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Determinants of technical efficiency in the ASEAN manufacturing industry

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ABSTRACT

This study investigates the determinants of technical efficiency in the manufacturing sector across six ASEAN economies Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam over the period 2000–2022. The purpose is to assess cross-country variations in efficiency performance and identify key macroeconomic and demographic drivers that shape long-term productivity. The analysis adopts a two-stage framework that combines Data Envelopment Analysis (DEA) with Tobit regression. The DEA results reveal substantial heterogeneity, with Singapore consistently achieving the highest efficiency, while Vietnam persistently lagged behind. Although an overall upward trend is observed, efficiency in Indonesia, Thailand, and Vietnam declined notably after the COVID-19 pandemic, reflecting the sector's vulnerability to external shocks. The Tobit regression results show that foreign direct investment (FDI) is a significant positive determinant, with a 1% increase in FDI inflows enhancing efficiency by 0.44%. In contrast, macroeconomic instability and demographic pressures undermine performance, as a 1% rise in inflation reduces efficiency by 1.14%, and a 1% increase in the elderly population share decreases efficiency by 2.88%. These findings highlight the importance of policies that promote sustained FDI inflows, stabilize inflation, and address aging through labor market reforms and productivity-enhancing measures. Strengthening manufacturing efficiency is essential for sustaining long-term growth, boosting global competitiveness, and advancing ASEAN's regional integration agenda.

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JEL Classification:
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Contribution/ Originality: This study employs a DEA approach to estimate the technical efficiency of the ASEAN manufacturing industry from 2000 to 2022, and Tobit regression is used to assess the determinants of technical efficiency. The results demonstrate that foreign direct investment enhances efficiency, while inflation hampers the efficiency of the ASEAN manufacturing industry over the study period.

1. INTRODUCTION

The manufacturing sector occupies a pivotal position in economic development by enhancing productivity, promoting industrial diversification, and creating employment opportunities. In developing economies, it functions as a critical driver of structural transformation and sustainable growth, helping to reduce reliance on volatile primary sectors. Within the ASEAN region, manufacturing accounts for approximately 5% of global manufacturing value added and represents a major pillar of gross domestic product (GDP) for most member states. From 1991 to 2020, it consistently ranked as the second-largest contributor to ASEAN's GDP, with particularly strong performance in subsectors such as chemicals, food and beverages, metals, and motor vehicles.

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Table 1. Average annual GDP share of manufacturing in ASEAN member countries, 1991–2010.

Countries	Average Annual Share Contribution		
	1991-2000	2001-2010	2011-2020
ASEAN	21.62	23.77	21.28
Brunei	16.41	16.06	14.33
Malaysia	25.98	26.75	22.60
Singapore	25.35	25.20	19.97
Indonesia	19.58	22.79	21.13
Thailand	26.77	29.67	27.15
Vietnam	9.42	15.23	16.20
Philippine	25.63	23.75	19.84
Myanmar	7.16	7.43	7.04
Cambodia	11.15	17.95	16.85
Lao PDR	8.40	9.77	8.36

Source: Asian Productivity Organization (APO) (2023).

Table 1 shows that the average annual GDP share of manufacturing in ASEAN member countries was uneven. The manufacturing contribution towards GDP rose from 21.62% in 1991–2000 to 23.77% in 2001–2010 before declining to 21.28% in 2011–2020. This slowdown coincided with global supply chain disruptions, most notably during the COVID-19 pandemic. Historical growth patterns in Figure 1 further reveal frequent volatility, with sharp contractions in the growth rate of the ASEAN manufacturing industry's output during the 1998 Asian Financial Crisis, the 2009 Global Financial Crisis, and the 2020 pandemic. Moreover, structural challenges such as labour-intensive production methods, slow adoption of advanced technologies, and limited innovation capacity have constrained productivity gains.

Previous studies, including Tan (2006), Vu (2016), and Yasin (2022), have investigated manufacturing efficiency at the firm or national level, highlighting foreign direct investment (FDI), export orientation, and technological change as key drivers. However, limited attention has been given to the influence of broader macroeconomic factors such as inflation, demographic shifts, and trade openness on manufacturing efficiency within the ASEAN context over the long term.

