistently with the results in Table 1, the MI shows that the LPI was, on average, 8 percent higher in 2023 than in the period before the pandemic (between 2012 and 2018). The MI is greater than 1 at a one percent confidence level; therefore, the change in the LPI indicates an 8 percent increase in productivity and improved logistics efficiency globally. Further analysis of the MI highlights that the frontier-shift effect is 1.286, which represents a 28.6 percent increase, and that this is also greater than 1 at the one percent significance level. The primary source of the improvement in the LPI is attributed mainly to the frontier-shift effect, reflecting how breakthrough changes impact the logistics frontier through technological advancements and best logistics practice.

However, the catch-up effect averages less than 1, at 0.841, indicating limited convergence towards the best-performing country and poor internal efficiency among countries in managing their logistics operations independently from frontier changes. Bayraktar et al. (2024) noted a similar trend between 2010 and 2018, prior to the pandemic. Recent studies suggest that this trend is continuing in the logistics sector, and has been intensified by the pandemic. Consequently, the ability to manage logistics operations at the country level has declined since the pandemic, and catch-up is not the primary factor behind changes in logistics productivity. Instead, the impact of technological advancements and the adoption of best logistics practice has been driving the improvements in logistics productivity after the pandemic, offsetting the catch-up effect and allowing the MI to reflect an overall enhancement in logistics efficiency worldwide.

Table 2. Malmquist Index (MI) scores: before and after the pandemic.

		Catch-Up Effect			Frontier Shift Effect			Malmquist Index		
			99% CI			99% CI			99% CI	
Regions	The number of countries	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
Global	136	0.841	0.804	0.879	1.286	1.273	1.299	1.079	1.036	1.124
East Asia & Pacific (EAP)	19	0.895	0.743	1.047	1.289	1.210	1.369	1.135	1.015	1.254
Europe & Central Asia (ECA)	45	0.844	0.766	0.923	1.277	1.249	1.304	1.083	0.978[ξ]	1.183
Latin America & Caribbean (LAC)	23	0.797	0.747	0.846	1.289	1.286	1.291	1.027	0.963	1.090
Middle East & North Africa (MENA)	17	0.877	0.770	0.984	1.296	1.292	1.300	1.137	0.996[ξ]	1.278
North America (NA)	2	0.895	-	-	1.303	-	-	1.166	-	-
South Asia (SA)[ξξ]	5	0.825	0.628	1.022	1.286	1.279	1.293	1.060	0.810	1.311
Sub-Saharan Africa (SSA)	25	0.811	0.750	0.872	1.289	1.287	1.291	1.044	0.967	1.122

CI: Confidence interval, [ξ]: > 1 for a 95% confidence interval, [ξξ]: Interpret CI with caution due to the small group size.

Table 2 illustrates the catch-up effect, frontier-shift effect, and the MI for the seven regions, along with the global averages. While the average MI scores exceed 1 for all the regions, only EAP, ECA, and MENA meet this threshold at a significant level of confidence, with confidence intervals of 99%, 95%, and 95%, respectively. For the other regions, the MI may not be significantly above 1. LAC, SA, and SSA may still face challenges in recovering from the pandemic in terms of logistics operations. These findings support our earlier descriptive analysis. For a deeper examination, the regional catch-up and frontier-shift effects are now explored.

For all regions except EAP and SA, the catch-up effect is below 1 (ranging from 0.797 to 0.895), which is consistent with the global trend. EAP may be the only exception here, as SA has too few countries for a meaningful statistical analysis to be conducted. NA and EAP have the highest catch-up score (0.895), despite this score remaining below 1. The struggle to catch up with best practices at the frontier may be linked to the pandemic, which hindered economic growth, led to stagnation, reduced investment, and created an entirely new environment for adaptation in each nation. EAP seems to have managed this better than other regions as regards logistics operations.

The regions show a frontier-shift effect score ranging from 1.277 to 1.303, which exceeds 1, indicating a structural and technological shift at the frontier. In terms of the frontier-shift effect, NA and MENA lead the way. Factors like technological advancements, enhancements in best practice, research and development, alterations in the regulatory landscape, and heightened competitiveness may drive this frontier shift. Regional MI scores above 1, with a 99% confidence level, clearly demonstrate that the pandemic has transformed the logistics industry and the provision of logistics services. In our earlier discussion regarding the regions and the LPI indicators, we noted the impact of technological advancements in *customs, infrastructure,* and *logistics competence and quality*, along with *tracking and tracing*, during the pandemic. The same regions are also highlighted here for their high frontier-shift effect scores, emphasising the role of technological advancements such as digitalisation and internet capabilities.

To summarise, our results indicate that, after the pandemic, logistics efficiency improved and that this was primarily due to the frontier-shift effect rather than internal efficiency at the country level. This suggests that global advancements in technology, digitalisation, and best logistics practice expanded the efficiency frontier, benefiting high-performing regions. However, regions with lower logistics efficiency, such as LAC and SSA, encountered difficulties in catching up, leading to larger efficiency gaps. Thus, while overall productivity increased, this was a result not of better national-level logistics management but rather of external technological advancements setting efficiency standards.

