

## RESEARCH ARTICLE

# Logistics efficiency and productivity in ASEAN countries: A frontier analysis

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## ABSTRACT

This study evaluates relative logistics efficiency and productivity change across eight Association of Southeast Asian Nations (ASEAN) economies using World Bank Logistics Performance Index data for 2016, 2018, and 2023. A non-oriented Slack-Based Measure (SBM) Data Envelopment Analysis (DEA) model is used to estimate year-specific relative efficiency, while a Malmquist Productivity Index (MPI) is used to examine productivity dynamics. The results show substantial cross-country heterogeneity within the sample. Singapore consistently lies on the estimated efficiency frontier, Malaysia and Thailand remain comparatively close to the frontier, and Vietnam records improvement over the observation period. The reported productivity decomposition indicates positive productivity change for all economies in the sample, with the technological-change component exceeding the efficiency-change component. Because the analysis is based on a small comparison set and perception-based LPI indicators, the findings are interpreted as relative benchmarking evidence rather than causal estimates of the mechanisms underlying logistics development. The study contributes an applied regional comparison that combines static efficiency benchmarking with intertemporal productivity assessment and highlights the value of multidimensional performance analysis for logistics management and policy discussion in ASEAN.

## KEYWORDS

logistics efficiency; ASEAN; data envelopment analysis; Logistics Performance Index; slack-based measure; Malmquist productivity index

## ARTICLE INFORMATION

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### 1. Introduction

Global supply chains have become increasingly interconnected and disruption-prone, placing greater emphasis on the efficiency, resilience, and adaptability of national logistics systems. The ability to move goods reliably across borders depends not only on

physical transport infrastructure but also on customs performance, logistics service quality, information visibility, and institutional coordination. These capabilities influence trade costs, delivery reliability, investment attractiveness, and the capacity of supply chains to absorb and recover from disruption.

Digital transformation is also reshaping logistics performance through automation, data integration, real-time visibility, and platform-based coordination. Recent research in Logistics shows that digital technologies can strengthen supply chain performance and resilience when they are supported by appropriate organizational and institutional capabilities (Atieh et al., 2025; Banomyong et al., 2025; Riad et al., 2024). For ASEAN, where logistics systems differ markedly in infrastructure maturity and institutional capacity, the interaction between operational efficiency and technological progress is therefore especially important. Among emerging economic regions, the Association of Southeast Asian Nations (ASEAN) provides an important context for examining logistics performance. The implementation of the ASEAN Economic Community (AEC) has accelerated trade liberalization and cross-border production networks, creating stronger interdependence among member states. Nevertheless, considerable differences remain in logistics infrastructure, customs efficiency, institutional quality, and technological readiness. These disparities influence the effectiveness of regional supply chains and create uneven opportunities for economic participation and competitiveness.

National logistics capability is commonly assessed using the World Bank's Logistics Performance Index (LPI), which evaluates countries across six dimensions: customs, infrastructure, international shipments, logistics competence, tracking and tracing, and timeliness. Because the LPI provides internationally comparable indicators, it has become one of the most frequently adopted tools for benchmarking logistics performance. However, the index primarily measures performance levels rather than the efficiency with which logistics-related resources are transformed into service outcomes. Consequently, countries with similar LPI scores may exhibit substantially different levels of operational efficiency, limiting the ability of descriptive comparisons to explain why performance differences exist.

To overcome this limitation, efficiency evaluation methods provide an alternative analytical perspective. Data Envelopment Analysis (DEA) is particularly suitable for assessing systems characterized by multiple inputs and outputs because it does not require the specification of a production function. Within the DEA family, the Slack-Based Measure (SBM) model offers an important advantage by explicitly incorporating input excesses and output shortfalls into efficiency assessment. This non-radial approach enables a more detailed diagnosis of inefficiency, especially in logistics systems where weaknesses often occur in specific operational components rather than uniformly across all performance dimensions.

Although DEA has been widely applied in transportation and logistics research, relatively few studies simultaneously evaluate cross-sectional efficiency and longitudinal productivity change at the national level. Static efficiency scores alone cannot reveal whether logistics systems are improving over time or identify the underlying sources of productivity growth. Integrating the SBM model with the Malmquist Productivity Index (MPI) therefore provides a more comprehensive analytical framework by combining efficiency measurement with dynamic productivity analysis. The decomposition of productivity into efficiency change and technological change further allows the identification of whether improvements originate from better resource utilization or from shifts in the technological frontier.

ASEAN represents an appropriate empirical setting for applying this integrated framework because its member economies differ substantially in terms of economic development, logistics infrastructure, institutional capacity, and digital transformation.

Understanding these differences is important not only for benchmarking national logistics systems but also for identifying opportunities to strengthen regional supply chain integration and enhance economic resilience.

Accordingly, this study evaluates logistics efficiency and productivity dynamics across ASEAN countries using the World Bank Logistics Performance Index data for 2016, 2018, and 2023. A Slack-Based Measure Data Envelopment Analysis model is employed to estimate relative logistics efficiency, while an SBM-based Malmquist Productivity Index is used to examine changes in productivity over time. By integrating these complementary approaches, the study provides both static and dynamic perspectives on logistics performance.

This research makes three principal contributions. First, it applies a non-radial efficiency framework capable of identifying slack-specific inefficiencies that are often overlooked by conventional radial DEA models. Second, it integrates SBM efficiency analysis with Malmquist productivity decomposition, enabling a comprehensive evaluation of logistics performance across both cross-sectional and temporal dimensions. Third, by focusing on ASEAN as a heterogeneous regional logistics system, the study generates empirical evidence that contributes to logistics benchmarking, supply chain performance evaluation, and regional logistics policy.

