# Sustainability-Adjusted Gravity Model for Indonesian Nutmeg Exports: Competitiveness and SDG-Oriented Trade Planning

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**ABSTRACT**

Indonesia is the world's largest producer and exporter of nutmeg, contributing up to 75% of global supply. However, its export performance has remained volatile compared to competitors such as Guatemala and Nepal. This paradox highlights the importance of moving beyond descriptive trade analysis toward models that integrate both competitiveness and sustainability dimensions. This study aims to develop a Sustainability-Adjusted Gravity Model (S-Gravity) to evaluate Indonesian nutmeg exports in relation to competitiveness and the Sustainable Development Goals (SDGs). The model expands on the conventional gravity framework by incorporating indicators of revealed comparative advantage, trade cost efficiency, and exchange rate stability. The analysis employs panel data covering the period 2005–2024 across seven primary importing countries: Vietnam, India, the Netherlands, Germany, Italy, the United States, and Japan. Competitiveness is first assessed using Revealed Comparative Advantage (RCA) and Symmetric RCA (SRCA), followed by panel regression under the random effects specification to identify macroeconomic and structural determinants of trade flows. Results show that Indonesia maintains a strong comparative advantage, though RCA trends suggest gradual erosion of relative strength. Exporter GDP and exchange rate depreciation significantly increase export volumes, while importer population exerts a negative effect, reflecting nutmeg's niche and industrial demand profile. SRCA and trade costs show positive but insignificant impacts, underscoring the need for sustainability-oriented improvements. The study concludes that aligning competitiveness with sustainability factors through the S-Gravity framework provides a more comprehensive tool for trade planning. Policy implications emphasize post-harvest quality control, logistics reform, and value addition as strategies to strengthen competitiveness while advancing SDG-oriented trade and inclusive development.

## 1. INTRODUCTION

Indonesia remains the world's leading producer and exporter of nutmeg, contributing approximately 60-75% of global supply, yet its export performance has been marked by persistent fluctuations over the past two decades [1]. Nutmeg holds strategic value given its applications in food, pharmaceutical, and cosmetic industries, but Indonesia's trade growth has not matched its production strength, leaving space for competitors like Guatemala and Nepal to secure more stable market positions [2]. This paradox highlights the need to examine not only export volumes but also the structural factors shaping competitiveness and sustainability in nutmeg trade [3]. In an era where global trade is increasingly linked with sustainability, Indonesia faces both significant opportunities and systemic challenges in positioning nutmeg within resilient international markets [4].

Scholars frequently employ comparative advantage indicators such as the Revealed Comparative Advantage (RCA) and the Symmetric RCA (SRCA) to analyze competitiveness

in agricultural commodities [5]. Empirical evidence suggests Indonesian nutmeg consistently records high RCA values, averaging above 17, placing it among the strongest agricultural exports worldwide [6]. However, high RCA scores do not automatically ensure trade stability, especially when inconsistencies persist in quality assurance, logistics systems, and compliance with global standards [7]. These shortcomings indicate the importance of moving beyond conventional competitiveness metrics toward frameworks that also incorporate sustainability considerations [8].

The gravity model has long been a robust framework for analyzing bilateral trade flows, relating export dynamics to economic size, distance, and structural frictions [9]. In agricultural trade, gravity models have demonstrated strong explanatory power, particularly when expanded to include variables like trade costs, exchange rates, and policy barriers [10]. Nonetheless, traditional gravity models tend to underrepresent sustainability dimensions, despite their growing relevance for commodities vulnerable to climate risks, certification requirements, and international quality

standards [11]. For nutmeg in particular, overlooking sustainability-related drivers risks underestimating the impact of logistics efficiency, quality control, and macroeconomic stability on long-term competitiveness [12].

Incorporating sustainability into competitiveness assessments has become a pressing research frontier in agricultural trade [13]. Post-harvest management, aflatoxin mitigation, and adherence to sanitary and phytosanitary (SPS) measures are now recognized as central determinants of export performance in spices and similar crops [14]. Additionally, trade cost efficiency and exchange rate volatility strongly influence the ability of exporters to maintain surpluses in increasingly competitive markets [15]. However, research integrating these sustainability-oriented variables into gravity-based models remains limited and underdeveloped, particularly in the spice trade [6, 16]. This study seeks to close this gap by advancing a Sustainability-Adjusted Gravity Model (S-Gravity) tailored for Indonesian nutmeg exports.

The integration of trade analysis with the Sustainable Development Goals (SDGs) is increasingly recognized as a strategic pathway for economic planning [17]. Nutmeg production and trade intersect directly with SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), as the crop supports rural incomes while serving global consumer markets [18]. For Indonesia, embedding nutmeg exports within an SDG-oriented framework offers a way to reinforce competitiveness while promoting inclusive economic growth [4, 19]. Despite its potential, few empirical studies have explicitly linked nutmeg trade to SDG-based policy frameworks, leaving a knowledge gap with significant policy implications [20].

Previous research on Indonesian spices has largely examined descriptive trade flows, comparative advantage indices, or selected macroeconomic drivers [21]. While these studies offer valuable insights, they fall short of integrating competitiveness with sustainability dimensions in a unified model. This lack of integration means policymakers and industry actors remain limited in their ability to assess how reforms in areas such as post-harvest quality upgrading, logistics improvements, or certification systems could translate into measurable trade benefits [22]. Addressing this gap requires a more comprehensive framework that merges traditional trade analysis with sustainability imperatives.

The unique trade dynamics of nutmeg further underscore the limitations of relying solely on conventional economic indicators [23]. Importer GDP, for example, often exerts limited influence, since nutmeg demand is driven less by household consumption and more by industrial requirements. Similarly, population size is not necessarily a predictor of higher demand, reflecting nutmeg's position as a niche and differentiated product [4]. These structural peculiarities demand the inclusion of sustainability-related variables such as competitiveness in quality upgrading and resilience in supply chains to capture the full scope of export performance [24].