This study seeks to address this gap by evaluating the technical efficiency of the manufacturing sector in six ASEAN economies, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam, over the period 2000 to 2022. Technical efficiency scores are estimated through Data Envelopment Analysis (DEA), while Tobit regression is employed to identify the principal determinants. The findings are expected to offer evidence-based insights to inform industrial policy, particularly with regard to attracting FDI, promoting macroeconomic stability, and addressing demographic challenges.

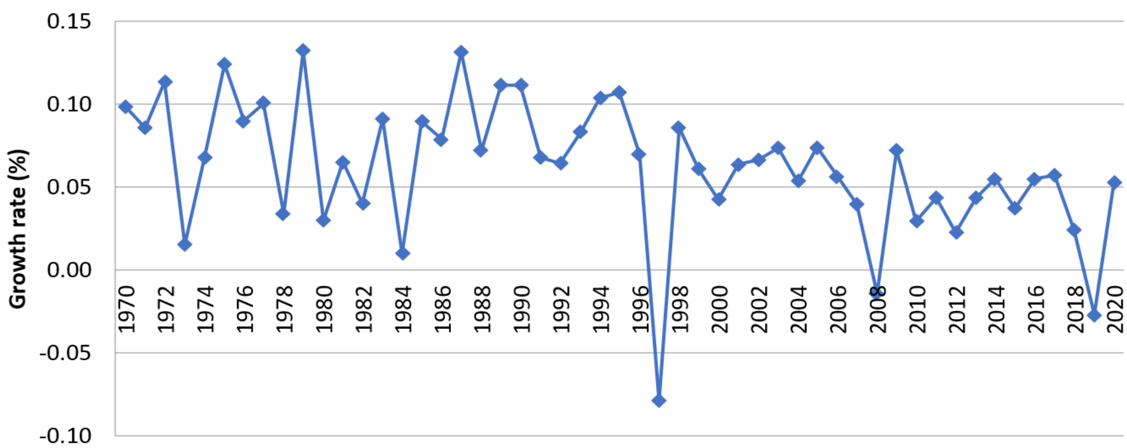

Figure 1. Growth rate of the output of the manufacturing industry in ASEAN (1970-2021).

Source: Asian Productivity Organization (APO) (2023).

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There are two main motivations for this study:

i) Slowing productivity and declining contribution of manufacturing to GDP in ASEAN.

The average growth rate of manufacturing output in ASEAN has consistently decreased over the past three decades, falling behind other Asian economies such as Taiwan, India, and Saudi Arabia. Similarly, the contribution of manufacturing to GDP has shifted from positive growth in the 1990s to negative growth in the 2000s and 2010s. This indicates both productivity and efficiency in ASEAN's manufacturing sector are weakening, justifying deeper investigation.

ii) Lack of cross-country efficiency studies in ASEAN manufacturing

Past studies tended to focus on single-country cases (e.g., Malaysia, Indonesia, Vietnam, Singapore, Philippines, Thailand), while comparative cross-country studies, particularly between developed ASEAN economies (e.g., Singapore) and less developed ones (e.g., Vietnam), are scarce. Furthermore, most studies confine analysis to the determinants of technical efficiency rather than addressing both technical efficiency and scale efficiency. This creates a gap that the current study aims to fill.

By employing a two-stage analysis, the data envelopment analysis method is used to estimate the efficiency of the ASEAN manufacturing industry, while Tobit regression is applied to identify the determinants of efficiency. The next section presents a review of past studies, both theoretical and empirical, followed by the methodology section. Subsequently, the results and analysis are discussed, and finally, the study concludes with key findings and policy implications.

2. LITERATURE REVIEW

2.1. Production Function and Efficiency Measurement

The Cobb–Douglas production function (Cobb & Douglas, 1928) has been widely used to describe the relationship between output and the primary inputs of labour and capital. Efficiency analysis builds on this framework by assessing how effectively inputs are transformed into outputs relative to a best-practice frontier. Data Envelopment Analysis (DEA) (Banker, Charnes, & Cooper, 1984; Charnes, Cooper, & Rhodes, 1978) is a non-parametric approach that allows the estimation of technical efficiency without assuming a specific functional form, making it particularly suited for cross-country productivity comparisons. The Cobb–Douglas production function is expressed as:

$Y = A L^\alpha K^\beta$

Where:

- Y = Total production.
- L = Labour input.
- K = Capital input.
- A = Technology factor.
- α and β = Output elasticities of labour and capital, respectively.