The remainder of this paper is organized as follows. Section 2 reviews the literature related to logistics performance measurement, efficiency analysis, and productivity evaluation. Section 3 presents the research methodology and data. Section 4 reports the empirical findings. Section 5 discusses the implications of the results for logistics management and regional development. Finally, Section 6 concludes the paper and outlines directions for future research.

## **2. Literature Review**

Evaluating logistics performance has become an increasingly important research topic as countries seek to strengthen supply chain competitiveness and improve participation in global production networks. The rapid development of international trade, digital technologies, and integrated logistics services has shifted academic attention from simple performance benchmarking toward a broader understanding of efficiency, productivity, and long-term logistics capability. Consequently, contemporary logistics research increasingly combines operational performance indicators with quantitative efficiency evaluation techniques to provide more comprehensive assessments of logistics systems.

This review is organized around three interconnected themes. The first examines the relationship between logistics performance and national competitiveness. The second discusses methodological developments in efficiency measurement, particularly the application of Data Envelopment Analysis (DEA). The third reviews research on productivity dynamics using the Malmquist Productivity Index (MPI). Collectively, these research streams provide the theoretical foundation for the analytical framework adopted in this study.

### **2.1 Logistics Performance as a Driver of National Competitiveness**

Efficient logistics systems facilitate international trade by reducing transportation costs, shortening delivery times, and improving supply chain reliability. Beyond their operational role, logistics capabilities influence investment attractiveness, export competitiveness, and regional economic integration. As economies become increasingly interconnected, the effectiveness of logistics systems has emerged as an important determinant of sustainable economic growth.

The World Bank's Logistics Performance Index (LPI) has become the most widely adopted framework for evaluating national logistics capability. By measuring customs efficiency, infrastructure quality, international shipment arrangements, logistics competence, tracking and tracing, and delivery timeliness, the LPI enables meaningful comparisons across countries and time

periods. Numerous empirical studies have demonstrated positive associations between higher logistics performance and stronger trade performance, improved economic competitiveness, and enhanced supply chain resilience (Munim & Schramm, 2018; Rezaei et al., 2018).

Although the LPI provides valuable benchmarking information, its descriptive nature limits its ability to explain why countries achieve different levels of logistics performance. Nations with similar overall scores may differ considerably in their efficiency of resource utilization. Consequently, relying solely on composite performance indicators provides only a partial understanding of logistics capability and highlights the need for complementary analytical approaches that explicitly evaluate operational efficiency.

## ***2.2 Methodological Developments in Logistics Efficiency Assessment***

Growing recognition of these limitations has encouraged the application of frontier-based efficiency evaluation methods. Among these, Data Envelopment Analysis (DEA) has become one of the most widely adopted techniques because it simultaneously considers multiple inputs and outputs without requiring assumptions regarding the underlying production function.

Early logistics applications primarily employed conventional radial DEA models to compare the relative performance of logistics providers, ports, and transportation systems. While these approaches successfully identified efficient decision-making units, they implicitly assumed proportional adjustments in inputs and outputs. Such assumptions may oversimplify logistics systems, where inefficiencies often arise from isolated operational bottlenecks rather than uniform performance deficiencies.

To overcome these shortcomings, researchers increasingly employ non-radial DEA models, particularly the Slack-Based Measure (SBM). Unlike radial approaches, SBM explicitly incorporates input excesses and output shortfalls into efficiency estimation, enabling more detailed identification of operational weaknesses. Recent applications have demonstrated the advantages of SBM in evaluating logistics sustainability, port performance, and national logistics systems under complex operational conditions (Rashidi & Cullinane, 2019; Bajec & Tuljak-Suban, 2019; Liu et al., 2022). Cross-country logistics benchmarking has also benefited from bootstrap DEA approaches that improve the robustness of comparative efficiency assessment (Pan et al., 2022).

Methodological developments have continued beyond static efficiency measurement. Advanced DEA variants, including network DEA, cross-efficiency evaluation, and Super-SBM models, have expanded the analytical capability of efficiency research by capturing multidimensional interactions within logistics systems (Li et al., 2024; Kao, 2024). These developments reflect an ongoing shift toward more comprehensive and realistic efficiency assessment frameworks.

## ***2.3 Measuring Productivity Change through the Malmquist Index***

While DEA provides valuable insights into relative efficiency at a particular point in time, logistics systems continuously evolve through technological innovation, institutional reform, and infrastructure development. Static efficiency measures therefore cannot fully explain long-term performance improvement.

The Malmquist Productivity Index addresses this limitation by measuring changes in productivity between consecutive periods. Through decomposition into efficiency change and technological change, MPI enables researchers to distinguish whether productivity improvements arise from better resource utilization or from outward shifts in the production frontier (Färe et al., 1994).

Recent logistics research consistently reports that technological progress has become the dominant source of productivity growth. Investments in digital logistics platforms, intelligent transportation systems, automation, and infrastructure modernization have contributed more substantially to productivity gains than simple improvements in operational efficiency (Jiang et al., 2020; Wang

et al., 2021). Consequently, combining DEA with MPI has become an increasingly common strategy for evaluating both current efficiency and long-term development trajectories.

Furthermore, integrating SBM distance functions into Malmquist analysis provides a more robust representation of productivity dynamics because productivity decomposition remains consistent with non-radial efficiency measurement. This integrated framework is particularly appropriate for heterogeneous logistics environments where performance disparities are driven by multiple operational constraints rather than proportional inefficiencies.

