



Indonesian Rubber Tire Export Potential in International Markets: A Stochastic Frontier Gravity Model Approach

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Abstract

Background: The transformation of Indonesia's rubber exports from raw materials to higher value-added downstream products has become a critical challenge in enhancing the country's international trade competitiveness. Although Indonesia is the world's second-largest exporter of natural rubber, its rubber tire (HS 4011) exports continue to account for a relatively small share of the global market despite steadily increasing international demand.

Objective: This study aims to analyze the factors affecting export inefficiency and to estimate the export potential of Indonesian rubber tires in the international market.

Methods: The study employs panel data from 68 export destination countries over the period 2015-2024 and applies the Stochastic Frontier Gravity Model (SFGM).

Results: The results indicate that exports are positively influenced by the economic size of destination countries, while geographical distance negatively affects trade. Export inefficiency decreases with real exchange rate depreciation and an increase in government effectiveness, but increases with import tariffs and landlocked destinations. Robustness checks confirm the stability of the main findings across model specifications, with Model 3 selected as the preferred specification after controlling for area and year effects. The estimated export potential reveals substantial unrealized opportunities, particularly in China (US\$1.26 billion), India (US\$535.76 million), Germany (US\$210.21 million), Japan (US\$201.93 million), and France (US\$178.87 million).

Conclusion: These findings show uneven market utilization and support a market-prioritization strategy centered on destinations with the largest unrealized export gaps, while consolidating high-efficiency markets and addressing market-access and logistics constraints in underutilized destinations.

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INTRODUCTION

Indonesia is the world's second-largest natural rubber exporter, with an 18.3% share of the global market in 2024 (Trademap, 2026). However, Indonesia's rubber export structure remains dominated by primary and semi-processed products, particularly Technical Specified Natural Rubber (TSNR) and Ribbed Smoked Sheet (RSS). Natural rubber products classified under HS 4001 accounted for 52.77% of Indonesia's total rubber exports in 2024. Despite its important position in the global rubber trade, the export value of HS 4001 showed a declining trend during 2015–2024, reaching US\$2.48 billion in 2023. At the global level, the markedly larger trade value

of finished tires relative to raw natural rubber indicates a structural shift toward higher-value downstream products, while destination-market concentration and supply-chain disruptions increase the strategic importance of diversification and resilient market access (Hong et al., 2025; Trademap, 2026; Yap et al., 2025).

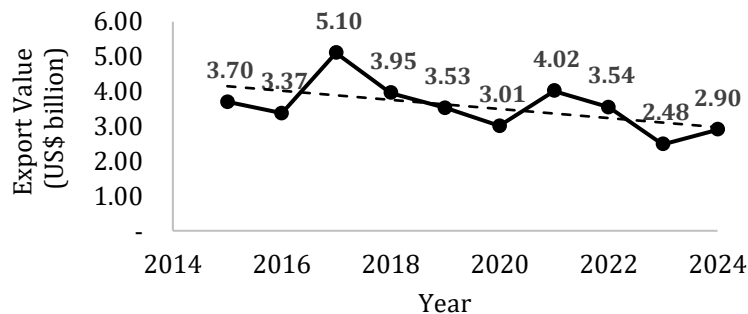


Figure 1. Indonesia's Natural Rubber (HS 4001) Export Value, 2015–2024
Source: compiled from Trademap (2026)

This downward trend indicates that Indonesia's advantage as a natural rubber producer has not yet been fully translated into higher export value through downstream products. In addition, low export efficiency indicates a persistent gap between Indonesia's actual and potential exports in several destination markets (Kalirajan, 2007; Yanti, 2025). For Indonesia, HS 4011 is therefore strategically relevant because it converts the country's upstream natural-rubber advantage into a manufactured product with substantially higher value-added potential; examining tire exports provides a direct test of whether downstreaming is translating resource endowments into stronger international market performance.

In line with developments in the global industry, international demand has increasingly shifted from rubber as a raw material toward higher-value downstream products, particularly new pneumatic rubber tires (HS 4011). Global imports of rubber tires reached US\$101.25 billion in 2024, substantially exceeding natural rubber imports, which amounted to only US\$16.88 billion (Trademap, 2026). This trend indicates substantial market opportunities for Indonesia's downstream rubber industry. However, these opportunities have not been fully utilized. In 2024, Indonesia's rubber tire exports amounted to approximately US\$1.6 billion, representing only 29.24% of its total HS 40 rubber exports, while HS 4001 remained the dominant product, accounting for 52.77%. Indonesia's share of the global rubber tire export market was also only 1.60%, considerably lower than that of major exporters such as China, Thailand, and Japan (Trademap, 2026). Furthermore, Indonesia's rubber tire exports remain concentrated in several major markets, particularly the United States, Japan, and Malaysia. Such market concentration may increase export vulnerability to changes in economic and trade conditions in destination countries (Hong et al., 2025). These conditions suggest that Indonesia has not yet fully transformed its comparative advantage in natural rubber production into a competitive advantage in downstream rubber products.

Increasing value added through downstream industrialization and market diversification is therefore an important component of Indonesia's rubber industry development strategy (Chafid, 2024). This strategy requires not only increased production capacity but also the identification of export markets with untapped potential and the factors that prevent actual exports from reaching their potential levels. In this context, export efficiency can be used to assess a country's ability to realize its trade potential. Export efficiency is defined as the ratio of actual exports to potential exports that could be achieved in the absence of trade barriers (Aminizadeh et al., 2025; Kalirajan, 1999). Accordingly, a low level of export efficiency indicates a gap between actual trade and the level of trade that could potentially be achieved.