4.3. Comparison of country efficiency scores: before and after

To benchmark cross-country logistics efficiencies, this study applies the CCR and SBM models within the DEA framework. The CCR model, relying on radial measurements, provides a classical measure of overall technical efficiency under proportional changes in inputs and outputs. It is crucial for initial cross-country logistics systems comparisons. This is supplemented by the SBM model, which allows for a more refined assessment by directly addressing input excesses and output shortfalls while pinpointing specific sources of inefficiency. The combination of the CCR and the SBM models ensures a comprehensive analysis, from resource-based and institutional theory perspectives, by capturing both aggregate efficiency levels and detailed operational inefficiencies in a way that is essential for policy interventions.

Building on our research model structure, in Table 3 the efficiency scores of the countries before and after the pandemic are calculated separately using the two different DEA models: the CCR model for overall technical efficiency and the SBM model with non-oriented VRS options. The first model determines the optimal weights for inputs and outputs to maximise the ratio of virtual outputs to virtual inputs, essentially assessing the efficiency of each decision-making unit (Cooper,

Table 3. Country efficiency scores: Before and after the pandemic.

Regions	CCR Overall Technical Efficiency			SBM Variable Return to Scale Efficiency		
	Mean		Pairwise t-test	Mean		Pairwise t-test
	Before	After		Before	After	
Global	0.362	0.335	4.708***	0.408	0.369	6.515***
Efficient Countries	Germany	Singapore		Germany, Belgium	Singapore, Finland	
East Asia & Pacific (EAP)	0.451	0.421	1.801*	0.506	0.480	1.670
Europe & Central Asia (ECA)	0.462	0.423	2.815***	0.522	0.471	3.505***
Latin America & Caribbean (LAC)	0.264	0.232	4.379***	0.291	0.244	6.117***
Middle East & North Africa (MENA)	0.314	0.315	−0.020	0.366	0.349	1.310
North America (NA) [ξ]	0.683	0.675	-	0.843	0.782	-
South Asia (SA)[ξξ]	0.244	0.232	1.159	0.272	0.241	3.611**
Sub-Saharan Africa (SSA)	0.236	0.213	3.605***	0.255	0.220	6.052***

*** Two-sided $p < 0.01$, ** Two-sided $p < 0.05$, * Two-sided $p < 0.1$,
[ξ]: Group size is so small to make a meaningful statistical analysis, [ξξ]: Interpret with caution due to the small group size.

Seiford, and Tone 2007). According to the CCR efficiency scores, Germany exhibited full efficiency before the pandemic, while Singapore achieved this afterwards. These countries serve as benchmarks for others. The SBM model simultaneously minimises input excesses and output deficits while accommodating variations in scale efficiencies across countries. According to the SBM results, Belgium and Finland, in addition to Germany and Singapore, can be identified as logistically efficient countries before and after the pandemic. However, both models indicate that the efficiency scores of countries decreased after the pandemic, with the differences in efficiency before and after being statistically significant. We can conclude that the pandemic substantially impacted logistics operations, and that, worldwide, logistics has yet to recover from its consequences. This supports our previous findings about the catch-up effect, and demonstrates a 15.9 percent decline in the efficiency scores for countries' logistics performances following the pandemic.

Although Germany and Belgium were not the leading countries in logistics performance efficiency in 2023, they remain among the top nations in overall logistics performance. Significant disruptions in transport networks and air freight and maritime shipping delays from East Asia have affected Germany's supply chain reliability (Goel, Saunoris, and Goel 2021; Loske 2020). Economic stagnation, supply chain inefficiencies, rising energy prices, and Russia's invasion of Ukraine have also contributed to logistical slowdowns in Belgium (International Monetary Fund 2022). In contrast, Finland has improved its customs operations and efficiency through digitalisation and streamlined clearance procedures (Finnish Customs 2023). Its high-quality infrastructure, skilled logistics operators, and strong on-time performance, along with effective collaboration with authorities and customers, have positioned Finland alongside Singapore as a global leader in logistics performance efficiency in 2023. Singapore rebounded strongly from the pandemic by capitalising on its strategic location, world-class port infrastructure, and proactive investments in logistics technology (World Bank 2023c). These changes among the top-performing logistics countries underscore the importance of supply chain resilience, digital transformation, and efficient border management in maintaining logistics performance.

While high-performing countries like Germany, Singapore, Belgium, and Finland illustrate the importance of proactive investment in logistics infrastructure and digitalisation, the broader regional analysis reveals more uneven outcomes. Table 3 also highlights the differences in regional efficiency scores. ECA, LAC, and SSA demonstrate statistically significant efficiency differences in both efficiency models, indicating lower logistics performance following the pandemic. These regions generally face persistent challenges such as underdeveloped transport networks, limited customs modernisation, and lower levels of supply chain digitalisation. For example, delays in customs clearance and weak multimodal transport options have been cited as key bottlenecks in many

Latin American and Sub-Saharan countries (World Bank 2018, 2023c). The pandemic further magnified these structural weaknesses, impeding recovery and widening the logistics performance gap between advanced and emerging regions. These findings underscore the critical role of institutional resilience and infrastructure adaptability in shaping post-crisis logistics outcomes.