## **2.4 Digital Transformation and Sustainable Logistics Development**

Recent studies increasingly recognize that logistics performance is shaped not only by physical infrastructure but also by technological capability and institutional adaptability. Digital transformation has altered logistics operations through automation, real-time information exchange, integrated platforms, and data-driven coordination. Empirical evidence indicates that digital technology, automation, and data integration can improve supply chain performance, while recent research also emphasizes the role of digital capabilities in resilience and disruption management (Atieh et al., 2025; Banomyong et al., 2025; Riad et al., 2024).

At the same time, sustainability has become an integral component of logistics management. Environmental performance, resource efficiency, and resilient logistics networks are increasingly treated as complementary objectives rather than independent policy goals. Efficiency research therefore benefits from frameworks that can identify resource-use gaps while remaining sensitive to technological and institutional change (Ibrahim, 2024).

## **2.5 Research Gap and Study Contribution**

Although previous studies have substantially advanced logistics performance evaluation, several important limitations remain. First, relatively few studies investigate ASEAN as an integrated logistics region despite considerable differences in economic development, institutional capacity, and logistics capability among member states. Second, many existing investigations examine either operational efficiency or productivity change independently, providing only a partial understanding of logistics system performance. Third, the application of non-radial DEA models integrated with dynamic productivity analysis remains relatively limited in regional logistics research.

This study addresses these limitations by combining the Slack-Based Measure model with an SBM-based Malmquist Productivity Index to evaluate logistics performance from both static and dynamic perspectives. The proposed framework enables the identification of slack-specific inefficiencies while simultaneously examining productivity evolution over time. By applying this integrated approach to ASEAN countries, the study contributes to a more comprehensive understanding of regional logistics efficiency and offers evidence that can support logistics planning, supply chain management, and regional policy formulation.

## **3. Methodology**

To investigate logistics performance across ASEAN countries, this study adopts a quantitative efficiency evaluation framework that combines static efficiency measurement with dynamic productivity analysis. The analytical design integrates the Slack-Based Measure (SBM) model within the Data Envelopment Analysis (DEA) framework and an SBM-based Malmquist Productivity Index (MPI). Together, these methods allow the assessment of both relative efficiency at a given point in time and changes in productivity across multiple observation periods.

The methodological framework was selected because national logistics systems involve multiple interrelated performance dimensions that cannot be adequately represented using conventional single-factor productivity measures. Furthermore, the

substantial diversity in economic development and logistics capability among ASEAN member states makes frontier-based efficiency analysis particularly suitable for comparative evaluation.

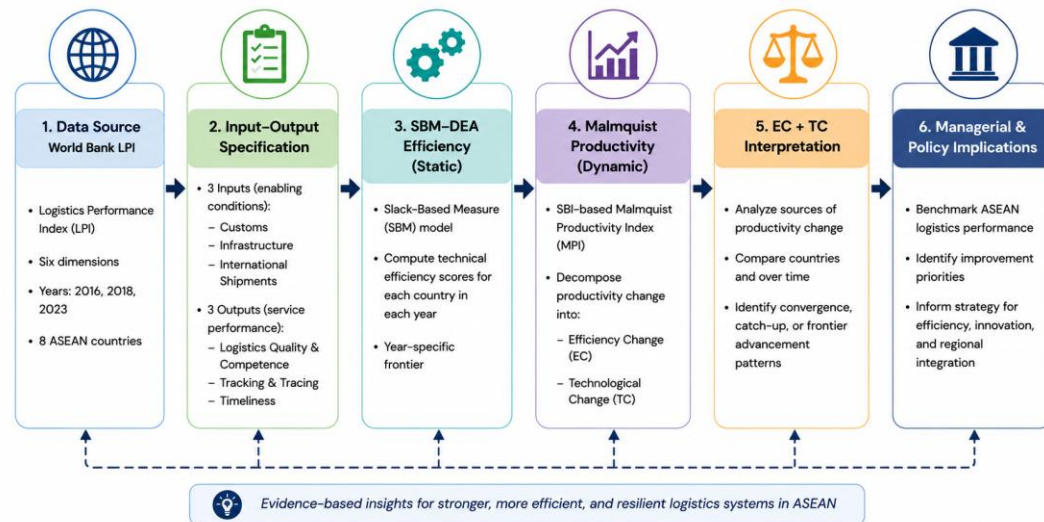


Figure 1. Analytical framework of the study.

### 3.1 Data Source and Variable Selection

The empirical analysis is based on secondary data obtained from the World Bank Logistics Performance Index (LPI) (World Bank, 2023). Observations from 2016, 2018, and 2023 were selected because they are the comparable LPI releases spanning the pre-pandemic and post-pandemic periods; the World Bank did not publish an LPI edition between 2018 and 2023. Eight ASEAN member countries with complete observations across all three releases were retained, yielding 24 country-year observations for descriptive analysis and a balanced set of eight decision-making units (DMUs) for each efficiency frontier.

The LPI evaluates national logistics capability using six dimensions that collectively represent the effectiveness of logistics services. For efficiency estimation, these indicators were classified into input and output variables according to their functional roles within logistics operations.

Variables representing resource requirements or operational constraints—including customs procedures, infrastructure, and international shipment arrangements—were treated as inputs. Indicators reflecting logistics service outcomes, namely logistics competence, tracking and tracing capability, and delivery timeliness, were specified as outputs.