The proposed S-Gravity Model expands upon the explanatory power of conventional frameworks by integrating competitiveness and sustainability dimensions [25]. Specifically, it introduces SRCA as a proxy for comparative advantage, trade cost efficiency as a measure of logistical sustainability, and exchange rate stability as an indicator of macroeconomic resilience [26]. Synthesizing these elements enables the model not only to assess trade flows but also to generate actionable insights for sustainable export planning [27]. This represents a step forward in aligning trade theory with sustainability imperatives in global commodity markets.

Ensuring that Indonesia's nutmeg exports remain competitive while meeting sustainability demands is essential for long-term sector resilience [28]. Without such integration, the country risks losing its comparative advantage to competitors that adapt more effectively to sustainability-driven standards. Conversely, aligning competitiveness with SDG-oriented planning offers Indonesia a pathway to contribute more meaningfully to economic growth, rural development, and trade resilience [29]. Nutmeg thus emerges not only as an agricultural commodity but also as a vehicle for advancing broader sustainable development objectives.

This study, therefore, follows a sequential conceptual pathway. First, we assess Indonesia's trade performance in nutmeg using conventional competitiveness indicators (RCA and SRCA) to establish the strength and evolution of its comparative advantage [30]. Second, we embed these competitiveness metrics into a gravity model of bilateral trade flows, where macroeconomic size, exchange rates, and trade costs capture structural determinants of exports. Third, we extend this gravity specification with sustainability-oriented structural factors competitiveness resilience (SRCA), trade cost efficiency, and exchange rate stability forming a S-Gravity framework.

It is important to note that the present study does not model SDG indicators directly within the econometric specification. Instead, the S-Gravity framework is interpreted as an input to SDG-oriented trade planning: it identifies how competitiveness and structural factors in nutmeg trade relate to SDG-relevant objectives such as food security (SDG 2), decent work and growth (SDG 8), and responsible production (SDG 12). The link to the SDGs thus operates at the level of policy interpretation rather than through explicit SDG metrics in the regression.

From this context, three research questions guide the analysis:

(1) How does the S-Gravity Model explain the competitiveness of Indonesian nutmeg exports?

(2) Which sustainability-related factors most significantly shape export performance?

(3) How can SDG-oriented trade strategies be aligned with long-term competitiveness in Indonesia's nutmeg sector?

## 2. METHODOLOGY

### 2.1 Research design

This study employs a quantitative research design grounded in international trade theory and econometric modeling. Specifically, the research integrates RCA, SRCA, and a panel gravity model to evaluate the competitiveness and sustainability of Indonesian nutmeg exports between 2005 and 2024. The methodological framework combines descriptive competitiveness analysis with econometric estimation to ensure robust insights into trade performance, macroeconomic determinants, and sustainability-oriented planning.

### 2.2 Data source and scope

The analysis relies on secondary data covering the period 2005–2024. Export volumes, values, and partner-country information were collected from UN Comtrade (2024).

Macroeconomic indicators, including exporter and importer GDP, exchange rates, and population figures, were obtained from the World Bank Development Indicators. Trade costs were derived from bilateral trade cost databases, and exchange rate volatility was calculated from monthly fluctuations. The sample includes Indonesia and its seven primary importing partners: Vietnam, India, the Netherlands, Germany, Italy, the United States, and Japan, which together account for the majority of Indonesian nutmeg trade.

## 2.3 Competitiveness indices

### 2.3.1 Revealed Comparative Advantage (RCA)

Competitiveness was first measured using the RCA index expressed as:

$$RCA_t = \frac{\dfrac{X\frac{nutmeg}{IDN,t}}{X\frac{total}{IDN,t}}}{\left(\dfrac{X\frac{nutmeg}{world,t}}{X\frac{total}{world,t}}\right)}$$

where,

$X_{nutmeg,IDN,t}$ = Indonesia's nutmeg exports at time t,
$X_{total,IDN,t}$ = total nutmeg exports at time t,
$X_{nutmeg,world,t}$ = nutmeg exports at time t,
$X_{total,world,t}$ = total world exports at time t.
RCA values greater than 1 indicate comparative advantage.

### 2.3.2 Symmetric RCA (SRCA)

To reduce the upward bias of RCA for dominant exporters, SRCA was applied, defined as:

$$SRCA_t = \left(\frac{RCA_t - 1}{RCA_t + 1}\right)$$

The SRCA provides a bounded measure between −1 and +1, with positive values indicating comparative advantage and negative values indicating disadvantage.

## 2.4 Gravity model specification

### 2.4.1 Baseline model

The determinants of Indonesian nutmeg exports were analyzed using a panel gravity model, estimated via Random Effects Model (REM) following the Hausman test results. The baseline specification is:

$$lnY_{ij,t} = \alpha + \beta^1 lnGDP_t^E + \beta^2 lnGDP_{j,t}^I + \beta^3 lnFX_t \\ + \beta^4 lnPOP_{j,t} + \beta^5 SRCA_t + \beta^6 lnTC_{j,t} \\ + \varepsilon_{ij,t}$$

where,

$Y_{ij,t}$ = export volume of nutmeg from Indonesia to country j at time t,
$GDP_t^E$ = Indonesia's GDP,
$GDP_{j,t}^I$ = GDP of importing country j,
$FX_t$ = exchange rate (Rupiah∨USD),
$POP_{j,t}$ = importer's population,
$SRCA_t$ = competitiveness index of Indonesian nutmeg,

$TC_{j,t}$ = bilateral trade facilitation index (composite trade cost proxy),
$\varepsilon_{ij,t}$ = error term.