EAP in the CCR model and SA in the SBM model show considerable efficiency losses, at 10% and 5% confidence levels, respectively. Interestingly, the differences in logistics performance efficiency in MENA are insignificant, suggesting a quick post-pandemic recovery for the region. In fact, MENA is a diverse region regarding logistics performance. Some countries in the region, such as Oman and Morocco, have high-level logistics strategies. Several studies report efforts to develop regional logistics hubs in countries such as Saudi Arabia and the UAE. However, the region also displays variable logistics performance. Port dwell times, which indicate effective port operations and infrastructure, are short in some countries, including Qatar, the UAE, Bahrain, Saudi Arabia, and Oman, but are longer in others, such as Tunisia, Libya, Mauritania, Morocco, Sudan, and Algeria (World Bank 2023c). Rail infrastructure in the region is very limited; ports, warehousing, transloading, and even telecommunications and IT infrastructure in some countries are below average (World Bank 2018). Red tape affects export and import transactions while decreasing the efficiency of border agencies.

Both the CCR and the SBM models rank NA, ECA, and EAP as the high-performing regions for logistics efficiency before and after the pandemic, while SSA, SA, and LAC are ranked as the low-performing regions. The high-performing regions primarily include high-income countries that benefit from established, high-quality infrastructure and institutions. Regarding logistics policy and investment, they often have strategic plans and institutions, such as the public–private organisation in the Netherlands, Dinalog, which develops strategic plans in logistics (World Bank 2018, 2023c). In contrast, the low-performing regions face deficiencies in logistics infrastructure, including ports, airports, and railroads, inefficient customs authorities, low-quality services, and insufficient tracking and tracing capabilities. Additionally, some countries in these underperforming areas also contend with significant governance issues (World Bank 2023c).

Our findings align closely with those of previous studies emphasising the importance of technological innovation and institutional efficiency for logistics performance (Martí, Martín, and Puertas 2017; Rashidi and Cullinane 2019). Like the patterns observed by Bayraktar et al. (2024) before the pandemic, we find that frontier shifts, rather than catch-up improvements, have primarily driven changes in logistics performance after the pandemic. However, while earlier studies suggested gradual convergence across global regions (Martí, Martín, and Puertas 2017), our results reveal a widening gap between the high-performing and the low-performing countries, particularly countries in LAC, SA, and SSA. This divergence indicates that dynamic capabilities and institutional readiness have become even more critical determinants of logistics resilience in the post-pandemic era, extending the theoretical discourse on logistics adaptability under extreme disruptions.

4.4. Contribution of LPI indicators to logistics efficiency: before and after

While our previous analysis shows that the average efficiency scores of countries have declined since the pandemic, it is crucial to investigate how the relative contributions of each indicator to the overall technical efficiency scores of these countries have changed. The CCR model of DEA is a radial model; therefore, the efficiency scores calculated for the countries also reflect the proportional differences among them. The CCR model assesses each country to compare it with the others, and determines its maximum possible efficiency score by assigning weights to the indicators. Naturally, a higher weight is linked to the indicators that differentiate a country from the others. Thus, a high contribution signifies strengths, while a low contribution indicates weaknesses or non-competitive indicators. In Table 4a, inputs and outputs are evaluated separately out of 100 to enable comparison of the contribution of each indicator.

Table 4a. Relative contribution of each LPI indicator to performance: global.

Relative contribution of LPI indicators		CCR-I (%)		CCR-O (%)		Mean	
		Before	After	Before	After	Before	After
Inputs	Customs	97.06	89.71	96.33	87.14	96.70	88.42
	Infrastructure	0	0	0	1.08	0	0.54
	Logistics Competence and Quality	2.94	10.29	3.67	11.78	3.30	11.04
	Total (%)	100	100	100	100	100	100
Outputs	International shipments	50.13	28.77	55.55	30.20	52.84	29.48
	Tracking and tracing	6.42	14.40	1.68	9.13	4.05	11.77
	Timeliness	43.45	56.83	42.77	60.67	43.11	58.75
	Total (%)	100	100	100	100	100	100

The analysis examining the CCR model results is presented in Table 3. Even though there is no difference between the input- and output-oriented efficiency scores in the CCR model, the weights used in each calculation differ slightly. Table 4a displays the contributions of each input and output indicator to the efficiency score for both orientations, and the averages of the input- and output-oriented weights in the last column of Table 4a. Among the inputs, *infrastructure* does not contribute to the efficiency calculations at all. This is true even for the regions (as shown in Table 4(b)), except for EAP after the pandemic, for which the contribution increased to 3.97 percent. This finding may result from the lack of significant proportional differences among the countries in the radial model concerning their *infrastructure*. Therefore, the *infrastructure* scores in the LPI vary among the regions, but their relative impact on efficiency is insignificant. On the contrary, *customs* plays a critical role in efficiency calculations (over 92 percent regionally), but its impact has slightly diminished after the pandemic (by 6.5 percent on average), as *logistics competence and quality* has gained importance. All the regions follow a similar pattern, as shown in Table 4b. Only NA and SA have no change in the contribution of *customs* (100 percent) from the pre- to the post-pandemic era. The change in LAC was also marginal.