Previous studies on Indonesia's rubber exports have provided insights into trade competitiveness and export performance, but most have focused on natural rubber (HS 4001) or employed the Revealed Comparative Advantage (RCA), Export Product Dynamics (EPD), and conventional Gravity Model approaches. These approaches are useful for assessing competitive

positions and the factors influencing trade flows, but they do not directly estimate export potential or the gap between actual and potential exports arising from trade barriers. Studies examining Indonesia's rubber tire exports (HS 4011) from an export efficiency perspective also remain limited. Therefore, an empirical gap remains regarding the magnitude of Indonesia's rubber tire export potential and the factors contributing to export inefficiency across destination markets. More specifically, Wardani and Mulatsih (2017) examined the competitiveness and determinants of Indonesian tire exports to Latin America, Pinandhita and Agustina (2019) focused on diversification toward nontraditional markets, and Andriantoni et al. (2020) and Sari (2024) analyzed macroeconomic determinants of Indonesian rubber exports. These streams are informative for competitiveness, diversification, and observed trade-flow determinants, but they do not jointly separate the attainable trade frontier from one-sided inefficiency. SFGM addresses this limitation by estimating potential trade and the distance of realized exports from that frontier, enabling the export gap to be quantified across destination markets (Devadason & Mubarik, 2021; K. Kalirajan, 1999; Tandra & Suroso, 2023).

From a theoretical perspective, bilateral export performance is influenced by economic conditions, trade costs, geographical characteristics, and institutional quality. In this study, these factors are represented by the economic size of the exporting and importing countries, geographical distance, the real exchange rate, import tariffs, landlocked status, and government effectiveness. Gross domestic product reflects economic capacity and trade demand, while the real exchange rate affects price competitiveness through changes in the relative prices of traded goods (Feenstra, 2002; Krugman et al., 2018; Luo, 2025). Geographical distance is widely recognized as a key determinant of trade costs, as greater distance tends to increase transportation expenses and related trade risks (Cevik, 2023), while import tariffs increase trade costs and may reduce import demand (Salvatore, 2019). Landlocked status may impose geographical constraints on international trade (Hirte et al., 2020), whereas government effectiveness is associated with the quality of the institutional environment into international trade (Kalirajan & Singh, 2008; Pertiwi et al., 2019; Tandra & Suroso, 2023).

To estimate export potential, this study employs the Stochastic Frontier Gravity Model (SFGM), which can identify the maximum attainable level of trade while measuring deviations of actual exports from the trade frontier. Kalirajan (1999) and Aminizadeh et al. (2025) developed this approach by integrating Stochastic Frontier Analysis into the Gravity Model. Unlike the conventional Gravity Model, which generally estimates the average relationship among variables, the SFGM enables the estimation of a trade frontier, representing the potential level of trade that could be achieved when trade barriers are minimized. The inefficiency component can subsequently be used to identify the factors that cause actual exports to fall below their potential levels.

Empirically, this study addresses a gap in the literature by applying the Stochastic Frontier Gravity Model (SFGM) to downstream rubber trade, with a specific shift in analytical focus from primary rubber commodities to the value-added manufactured product of rubber tires (HS 4011) across 68 destination markets. Its empirical novelty lies in identifying the determinants of trade inefficiency that are not captured by conventional gravity models, while incorporating area and year fixed effects to account for unobserved spatial and temporal heterogeneity, including time-invariant geographical characteristics and macroeconomic shocks. The study's principal applied contribution is therefore not merely the use of SFGM, but the mapping of destination markets according to trade efficiency and the magnitude of unrealized export gaps, which provides an empirical basis for prioritizing Indonesia's rubber-tire market diversification strategy.

Theoretically, this study extends the gravity framework by incorporating a trade-efficiency perspective into bilateral trade analysis. Whereas conventional gravity models primarily explain observed trade flows, the SFGM distinguishes between the trade frontier and realized trade, thereby enabling an assessment of the extent to which potential bilateral trade is realized. The analysis further extends beyond trade efficiency by identifying Indonesia's untapped export potential and export gaps over the study period. Thus, the study broadens the analytical scope of gravity theory from explaining realized trade flows to assessing the extent to which bilateral trade opportunities, particularly for rubber tires (HS 4011) can be effectively realized. This market-prioritization perspective connects the trade-efficiency framework to policy decisions by distinguishing large but underutilized markets from destinations where existing

export potential is already relatively well realized.

Based on the above considerations, this study aims to: (1) analyze the factors influencing the export inefficiency of Indonesia's rubber tire products in international markets; and (2) estimate the export potential of Indonesia's rubber tire products in international markets. Theoretically, the study contributes to international-trade analysis by linking the gravity framework with a frontier-based measure of unrealized bilateral trade. Practically, the results provide the government and the national tire industry with evidence for prioritizing market expansion, negotiating market access, improving logistics, and allocating export-promotion resources across destination countries.

METHOD

The study employed secondary panel data comprising 68 trading partner countries that served as destinations for Indonesian rubber tire exports (HS 4011) during the period 2015–2024. The selection of the 68 destination countries was based on two criteria: export value ranking and data completeness. First, Indonesian rubber tire export values across all destination countries were ranked in descending order. Countries with the highest export values were subsequently selected, subject to the availability of complete observations for all variables included in the SFGM. This procedure resulted in a sample of 68 destination countries. The requirement for complete data was imposed to maintain a balanced panel and ensure the consistency and comparability of the SFGM parameter estimates.