### 2.4.2 Sustainability adjustment

The interaction terms are theoretically motivated by the notion that competitiveness and structural frictions jointly shape export performance. A high level of comparative advantage (captured by SRCA) may not automatically translate into larger exports if trade costs remain high or if exchange rates are highly volatile. Conversely, reductions in trade costs or improvements in macroeconomic stability are likely to yield larger export gains in sectors that already possess a strong comparative advantage. This complementarity between competitiveness and structural conditions has been emphasized in the agri-food trade and trade facilitation literature, where trade cost reductions disproportionately benefit sectors with strong revealed advantages and established market linkages [10, 21].

Accordingly, we extend the baseline gravity specification by incorporating interaction terms between competitiveness and (i) trade frictions and (ii) exchange-rate volatility:

$$\ln Y_{ij,t} = \cdots + \gamma_1\left(SRCA_t \times \ln TC_{j,t}\right) \\ + \gamma_2(SRCA_t \times VOLFX_t) + \varepsilon_{ij,t}$$

where,

- $Y_{ij,t}$ is the export volume of Indonesian nutmeg shipped to importer $j$ in year $t$ (the dependent variable used consistently throughout the gravity estimations; $\ln Y_{ij,t}$ denotes its natural logarithm);
- $SRCA_t$ is the Symmetric Revealed Comparative Advantage of Indonesian nutmeg in year $t$, bounded in $[-1, +1]$;
- $TC_{j,t}$ is the bilateral trade cost / trade-friction proxy between Indonesia and importer $j$ in year $t$ (expressed in logarithmic form $\ln TC_{j,t}$ to retain elasticity interpretation; higher values indicate higher trade frictions);
- $VOLFX_t$ is exchange rate volatility in year $t$, constructed from monthly fluctuations of the Rupiah exchange rate (details provided in the data section/appendix);
- $\varepsilon_{ij,t}$ is the idiosyncratic error term.

The interaction term $SRCA_t \times \ln TC_{j,t}$ captures whether the export payoff from competitiveness depends on the level of trade frictions: when competitiveness is high, reductions in trade frictions are expected to yield larger export gains. Similarly, $SRCA_t \times VOLFX_t$ tests whether exchange-rate instability dampens the ability of a competitive exporter to expand shipments, because volatility increases pricing uncertainty and contracting risk.

## 2.5 Estimation procedure

The estimation proceeded in three stages:
1. Competitiveness analysis using RCA and SRCA to establish Indonesia's comparative advantage relative to other nutmeg exporters.
2. Panel regression applying REM to test the significance of macroeconomic, demographic, and competitiveness factors. Model selection between REM and Fixed Effects

was based on the Hausman test, which supported REM as more efficient.
3. Sustainability Adjusted Model by incorporating interaction terms to assess the joint role of competitiveness, trade costs, and macroeconomic stability.

## 2.6 Model diagnostics

To ensure reliability, diagnostic checks were performed:
- Goodness of fit via $R^2$ and adjusted $R^2$.
- F-test for overall significance.
- T-tests for individual coefficients.
- Robustness checks with lagged variables and alternative specifications.

The methodological structure thus integrates competitiveness measures with econometric modeling to produce a comprehensive and policy-relevant framework, as illustrated in Figure 1.
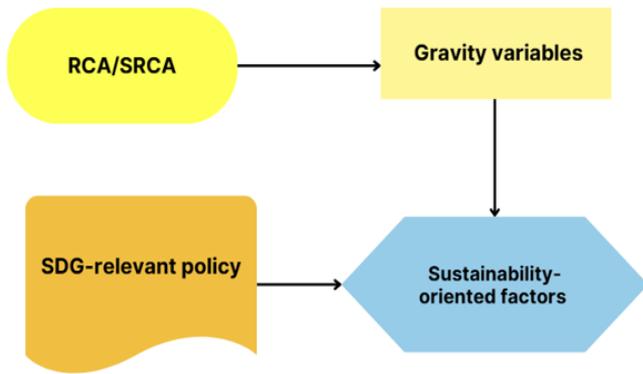


**Figure 1.** Conceptual pathway of the Sustainability-Adjusted Gravity framework

## 3. RESULTS AND DISCUSSION

### 3.1 Competitiveness analysis of Indonesian nutmeg

The competitiveness of Indonesian nutmeg exports was initially assessed using the RCA index, which measures relative trade advantage. The RCA formula is expressed in the method section.

A value of RCA greater than one indicates the presence of comparative advantage, while higher values imply stronger competitive positions.

**Table 1.** RCA of major nutmeg exporting countries (2005–2024)

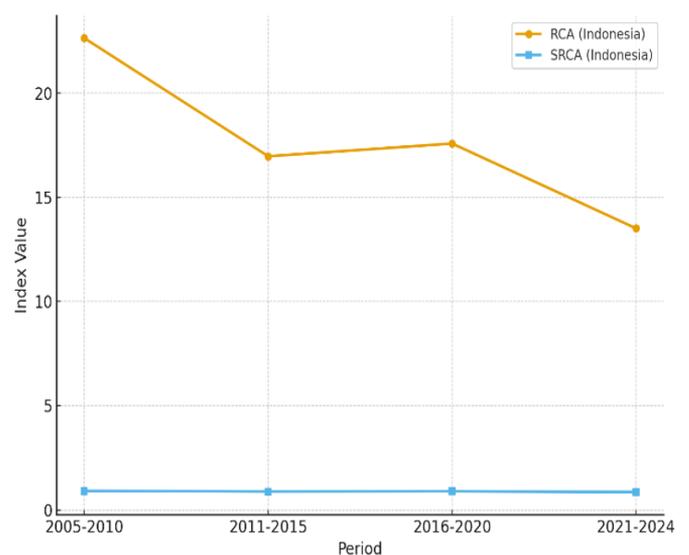| Period | Indonesia | Guatemala | India | Nepal |
|---|---|---|---|---|
| 2005–2010 | 22.64 | 993.23 | 7.32 | 79.30 |
| 2011–2015 | 16.97 | 893.16 | 6.28 | 359.45 |
| 2016–2020 | 17.58 | 544.99 | 8.84 | 1077.83 |
| 2021–2024 | 13.51 | 731.30 | 6.15 | 710.02 |
| **Average** | **17.67** | **790.67** | **7.15** | **557.00** |