A similar analysis is conducted for the outputs. Table 4a shows a notable reduction in the contribution of *international shipments*, indicating a global weakness, while *tracking and tracing* and *timeliness* have gained importance. However, by region, NA stands out from all the other regions. While the region's main strength before the pandemic was *tracking and tracing*, it became *timeliness*. While keeping up with global tendencies, the main strength of SA shifted drastically from *international shipments* to *timeliness*. This finding aligns with observations made during the pandemic. In the post-pandemic era, while the significance of competitive pricing has decreased, the close tracking of logistics transactions and the timely delivery of physical goods has become more crucial.

4.5. Inefficiency gaps: before and after

Using non-oriented, VRS SBM-Max slack analysis, Table 5 illustrates the average percentages of regional slacks that are preventing countries from reaching the efficiency frontier. Simultaneously, the slacks indicate percentage inefficiency gaps, identifying the potential improvement areas in the LPI indicators benchmarked to the best logistics performance cases and suggesting directions for enhancement in the regions.

The inefficiency gaps for *infrastructure*, *tracking and tracing*, and *timeliness*, three indicators of LPI, did not change significantly from the pre-pandemic era to the post-pandemic era globally. *Infrastructure* remains the most critical logistics indicator for potential improvement across all countries, with the highest slack percentages of 51.37 and 52.49 before and after the pandemics, respectively. It is the largest area for potential improvement for logistics performance efficiency globally. The only region in which inefficiency gaps are relatively small and *infrastructure* is not the top priority is NA, where *international shipments* rank as the primary area on which to focus. As expected, the SA and SSA regions exhibit the largest inefficiency gaps in *infrastructure*,

Table 4b. The regional change in the relative contribution of each LPI indicator to mean performance.

	Customs		Infrastructure		Logistics Competence and Quality		International Shipments		Tracking and Tracing		Timeliness	
Regions	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
East Asia & Pacific (EAP)	100.00	85.12	0.00	3.97	0.00	10.91	51.64	38.11	0.00	10.12	48.36	51.77
Europe & Central Asia (ECA)	92.06	80.68	0.00	0.00	7.94	19.32	42.58	26.30	5.26	13.45	52.16	60.25
Latin America & Caribbean (LAC)	95.46	94.95	0.00	0.00	4.54	5.05	66.07	26.26	0.00	4.64	33.93	69.10
Middle East & North Africa (MENA)	100.00	86.24	0.00	0.00	0.00	13.76	61.88	17.51	0.00	18.97	38.12	63.52
North America (NA)	100.00	100.00	0.00	0.00	0.00	0.00	0.01	0.00	99.99	46.45	0.00	53.55
South Asia (SA)	100.00	100.00	0.00	0.00	0.00	0.00	82.20	23.29	0.00	0.00	17.80	76.71
Sub-Saharan Africa (SSA)	100.00	96.01	0.00	0.00	0.00	3.99	57.84	44.91	0.00	8.01	42.16	47.08

with deficiencies in ports, airports, highways, railways, and telecommunication services. These deficiencies negatively impact the logistics operations of countries and are fundamental targets for improvement. At the regional level, inefficiency gaps in *tracking and tracing* and *timeliness* did not change significantly, except for the EAP region, which showed slight improvements by reducing the inefficiency gap in *tracking and tracing*.

As a result of the pandemic, inefficiency gaps have increased in the areas of *customs* and *international shipments*, as shown in Table 5. *Customs* experienced a significant decline due to the pandemic (7.44 percent, p-value < 0.01), and after the pandemic became the LPI indicator with the most critical inefficiency gap. This deterioration can also be observed in the EAP, ECA, LAC, and SSA regions, where statistically significant differences exist. However, it was not significant in the other regions, although there was a slight increase. This finding underscores the need to reduce clearance times and bureaucratic hurdles, and the importance of digitalising customs operations in the post-pandemic era. In Table 5, *international shipments* are another LPI indicator that has significantly worsened globally, with the inefficiency gap having increased by 3.61 percent. However, LAC is the only region that experienced a statistically significant decline in the inefficiency gap for *international shipments*. This suggests that logistics prices, which increased as a result of the pandemic, have not yet stabilised. Therefore, increased efforts are necessary to discover new initiatives to lower logistics costs for competitive pricing.

The only inefficiency gap with positive progress among the LPI indicators was *logistics competence and quality*, which improved slightly after the pandemic (3.1 percent, p-value < 0.05). However, this change was statistically significant only in the ECA region. The pandemic may accelerate enhancements in customs bureaucracy, transportation network efficiency, and logistics services. The urgent need to deliver essential goods more quickly despite limited resources could drive countries to prioritise their internal operations and identify improvement opportunities in response to the pandemic.

The findings also broaden the theoretical conversation by highlighting how dynamic capabilities and institutional preparedness shaped post-pandemic logistics resilience, moving beyond earlier assumptions of global convergence. This study contributes to the literature on logistics adaptability during extreme disruptions by pointing to an expanding performance gap between regions. This suggests the need for more context-sensitive theoretical models that consider regional and institutional differences.

4.6. Policy implications for global logistics efficiency after COVID-19

Table 6 summarises our findings from the earlier sections to give an overview of global logistics and the policy implications. The change in LPI scores between the pre- and post-pandemic eras parallels the change in the efficiencies represented by the MI. The LPI has improved, and the MI is greater than 1 globally and regionally. This behaviour for the LPI and the MI indicates not only progress in logistics performance but also progress in logistics efficiency. LAC, SA, and SSA are the regions in which no significant progress is observed in logistics performance or efficiency.