This framework has been widely applied in productivity and efficiency studies, including those focused on the manufacturing sector.

2.2. Empirical Evidence on Manufacturing Efficiency

A substantial and expanding body of literature employs stochastic frontier analysis (SFA) and meta-frontier frameworks to estimate technical efficiency (TE) in manufacturing and to decompose inefficiency into technology-gap and firm-level components (Karakaya & Bilgin, 2016; Nguyen, Le, Cai, & Simioni, 2021; Zhou, Ang, & Wang, 2013). Using a large firm-level panel with a meta-frontier SFA, Nguyen et al. (2021) report that Vietnamese manufacturing firms operated, on average, at only 52% of the meta-frontier, implying that nearly half of the potential output was lost to inefficiency. Further demonstrate that ownership structure plays a decisive role in explaining efficiency differentials among small and medium-sized manufacturing enterprises in Vietnam. Their stochastic meta-

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frontier analysis revealed significant technology gaps between state-owned and non-state-owned firms, with the latter often operating closer to the frontier.

Evidence from Indonesian manufacturing also underscores cross-country differences. Astanto, Suyanto, Santoso, and Salim (2022) find an average TE of 88% among Indonesian firms, suggesting much closer proximity to the frontier, while highlighting heterogeneity across industries and firm clusters within a single country. Karakaya and Bilgin (2016), applying stochastic meta-frontier methods to Turkish manufacturing subsectors shows that scale effects are important: subsectors with larger average firm sizes achieved higher efficiency, whereas smaller subsectors exhibited more pronounced technology gaps. Similarly, Zhou et al. (2013) analyse provincial technology gaps in China and find that regional disparities in technology levels translate into significant differences in TE, underscoring the importance of regional heterogeneity in technological capabilities.

Extending the scope to a long time span, Navarro-Chávez (2025) employ a translog SFA of manufacturing value-added from 1984 to 2022 for Canada, Mexico, and the United States, estimating an aggregate TE of 0.882. Within this group, Mexico (0.769) outperformed Canada (0.752) and the United States (0.670), suggesting that structural factors and technology adoption vary considerably even among high-income economies. Complementing these findings, González-Blanco et al. (2024) identify human-capital quality, capital intensity, and digital adoption as significant positive determinants of TE, reinforcing the view that both structural and technological drivers critically shape efficiency outcomes.

2.3. Determinants of Technical Efficiency

Although foreign direct investment (FDI) is consistently identified as a positive driver of efficiency (Sari, Restikasari, Ajija, Islamia, & Muchtar, 2021), the magnitude of its effect differs across contexts. For instance, Vu (2016) documented substantial gains among Vietnamese FDI firms, whereas Yasin (2022) reported more modest improvements in Indonesia, reflecting variations in absorptive capacity. Sur and Nandy (2018) further argued that FDI-induced efficiency gains depend not only on passive competitive pressures or general information spillovers but also on supplier development, upgrades in absorptive capacity including skills and quality systems and stronger linkages between foreign-owned and domestic firms.

Demographic factors also demonstrate heterogeneous effects. Osathanunkul, Dumrong, Yamaka, and Maneejuk (2023) found significant negative impacts of population aging in ASEAN+3 economies, while Saiyut, Bunyasiri, Sirisupluxana, and Mahathanaseth (2019) observed that age structure influenced agricultural efficiency in Thailand in a different manner, highlighting sector-specific variations in labour intensity. Similarly, Pathak, Leu, Robertson, and Siriwardana (2024) showed that trade liberalization positively influenced technical efficiency in Nepal's manufacturing sector, although the effect lost statistical significance once additional factors were incorporated in a stochastic frontier framework.

Macroeconomic instability emerges as another critical determinant. Maji, Laha, and Sur (2020), using SFA and Tobit regression, it was reported that inflation exerted significant negative effects on technical efficiency in several Indian subsectors, including auto parts, electrical equipment, pharmaceuticals, biotechnology, and textiles. Tarkom and Ujah (2023) further argued that price instability depresses efficiency by increasing input-cost volatility, shortening planning horizons, and delaying process upgrades. Large-panel evidence indicates that inflation reduces efficiency, while high interest rates further constrain performance by raising the cost of working capital and capital expenditure, with these effects amplified under conditions of heightened policy uncertainty.