Source: UN Comtrade (2024), processed by authors

The RCA results confirm that Indonesia maintains a strong comparative advantage in nutmeg exports, with values consistently above 15 throughout the study period (Table 1). However, a declining trend is evident, as RCA values fell from 22.64 in 2005–2010 to 13.51 in 2021–2024. This trajectory

suggests that while Indonesia remains highly competitive, its relative strength has weakened due to structural pressures such as rising trade costs, inconsistent quality assurance, and stricter compliance requirements in global markets. In comparison, Guatemala and Nepal recorded exceptionally high RCA scores, indicating their dominance in specialised export niches, while India maintained more moderate competitiveness with an average of 7.15.

The downward trend in Indonesia's RCA warrants closer interpretation. Several strands of empirical work suggest that this erosion is linked to quality, productivity, and external shocks. First, studies on Indonesian nutmeg and spices highlight persistent issues in post-harvest handling, aflatoxin contamination, and inconsistent moisture control, which have led to rejections and stricter requirements in key markets [2, 6, 14, 23]. Second, climate variability and ageing tree stock are reported to affect yields and quality, contributing to production instability and lower exportable surpluses [4, 19]. Third, competitor countries such as Guatemala and Nepal have upgraded processing, certification, and branding, allowing them to capture higher-value market segments despite smaller production bases [4, 23]. Taken together, these factors help explain why Indonesia's RCA has declined even though the country remains the largest global supplier: quality and reliability constraints have eroded its relative advantage vis-à-vis more specialised and quality-differentiated competitors.

To address the upward bias inherent in RCA, the SRCA index was employed. The SRCA provides a balanced measure between −1 and +1, where positive values indicate comparative advantage. Indonesia's SRCA remained high and relatively stable at an average of 0.886 (Table 2), signalling robust competitiveness despite the downward RCA trend. Guatemala's near-perfect SRCA of 0.997 highlights its overwhelming strength, while Nepal's rapid rise from 0.199 in 2005–2010 to 0.997 in 2021–2024 demonstrates the ability of smaller exporters to enhance their position through quality improvements and structural reforms. Indonesia's modest decline from 0.910 to 0.861, although less dramatic, signals increasing external pressures that could challenge long-term sustainability if left unaddressed (Figure 2).



**Figure 2.** Trends in Indonesia's RCA and SRCA for nutmeg, 2005–2024

**Table 2.** SRCA of major nutmeg exporting countries (2005–2024)

| Period | Indonesia | Guatemala | India | Nepal |
|---|---|---|---|---|
| 2005–2010 | 0.910 | 0.998 | 0.756 | 0.199 |
| 2011–2015 | 0.884 | 0.998 | 0.717 | 0.598 |
| 2016–2020 | 0.892 | 0.996 | 0.793 | 0.998 |
| 2021–2024 | 0.861 | 0.997 | 0.693 | 0.997 |
| **Average** | **0.886** | **0.997** | **0.740** | **0.698** |

Source: UN Comtrade (2024), processed by authors

### 3.2 Panel regression results

To analyze the macroeconomic and structural determinants of Indonesian nutmeg exports, a REM was estimated. The econometric specification is expressed as:

$$\ln Y_{ij,t} = \alpha + \beta_1 \ln G\,DP_t^E + \beta_2 \ln G\,DP_{j,t}^I$$
$$+\beta_3 \ln F\,X_t + \beta_4 \ln P\,OP_{j,t}$$
$$+\beta_5 SRCA_t + \beta_6 \ln T\,C_{j,t} + \varepsilon_{ij,t}$$

The lack of statistical significance of SRCA in the REM should not be interpreted as evidence that comparative advantage is irrelevant for nutmeg exports. Methodologically, SRCA varies over time but not across partner countries, which limits its cross-sectional variation in a panel with only seven importers and reduces its power to explain bilateral differences once macroeconomic variables are controlled for. Substantively, SRCA remains highly informative in the descriptive analysis (Section 3.1), where it captures the persistence and gradual erosion of Indonesia's specialization in nutmeg. In the S-Gravity framework, SRCA is therefore interpreted as a medium-run competitiveness and resilience indicator that interacts with trade costs and exchange rate volatility, rather than as a standalone short-run determinant of bilateral export volumes.

**Table 3.** Random effects estimation results (2005–2024)

| Variable | Coefficient | t-Statistic | Prob. | Significance |
|---|---|---|---|---|
| Constant | 14.209 | 5.0416 | 0.0000 | *** |
| Exporter GDP | 0.5232 | 4.4279 | 0.0000 | *** |
| Importer GDP | -0.0134 | -0.1567 | 0.8757 | ns |
| Exchange Rate | 0.1754 | 4.2614 | 0.0000 | *** |
| Population | -0.3058 | -2.2333 | 0.0272 | ** |
| SRCA | 2.2444 | 1.3823 | 0.1692 | ns |
| Trade Costs | 0.0821 | 0.6885 | 0.4923 | ns |
| R-squared | 0.3558 | – | – | – |
| F-statistic | 12.2456 | – | 0.0000 | *** |

*** $p<0.01$, ** $p<0.05$, ns = not significant*

The REM provides further insight into the drivers of Indonesian nutmeg exports, as shown in Table 3. Exporter GDP shows a strong and significant positive effect (0.5232), confirming that domestic production capacity is the foundation of export growth. Exchange rate depreciation also boosts export volumes (0.1754), underscoring the role of price competitiveness. However, importer population has a negative and significant effect (-0.3058), reflecting the fact that nutmeg demand does not scale with population size but with industrial demand and niche consumption patterns.