Table 6 shows that, globally and regionally, when there is statistically significant progress in the LPI and when the MI exceeds 1, the driving factor behind this change is the frontier-shift effect, as observed in EAP, ECA, and MENA as well as worldwide. The frontier-shift effect refers to changes in technology, investments in research and development, and the adoption of new technological innovation processes, leading to logistics improvements. Among these regions, EAP is the only one in which the catch-up effect is not significantly different from 1. An insignificant change in efficiency scores for CCR and SBM testifies to this. However, EAP has seen a significant increase in the *customs* inefficiency gap, as shown in Table 6. DEA models give less weight to the deteriorating indicators when assessing a region's efficiency scores. So, the weight for *customs* is reduced while the weight for *logistics competence and quality* is increased. Our analysis implies that the frontier-shift effect should be the main reason for the increasing inefficiency gap for *customs* in the EAP

Table 5. Percentage inefficiency gaps for each LPI indicator (%).

Regions	Mean (%)	Customs	Infrastructure	Logistics Competence and Quality	International Shipments	Tracking and Tracing	Timeliness
Global	Before	42.39	51.37	47.94	40.84	45.17	36.39
	After	49.83	52.49	44.84	44.45	44.49	36.69
	t-test	−5.305**	−0.815	2.533*	−2.527*	0.5	−0.241
East Asia & Pacific (EAP)	Before	27.52	37.63	35.56	30.84	33.30	27.09
	After	34.31	35.06	32.10	34.28	28.20	26.86
	t-test	−2.978***	1.026	1.343	−0.995	1.879*	0.065
Europe & Central Asia (ECA)	Before	27.89	33.99	32.50	28.66	30.33	22.70
	After	32.98	34.85	28.62	31.15	29.62	23.79
	t-test	−2.569**	−0.485	2.308**	−1.462	0.327	−0.652
Latin America & Caribbean (LAC)	Before	52.71	65.42	59.43	49.25	56.05	46.63
	After	63.85	68.08	57.65	56.77	55.89	44.92
	t-test	−3.323***	−0.837	0.995	−2.147**	0.05	0.687
Middle East & North Africa (MENA)	Before	49.11	47.91	52.33	44.12	49.30	37.92
	After	52.31	52.49	49.85	47.52	45.39	37.46
	t-test	−0.64	−0.847	0.453	−0.648	1.257	0.106
North America (NA)	Before	1.21	1.54	5.13	13.22	2.58	7.73
	After	4.68	3.85	4.44	16.89	1.83	9.02
	t-test[ξ]	-	-	-	-	-	-
South Asia (SA)	Before	60.19	79.40591	64.22	59.13	67.44	54.45
	After	61.17	85.37	60.53	65.46	76.73	49.09
	t-test[ξξ]	−0.134	−0.893	1.085	−0.614	−1.353	1.141
Sub-Saharan Africa (SSA)	Before	65.46	80.87	71.78	58.96	67.06	56.31
	After	78.70	80.45	68.63	60.69	69.49	58.99
	t-test	−3.094***	0.095	0.787	−0.401	−0.535	−0.683

*** Two-sided $p < 0.01$, ** Two-sided $p < 0.05$, * Two-sided $p < 0.1$.
[ξ]: Group size is so small to make a meaningful statistical analysis, [ξξ]: Interpret with caution due to the small group size.

region. This gap reminds us of the inadequate technological investment in *customs* and of the problem of adopting technological innovation. On the other hand, a minor improvement in *tracking and tracing* largely stems from adopting technological innovation and investing in tracking solutions in EAP.

Table 6 shows that both ECA and MENA have significant catch-up effects, with a value of less than 1, but only ECA shows deteriorating CCR and SBM efficiencies. The only notable increase in the inefficiency gap for ECA is in *customs*. The reduced weight for *customs* in Table 6 also confirms this. Therefore, the suggestion for ECA in response to the changes after the pandemic would be to enhance operational efficiencies and management techniques in *customs*. Despite the result for *customs*, the inefficiencies in *logistics competence and quality* improve in the region, mainly because of operational efficiencies and the adoption of best practices. On the other side, MENA is slightly different from ECA. The catch-up effect for the MENA region is significantly lower than 1, but the efficiency changes and inefficiency gaps before and after the pandemic are insignificant. The only sign of any deterioration is the reduced weight for *international shipments*. Therefore, these somewhat conflicting results for MENA may be explained by deviations within the characteristics of the countries and regional instabilities.

The other three regions, namely, LAC, SA, and SSA, have no improvement in their LPI scores after the pandemic, and their MI values are not significantly different from 1, demonstrating no significant change in logistics performance metrics. We may comment that technological changes and innovative solutions compensate for operational and managerial deficiencies. As one of these regions, SA has a significant frontier-shift effect but an insignificant catch-up effect of less than 1. Since the number of countries in this group is small and their differences are high, the statistical analysis may not produce precise results. The reduced weight for *international shipments* is the only sign of deterioration in regional logistics. As for MENA, researchers and regional policymakers should follow SA closely. On the other hand, LAC and SSA show identical results and tendencies. The inefficiency gaps for LAC illustrate that *customs* and *international shipments* have worsened

Table 6. Summary of the analysis results: before and after the pandemic.