Following Martí et al. (Martí et al., 2017), the three LPI dimensions of customs, infrastructure, and international shipments are treated as supply-chain enabling conditions (inputs), whereas logistics quality and competence, tracking and tracing, and timeliness represent logistics service-performance outcomes (outputs). The input indicators are transformed using the monotone decreasing expression  $(5 - \text{score})$ . This transformation converts higher LPI input scores, which denote more favorable logistics conditions, into lower input requirements consistent with the DEA principle of minimizing inputs while maximizing outputs. The transformed inputs should therefore not be interpreted as physical resource consumption; rather, they represent deficiencies or burdens in the enabling conditions of the national logistics system that are minimized relative to observed logistics service outcomes.

The selected variables are summarized in Table 1. The classification reflects the operational structure of the Logistics Performance Index and the production logic underlying DEA. Input variables represent logistics resources and operational conditions that

support service delivery, whereas output variables capture observable logistics performance. This specification enables the efficiency model to evaluate how effectively logistics capability is transformed into logistics service outcomes across ASEAN countries.

*Table 1. Input and Output Variables for DEA Model*

| DEA Variable | Indicator                      | Description                                   | Source         |
|--------------|--------------------------------|-----------------------------------------------|----------------|
| Inputs       | Customs                        | Efficiency of customs clearance               | World Bank LPI |
| Inputs       | Infrastructure                 | Quality of trade and transport infrastructure | World Bank LPI |
| Inputs       | International Shipments        | Ease of arranging international shipments     | World Bank LPI |
| Outputs      | Logistics Quality & Competence | Quality of logistics services                 | World Bank LPI |
| Outputs      | Tracking & Tracing             | Ability to track shipments                    | World Bank LPI |
| Outputs      | Timeliness                     | Frequency of on-time deliveries               | World Bank LPI |

Note: Input indicators are transformed as  $(5 - \text{LPI score})$ . Lower transformed values represent more favorable logistics enabling conditions. These constructed inputs represent deficiencies in enabling conditions rather than physical resource consumption.

Table 1 provides the foundation for the subsequent efficiency analysis. Based on this input-output specification, the study applies the Slack-Based Measure framework to estimate the relative efficiency of national logistics systems and to identify opportunities for performance improvement.

The efficiency analysis includes eight DMUs and six LPI dimensions (three inputs and three outputs), resulting in a relatively small DMU-to-variable ratio. Conventional DEA rules of thumb generally recommend a larger number of DMUs to enhance discriminatory power. These recommendations, however, are heuristic rather than necessary conditions for model estimation. The present specification is retained because the study focuses specifically on ASEAN economies with complete observations across all three LPI releases and because the six-dimensional input-output structure follows an established DEA-LPI specification. Accordingly, the resulting efficiency scores are interpreted as relative benchmarking measures within the ASEAN sample rather than as estimates of an unrestricted global logistics production frontier.

### **3.2 Robustness Analysis and DMU-to-Variable Adequacy**

Given the relatively small number of ASEAN economies included in the analysis, a sensitivity analysis was conducted to assess whether model dimensionality materially affects the resulting efficiency rankings. The baseline SBM specification contains three inputs and three outputs. Six reduced-dimensional specifications were therefore estimated by sequentially excluding one of the six LPI dimensions while retaining the conceptual input-output classification of the remaining variables. Spearman rank correlations were then calculated between the country rankings generated by each reduced specification and those obtained from the baseline model for 2016, 2018, and 2023.

This procedure is used as a robustness assessment rather than as a claim that the eight-DMU sample satisfies every conventional DEA rule of thumb. The objective is to determine whether the comparative ordering of ASEAN logistics systems is sensitive to any single LPI dimension. High rank correlations would indicate that the principal comparative conclusions remain stable when model dimensionality is reduced.

The LPI indicators are perception-based national assessments rather than directly observed physical quantities. Consequently, measurement uncertainty may affect estimated DEA frontiers, particularly with a small comparison set. In addition, the 2018–2023 interval spans the COVID-19 disruption and changes in the 2023 LPI data-collection framework. Intertemporal results should therefore be interpreted cautiously as descriptive productivity comparisons based on the published LPI releases rather than as precise causal estimates.

### 3.3 Selection of the DEA–SBM Framework

The principal objective of this research is to compare the relative logistics efficiency of ASEAN countries while considering multiple operational dimensions simultaneously. DEA is particularly appropriate for this purpose because it evaluates comparative performance without requiring assumptions regarding the functional relationship between inputs and outputs.

This characteristic is especially valuable when analysing national logistics systems. Countries often exhibit uneven development across logistics dimensions; for example, a country may possess relatively advanced transport infrastructure while simultaneously experiencing inefficient customs administration or weak logistics service capability. Because these deficiencies do not occur proportionally, a non-radial framework provides a more realistic assessment than traditional DEA models.

To evaluate logistics efficiency across ASEAN countries, this study adopts the Slack-Based Measure (SBM) model introduced by Tone (2001). Unlike traditional radial DEA models that assume proportional input contraction or output expansion, the SBM framework directly incorporates input excesses and output shortfalls (slacks) into the efficiency score. (Tone, 2001)

Let  $x_0 \in \mathbb{R}^m$  and  $y_0 \in \mathbb{R}^s$  denote the input and output vectors of the DMU under evaluation. The non-oriented SBM efficiency score is defined as follows (Tone, 2001):

$$\rho^* = \min [1 - (1/m) \sum_{i=1}^m (s_i^-/x_{i0})] / [1 + (1/s) \sum_{r=1}^s (s_r^+/y_{r0})] \quad (1)$$

subject to

$$x_0 = X\lambda + s^-, \quad y_0 = Y\lambda - s^+, \quad e^T\lambda = 1, \quad \lambda \geq 0, \quad s^- \geq 0, \quad s^+ \geq 0. \quad (2)$$

where  $X$  and  $Y$  are the input and output matrices;  $\lambda$  is the intensity vector;  $s^-$  and  $s^+$  are input and output slack vectors;  $m$  and  $s$  are the numbers of inputs and outputs, respectively; and  $e$  is a vector of ones. The VRS restriction  $e^T\lambda = 1$  is used because ASEAN economies differ substantially in scale, infrastructure endowment, and institutional development.