The 2015–2024 study period was selected to provide a ten-year observation window, thereby allowing the analysis to capture changes in Indonesia's rubber tire export performance and developments in international trade conditions. In addition, 2024 was selected as the final observation year because it represented the most recent year for which complete trade data were available for the variables examined in the study. The 68-country design was chosen to balance broad market coverage with the requirement for a complete, balanced panel across all SFGM variables. Because the selection partly depended on observed export values, the design may have underrepresented low-base destinations that had not yet generated large current trade flows but could have possessed future growth potential. Accordingly, the estimated frontier and market rankings should be interpreted as applying to the observed 68-destination sample rather than to the universe of all possible export markets. This limitation was considered when drawing implications for market expansion.

The dependent variable is the natural logarithm of the nominal export value of rubber tires (HS 4011) ($X_{tires_{ijt}}$), expressed in current US\$ and sourced from the UN Comtrade database. The independent variables include Indonesia's real GDP (PDB_{it}), the importing country's real GDP (PDB_{jt}), geographical distance ($dist_{ij}$), real exchange rate (Rer_{ijt}), the effectively applied import tariff on HS 4011 products ($Tarif_{jt}$), Landlocked dummy ($D_{landlocked_j}$), and Government Effectiveness (GE_{it}).

Table 1

Sources of data used in the study

Variables	Unit/Type	Definition	Source
$X_{tires_{ijt}}$	US\$ (log)	export value of rubber tires product (HS 4011) to partner j	Un Comtrade
GDP_{it}	US\$ (log)	Indonesia's total real GDP	World Bank
GDP_{jt}	US\$ (log)	the importing country's total real GDP	World Bank
$dist_{ij}$	Kilometers (log)	The geographical distance between Indonesia (i) and the importing country (j)	CEPII
Rer_{ijt}	Rp/LCU (log)	Real exchange rate	Pasific Exchange Rate dan CEIC
$Tarif_{jt}$	%	the effectively applied import tariff on HS 4011 products	ITC MacMap
$D_{landlocked_j}$	Binary	1 = for landlocked importing countries; 0 = otherwise	CEPII
GE_{it}	Index (0-100)	Government Effectiveness	World Bank

Data Analysis Method

Panel Unit Root Test

Statistically, panel data must satisfy the stationarity assumption to ensure valid and reliable model estimation. Therefore, a panel unit root test was conducted to verify that the data were stationary and free from unit root problems. Applying an appropriate panel unit root test enhances the reliability of the estimated parameters and the validity of statistical inference (Wibowo, 2025). In this study, stationarity was assessed using the Levin–Lin–Chu (LLC) panel unit root test, which combines cross-sectional and time-series information to improve the power of detecting unit roots in panel data (Ghassan, 2025; Levin et al., 2002). The data were considered stationary when the p-value was less than the 5% significance level.

Multicollinearity

Multicollinearity refers to a high degree of correlation among the independent variables in a model. It was assessed using the Variance Inflation Factor (VIF), with a VIF value greater than 10 generally indicating a high level of multicollinearity. The results of the multicollinearity test for the variables included in the model are presented below.

Table 2

Results of the Multicollinearity Test

	VIF	1/VIF
Indonesia's total real GDP	1.00	0.999125
Importing country's total real GDP	1.21	0.826098
Geographical distance	1.14	0.880336
Real exchange rate	1.01	0.993050
import tariffs	1.16	0.864025
landlocked	1.08	0.926366
Government Effectiveness	1.13	0.888214
Mean VIF	1.10	

Source: Authors' calculations using STATA (2026).

The results showed that all independent variables had VIF values below 10, with the highest VIF value of 1.21 observed for the importing country's total real GDP. In addition, the mean VIF of 1.10 indicated that the overall correlation among the independent variables was low. Therefore, there was no indication of high multicollinearity in the model, and all independent variables were considered suitable for inclusion in the SFGM estimation.

Robustness Check

A robustness check was conducted to assess the consistency of the estimation results across alternative model specifications. The analysis applied fixed effects sequentially, starting with the baseline model, followed by the inclusion of area fixed effects to control for area-specific characteristics, and finally, area and year fixed effects to control for annual global macroeconomic shocks. This approach controlled for unobserved heterogeneity and assessed the stability of the key coefficients (Ghassan, 2025; Lu & White, 2014). The selection of area and year fixed effects followed Zhang, Kalirajan, and Chen (2024), who employed these specifications in their estimation of a two-tier stochastic frontier gravity model.

Stochastic Frontier Gravity Model

The gravity model posits that bilateral trade is determined by the economic size of the exporting and importing countries and the geographical distance between them. In its basic form, the relationship can be expressed as follows (Paul, 2025; Tinbergen, 1962):

$$Xtyres_{ijt} = \frac{(GDP_{it})^{\alpha}(GDP_{jt})^{\beta}}{(dist_{ij})^{\tau}} \quad (1)$$

in which $Xtyres_{i,j}$ denotes bilateral trade in rubber tires (HS 4011), GDP_{it} and GDP_{jt} represent the economic size of the exporting and importing countries, respectively, and $dist_{ij}$

denotes the geographical distance between the trading partners as a proxy for trade costs (Paul, 2025; Tinbergen, 1962). Accordingly, the GDP of both trading partners and geographical distance constitute the core determinants of potential bilateral trade. In empirical applications, the gravity model is commonly transformed into its natural logarithmic form to obtain a linear specification that facilitates estimation (Baldwin & Taglioni, 2011; Jin et al., 2023). This gravity framework was subsequently extended into the Stochastic Frontier Gravity Model (SFGM) to estimate potential exports and identify the gap between actual and potential trade flows (Aminizadeh et al., 2025; Kalirajan & Shand, 1999) :

$$\ln X_{tyres_{ijt}} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln dist_{ijt} + v_{ijt} - u_{ijt} \quad (2)$$