Interestingly, SRCA shows a large positive coefficient (2.2444) but is not statistically significant. This suggests that comparative advantage alone cannot sustain exports without structural and sustainability support, such as efficient logistics, post-harvest quality control, and certification mechanisms. Trade costs also appear with a positive but insignificant effect, highlighting inefficiencies in Indonesia's logistics and trade facilitation systems. The model explains most of the variation in exports with an R² value of 0.356, indicating moderate explanatory power for the selected variables.

The positive sign of the trade cost variable, although statistically insignificant, merits comment. The bilateral trade cost proxy employed in this study is derived from ESCAP World Bank bilateral trade cost database and is a composite index that reflects overall trade facilitation and market access conditions. Higher index values therefore correspond to more efficient trade environments rather than higher costs. Under this definition, the positive coefficient aligns with the expectation that more favorable trade conditions support larger export volumes. Nonetheless, the composite nature of the indicator raises the possibility of measurement error and endogeneity (e.g., countries with higher trade volumes may also invest more in trade facilitation). We therefore interpret this coefficient cautiously and emphasize the need for future work to disentangle trade policy, logistics performance, and reverse causality using more granular or instrumental-variable approaches.

### 3.3 Country-level effects

The REM also provided country-specific intercepts that reveal heterogeneity among Indonesia's export destinations.
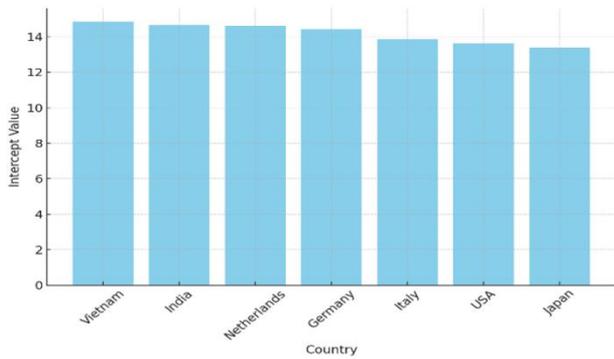
**Table 4.** Country intercept effects for nutmeg exports

| Country | Intercept (Country-Specific Effect) |
|---|---|
| Vietnam | 14.863 |
| India | 14.673 |
| Netherlands | 14.607 |
| Germany | 14.423 |
| Italy | 13.878 |
| USA | 13.624 |
| Japan | 13.397 |

Source: Author's calculation based on REM

Table 4 shows that the country-specific intercepts reveal clear heterogeneity across Indonesia's main export destinations. Vietnam emerges as the most responsive and strategically vital partner, reflecting both its role as a major consumer and as a re-export hub that processes nutmeg into higher value derivatives for redistribution. India and the Netherlands follow, driven by sustained industrial demand for raw and semi-processed nutmeg. Germany and Italy show moderate intercepts, reflecting quality-sensitive markets with stringent standards, while Japan and the United States present lower intercepts, highlighting their role as smaller but premium-oriented markets.

Vietnam stands out with the highest intercept (14.863) as shown on Figure 3, underscoring its role as both a consumer and a re-export hub where raw nutmeg is processed into higher value derivatives. India and the Netherlands follow closely, reflecting their strong industrial demand. Germany and Italy show moderate intercepts, highlighting regulation-driven but stable demand in European markets. In contrast, Japan and the United States record the lowest intercepts, pointing to smaller but premium-oriented markets.

**Figure 3.** Country intercept effects for Indonesian nutmeg exports

These findings suggest that Indonesia must pursue differentiated trade strategies. For volume-driven markets such as Vietnam and India, efficiency improvements in logistics and bulk trade are essential. In contrast, European markets demand strict compliance with food safety, traceability, and organic certification. Japan and the United States offer opportunities for premium branding and value-added nutmeg products, such as oils and oleoresins. Recognizing these differences ensures that policy interventions are not generalized, but instead tailored to the distinct requirements of each market.

### 3.4 Discussion

The integration of competitiveness measures and panel regression analysis yields three critical insights that are highly relevant for both trade theory and practice. First, the findings show that competitiveness alone, as measured by RCA and SRCA, does not guarantee export growth. Although Indonesia consistently records a strong comparative advantage, the regression results reveal that SRCA is not statistically significant in driving export volumes. This aligns with previous studies indicating that competitiveness must be accompanied by structural reforms such as quality certification, logistics improvements, and compliance with global standards to achieve sustained export performance [6]. The results therefore emphasize that competitiveness must be contextualized within sustainability-oriented trade strategies [13, 17].

Second, macroeconomic drivers such as exporter GDP and exchange rates emerge as decisive factors shaping Indonesian nutmeg exports. The positive role of GDP reflects that expanding domestic production capacity remains central to sustaining export growth. Similarly, the significant positive impact of exchange rate depreciation shows that price competitiveness continues to matter in global spice markets. These findings are consistent with earlier work demonstrating that macroeconomic stability, production scale, and exchange rate dynamics play crucial roles in determining agricultural export competitiveness [16, 23]. Hence, strengthening Indonesia's nutmeg sector requires a balanced focus on both domestic capacity-building and macroeconomic policy stability.

Third, the heterogeneity revealed by country-specific intercepts underscores the importance of differentiated market strategies. Vietnam, with the highest intercept, illustrates its role not only as a consumer market but also as a re-export hub, which mirrors evidence from studies highlighting Southeast Asia's growing role in global spice redistribution [19, 21].