The key advantage of SBM lies in its non-radial nature: inefficiencies are not assumed to occur proportionally across inputs or outputs. Instead, slack-specific inefficiencies are explicitly measured. This property is particularly important in the ASEAN context, where structural imbalances (e.g., strong infrastructure but weak customs, or vice versa) are common. (Tone, 2001)

### 3.4 Measurement of Logistics Efficiency

Efficiency estimation was conducted using the non-oriented SBM model under variable returns to scale (VRS). This specification evaluates input excesses and output shortfalls simultaneously while recognising that national logistics systems operate under different economic conditions and should not be expected to exhibit identical production scales.

Each ASEAN country is treated as a decision-making unit (DMU). Efficiency scores are bounded between zero and one, where a value of one indicates that the observed logistics system lies on the efficient production frontier relative to the sample. Scores below one represent varying degrees of inefficiency, indicating opportunities for improving logistics outcomes through better utilisation of existing resources rather than simply increasing investment.

An important advantage of the SBM framework is its ability to identify the magnitude of individual input excesses and output shortfalls. Consequently, the model provides more informative diagnostic evidence than radial efficiency measures, facilitating interpretation of country-specific logistics weaknesses.

The formulation in Equations (1)–(2) follows the original SBM framework proposed by Tone (Tone, 2001).

### 3.5 Measurement of Productivity Change

Although static efficiency scores provide year-specific benchmarking information, they do not describe intertemporal productivity change. To provide a dynamic comparison, this study reports a Malmquist Productivity Index alongside the SBM efficiency analysis. The Malmquist framework measures productivity change between two consecutive observation periods by comparing distance functions estimated from the efficiency frontier. In the present study, productivity growth is decomposed into two complementary components.

1. Efficiency Change (EC) reflects the extent to which a country moves closer to or further away from the best-practice frontier.
2. Technological Change (TC) represents shifts in the frontier itself that arise from technological advancement, infrastructure development, institutional reform, or innovation.

Overall productivity improvement is indicated by MPI values exceeding unity, whereas values below one indicate productivity deterioration. By integrating SBM distance functions into the Malmquist framework, productivity decomposition remains fully consistent with the non-radial efficiency model employed throughout this research.

For two adjacent periods  $t$  and  $t+1$ , the Malmquist productivity index is defined using DEA distance functions as follows (Färe et al., 1994):

$$MPI_{0^t, t+1}^t = \{ [D_0^t(x^{t+1}, y^{t+1}) / D_0^t(x^t, y^t)] \times [D_0^{t+1}(x^{t+1}, y^{t+1}) / D_0^{t+1}(x^t, y^t)] \}^{1/2} \quad (3)$$

$$MPI = EC \times TC, \quad (4)$$

where  $MPI > 1$  indicates productivity growth,  $MPI = 1$  indicates no change, and  $MPI < 1$  indicates productivity decline.

All calculations were based on the transformed LPI variables defined in Table 1. Efficiency frontiers were estimated separately for each observation year, and the balanced country set was maintained across periods. Because the two observed transitions cover unequal calendar intervals (2016–2018 and 2018–2023), the reported productivity results should be interpreted as descriptive changes over the available LPI observation periods rather than as directly comparable annual growth rates.

### 3.6 Assumptions and Scope of Analysis

Several assumptions should be considered when interpreting the findings. First, DEA evaluates efficiency on a relative basis; therefore, efficiency scores depend on the performance of countries included in the comparison set rather than on an absolute benchmark. Second, the analysis relies on aggregate national indicators provided by the LPI, which do not capture firm-level operational differences within individual logistics sectors.

Finally, although the selected study period enables comparison across multiple survey years, the available observations remain limited. Accordingly, the results should be interpreted as evidence of comparative logistics performance rather than definitive causal relationships.

#### 4. Data and Empirical Results

The proposed analytical framework generates evidence on both the current efficiency of national logistics systems and their productivity evolution over time. The results are presented sequentially. First, descriptive statistics provide an overview of the characteristics of the logistics indicators. Second, static efficiency scores obtained from the SBM model are analysed. Finally, productivity dynamics are examined using the SBM-based Malmquist Productivity Index.

##### 4.1 Characteristics of the Logistics Indicators

Table 2 summarizes the descriptive statistics of the six Logistics Performance Index indicators used in the empirical analysis. The results reveal noticeable variation across ASEAN countries, confirming that logistics capability remains uneven throughout the region. Although the average values indicate moderate logistics performance, the observed ranges demonstrate considerable differences in customs administration, infrastructure quality, logistics services, and delivery reliability.

Among the six indicators, timeliness records the highest average value, suggesting that delivery reliability has generally improved across ASEAN. In contrast, customs efficiency exhibits the lowest average score and relatively large dispersion, implying that border procedures continue to represent one of the principal constraints on regional logistics performance. The relatively high standard deviations observed for several indicators further reflect the heterogeneous levels of economic development and institutional maturity among ASEAN member states.