Despite these insights, longitudinal research examining the joint influence of FDI, demographic change, trade openness, and macroeconomic instability on manufacturing efficiency across ASEAN economies remains limited. This study addresses this gap by applying Data Envelopment Analysis (DEA) to measure efficiency and Tobit regression to identify macroeconomic and demographic determinants over the period 2000–2022.

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3. EMPIRICAL METHODOLOGY

3.1. Data and Variables

The study covers six ASEAN economies: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam over the period 2000–2022. Data were obtained from the United Nations Industrial Development Organization (UNIDO), the United Nations Population Division, and the World Bank. All monetary variables, including manufacturing GDP, gross capital formation, foreign direct investment (FDI), and government spending, were converted into constant 2015 US dollars using World Bank deflators. This adjustment removes price effects and ensures comparability across countries and over time. Employment (measured as the number of workers in manufacturing industries) and demographic indicators (the share of the population aged 65 years and above) were retained in their natural units. Importantly, the dataset is a balanced panel with no missing observations, which enhances the robustness of the DEA and Tobit regression analyses.

The description of the variables used is shown in Table 2:

Table 2. Description of variables.

No.	Variable type	Variables	Definition /Formula	Source
1	Output variable	Manufacturing GDP, GDP	Manufacturing output at current prices for the entire economy, adjusted by the Asian Productivity Organization.	Alcalá-Ordóñez, Alcalá-Olid, and Cárdenas-García (2023); Mujaddad and Ahmad (2016); Tan (2006) and Söderbom and Teal (2004)
2	Input variables	Labour employment in manufacturing, EMP	Number of employees in manufacturing industries	Savović and Mimović (2022); Mujaddad and Ahmad (2016); Tan (2006) and Söderbom and Teal (2004)
		Gross capital formation, CAP	Investment in physical assets such as machinery, equipment, buildings, and infrastructure.	Amornkitvikai and Pholphirul (2023)
2	Determinants	Trade openness (TOs)	The sum of imports and exports divided by the total GDP of the country.	Zhu (2022), Bhaumik (2022), and Sun, Hone, and Doucouliago (1999)
		Foreign Direct Investment (FDI)	The net value of inflow foreign direct investment to the recipient country in US$	Bhaumik (2022) and Liu and Zou (2013)
		Inflation (INF)	Measured by the consumer price index, which reflects the change in the annual percentage cost to the average consumer for acquiring a basket of goods and services that may be fixed or changed at a specified interval. The Laspeyres formula is used in the study.	Helmy (2022), Kumar, Webber, and Perry (2011), and Freeman and Yerger (2000)
		Population age 65 years and above, 65Y	The percentage of people aged 65 years and older in the total population.	Saiyut et al. (2019)
		Government spending, GOV	The general government final consumption expenditure includes all government current expenditures for purchasing goods and services.	Auci, Castellucci, and Coromaldi (2021)

3.2. Stage 1: Measuring Technical Efficiency

Technical efficiency scores were estimated using output-oriented DEA under variable returns to scale (Banker et al., 1984). This approach benchmarks each country against the most efficient peers in the sample, producing scores between 0 and 1, where 1 indicates full efficiency. The formula for measuring technical efficiency is shown in Equation 1:

$$max\, \theta \qquad (1)$$

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Subject to:

$Y\lambda \geq y_0$

$\theta X\lambda \leq x_0$

$\lambda \geq 0$

Where:

- X, Y is input and output matrices for all DMUs.
- x_0, y_0 are the inputs and outputs of the DMU being evaluated.
- $\lambda$are weights assigned to peer DMUs.
- θ is efficiency score $(0 \leq \theta \leq 1)$.

3.3. Stage 2: Determinants of Efficiency

In the second stage, DEA efficiency scores were regressed on the selected determinants using the Tobit model (Tobin, 1958), which accounts for the bounded nature of the dependent variable. For Tobit panel regression model analysis, the complete empirical equations are shown below:

$$EFF_{it}^{*} = \beta_0 + \beta_1 INF_{it} + \beta_2 TO_{it} + \beta_3 FDI_{it} + \beta_4 65Y_{it} + \beta_5 GOV_{it} + \alpha_1 + \epsilon_{it} \quad (2)$$

Where by:

- EFF_{it}^{*} = Latent efficiency score of manufacturing industry for ASEAN country i at time t.
- EFF_{it}= Observed efficiency = Max (0, min (EFF_{it}^{*}, 1)).
- INF, TO, FDI, 65Y, GOV = Explanatory variables affecting efficiency of the manufacturing.
- α_i = Country–specific unobserved effect (Fixed/random).
- $\epsilon_{it} \sim N(0, \sigma^2)$ = Error term.