India and the Netherlands also stand out as key destinations driven by industrial demand, while Germany and Italy reflect quality-sensitive European markets. In contrast, Japan and the United States represent niche but premium-oriented markets, consistent with research suggesting that developed economies increasingly prioritize certification, traceability, and branding in agricultural imports [20, 27]. This heterogeneity highlights the need for Indonesian exporters to adopt market-specific approaches rather than one-size-fits-all strategies.

From a broader perspective, the findings demonstrate that competitiveness and sustainability must be viewed as complementary, not separate, dimensions of trade planning. Previous literature emphasizes that without sustainable practices such as post-harvest improvements, eco-certification, and supply chain traceability, comparative advantage in commodities like spices can erode rapidly [28]. Empirical work on spatial price integration and asymmetric adjustment in red shallot markets between rural and urban areas in North Sumatra similarly shows that market efficiency, if not aligned with smallholder resilience, can generate uneven welfare outcomes and undermine rural sustainability [31]. Related evidence from integrated agriculture in Southeast Aceh also indicates that strengthening rural economies requires aligning commodity value chains with broader regional planning and sustainability objectives [32]. Indonesia's nutmeg sector thus faces a dual challenge: maintaining its global market share while adapting to increasingly stringent sustainability requirements, in a way that also supports rural livelihoods and territorial development. This underscores the potential of the S-Gravity to provide policymakers with a tool that links macroeconomic, competitiveness, and sustainability variables into one coherent framework.

## 4. CONCLUSION AND POLICY IMPLICATION

### 4.1 Conclusion

This study investigated the competitiveness and sustainability of Indonesian nutmeg exports by applying RCA, SRCA, and a panel gravity model across major importing countries over the period 2005–2024. The results confirm that Indonesia holds a strong comparative advantage, with high RCA and SRCA values, but the downward trend in RCA reflects emerging vulnerabilities in global markets. The econometric analysis demonstrates that exporter GDP and exchange rate dynamics significantly influence export volumes, while importer population exerts a negative effect, highlighting nutmeg's niche and industrial demand characteristics. Although SRCA contributes positively, it was not statistically significant, suggesting that competitiveness alone is insufficient to ensure sustained export growth without supportive structural and sustainability conditions.

The country-level results reveal important market heterogeneity. Vietnam emerged as the most responsive and strategically vital partner, followed by India and the Netherlands, while Japan and the United States were identified as smaller but premium-oriented destinations. These findings underscore the importance of differentiated trade strategies across markets. Overall, this research contributes a new framework the S-Gravity Model—that integrates competitiveness and sustainability into a single analytical tool. By linking comparative advantage metrics with sustainability-oriented trade planning, the study demonstrates how

Indonesia's nutmeg sector can strengthen its position in global markets while supporting broader development objectives.

## 4.2 Policy implications

The empirical evidence from the competitiveness indices (Tables 1-2), the S-Gravity estimations (Table 3), and the country-level intercepts (Table 4) yields several interrelated policy implications for strengthening Indonesia's nutmeg sector in a sustainable and globally competitive manner.

1. Strengthening production and value addition

The consistently high but declining RCA and SRCA values (Tables 1-2) indicate that Indonesia retains a strong comparative advantage in nutmeg, yet faces gradual erosion of its relative position due to structural constraints. Combined with the positive and highly significant coefficient on exporter GDP in the gravity model (Table 3), these findings suggest that expanding and upgrading domestic production capacity is central to sustaining export performance. Investment in modern agricultural practices, improved planting material, post-harvest technology (drying, storage, and aflatoxin control), and internationally recognised quality certification can stabilise and enhance Indonesia's comparative advantage. Such measures support SDG 2 (Zero Hunger) by strengthening rural livelihoods and food-related value chains, and SDG 12 (Responsible Consumption and Production) by reducing post-harvest losses and improving product safety.

2. Stabilising macroeconomic conditions

The exchange rate variable exhibits a positive and statistically significant effect on export volumes (Table 3), indicating that Rupiah depreciation tends to increase nutmeg exports through improved price competitiveness. However, excessive exchange rate volatility can undermine contract stability and investment planning, particularly for smallholders and exporters with limited hedging capacity. This underscores the need for macroeconomic policies that combine competitive yet predictable exchange rate dynamics with instruments such as export credit schemes, hedging facilities, and risk-management support for agri-exporters. Such macro-stability measures contribute to SDG 8 (Decent Work and Economic Growth) by providing a more secure environment for long-term investment in nutmeg-based value chains.

3. Reducing trade costs and improving logistics

The trade cost variable appears with a positive but statistically insignificant coefficient in the baseline S-Gravity model (Table 3), and is interpreted as a composite indicator of trade facilitation rather than purely higher costs. Its non-significance suggests that existing improvements in trade facilitation have not yet translated systematically into nutmeg export gains, pointing to remaining inefficiencies in logistics and border procedures. Targeted reforms such as upgrading port and storage infrastructure, enhancing cold-chain and container availability for spices, digitalising customs procedures, and strengthening regional transport corridors can reduce effective transaction costs and make Indonesia's nutmeg exports more responsive to trade facilitation improvements. These interventions align with SDG 9 (Industry, Innovation and Infrastructure) and indirectly support SDG 12 through more efficient, less wasteful supply chains.

4. Market differentiation strategies

The country-specific intercepts estimated in the REM (Table 4 and Figure 3) reveal marked heterogeneity across Indonesia's main export destinations. Vietnam has the highest intercept, followed by India and the Netherlands, while Germany, Italy, Japan, and the United States exhibit lower but more quality-oriented profiles. These differences imply that export planning cannot rely on a one-size-fits-all strategy. For volume-driven markets such as Vietnam and India, where baseline export propensities are highest, policy should prioritise efficiency in bulk trade: reliable supply, competitive pricing, and streamlined logistics. For European markets (the Netherlands, Germany, Italy), where quality standards and regulations are stringent, compliance with sanitary and phytosanitary requirements, organic and sustainability certification, and robust traceability systems is essential. For Japan and the United States, which show smaller but premium-oriented intercepts, Indonesia should emphasise branding, geographical indications, and high-value derivatives such as nutmeg oil and oleoresins. This differentiated approach allows trade policy to leverage the country-level patterns uncovered by the S-Gravity model.