		DEA-MI Model			Efficiency Changes		Weights Changes						Inefficiency Gap						
Regions	LPI	Catch-Up Effect	Frontier Shift Effect	Malmquist Index	CCR (Technical)	SBM (Slack Based)	Customs	Infrastructure	Logistics Competence & Quality	International shipments	Tracking and tracing	Timeliness	Customs	Infrastructure	Logistics Competence & Quality	International shipments	Tracking and tracing	Timeliness	Policy to Focus on
Global	↑↑↑	⤵⤵⤵	⤴⤴⤴	⤴⤴⤴	↓↓↓	↓↓↓	↘		↗	↘↘	↗	↗↗	↑↑		↓	↑			Customs, international shipments
East Asia & Pacific (EAP)	↑↑		⤴⤴⤴	⤴⤴⤴	↓		↘		↗	↘	↗		↑↑↑				↓		Innovate customs
Europe & Central Asia (ECA)	↑↑	⤵⤵⤵	⤴⤴⤴	⤴⤴	↓↓↓	↓↓↓	↘		↗	↘↘	↗	↗↗	↑↑		↓↓				Operational efficiency in customs
Latin America & Caribbean (LAC)		⤵⤵⤵	⤴⤴⤴		↓↓↓	↓↓↓				↘↘↘		↗↗↗	↑↑↑			↑↑			Customs, International shipments
Middle East & North Africa (MENA)	↑	⤵⤵⤵	⤴⤴⤴	⤴⤴			↘		↗	↘↘↘	↗↗	↗↗							Differences among countries, regional instabilities
South Asia (SA)			⤴⤴⤴			↓↓				↘↘↘		↗↗↗							Small country set, International shipments
Sub-Saharan Africa (SSA)		⤵⤵⤵	⤴⤴⤴		↓↓↓	↓↓↓				↘	↗		↑↑↑						Customs, International shipments

↑, ↗: Increase; ↓, ↘: Decrease; ⤴: >1; ⤵: <1.
↑, ↓, ⤴, ⤵: p-value < 0.1; ↑↑,↓↓, ⤴⤴, ⤵⤵: p-value < 0.05; ↑↑↑,↓↓↓, ⤴⤴⤴, ⤵⤵⤵: p-value < 0.01.
↗, ↘: >5% and <15%; ↗↗, ↘↘: >15%; ↗↗↗, ↘↘↘: >30%.

significantly, and the weight for *international shipments* has also reduced after the pandemic. For SSA, *customs* has significant inefficiency gaps. For both regions, *customs* and *international shipments* are the two primary areas in which they can enhance their capabilities through better operational practices and technological innovations.

From a policy perspective, the results suggest that investments in digitalisation, customs modernisation, and multimodal transport infrastructure are critical, particularly for underperforming regions such as Latin America, South Asia, and Sub-Saharan Africa. Institutional resilience and adaptive capabilities could significantly contribute to closing the widening global logistics performance gap and enhancing preparedness for future disruptions.

5. Conclusion

The SC problems faced during the COVID-19 pandemic brought logistics operations onto the daily agenda of ordinary people. The public has become more aware of the importance of logistics in meeting their daily needs in a timely and cost-effective manner. Along with this heightened public awareness, the pandemic has compelled countries to rethink their logistics applications and develop innovative solutions. Since each country possesses different expertise, capabilities, technological bases, and income levels, their performances also show variation. Therefore, analysing the logistics performance efficiency of countries and regions is critical for drawing conclusions about the impacts of the pandemic. To gain insights from a cross-country comparison of logistics practices before and after the pandemic, this study evaluates the logistics performance of various countries based on the LPI developed by the World Bank. Aggregated LPI indicators from 2010 to 2018, along with a recent 2023 LPI report, inform the DEA methodology used to compare logistics efficiencies across countries. The logistics governance skills of countries and the areas for improvement are analysed regionally before and after the pandemic. Our descriptive analysis indicates a statistically significant enhancement in overall logistics activities worldwide following the pandemic. A notable increase in all three input indicators, *customs*, *infrastructure*, and *logistics competence*, is observed. However, the effects of the pandemic on the output indicators vary. While *tracking and tracing* systems show significant progress, the *timeliness* of logistics activities has deteriorated after the pandemic. Ultimately, this research highlights areas requiring attention to enhance logistics performance efficiency regionally in the post-pandemic era.