3.4. Multicollinearity Test

Multicollinearity arises when independent variables in a multiple regression model exhibit near-linear dependencies, indicated by high intercorrelations. This condition undermines the statistical analysis by inflating the standard errors of the regression coefficients, which in turn reduces the likelihood of these coefficients being deemed statistically significant. The Variance Inflation Factor (VIF) is a standard diagnostic tool for detecting and quantifying the severity of multicollinearity (Puthanpura, 2024).

Table 3. Multicollinearity test on the determinant factors.

Determinants	Collinearity Tolerance	Statistic VIF
Inflation	0.836	1.197
Population ages 65 and above	0.478	2.092
Trade openness	0.355	2.816
Foreign direct investment	0.495	2.020
Government spending	0.446	2.241

4. RESULTS AND DISCUSSION

4.1. Multicollinearity Test

As presented in Table 3, the Variance Inflation Factor (VIF) values for all independent variables are below the common threshold of 10 (Cohen, Cohen, West, & Aiken, 2003; Hair, Black, Babin, Anderson, & Tatham, 2006; Jeng, 2023), indicating no significant multicollinearity. This conclusion is further supported by tolerance values, all of which exceed 0.1, a standard below which multicollinearity becomes a concern (Kyriazos & Poga, 2023). Therefore, the regression model is free from detrimental multicollinearity among its determinants.

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4.2. Technical Efficiency Trend

DEA results in Table 4 and Figure 2 indicate substantial variation in manufacturing technical efficiency (TE) across the six ASEAN economies from 2000–2022. Singapore consistently achieved the highest TE scores, reaching full efficiency (1.000) in multiple years. Vietnam, in contrast, recorded the lowest average TE (0.4245), with a declining trend over the study period.

Malaysia and the Philippines demonstrated gradual improvement, while Indonesia and Thailand experienced fluctuations, particularly during global economic shocks. Notably, TE in Indonesia fell from an average of 0.5541 (2000–2009) to 0.4696 (2010–2019), before recovering slightly in 2020–2022. The COVID-19 pandemic had uneven impacts: Singapore, Malaysia, and the Philippines maintained or improved efficiency, whereas Indonesia, Thailand, and Vietnam faced declines.

Table 4. Technical efficiency of the manufacturing industry in selected ASEAN countries, 2000–2022.

Years	Technical efficiency					
	Indonesia	Malaysia	Philippine	Singapore	Thailand	Vietnam
2000	0.6538	0.4279	0.7651	0.4580	0.4770	0.5987
2001	0.6056	0.4742	0.6423	0.6202	0.4719	0.5278
2002	0.6422	0.4886	0.5962	0.6525	0.4644	0.4732
2003	0.5395	0.5125	0.6344	0.8949	0.4375	0.4400
2004	0.5667	0.5231	0.6183	0.6607	0.4244	0.4392
2005	0.5473	0.5606	0.6807	0.7074	0.3800	0.4390
2006	0.5281	0.5563	0.8059	0.6940	0.4160	0.4131
2007	0.5370	0.5860	0.8244	0.7379	0.4389	0.3586
2008	0.4697	0.6608	0.6950	0.6679	0.4122	0.4109
2009	0.4510	0.7759	0.8123	0.7482	0.5289	0.4138
2010	0.4449	0.6483	0.6872	0.7322	0.4534	0.4305
2011	0.4529	0.6508	0.6841	0.8020	0.4548	0.4553
2012	0.4413	0.6130	0.7350	0.7557	0.4595	0.4515
2013	0.4705	0.6178	0.7301	0.7989	0.4532	0.4492
2014	0.4678	0.6382	0.7435	0.8061	0.5051	0.4536
2015	0.4745	0.6684	0.7644	0.9187	0.5438	0.4153
2016	0.4884	0.6704	0.6991	0.9188	0.5775	0.4095
2017	0.4877	0.6789	0.7006	0.8530	0.5550	0.3822
2018	0.4794	0.7305	0.6868	0.8797	0.5184	0.3741
2019	0.4885	0.8063	0.7289	0.9128	0.5684	0.3676
2020	0.5091	0.8203	1.0000	0.9678	0.5668	0.3670
2021	0.5252	0.7345	0.8979	1.0000	0.4683	0.3462
2022	0.5651	0.7105	0.8156	1.0000	0.4737	0.3482
Mean (2000-2009)	0.5541	0.5566	0.7075	0.6842	0.4451	0.4514
Mean (2010-2019)	0.4696	0.6723	0.7160	0.8378	0.5089	0.4189
Mean (2020-2022)	0.5331	0.7551	0.9045	0.9893	0.5029	0.3538