In the SFGM, the composite error term (ε_{ijt}) is decomposed into a two-sided error term (v_{ijt}), which captures measurement errors and random shocks, and a one-sided inefficiency term (u_{ijt}), which captures trade barriers associated with bilateral trade cost that cause actual exports to fall below their potential level. A larger (u_{ijt}) indicates greater export inefficiency, whereas ($u_{ijt} = 0$) represents full export efficiency. Bilateral trade cost reflects the combined effects of factors that are difficult to observe directly, including historical and cultural ties, communication, and socio-political and institutional conditions (Manzoor & Mir, 2023; Yotov et al., 2016). To identify the sources of these trade constraints more specifically, this study includes the real exchange rate, import tariffs, landlocked dummy, and government effectiveness as determinants of export inefficiency. The selection of explanatory variables is based on a synthesis of previous empirical studies, including Kalirajan and Singh (2008), Pertiwi, Herianingrum, Ubaidillah, Mustofa and Muhammad (2019), Devadason and Mubarik (2021), Suryanto and Sukaesih (2022), Takele and Tveter (2025). Accordingly, the export inefficiency model is specified as follows:

$$u_{ijt} = \delta_0 + \delta_1 \ln Rer_{ijt} + \delta_2 Tarif_{jt} + \delta_3 Dlandlocked_j + \delta_4 GE_{it} + w_{ijt} \quad (3)$$

The natural logarithm of the real exchange rate ($\ln Rer_{ijt}$) reflects price competitiveness Krugman et al. (2018) and Luo (2025) import tariffs ($Tarif_{jt}$) increase trade costs and may constrain export performance (Salvatore, 2019), while landlocked ($Dlandlocked_j$) status represents geographical constraints that can hinder international trade (Hirte et al., 2020; Luo, 2025), Government effectiveness (GE_{it}) reflects bureaucratic capacity, the quality of public services, and the effectiveness of policy implementation, which can facilitate trade performance (Luo, 2025; Tamas & Miron, 2021). Where (δ_0) denotes the constant term, ($\delta_1 \dots \delta_n$) represent the estimated parameters, and (w_{ijt}) denotes the error term.

The model parameters were estimated using maximum likelihood estimation (MLE), which generates two key indicators: the gamma coefficient gamma (γ) and trade efficiency (TRE). The gamma coefficient is used to measure the proportion of total variation in trade attributable to export inefficiency factors. The gamma coefficient is expressed as follows:

$$\gamma = \frac{\sum_{t=1}^T \sigma_{u,t}^2}{\sum_{t=1}^T (\sigma_{u,t}^2 + \sigma_{v,t}^2)} \quad (4)$$

In the model, γ denotes the gamma parameter, bounded between 0 and 1 ($0 \leq \gamma \leq 1$); (σ^2) represents the total variance of the error term; and t denotes the time period (year). Trade Efficiency (TRE_{*t*}) is defined as the ratio of actual exports to potential exports, reflecting the extent to which a country realizes its export potential. Mathematically, the measure is expressed as follows:

$$TRE_{ijt} = \frac{\exp[X_{ijt}]}{\exp[f(T; \beta) + v_{ijt}]} = \exp[-u_{ijt}] \quad (5)$$

(TRE_{ijt}) denotes trade efficiency, which is measured as the ratio of actual trade to the potential trade level. $\exp[X_{ijt}]$ represents the observed trade value, while $\exp[f(T; \beta) + v_{ijt}]$ denotes the potential export level that could be achieved between two countries given the underlying trade determinants under a hypothetical condition of zero trade barriers. The term

(u_{ijt}) represents the inefficiency component, defined as $(\epsilon_{ijt} - \frac{\sigma_v^2}{\sigma_u^2})$, where (ϵ_{ijt}) denotes the total error term. Trade Efficiency (TRE_{ijt}) ranges between 0 and 1. A TRE value equal to 1 indicates that actual trade has attained its potential level.

Accordingly, the potential export value, representing the maximum attainable export level from Indonesia to importing country j in period t , is estimated as the ratio of actual exports to trade efficiency:

$$Potential\ export_{ijt} = \frac{Xtires_{ijt}}{TRE_{ijt}} \quad (6)$$

where $(Potential\ export_{ijt})$ denotes the potential export value of rubber tires, $(Xtires_{ijt})$ represents the actual export value from Indonesia to importing country j in period t , and (TRE_{ijt}) denotes trade efficiency. The export gap is subsequently calculated as the difference between potential and actual exports:

$$Export\ gap_{ijt} = Potential\ export_{ijt} - Xtires_{ijt} \quad (7)$$

A larger export gap indicates greater unrealized export potential between Indonesia and the importing country. Subsequently, the presence of trade inefficiency effects in the model is evaluated using the Likelihood Ratio (LR) test (Kumbhakar & Parmeter, 2019; Zhang & Du, 2026). The mathematical formulation of the LR test is given as follows:

$$LR\ test = -2[L(H_0) - L(H_1)] \quad (8)$$

The calculated likelihood ratio statistic is subsequently compared with the critical values reported in the table developed by Kodde and Palm (1986) and Dufour et al. (2025).