These descriptive statistics support the use of efficiency analysis because simple comparisons of average performance cannot reveal how effectively individual countries transform logistics resources into service outcomes.

*Table 2. Descriptive Statistics of LPI Variables (2016–2023)*

| Variable                | Mean | Min  | Max  | Std. Dev. |
|-------------------------|------|------|------|-----------|
| Customs                 | 2.80 | 2.30 | 4.00 | 0.45      |
| Infrastructure          | 3.10 | 2.50 | 4.30 | 0.50      |
| International Shipments | 3.00 | 2.40 | 4.10 | 0.47      |
| Logistics Quality       | 3.20 | 2.60 | 4.40 | 0.52      |
| Tracking & Tracing      | 3.30 | 2.70 | 4.50 | 0.48      |
| Timeliness              | 3.50 | 2.90 | 4.60 | 0.44      |

Collectively, the descriptive statistics demonstrate sufficient variation among ASEAN countries to justify subsequent efficiency analysis.

##### 4.2 Static Logistics Efficiency

The Slack-Based Measure model was applied to estimate the relative logistics efficiency of ASEAN countries. The resulting efficiency scores are reported in Table 3.

*Table 3. SBM Efficiency Scores (VRS) by Country*

| Country     | 2016  | 2018  | 2023  | Average |
|-------------|-------|-------|-------|---------|
| Singapore   | 1.000 | 1.000 | 1.000 | 1.000   |
| Malaysia    | 0.92  | 0.94  | 0.95  | 0.94    |
| Thailand    | 0.88  | 0.90  | 0.92  | 0.90    |
| Vietnam     | 0.75  | 0.80  | 0.85  | 0.80    |
| Indonesia   | 0.70  | 0.75  | 0.78  | 0.74    |
| Philippines | 0.72  | 0.76  | 0.80  | 0.76    |
| Cambodia    | 0.55  | 0.60  | 0.62  | 0.59    |
| Lao PDR     | 0.50  | 0.55  | 0.58  | 0.54    |

Despite the relatively small comparison set, the SBM model retains discriminatory capacity within the ASEAN sample. Only Singapore attains an efficiency score of 1.000, whereas the remaining seven economies exhibit efficiency scores below unity across the observation periods. Thus, the selected specification does not produce widespread frontier saturation, although the efficiency estimates should nevertheless be interpreted cautiously given the limited number of DMUs.

The analysis reveals a clear differentiation in logistics efficiency across the region. Singapore consistently achieves an efficiency score of one throughout the observation period, indicating that its logistics system operates on the best-practice frontier relative to the sample. This outcome reflects the country's long-term investments in transport infrastructure, advanced digital logistics platforms, efficient customs administration, and highly integrated supply chain management practices.

Malaysia and Thailand constitute a second group of relatively efficient economies. Although both countries perform well, their efficiency scores remain slightly below the frontier, indicating the presence of limited operational inefficiencies. Rather than suggesting systemic weaknesses, these results imply that incremental improvements in customs procedures, intermodal coordination, and logistics service integration could further enhance overall performance.

Vietnam demonstrates a consistent upward trajectory during the study period, with efficiency improving from 0.75 in 2016 to 0.85 in 2023. This pattern suggests that recent investments in transport infrastructure, manufacturing expansion, and logistics modernization have translated into measurable improvements in operational efficiency. Compared with other emerging ASEAN economies, Vietnam appears to be narrowing the performance gap with the region's higher-performing countries.

Indonesia and the Philippines exhibit intermediate efficiency levels. Although both economies have implemented significant logistics development initiatives, the results indicate that improvements remain constrained by structural factors, including geographic fragmentation, infrastructure bottlenecks, and institutional coordination challenges. Consequently, efficiency gains have been gradual rather than substantial.

Cambodia and Lao PDR record the lowest efficiency scores throughout the study period. Their relatively weak performance is likely associated with limited transport infrastructure, lower institutional capacity, and less developed logistics service industries. These findings suggest that infrastructure investment alone may be insufficient to improve logistics performance unless accompanied by reforms that strengthen administrative efficiency and logistics capability.

Overall, the efficiency estimates indicate that logistics capability in ASEAN follows a hierarchical pattern in which highly developed economies consistently outperform emerging economies. Nevertheless, the steady improvement observed in several middle-income countries suggests that logistics reforms and infrastructure investments are gradually narrowing regional performance disparities.

To facilitate comparison among countries, Table 4 summarizes the average logistics efficiency ranking over the study period. The ranking highlights persistent differences in logistics capability while also illustrating gradual convergence among several emerging ASEAN economies. While substantial differences persist among ASEAN countries, the gradual improvement observed in several developing economies indicates that regional logistics capability is evolving, albeit at different rates. Overall, the results demonstrate that logistics performance within ASEAN is characterized by considerable heterogeneity rather than uniform regional development.

Table 4. Average Efficiency Ranking

| Rank | Country     | Avg Efficiency |
|------|-------------|----------------|
| 1    | Singapore   | 1.000          |
| 2    | Malaysia    | 0.94           |
| 3    | Thailand    | 0.90           |
| 4    | Vietnam     | 0.80           |
| 5    | Philippines | 0.76           |
| 6    | Indonesia   | 0.74           |
| 7    | Cambodia    | 0.59           |
| 8    | Lao PDR     | 0.54           |

#### 4.3 Robustness of Efficiency Rankings

To evaluate whether the relatively small DMU-to-variable ratio materially affects the comparative results, the baseline efficiency rankings were compared with rankings obtained from six leave-one-variable-out specifications. Table 5 reports the Spearman rank correlations. Across all 18 year-specification comparisons, the coefficients range from 0.976 to 1.000, indicating exceptionally high rank stability. Excluding Customs or Timeliness produces an identical country ordering in all three years, while even the lowest observed correlation remains 0.976.