5.1. Theoretical implications

The findings of this study have several theoretical implications for the field of logistics and transportation. Utilising the LPI report published in 2023, this research is among the first studies to evaluate the efficiency of logistics performance in countries by region. This study calculates the MI by examining DEA to capture the evolving influence of logistics dimensions on performance following the pandemic. Between the pre- and the post-pandemic periods, the MI indicates an average 7.9 percent increase in the logistics performance of countries worldwide based on the LPI. However, this may not be statistically general for all regions, as some, such as LAC, SA, and SSA, may still be struggling to recover from the pandemic in their logistics operations. This overall improvement is primarily attributed to a frontier-shift effect driven by technological advancements and best logistics practice, with an average 28.6 percent multiplier impact on the MI. The positive influence of technological advancements on logistics performance underscores the significance of integrating digital technologies into logistics operations. NA and MENA are the leading regions in this transformational shift. This finding aligns with the literature underlining the role of automation, AI, and data analytics in enhancing logistics efficiency (Klumpp and Ruiner 2022; Loske and Klumpp 2021). However, the catch-up effect is less than 1, indicating an average 15.9 percent decline in each country's internal efficiency in handling logistics operations independently. Our individual efficiency scores, measured both before and after the pandemic, further support this efficiency loss. However, EAP as a region may show a slightly better performance than the global averages. Thus, this approach provides a more nuanced understanding of how logistics performance evolves over time, especially in response to disruptive events like the COVID-19 pandemic, complementing past research utilising the MI (e.g. Acar and Torgalöz 2022).

Moreover, comparing countries' efficiency scores before and after the COVID-19 pandemic reveals a statistically significant decrease in post-pandemic efficiency scores. This decline is consistent across the CCR and SBM models which, respectively, indicate an average deterioration of 2.7 and 3.9 percent in the efficiency of the countries' logistics performance. However, this may not hold true for the MENA region, where the decline in efficiency scores cannot be statistically justified. MENA, with its oil-rich countries and politically and geographically strategic locations, controls crucial logistics and energy pathways. Investments in infrastructure by early technology adopter countries, such as the UAE and Saudi Arabia, may aid the region in recovering from the impacts of the pandemic (World Bank 2025).

Analysing the relative contribution of the LPI indicators to the efficiency scores highlights some shifts in the post-pandemic era. In an efficiency study like ours, an increase in contributors signifies improved areas, while a decrease indicates a field that has deteriorated. While *customs* remain crucial, *logistics competence and quality* gains significance, reflecting evolving priorities in the wake of the pandemic. In terms of output indicators, *international shipments* loses significance in its contribution to the efficiency scores. At the same time, the observations show that *tracking and tracing* and *timeliness* have become more vital after the pandemic in identifying efficiencies. In the post-pandemic era, competitive pricing may be replaced by the timely availability of goods, while *tracking and tracing* logistics for transactions and the timely delivery of physical goods may become more significant. However, the declining contribution of *international shipments* and the absence of *infrastructure* as a contributor highlight the key areas for improvement. In relation to the evolving regional capabilities and weaknesses, we should also mention the significant shift from *international shipments* to *timeliness* for SA and from *tracking and tracing* to *timeliness* for NA.

By identifying areas of substantial improvement, those with significant differences between the pre-and the post-pandemic eras, the study underscores the persistent importance of *customs* and *international shipments,* particularly in mitigating deficiencies exacerbated by the pandemic. Using the slacks to perform the SBM analysis, our findings emphasise the need for countries to address challenges in *customs* bureaucracy and *international shipments* to ensure competitive prices and efficient logistics operations. *Customs* operations were affected by the pandemic worldwide, but their efficiency significantly deteriorated in the EAP, ECA, LAC, and SSA regions. Similarly, *international shipments* have high inefficiency gaps around the world, but LAC is the only region that statistically shows further deterioration after the pandemic. Interestingly, our SBM analysis does not find any significant change in the *infrastructure* efficiency after the COVID-19 pandemic. However, among the LPI indicators the same analysis observes the highest deficiencies in *infrastructure*, both before and after the pandemic. As expected, LAC, SA, and SSA have the largest regional deficiencies. Therefore, *infrastructure* remains the primary target for improving logistics performance, regardless of the pandemic. In summary, our study identifies that it is crucial to enhance *infrastructure* as a logistics indicator, while the significance of *customs* and *international shipments* has intensified as a result of the pandemic. This supports existing theories regarding the foundational role of these elements in logistics performance (Çemberci, Civelek, and Canbolat 2015; Liu et al. 2018; Luz et al. 2016; Sumantri and Lau 2011).

By contrast, *logistics competence and quality* is the only LPI indicator that shows a slight improvement after the pandemic, reflecting the positive effects of COVID-19. Additionally, ECA is the only region in which this impact is significant. Thus, our study underscores the evolving dynamics of post-pandemic global logistics and stresses the importance of resilience and adaptation in navigating future challenges in the logistics sector. The ability to adapt to disruptions and rapidly changing conditions is essential for maintaining logistics performance and achieving competitive advantage.

Overall, our study extends the RBV outlined by Barney (1991) by demonstrating that national-level logistics infrastructure and customs procedures are critical strategic resources. While traditional RBV literature focuses on advantages at the firm level, our research illustrates how these resources translate into competitive advantages for countries in the global marketplace. As we analyse adjustments in logistics performance after COVID-19, our paper also demonstrates how dynamic capabilities at the country level are crucial for addressing external shocks swiftly. The improvements noted in logistics competence and quality highlight the necessity of flexibility and innovation. Furthermore, our study emphasises that the institutional environment – characterised by regulatory frameworks and governance structures (North 1990) – plays a crucial role in shaping logistics outcomes. The observed post-pandemic decline in customs efficiency, for example, illustrates how institutional bottlenecks can hinder performance. In summary, our paper contributes to the theory by extending the established frameworks to a national and global context, empirically validating the role of country-level critical resources and dynamic capabilities in the LPI, and integrating institutional perspectives.