RESULTS AND DISCUSSION

Results

Summary Statistic Data

Table 2 presents the descriptive statistics of all variables used in this study. A total of 680 observations were available for each variable, with no missing values. The natural logarithm of Indonesia's rubber tire (HS 4011) export value to 68 destination countries had a mean of 14.951 and a median of 14.846, ranging from 10.048 to 20.670. Most variables exhibited low to moderate coefficients of variation (CV), indicating a relatively moderate degree of data dispersion. The import tariff variable contained 398 zero-value observations, reflecting the application of preferential or zero tariffs on Indonesia's rubber tire exports under trade agreements or the tariff policies of importing countries. These zero values represent valid observations rather than missing data and were therefore retained in the estimation.

Table 3

Summary statistic of the variables used in the model

Variable	Obs (N)	Mean	Median	SD	Min.	Max.	CV (%)	Zero Values (N)	Missing Values (N)
$Xtires_{ijt}$	680	14.951	14.846	2.003	10.048	20.670	13.398	0.000	0.000
$LnGDP_{it}$	680	28.862	28.867	0.108	28.679	29.043	0.376	0.000	0.000
$LnGDP_{jt}$	680	26.945	26.927	1.578	23.711	31.145	5.855	0.000	0.000
$LnDist_{ijt}$	680	9.108	9.264	0.639	6.787	9.892	7.014	0.000	0.000
$LnRer_{ijt}$	680	6.947	7.775	2.690	-0.436	10.700	38.721	0.000	0.000
$Tarif_{jt}$	680	3.624	0.000	5.312	0.000	25.287	146.602	398	0.000
$DLanlocked_j$	680	0.088	0.000	0.284	0.000	1.000	321.692	620	0.000
GE_{it}	680	54.896	55.167	1.939	50.122	57.413	3.532	0.000	0.000

Source: Authors' calculations (2026), the sources of data are available in Table 1

Meanwhile, the landlocked dummy variable contained 620 zero-value observations, indicating that the majority of Indonesia's trading partners have direct access to seaports.

Panel Unit Root Test

The results of the Levin–Lin–Chu (LLC) panel unit root test (Table 4) indicate that all variables used in this study are stationary at the level. This is evidenced by a probability value of 0.0000, which is lower than the 5% significance level.

Table 4

Unit Root Test Result

	Statistic	prob
Indonesia's total real GDP	-17.167	0.000
Importing country's total real GDP	-3.776	0.000
Real exchange rate	-23.334	0.000
import tariffs	-4.907	0.000
Government Effectiveness	-25.617	0.000

Source: Authors' calculations using Eviews12 (2026).

The geographical distance and landlocked variables were excluded from the stationarity test as it is a time-invariant dummy variable, for which the concept of a unit root is not applicable.

Discussion

Determinants of Indonesia's Rubber Tire Exports and Export Inefficiency

Table 5 presents the maximum likelihood estimates of the SFGM under three model specifications. The specifications differ in the inclusion of fixed effects, with Model 2 controlling for area fixed effects and Model 3 additionally incorporating year fixed effects to account for unobserved area-specific heterogeneity and time-specific effects during the study period. The coefficients of the main frontier variables remain relatively stable in sign and statistical significance across the three specifications, particularly for the importing country's GDP and geographical distance. This indicates that the core gravity relationships are generally consistent across alternative specifications. The estimated gamma (γ) coefficients are 0.892, 0.999, and 0.998 for Models 1, 2, and 3, respectively, and are statistically significant at the 1% level. In Model 3, the gamma value of 0.998 indicates that approximately 99.8% of the composite error variance is attributable to the inefficiency component, whereas only 0.2% is explained by random disturbances. This finding suggests that deviations of actual exports from the estimated trade frontier are predominantly associated with export inefficiency rather than random disturbances.

Table 5

Maximum likelihood estimates of the SFGM for Indonesia's Rubber Tire Exports in Destination Countries, 2015-2024

	Model 1	Model 2	Model 3
Frontier Model Estimation			
LnGDP _{it}	-0.320 (0.320)	-0.326 (0.408)	0.579 (0.212)
LnGDP _{jt}	0.934 *** (29.382)	0.865 *** (85.449)	0.847 *** (32.095)
Lndist _{ijt}	-0.469 *** (6.110)	-0.182 *** (3.840)	-0.191 *** (5.025)
Export Inefficiency Model Estimation			
LnRer _{ijt}	-0.631 (0.530)	-1.449 * (1.744)	-2.408 ** (2.247)
Tarif _{jt}	0.012 (0.580)	0.017 * (1.745)	0.022 ** (2.093)
<i>Dlandlocked_j</i>	0.166 *** (4.667)	1.170 *** (6.305)	1.162 *** (5.878)
<i>GE_{it}</i>	-0.239 *** (9.168)	-0.069 *** (7.220)	-0.063 *** (4.403)
Area fixed effect		Controlled	Controlled
Year fixed effect			Controlled

	Model 1	Model 2	Model 3
<i>Sigma-squared</i>	2.628 ***	1.567 ***	1.586 ***
<i>Gamma</i>	0.892 ***	0.999 ***	0.998 ***
<i>LR-test</i>	114.595	163.674	155.863

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

Source: Authors' calculations using Frontier 4.1 software (2026).

Furthermore, The LR-test statistics of 114.595, 163.674, and 155.863 further indicate the presence of a statistically significant inefficiency component in the stochastic frontier specifications. Among the three specifications, Model 3 is selected as the preferred specification because it provides the most comprehensive control for both area-specific and time-specific effects. Accordingly, the subsequent discussion focuses on the estimation results of Model 3.