These results indicate that the relative ordering of ASEAN logistics systems is not driven by any single LPI dimension and remains highly stable when model dimensionality is reduced. The sensitivity analysis therefore provides additional support for retaining the theoretically grounded three-input/three-output specification. Nevertheless, because DEA efficiency scores are sample dependent, the results should continue to be interpreted as relative ASEAN benchmarking measures rather than as estimates of a universal logistics production frontier.

Table 5. Robustness Analysis Based on Spearman Rank Correlations

| Excluded LPI Dimension           | 2016  | 2018  | 2023  | Mean  |
|----------------------------------|-------|-------|-------|-------|
| Customs                          | 1.000 | 1.000 | 1.000 | 1.000 |
| Infrastructure                   | 1.000 | 0.976 | 1.000 | 0.992 |
| International Shipments          | 0.976 | 0.976 | 0.976 | 0.976 |
| Logistics Quality and Competence | 1.000 | 0.976 | 1.000 | 0.992 |
| Tracking and Tracing             | 0.976 | 1.000 | 0.976 | 0.984 |
| Timeliness                       | 1.000 | 1.000 | 1.000 | 1.000 |

Note: Values are Spearman rank correlations between the baseline three-input/three-output SBM ranking and the ranking obtained after excluding the indicated LPI dimension. Values close to 1 indicate strong rank stability.

#### 4.4 Productivity Dynamics

Static efficiency analysis provides only a partial view of logistics system performance because it does not capture changes over time. To examine long-term development, the SBM-based Malmquist Productivity Index was employed, with the results reported in Table 6.

Table 6. Malmquist Productivity Index (MPI) Decomposition

| Country     | EC (Efficiency Change) | TC (Technological Change) | MPI  |
|-------------|------------------------|---------------------------|------|
| Singapore   | 1.00                   | 1.05                      | 1.05 |
| Malaysia    | 1.02                   | 1.06                      | 1.08 |
| Thailand    | 1.01                   | 1.07                      | 1.08 |
| Vietnam     | 1.05                   | 1.08                      | 1.13 |
| Indonesia   | 1.04                   | 1.06                      | 1.10 |
| Philippines | 1.03                   | 1.07                      | 1.10 |
| Cambodia    | 1.02                   | 1.05                      | 1.07 |
| Lao PDR     | 1.01                   | 1.04                      | 1.05 |

Overall, the estimated MPI values indicate that most ASEAN countries experienced positive productivity growth during the study period. However, the decomposition of productivity change reveals that technological progress consistently contributes more strongly than improvements in technical efficiency. This finding suggests that productivity gains have primarily resulted from advancements in logistics technology, infrastructure modernization, digital transformation, and institutional innovation rather than from improvements in the utilization of existing logistics resources.

The distinction between technological change and efficiency change is particularly important for understanding regional logistics development. Countries can achieve productivity growth by adopting more advanced logistics systems even when operational inefficiencies remain. Consequently, outward shifts in the production frontier do not necessarily imply that less efficient economies are converging toward best-practice performance.

Vietnam's MPI value of 1.13 indicates a notable example of this pattern. The country exhibits both positive efficiency improvement and relatively strong technological progress, indicating simultaneous enhancement of operational capability and modernization of logistics infrastructure. In contrast, economies with modest efficiency gains but stronger technological change appear to benefit primarily from investment-led improvements rather than more effective resource utilization.

From a regional perspective, these findings suggest that ASEAN logistics development is increasingly driven by innovation and technological upgrading. Nevertheless, the persistence of efficiency disparities indicates that modernization alone cannot eliminate structural differences among member states. Continued improvements in institutional quality, customs administration, and logistics management remain essential if lower-performing countries are to narrow the efficiency gap.

Collectively, the MPI results indicate that sustained productivity improvement in ASEAN depends not only on technological advancement but also on continued efforts to improve operational efficiency and institutional effectiveness.

## 5. Discussion and Implications

As shown in Tables 3–6, the empirical findings provide a broader understanding of how logistics systems evolve within a region characterized by diverse levels of economic development and institutional capacity. Rather than demonstrating a uniform pattern of improvement, the analysis reveals that ASEAN countries follow different trajectories of logistics development. These differences are reflected not only in current efficiency levels but also in the mechanisms through which productivity improves over time.

### 5.1 Implications for Logistics Efficiency Research

A key contribution of this study is the application of the Slack-Based Measure framework to national logistics systems. Unlike conventional DEA models that assume proportional adjustments, the SBM approach identifies inefficiencies associated with

specific logistics components. This distinction is particularly relevant for ASEAN, where logistics capability is shaped by uneven development across customs administration, transport infrastructure, logistics competence, and service reliability.

The results demonstrate that countries with comparable overall logistics performance may exhibit very different patterns of resource utilization. Consequently, logistics benchmarking should extend beyond aggregate performance indicators and incorporate efficiency analysis capable of identifying operational bottlenecks. The findings therefore support recent developments in logistics performance research that advocate more disaggregated and diagnostic approaches to efficiency evaluation.

### **5.2 Understanding Productivity Growth**

The decomposition of the Malmquist Productivity Index provides additional insight into the sources of logistics improvement. Across most ASEAN countries, technological change contributes more substantially to productivity growth than improvements in operational efficiency. This suggests that recent gains have been driven primarily by investments in infrastructure modernization, digital logistics technologies, and institutional innovation rather than by more efficient use of existing logistics resources.