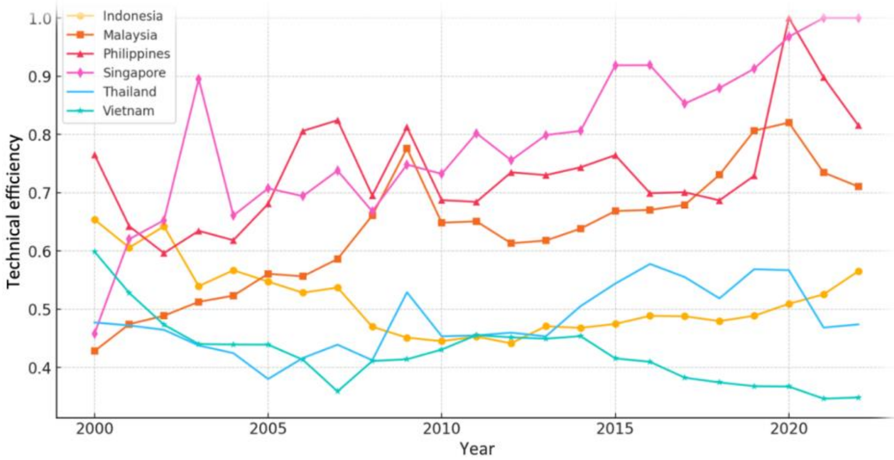

Figure 2. Technical efficiency for selected ASEAN member countries manufacturing (2000 – 2022).

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4.3. Determinants of Technical Efficiency

Tobit regression results (Table 5) identify three statistically significant determinants of TE

Table 5. Tobit regression results on factors influencing manufacturing efficiency in ASEAN.

Variable	Coefficient	Std. Error	p-value	Effect
FDI	0.0044***	0.0006	<0.0001	Positive, significant
INF	-0.0114***	0.0033	0.0004	Negative, significant
65Y	-0.0288***	0.0064	<0.0001	Negative, significant
TO	0.0000608	0.0002	0.7155	Not significant
GOV	0.00000166	0.0006	0.9774	Not significant

Note: *** denotes 1% significance level.

The Tobit regression results presented in Table 5 highlight three macroeconomic factors with statistically significant effects on manufacturing efficiency in ASEAN economies: foreign direct investment (FDI), inflation, and demographic aging. FDI exerts a positive influence, with a 1% increase in inflows associated with a 0.44% improvement in technical efficiency. This finding underscores the catalytic role of multinational corporations in facilitating technology transfer, disseminating advanced managerial practices, and integrating domestic firms into global value chains, thereby enhancing proximity to the efficiency frontier. The result aligns with Chizema (2025), who argues that FDI significantly contributes to economic development when complemented by strong human capital and institutional quality. Similarly, Nisar, Khalid, Ali, and Khalid (2024) demonstrated that foreign investment enhances technical efficiency through knowledge spillovers and input complementarities. Nevertheless, the absorptive capacity of host countries remains a critical mediating factor, emphasizing the need for policies that promote skills development and strengthen institutional frameworks to fully realize the benefits of FDI.

In contrast, inflation exhibits a negative and statistically significant effect on manufacturing efficiency, with a 1% increase in inflation leading to an approximate 1.14% decline in efficiency. Elevated and volatile inflation raise production costs, distort price signals, and weaken resource allocation mechanisms, thereby discouraging firms from investing in productivity-enhancing innovations. Consistent with this finding, Maji et al. (2020) argued that the significance of inflation in the inefficiency equation reflects a cost–coordination problem: as input prices become increasingly volatile, firms face shorter planning horizons, greater working-capital requirements, and a tendency to postpone process and technological upgrades.