The estimation results of Model 3 indicate that all variables in the frontier model exhibit the expected signs predicted by the Gravity Model. Indonesia's total real GDP (LnGDP_{it}) has a positive but statistically insignificant coefficient of 0.579. This finding indicates that an increase in Indonesia's economic size is associated with higher rubber tire exports, although the relationship is not statistically significant. Likewise, the importing country's total real GDP (LnGDP_{jt}) has a positive and highly significant effect at the 1% level, with an elasticity of 0.847, indicating that countries with larger economies possess greater purchasing power and import demand for Indonesian rubber tires (Tinbergen, 1962; Tweeten, 1992). In contrast, geographical distance (Lndist_{ijt}) has a negative and significant effect, with an elasticity of -0.191 , implying that greater transportation, logistics, and transaction costs associated with longer distances reduce Indonesia's rubber tire exports (Krugman et al., 2018; Luo, 2025). These findings are consistent with previous studies by (Andriantoni et al., 2020; Pinandhita & Agustina, 2019; Sari, 2024; Wardani & Mulatsih, 2017) Beyond aggregate purchasing power, higher destination-country GDP can also reflect a larger vehicle stock, stronger automotive production and distribution networks, and greater replacement-tire demand, all of which expand the absorptive capacity for imported tires. Conversely, because tires are relatively bulky products, greater geographical distance can raise freight, inventory-holding, insurance, and delivery-time costs, reducing the ability of Indonesian exporters to convert market demand into realized trade.

The export inefficiency model further shows that the real exchange rate (LnRer_{ijt}) has a negative and significant effect at the 5% level. Since this variable is specified in logarithmic form, the estimated coefficient of -2.408 indicates that a 1% depreciation of the real exchange rate is associated with a 2.408% reduction in export inefficiency through improved price competitiveness in international markets (Tandra & Suroso, 2023). Exchange rate depreciation may also increase export supply elasticity by raising the cost of imported production inputs, thereby encouraging firms to expand exports (Riwu et al., 2025; Welldy & Widyawati, 2019). Conversely, import tariffs imposed by destination countries (Tarif_{jt}) positively affect export inefficiency, suggesting that higher tariffs widen the gap between actual and potential exports by increasing trade costs (Handley & Limão, 2017; Krugman et al., 2018; Luo, 2025). Government effectiveness (GE_{it}) are found to have negative effects on export inefficiency, indicating that effective governance in Indonesia, particularly through better policy implementation help reduce trade barriers and improve export efficiency (Hotsawadi & Gea, 2025; Lemurt et al., 2024; Wang et al., 2022). Meanwhile, the landlocked dummy variable (Dlandlocked_j) has a positive and significant effect, indicating that destination countries without direct access to the sea tend to experience higher export inefficiency due to greater logistics costs, longer transportation times, and dependence on transit countries (Gyawali, 2023; Paudel & Cooray, 2018). Economically, these effects operate through distinct channels: exchange-rate depreciation improves relative export prices; tariffs directly increase landed costs; stronger government effectiveness reduces administrative and policy frictions; and landlocked geography adds transit dependence and multimodal logistics costs. The combined effects explain why similar market sizes can generate markedly different realized export efficiencies.

Export Efficiency of Indonesia's Rubber Tire Exports

The estimation results indicate that the export efficiency of Indonesian rubber tires varies across regions, with substantial gaps remaining between actual and potential exports (Table 6).

Table 6

Export Efficiency of Indonesian Rubber tires in Destination Countries

Country	Trade Efficiency	Actual export value (million US\$)	Potential export value (million US\$)	Export gap value (million US\$)	Country	Trade Efficiency	Actual export value (million US\$)	Potential export value (million US\$)	Export gap value (million US\$)
Asian Region									
Philippines	0.806	67.42	83.67	16.26	Cambodia	0.122	1.58	13.00	11.42
Malaysia	0.711	71.76	100.93	29.17	Qatar	0.085	2.14	25.18	23.05
UEA	0.479	23.51	49.10	25.59	South Korea	0.073	11.54	157.15	145.62
Japan	0.358	112.82	314.75	201.93	Kuwait	0.063	1.24	19.69	18.45
Saudi Arabia	0.278	32.72	117.56	84.84	Pakistan	0.061	5.13	84.26	79.12
Thailand	0.246	29.53	120.03	90.50	Türkiye	0.039	5.21	132.01	126.80
Vietnam	0.190	17.36	91.16	73.80	Mongolia	0.027	0.16	5.90	5.75
Singapore	0.136	10.95	80.73	69.77	India	0.015	7.90	543.66	535.76
Hong Kong	0.135	5.91	43.73	37.81	China	0.005	6.43	1,262.7	1,256.3
Europe Region									
Netherlands	0.601	44.53	74.10	29.57	Hungary	0.094	2.50	26.68	24.17
Latvia	0.304	2.03	6.68	4.65	Estonia	0.084	0.46	5.54	5.07
Romania	0.271	13.85	51.08	37.23	Greece	0.079	2.21	28.04	25.84
Germany	0.183	47.07	257.28	210.21	Spain	0.061	7.49	122.66	115.18
UK	0.178	32.20	181.36	149.16	Portugal	0.054	1.56	29.23	27.66
Belgium	0.176	8.01	45.59	37.58	France	0.046	8.66	187.53	178.87
Iceland	0.149	0.39	2.60	2.22	Croatia	0.043	0.54	12.40	11.86
Cyprus	0.135	0.64	4.74	4.10	Lithuania	0.042	0.45	10.89	10.44
Slovenia	0.116	1.02	8.76	7.74	Czech Rep.	0.029	1.05	36.28	35.23
Poland	0.115	10.27	89.15	78.88	Denmark	0.024	0.70	29.32	28.62
Italy	0.113	18.41	163.50	145.09	Norway	0.020	0.68	34.23	33.55
Sweden	0.112	4.90	43.87	38.98	Ireland	0.017	0.58	34.58	34.01
Finland	0.103	2.50	24.23	21.73					
North America Region									
United States	0.852	739.23	867.81	128.58	Guatemala	0.081	1.22	15.03	13.81
Panama	0.371	4.10	11.07	6.97	El Salvador	0.080	0.47	5.86	5.39
Canada	0.246	28.90	117.25	88.36	Costa Rica	0.065	0.65	9.91	9.26
Mexico	0.206	28.85	140.32	111.47	Nicaragua	0.037	0.16	4.31	4.16
Honduras	0.110	0.62	5.69	5.07					
South America Region									
Colombia	0.132	6.80	51.65	44.85	Uruguay	0.048	0.41	8.71	8.29
Brazil	0.115	21.52	186.80	165.28	Peru	0.047	1.51	32.00	30.49
Chile	0.053	1.90	36.05	34.16	Bolivia	0.032	0.29	9.21	8.92
Paraguay	0.052	0.43	8.34	7.91					
African Region									
Egypt	0.251	24.42	97.41	72.99	Nigeria	0.029	2.08	72.55	70.47
Morocco	0.213	5.28	24.77	19.49	Uganda	0.021	0.23	10.95	10.72
Mauritius	0.128	0.49	3.87	3.38	Côte d'Ivoire	0.018	0.23	13.02	12.78
Kenya	0.055	1.19	21.76	20.58					
Oceania Region									
New Zealand	0.741	14.88	20.09	5.20	Australia	0.556	56.16	100.93	44.78