This distinction is important because technological progress alone does not guarantee convergence among countries. Economies operating below the efficiency frontier may continue to benefit from innovation while maintaining relatively large efficiency gaps. From a regional perspective, sustained productivity growth therefore requires not only continued investment in logistics technology but also improvements in governance, organizational capability, and operational management.

### **5.3 Managerial Implications**

The findings provide several practical implications for logistics managers and supply chain practitioners. First, efficiency improvement should focus on the specific logistics activities that constrain overall system performance instead of adopting broad resource expansion strategies. Investments directed toward customs modernization, digital information exchange, and inter-organizational coordination are likely to generate greater performance improvements than generalized infrastructure expenditure. Second, the results highlight the strategic importance of technological and digital upgrading. Because technological change contributes more strongly to productivity growth than efficiency change in the MPI decomposition, investments in interoperable information systems, electronic customs, real-time shipment visibility, and data integration may help shift the logistics frontier outward. However, recent evidence also cautions that digital technologies create value when accompanied by organizational readiness, coordination, and resilience capabilities (Atieh et al., 2025; Banomyong et al., 2025; Riad et al., 2024).

Finally, benchmarking against high-performing logistics systems can assist organizations and policymakers in identifying effective operational practices. Singapore's frontier efficiency score (Table 3) demonstrates how coordinated investment in infrastructure, institutional quality, and digital logistics can create sustained competitive advantages.

### **5.4 Policy Implications**

At the policy level, the analysis suggests that reducing logistics disparities across ASEAN requires a combination of physical investment and institutional reform. While infrastructure development remains an essential prerequisite for efficient logistics operations, complementary improvements in customs administration, regulatory harmonization, and digital governance are equally important.

The findings also reinforce the importance of regional cooperation. Greater alignment of customs procedures, cross-border information systems, and logistics regulations would facilitate smoother trade flows and improve supply chain resilience

throughout ASEAN. Rather than focusing solely on national competitiveness, policymakers should consider logistics development as a regional strategy that enhances the collective performance of the ASEAN economic community.

## **6. Conclusions**

This study developed an integrated framework for evaluating logistics performance by combining Slack-Based Measure Data Envelopment Analysis with the Malmquist Productivity Index. Applying this framework to ASEAN countries enabled the simultaneous assessment of relative logistics efficiency and productivity dynamics over time, providing a more comprehensive perspective than conventional benchmarking approaches based solely on logistics performance indicators.

The findings demonstrate considerable variation in logistics efficiency among ASEAN member states. Singapore consistently defines the efficiency frontier, whereas several developing economies continue to experience operational inefficiencies associated with infrastructure constraints, institutional limitations, and uneven logistics capability. These results indicate that similar logistics performance levels do not necessarily imply comparable efficiency in resource utilization.

The productivity analysis further reveals that technological progress has been the principal driver of logistics improvement throughout the region. Although many countries experienced positive productivity growth, advances were primarily associated with frontier expansion resulting from modernization and digital transformation rather than convergence toward best-practice efficiency. This distinction suggests that continued investment in technology should be accompanied by efforts to strengthen managerial capability, institutional quality, and operational effectiveness if regional disparities are to be reduced.

From a methodological perspective, the study demonstrates the value of integrating non-radial efficiency measurement with dynamic productivity analysis. The combined SBM–MPI framework provides richer diagnostic information than either method alone by simultaneously identifying operational inefficiencies and explaining the sources of productivity change. Consequently, the proposed approach offers a useful analytical framework for future logistics efficiency studies conducted at national or regional levels.

The study also contributes practical insights for policymakers and logistics practitioners. Efficiency improvement should emphasize targeted interventions addressing specific operational bottlenecks, while regional cooperation should focus on customs harmonization, digital connectivity, and institutional coordination. Such initiatives are likely to strengthen supply chain resilience and improve the overall competitiveness of ASEAN logistics systems.

Several limitations should be acknowledged. The analysis relies on aggregate national indicators provided by the World Bank Logistics Performance Index and therefore cannot capture variations among industries or firms within individual countries. A further limitation concerns the relatively small number of DMUs compared with the dimensionality of the DEA model. Although the selected specification preserves the established six-dimensional LPI structure and the sensitivity analysis shows very high rank stability across reduced-dimensional specifications, the limited comparison set may still affect frontier stability and the magnitude of individual efficiency scores. The estimates should therefore be interpreted as relative ASEAN benchmarking results rather than universally generalizable efficiency measures. Future studies may extend the comparison set to a broader group of economies and employ bootstrap DEA, alternative frontier specifications, dimensionality-reduction procedures, network or dynamic DEA models, and firm-level logistics data to further assess robustness and external validity.

Overall, this study demonstrates that combining efficiency analysis with productivity measurement provides a more informative understanding of logistics system performance than descriptive benchmarking alone. The proposed framework contributes to

both logistics management research and evidence-based policy development by offering a systematic approach for evaluating logistics capability in heterogeneous regional environments.

More broadly, the integrated SBM–MPI framework provides a transferable decision-support approach for governments and logistics practitioners seeking to benchmark national logistics systems, distinguish operational catch-up from technological frontier shifts, and prioritize interventions that strengthen digital connectivity, supply chain resilience, and regional logistics competitiveness.

### Author Contributions

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### Data Availability Statement

The data used in this study are derived from the World Bank Logistics Performance Index (LPI), which is publicly available at: <https://lpi.worldbank.org/>

### Conflicts of Interest

The authors declare no conflict of interest.

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