5. Embedding sustainability in trade policy

The combination of high yet declining RCA/SRCA values (Tables 1-2), the limited direct effect of SRCA in the baseline regression (Table 3), and the role of structural variables (trade facilitation, exchange rate dynamics, and country-specific effects) collectively demonstrate that competitiveness alone is insufficient for long-term export growth. Instead, competitiveness must be embedded within a broader sustainability-oriented framework that strengthens quality, resilience, and inclusiveness along the value chain. In the context of the S-Gravity framework, this implies that trade policy should provide incentives for eco-certification, social and environmental standards, and digital traceability systems, while supporting inclusive business models that link smallholders to higher-value markets. Such measures directly support SDGs 8 and 12 and help position Indonesia as a responsible and resilient nutmeg supplier in global markets.

By operationalising the S-Gravity framework in this way, linking the econometric results to targeted interventions in production upgrading, macroeconomic management, trade facilitation, market differentiation, and sustainability governance Indonesia can convert its existing comparative advantage into a more durable, sustainable competitive advantage. The integration of macroeconomic stability, reduced trade frictions, and market-specific strategies with sustainability principles offers a concrete pathway to secure Indonesia's leadership in the global nutmeg trade while simultaneously advancing national development and contributing to the global sustainability agenda.

## 4.3 Limitations and future research

The trade data used in this study are subject to several well-known limitations. First, UN Comtrade primarily records formal, customs-declared flows and may under-represent informal or small-scale cross-border trade. Second, nutmeg is often re-exported via intermediary hubs, especially in Europe, which implies that recorded imports from countries such as the Netherlands may partly reflect re-exports rather than final consumption. Third, HS-based classification may conflate nutmeg and related products (e.g., mace or mixed spice preparations) when reporting practices differ across countries. These issues introduce measurement noise into the bilateral export series and may bias the level of trade flows, although they are less likely to alter the direction of estimated

relationships. We explicitly acknowledge these constraints in the Limitations section and encourage future work to triangulate customs data with firm-level or certification databases.

## REFERENCES

[1] Lontoh, R., Hanani, N., Riyanti Isaskar, S. (2025). Competitiveness of the Indonesian nutmeg commodity in the international market. Transactions of the Chinese Society of Agricultural Machinery, 56(1): 1-17. https://doi.org/10.62321/issn.1000-1298.2025.1.1

[2] Sulistiono, W., Assagaf, M., Darniadi, S., Wahab, A. (2022). Maintain and improve the quality of nutmeg seeds (Myristica fragrans) through the on farm to postharvest strategy on north Maluku. IOP Conference Series: Earth and Environmental Science, 1024(1): 012080. https://doi.org/10.1088/1755-1315/1024/1/012080

[3] Supriana, T., Pane, T.C., Sihombing, L. (2024). Analysis of factors affecting Indonesian nutmeg export volumes to sustainability of Indonesian nutmeg production. IOP Conference Series: Earth and Environmental Science, 1413(1): 012099. https://doi.org/10.1088/1755-1315/1413/1/012099

[4] Rochdiani, D., Wardhana, D., Deliana, Y., Suminartika, E., Wiyono, S.N., Suardi, T.F. (2025). Competitiveness of Indonesia's nutmeg in global market. Open Agriculture, 10(1): 20220404. https://doi.org/10.1515/opag-2022-0404

[5] Balogh, J.M. (2024). Agri-food trade competitiveness in Latin America and the Caribbean region. In Value Chain Dynamics in a Biodiverse Environment: Advances in Biodiversity, Sustainability, and Agri-food Supply Chain Development, pp. 15-36. https://doi.org/10.1007/978-3-031-49845-9_2

[6] Sujianto, S., Pribadi, E.R., Saptati, R.A., Mahendri, I., Santoso, A.B., Sondakh, J.O.M., da Silva, H.B. (2024). Assessing Indonesian nutmeg commodity trade competitiveness and developing sustainable strategies in the global market. Agris on-line Papers in Economics and Informatics, 16(3): 121-138. https://doi.org/10.7160/aol.2024.160309

[7] Purba, H.J., Yusufi, E.S., Hestina, J. (2021). Performane and competitiveness of Indonesian nutmeg in export market. E3S Web of Conferences, 232: 02018. https://doi.org/10.1051/e3sconf/202123202018

[8] Khan, M.I., Yasmeen, T., Khan, M., Hadi, N.U., Asif, M., Farooq, M., Al-Ghamdi, S.G. (2025). Integrating industry 4.0 for enhanced sustainability: Pathways and prospects. Sustainable Production and Consumption, 54: 149-189. https://doi.org/10.1016/j.spc.2024.12.012

[9] Capoani, L. (2023). Review of the gravity model: Origins and critical analysis of its theoretical development. SN Business & Economics, 3(5): 95. https://doi.org/10.1007/s43546-023-00461-0

[10] Abdullahi, N.M., Huo, X., Zhang, Q., Bolanle Azeez, A. (2021). Determinants and potential of agri-food trade using the stochastic frontier gravity model: Empirical evidence from Nigeria. Sage Open, 11(4): 21582440211065770. https://doi.org/10.1177/21582440211065770

[11] d'Albertas, F., Ruggiero, P., Pinto, L.F.G., Sparovek, G., Metzger, J.P. (2023). Agricultural certification as a complementary tool for environmental law compliance. Biological Conservation, 277: 109847. https://doi.org/10.1016/j.biocon.2022.109847