Source: Authors' calculations using Frontier 4.1 software (2026).

In the Asian region, export efficiency varies substantially across destination markets, reflecting differences in market conditions, competition, and trade barriers. The Philippines records the highest efficiency at 80.6%, followed by Malaysia at 71.1% and the United Arab Emirates at 47.9%. In contrast, the lowest efficiency levels are observed in China (0.5%), India

(1.5%), and Türkiye (3.9%), indicating that a substantial share of Indonesia's export potential to these markets remains unrealized. China records the largest export gap in Asia at US\$1,256.3 million, followed by India at US\$535.76 million and Japan at US\$201.93 million. These substantial gaps indicate that low export efficiency does not necessarily reflect weak market size, but may also be associated with market-access constraints, competition, and trade costs. In markets such as Qatar, Kuwait, and Saudi Arabia, trade barriers and logistics costs may constrain competitiveness, including through tariffs and domestic trade policies. Saudi Arabia, for instance, has strengthened localization policies under Saudi Vision 2030 (Abuhussain, 2025; Matthews et al., 2026), while its tariffs have ranged from 7–20% since 2020 and Qatar maintains tariffs of around 5% (Komalasari, 2025; Ningsih & Nisaa, 2020). Japan presents a different pattern, with an efficiency level of 35.8% and a substantial export gap of US\$201.93 million despite a 0% import tariff on rubber tires. This suggests that low tariff barriers alone do not necessarily ensure optimal market utilization, as demand conditions, automotive industry performance, competition, and other trade-related factors also influence export performance. The 5.8% decline in Japan's automotive production in 2024 may indicate weaker market demand ([ITPC OSAKA] Indonesian Trade Promotion Center Osaka, 2018; Azizah et al., 2023). Meanwhile, the relatively low efficiency observed in India, South Korea, Vietnam, and Türkiye suggests that export opportunities remain constrained by market-access conditions, trade barriers, and competition from domestic and global producers ([ITPC OSAKA] Indonesian Trade Promotion Center Osaka, 2018; Azizah et al., 2023). Nevertheless, the Indonesia–United Arab Emirates Comprehensive Economic Partnership Agreement (IUAE-CEPA) and Indonesia–Korea Comprehensive Economic Partnership Agreement (IK-CEPA), both implemented since 2023, may provide opportunities to reduce trade barriers and improve market utilization (Purwanto, 2024).

In Europe, export efficiency remains relatively low across most destination markets, although substantial differences exist in their unrealized export potential. The Netherlands records the highest efficiency at 60.1%, followed by Latvia at 30.4% and Romania at 27.1%. Germany, however, records the largest export gap in the region at US\$210.21 million, followed by France at US\$178.87 million and Italy at US\$145.09 million. These findings indicate that larger market potential does not necessarily translate into higher export efficiency. The Netherlands presents a relatively distinct case because its role as a European distribution hub through the Port of Rotterdam may provide logistical advantages and reduce trade costs, as reflected in the concept of geo distance (Nefs et al., 2022; Sbitenkova, 2024). Nevertheless, its efficiency level of 60.1% indicates that Indonesia's export potential in this market has not yet been fully realized. During the study period, Indonesian products continued to face limited preferential access to the EU market in the absence of an implemented Indonesia-European Union Comprehensive Economic Partnership Agreement (IEU-CEPA), while competition from geographically closer suppliers, such as Poland, Slovakia, and Türkiye, provided advantages in transportation and distribution costs. Prospects for reducing tariff barriers improved following the signing of the IEU-CEPA in 2025, which is expected to eliminate most trade tariffs once implemented (Ardelia, 2026).