Similarly, demographic aging exerts an even stronger negative effect, with a 1% increase in the share of the elderly population reducing efficiency by approximately 2.88%. This result aligns with the empirical findings of Osathanunkul et al. (2023), who documented that an aging workforce tends to increase absenteeism, exacerbate skill shortages, and reduce adaptability to new technologies. While older workers contribute valuable experience and institutional knowledge, their slower adoption of digital innovations and higher health-related costs pose structural challenges to productivity. Addressing these demographic pressures necessitates targeted workforce adaptation strategies, including lifelong learning initiatives, flexible retirement schemes, and sustained investments in health and digital reskilling.

Interestingly, both trade openness and government expenditure were statistically insignificant in this model, indicating that the expansion of trade or fiscal spending alone does not automatically enhance efficiency unless such resources are strategically directed toward productive domains such as research and development (R&D), infrastructure, and human capital development (Chizema, 2025).

Overall, the findings highlight that FDI inflows remain a powerful driver of manufacturing efficiency, but their benefits can only be fully realized when paired with stable macroeconomic conditions and adaptive labor policies. Inflation control is therefore essential to preserve efficiency gains, while proactive responses to population aging are necessary to sustain long-term productivity in the ASEAN manufacturing sector.

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4.4. Policy Implication

The findings suggest that ASEAN governments should enhance FDI attraction strategies by improving investment climates and integrating local firms into global supply chains while controlling inflation in order to maintain cost competitiveness in manufacturing. Additionally, ASEAN economies should mitigate demographic impacts through workforce upskilling, automation, and labor market reforms, as well as recognize that trade liberalization and government spending must be paired with targeted industrial policies to translate into higher efficiency.

5. CONCLUSION

This study assessed the technical efficiency of the manufacturing sector in six ASEAN economies Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam over the period 2000–2022. Employing Data Envelopment Analysis (DEA) and Tobit regression, the study generated three principal findings.

First, Singapore consistently recorded the highest efficiency scores, whereas Vietnam remained the least efficient throughout the study period. The remaining countries exhibited moderate but fluctuating efficiency levels over time.

Second, while most ASEAN economies experienced improvements in efficiency prior to 2020, Indonesia, Thailand, and Vietnam registered notable declines following the COVID-19 pandemic, underscoring the sector's vulnerability to external shocks.

Third, the determinant analysis indicated that foreign direct investment (FDI) significantly enhances efficiency, whereas inflation and demographic aging have detrimental effects. Specifically, a 1% increase in FDI was associated with a 0.44% rise in efficiency, while a 1% increase in inflation and in the share of the elderly population reduced efficiency by 1.14% and 2.88%, respectively.

These findings yield several important policy implications. ASEAN governments should prioritize measures to attract and sustain high-quality FDI by improving investment environments, strengthening regulatory institutions, and fostering linkages between domestic firms and global value chains.

Concurrently, monetary authorities must pursue policies that maintain price stability, while governments should implement long-term labor market reforms and continuous skills development programs to mitigate the adverse effects of demographic aging. Strengthening manufacturing efficiency will be critical for sustaining economic growth, enhancing competitiveness, and advancing the region's integration and development objectives.

5.1. Limitations and Directions for Future Research

This study is subject to several limitations. First, it relies on aggregated country-level data, which may obscure firm-level heterogeneity and cross-industry variation within the ASEAN manufacturing sector. Moreover, the DEA framework attributes all deviations from the frontier to inefficiency and, therefore, cannot distinguish inefficiency from random shocks, an important limitation during volatile periods such as the COVID-19 pandemic. In addition, data constraints prevented the inclusion of potentially relevant factors such as institutional quality, digital and technological adoption, and labour-market flexibility, raising the possibility of omitted-variable bias. Finally, the two-stage approach employing censored (Tobit) regression does not fully account for serial correlation and sampling variability in DEA scores, nor does it address potential endogeneity between efficiency and its determinants.

Future research could address these limitations by utilizing firm- or sector-level panel data to capture microeconomic drivers and within-country heterogeneity. Adopting stochastic frontier analysis (SFA), including panel and meta-frontier extensions, would allow the separation of inefficiency from statistical noise and better accommodate technological heterogeneity across countries and industries. Furthermore, applying double-bootstrap DEA procedures or alternative bounded-dependent-variable models such as fractional or beta regression, as well as instrumental variable (IV) or generalized method of moments (GMM) techniques, could help mitigate inference and endogeneity concerns.

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