[12] Ohakwe, C.R., Wu, J. (2025). The impact of macroeconomic indicators on logistics performance: A comparative analysis using simulated scenarios. Sustainable Futures, 9: 100567. https://doi.org/10.1016/j.sftr.2025.100567

[13] Qazi, A. (2024). Exploring the impact of global competitiveness pillars on sustainable development. Environmental Impact Assessment Review, 105: 107404. https://doi.org/10.1016/j.eiar.2023.107404

[14] Meneely, J.P., Kolawole, O., Haughey, S.A., Miller, S.J., Krska, R., Elliott, C.T. (2023). The challenge of global aflatoxins legislation with a focus on peanuts and peanut products: A systematic review. Exposure and Health, 15(2): 467-487. https://doi.org/10.1007/s12403-022-00499-9

[15] Qiu, B., Das, K.K., Reed, W.R. (2020). The effect of exchange rates on Chinese trade: A dual margin approach. Emerging Markets Finance and Trade, 56(15): 3709-3731. https://doi.org/10.1080/1540496X.2019.1570842

[16] Kim, D., Steinbach, S., Zurita, C. (2025). Virtual water trade and economic integration: The role of trade agreements in global water redistribution. Applied Economic Perspectives and Policy, 47(5): 1998-2018. https://doi.org/10.1002/aepp.70021

[17] Claro, P.B.D.O., Esteves, N.R. (2021). Sustainability-oriented strategy and sustainable development goals. Marketing Intelligence & Planning, 39(4): 613-630. https://doi.org/10.1108/MIP-08-2020-0365

[18] Kirby, D.A., Healey-Benson, F. (2025). Harmonious entrepreneurship: A sustainable model for addressing global inequality. Journal of Entrepreneurship in Emerging Economies, 17(1): 26-44. https://doi.org/10.1108/JEEE-12-2023-0497

[19] Kühling, M., Alamsyah, Z., Sibhatu, K.T. (2022). Agrarian change, livelihood dynamics and welfare outcomes: Evidence from plantation crop farmers in Indonesia. Journal of Environmental Management, 311: 114864. https://doi.org/10.1016/j.jenvman.2022.114864

[20] Ralph, A.N., Peter, Q., Festus, T.E., Emmanuel, A.N., Butu, M.M., Ellen, H.N. (2025). Interlinkages Between Agri-food trade and the SDGs at the global, regional and local level. Journal of International Development, 37(4): 951-977. https://doi.org/10.1002/jid.3994

[21] Hoang, V.V. (2020). Investigating the agricultural competitiveness of ASEAN countries. Journal of Economic Studies, 47(2): 307-332. https://doi.org/10.1108/JES-10-2018-0366

[22] Tiits, M., Kalvet, T., Ounoughi, C., Yahia, S.B. (2024). Relatedness and product complexity meet gravity models of international trade. Journal of Open Innovation: Technology, Market, and Complexity, 10(2): 100288. https://doi.org/10.1016/j.joitmc.2024.100288

[23] Gordon, A. (2020). Market & technical considerations for spices: Nutmeg & Mace case study. In Food Safety and Quality Systems in Developing Countries, pp. 367-414. https://doi.org/10.1016/B978-0-12-814272-1.00009-7

[24] Osei, M.B., Papadopoulos, T., Acquaye, A., Stamati, T. (2023). Improving sustainable supply chain performance through organisational culture: A competing values

framework approach. Journal of Purchasing and Supply Management, 29(2): 100821. https://doi.org/10.1016/j.pursup.2023.100821

[25] Morland, C., Tandetzki, J., Schier, F. (2025). An evaluation of gravity models and artificial neuronal networks on bilateral trade flows in wood markets. Forest Policy and Economics, 172: 103457. https://doi.org/10.1016/j.forpol.2025.103457

[26] Mizik, T. (2021). Agri-food trade competitiveness: A review of the literature. Sustainability, 13(20): 11235. https://doi.org/10.3390/su132011235

[27] Ikram, M., Sadki, J.E. (2024). Resilient and sustainable green technology strategies: A study of Morocco's path toward sustainable development. Sustainable Futures, 8: 100327. https://doi.org/10.1016/j.sftr.2024.100327

[28] Wahyudi, A., Wulandari, S., Aunillah, A., Alouw, J.C. (2020). Sustainability certification as a pillar to promote Indonesian coffee competitiveness. IOP Conference Series: Earth and Environmental Science, 418(1): 012009. https://doi.org/10.1088/1755-1315/418/1/012009

[29] McElwee, P., Calvin, K., Campbell, D., Cherubini, F., et al. (2020). The impact of interventions in the global land and agri-food sectors on nature's contributions to people and the UN Sustainable Development Goals. Global Change Biology, 26(9): 4691-4721. https://doi.org/10.1111/gcb.15219

[30] González-Sánchez, R., Settembre-Blundo, D., Ferrari, A.M., García-Muiña, F.E. (2020). Main dimensions in the building of the circular supply chain: A literature review. Sustainability, 12(6): 2459. https://doi.org/10.3390/su12062459

[31] Sebayang, T., Wibowo, R.P., Sembiring, S.A.A., Lubis, A.A.R.D. (2025). Spatial price integration and asymmetric threshold effects in red shallot markets between urban and rural areas: Evidence from North Sumatra, Indonesia. International Journal of Sustainable Development & Planning, 20(8): 3553-3563. https://doi.org/10.18280/ijsdp.200835

[32] Roza, D.F., Lubis, S.N., Sihombing, L., Kesuma, S.I., Lubis, A.A.R.D. (2025). Strengthening rural economies through integrated agriculture: Evidence from southeast Aceh using input–output modeling. International Journal of Sustainable Development & Planning, 20(4): 1595-1601. https://doi.org/10.18280/ijsdp.200421