In North America, the United States records the highest export efficiency at 85.2%, as well as the largest actual and potential export values. Indonesia's actual exports to the United States reach US\$739.23 million, while potential exports are estimated at US\$867.81 million, resulting in an export gap of US\$128.58 million. This finding indicates that although the U.S. market is relatively well utilized, considerable room for further export expansion remains. This performance may be associated with strong replacement-tire demand and changing competitive conditions resulting from antidumping measures against several suppliers (Doarest & Wihardja, 2026; Xiong, 2017). In contrast, Mexico and Central American markets exhibit relatively low efficiency, with Mexico recording an efficiency level of 20.6% and an export gap of US\$111.47 million. These conditions may reflect tariff barriers, limited FTA coverage, competition from regional suppliers benefiting from United States-Mexico-Canada Agreement (USMCA) and the Central America-Dominican Republic Free Trade Agreement (CAFTA-DR), and distance that increases logistics costs from Indonesia to the region (Behari Dave, 2025; Handoyo et al., 2024). These distance-related constraints are also reflected in Indonesia–North America shipping times of approximately 27–45 days, potentially increasing trade costs and vulnerability to supply-chain disruptions.

In South America, Indonesia's export efficiency remains relatively low, with the highest

efficiency recorded in Colombia at only 13.2%, followed by Brazil at 11.5%. Brazil records the largest export gap in the region at US\$165.28 million, followed by Colombia at US\$44.85 million. These substantial gaps indicate that the export potential of South American markets remains underutilized. The relatively low efficiency observed across the region may reflect a combination of tariff barriers, distance, logistics costs, and competition from regional suppliers. Chile, for example, records an efficiency level of only 5.3% despite the IC-CEPA providing preferential tariffs of approximately 0–3%, suggesting that tariff reductions alone have not yet resulted in optimal market utilization because shipping distance and competition from major suppliers remain important constraints ([Trademap, 2026](#)). Geographical constraints are particularly evident in landlocked countries such as Paraguay and Bolivia, which depend on transit ports in other countries, thereby lengthening distribution chains and increasing trade costs. Peru and Uruguay also exhibit low export efficiency, at 4.7% and 4.8%, respectively. The IP-CEPA signed in 2025 may improve Peru's market access through the gradual elimination of tariffs ([Hutagaol, 2025](#); [Primayanti, 2025](#)).

In Africa and Oceania, export efficiency also varies considerably across destination markets, indicating that substantial export potential remains unrealized. In Africa, Egypt records the highest efficiency at 25.1% and the largest export gap at US\$72.99 million, followed by Nigeria with an export gap of US\$70.47 million. These findings indicate that although Egypt is relatively more efficient than other African markets, a substantial share of its export potential remains untapped. Tariff barriers, exchange-rate volatility, and disruptions along the Red Sea shipping route may increase shipping costs and transit times from Indonesia relative to geographically closer suppliers ([Yap et al., 2025](#)). Mauritius presents a relatively promising market, with an efficiency level of 12.8%, supported by its dependence on imports and relatively open trade environment. Developments under the Indonesia–Mauritius Preferential Trade Agreement may further improve market access ([Louis, 2024](#)). In contrast, the low efficiency observed in Kenya, Nigeria, Côte d'Ivoire, and Uganda suggests persistent constraints associated with tariffs and distance; Uganda's landlocked position further increases distribution costs through regional transit ports ([Chakroborty, 2022](#)). In Oceania, New Zealand records an efficiency level of 74.1%, while Australia records 55.6%. Nevertheless, Australia has a larger export gap of US\$44.78 million compared with only US\$5.20 million for New Zealand, indicating greater room for export expansion despite Australia's relatively high efficiency. Preferential tariff access through Indonesia-Australia Comprehensive Economic Partnership Agreement (IA-CEPA) and the ASEAN-Australia-New Zealand Free Trade Area (AANZFTA) provides advantages for Indonesian products, but logistics costs, maritime connectivity, and competition from countries integrated into the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) indicate that trade efficiency is determined not only by tariffs but also by trade costs and supply-chain integration ([Judijanto et al., 2024](#); [Kementerian Koordinator Bidang Perekonomian, 2025](#); [Nasrullah, 2025](#)).

CONCLUSION

The study finds that destination-market GDP expands Indonesian rubber tire exports, whereas geographical distance constrains them; export inefficiency declines with real exchange rate depreciation and stronger government effectiveness but rises with import tariffs and landlocked destinations. Model 3 remains the preferred specification after controlling for area and year effects, and the estimated export gaps show that large markets such as China, India, Germany, Japan, France, Brazil, and the United States still contain substantial unrealized potential.

The main contribution is a destination-market map that combines export efficiency with export-gap magnitude, allowing policy makers and the national tire industry to distinguish markets for expansion from markets that should be consolidated. Priority should therefore be given to large-gap destinations through market-access initiatives, targeted export promotion, and logistics improvements, while relatively efficient markets should be protected and deepened.

The analysis does not incorporate non-tariff measures such as technical regulations, quality standards, and customs procedures. Future research should integrate these indicators and examine low-base or emerging destinations outside the present 68-country sample to test whether additional high-growth opportunities are being missed.

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AUTHOR CONTRIBUTION STATEMENT

Ni Ketut Dela Yanti contributed to the conceptualization, methodology development, data collection, data analysis, interpretation of results, and preparation of the original manuscript draft. A. Faroby Falatehan contributed to the research design, validation of the analytical framework, review, and critical revision of the manuscript. Dedi Budiman Hakim contributed to methodological guidance, supervision, validation of findings, and final review of the manuscript. All authors have read and approved the final version of the manuscript and agreed to be accountable for all aspects of the research.

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