5.2. Policy implications

Our study's findings also underscore the theoretical significance of policy and regulatory frameworks in shaping logistics performance. Policymakers play a vital role in fostering an enabling environment for efficient and resilient logistics operations, especially in the face of global disruptions (Golgeci, Yildiz, and Andersson 2020). To this end, the results of this cross-country comparison offer timely and invaluable guidance to policymakers in shaping logistics priorities, particularly in the aftermath of the COVID-19 pandemic. A key implication for policymakers is to prioritise investments in technology and digitalisation within their logistics operations. As the study highlights, advances in the logistics industry are driven by technological progress. Innovations in automation, AI, and data analytics have become essential tools for optimising routes, managing inventory, and enhancing overall efficiency. Therefore, policymakers should incentivise the integration of advanced technologies – such as automation, AI, and data analytics – into logistics operations. This can be accomplished through targeted tax credits, public–private partnerships, and grants designed to modernise logistics infrastructure. For example, setting up innovation hubs or technology incubators that focus on logistics solutions can assist small and medium-sized enterprises in adopting cutting-edge technologies. Additionally, governments can sponsor pilot projects that showcase the advantages of these technologies, offering concrete case studies that can be replicated at a national level.

Furthermore, the findings suggest that *customs* efficiency and *international shipments* should be improved. Streamlining customs processes and enhancing tracking capabilities can help minimise delays and bottlenecks in the SC, thereby improving overall logistics performance. Policymakers should collaborate with relevant stakeholders to craft regulatory reforms and to invest in technologies that facilitate seamless customs clearance and real-time tracking of goods. They should, for instance, encourage the adoption of electronic data interchange (EDI) systems and blockchain-based solutions to ensure the secure, transparent, and efficient processing of trade documentation. Pilot programs in ports and border crossings could serve as demonstrations for wider implementation. Furthermore, to enhance the efficiency of international shipments, policy actions should focus on both technological and regulatory reforms. For instance, policymakers might develop national frameworks that mandate the use of real-time tracking systems. Policies could require carriers to implement standardised tracking technologies, which would be integrated with centralised data platforms accessible to all stakeholders. Case studies from countries that have successfully adopted such systems can offer blueprints for wider applications. Similarly, policymakers might prioritise investments in essential infrastructure, such as dedicated logistics parks and intermodal transportation hubs, which promote smoother transitions between different transport modes. Funding mechanisms could include public–private partnerships and infrastructure bonds.

5.3. Limitations and further research areas

Despite the valuable insights from this study, several limitations deserve acknowledgment. First, the study relies on retrospective data and cross-country analysis, which may overlook nuanced variations in logistics performance. Future research could benefit from investigations into the common characteristics of different countries, such as their levels of technological advancement, competitiveness, and income, to explore the drivers of logistics efficiency over time. Examining logistics performance and resilience within a specific region could yield region-specific insights, best practices, and policy recommendations to enhance logistics efficiency.

To address the reliability of our findings, we employed several validation approaches. First, a regional breakdown analysis was conducted to capture variations in logistics efficiency across the seven regions, providing a more nuanced interpretation. Second, the Malmquist Index (MI) analysis allowed a deeper insight into performance shifts by differentiating between the frontier-shift effect and the catch-up effect. Third, we examined LPI indicator contributions and inefficiency gaps to identify key drivers for efficiency gains and persistent inefficiencies. While these validation steps strengthen our analysis, future research could expand our validation by using alternative efficiency models, such as stochastic frontier analysis, integrating firm-level logistics data, or extending the time horizon beyond 2023 when this data becomes available. Sensitivity tests with different DEA models could further assess the consistency of the efficiency rankings. These extensions would refine our understanding of logistics performance dynamics in response to global disruptions and technological advancements.

This study employs the input and output indicators of the LPI framework to gauge logistics performance. Thus, many critiques of the LPI in the literature may similarly apply to our results. The LPI may not entirely encompass all the factors contributing to superior performance in the logistics sector. Future research might broaden the metrics to include technical and social data, as well as sustainability, resilience, and customer satisfaction measures, for a more comprehensive assessment of logistics efficiency.

In addition to these limitations, the methodological approach itself warrants cautious reflection. One limitation of this study relates to the methodology of the DEA itself. While DEA models are effective at benchmarking the logistics efficiencies of countries, their accuracy depends on the extent to which their underlying assumptions are satisfied. One key assumption concerns the comparability of countries' logistics frameworks, which remains an open issue and requires cautious interpretation. In addition, DEA results are sensitive to the accuracy and quality of the input and output data, making the reliability of the country-level data a critical factor for ensuring meaningful comparisons.

Our study identifies technology as a key driver of progress in logistics over the past few decades. Therefore, exploring the adoption and impact of emerging technologies such as blockchain, the IoT, and predictive analytics on logistics efficiency in real-world settings may inform future strategies and investments. By concentrating on these areas, we can better understand the complex interplay between global events, technological breakthroughs, and logistics dynamics, which will help us create more resilient, efficient, and sustainable SCs.

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Data derived from public domain resources

The data that support the findings of this study are available at the World Bank at www.lpi.worldbank.org. These data were derived from the following resources available in the public domain: www.lpi.worldbank.org.

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