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MODELING THE LIKELIHOOD OF SUSTAINABLE DEVELOPMENT ACHIEVEMENT THROUGH TRADE OPENNESS: A BAYESIAN LOGISTIC REGRESSION APPROACH

MODELAGEM DA PROBABILIDADE DE ALCANÇO DO DESENVOLVIMENTO SUSTENTÁVEL ATRAVÉS DA ABERTURA COMERCIAL: UMA ABORDAGEM DE REGRESSÃO LOGÍSTICA BAYESIANA

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Abstract
This study investigates how trade openness affects the probability of achieving sustainable development across countries. Using panel data from 73 countries during 2002–2020, we employ a Bayesian logistic regression to model the likelihood that a country attains a relatively high level of sustainable development, measured by a composite index aligned with the Sustainable Development Goals. The results indicate that trade openness has a positive and robust effect on the probability of achieving sustainable development. Importantly, the findings also reveal nonlinear effects, suggesting that both excessive trade expansion and abnormally low trade openness may weaken this positive impact. This highlights that the trade–sustainable development relationship is heterogeneous and context dependent. By adopting a Bayesian logistic framework, the study explicitly captures parameter uncertainty and cross country heterogeneity, offering a more refined assessment of sustainability outcomes. The findings provide policy relevant insights by emphasizing the need for balanced trade strategies and supportive institutional conditions to ensure that trade contributes effectively to long term sustainable development.

Keywords: Sustainable Development. Trade Openness. Bayesian Logistic Regression.

Resumo
Este estudo investiga como a abertura comercial afeta a probabilidade de alcançar o desenvolvimento sustentável entre os países. Utilizando dados em painel de 73 países durante o período de 2002 a 2020, empregamos uma regressão logística Bayesiana para modelar a probabilidade de um país atingir um nível relativamente alto de desenvolvimento sustentável, medido por um índice composto alinhado aos Objetivos de Desenvolvimento Sustentável. Os resultados indicam que a abertura comercial tem um efeito positivo e robusto sobre a probabilidade de alcançar o desenvolvimento sustentável. É importante ressaltar que as descobertas também revelam efeitos não lineares, sugerindo que tanto a expansão comercial excessiva quanto uma abertura comercial anormalmente baixa podem enfraquecer esse impacto positivo. Isso destaca que a relação entre comércio e desenvolvimento sustentável é heterogênea e dependente do contexto. Ao adotar uma estrutura logística Bayesiana, o estudo captura explicitamente a incerteza dos parâmetros e a heterogeneidade entre os países, oferecendo uma avaliação mais refinada dos resultados de sustentabilidade. As descobertas fornecem insights relevantes para políticas públicas, enfatizando a necessidade de estratégias comerciais equilibradas e condições institucionais favoráveis para garantir que o

comércio contribua efetivamente para o desenvolvimento sustentável a longo prazo.

Palavras-chave: *Desenvolvimento Sustentável. Abertura Comercial. Regressão Logística Bayesiana.*

1 INTRODUCTION

Environmental challenges have become a global concern, requiring appropriate policy instruments and measures to address environmental degradation without hindering economic growth (Kwilinski et al., 2023). In response to these challenges, the European Commission adopted the European Green Deal (European Commission, 2019), which provides a strategic framework for achieving carbon neutral economic growth. At present, the global economy is undergoing a profound transformation, as the shift from a "brown" to a "green" economic structure requires national development strategies to be reshaped toward sustainability. Within the context of the United Nations 2030 Agenda and its 17 Sustainable Development Goals (SDGs), trade is no longer viewed solely as a driver of economic growth but is increasingly linked to the social and environmental dimensions of sustainable development. In this setting, trade openness plays a growing role in global economic integration and is widely regarded as a key engine of economic growth (Papadas, 2024; Halim & Moudud-Ul-Huq, 2024). By expanding cross border flows of goods, services, and capital, trade liberalization can improve resource allocation efficiency, facilitate technology transfer, and enhance labor productivity (Wang et al., 2024). However, recent studies suggest that the relationship between trade openness and sustainable development is complex, heterogeneous, and nonlinear (Dou et al., 2023). Some empirical evidence indicates that trade liberalization can support the achievement of sustainable development goals by increasing income, reducing poverty, and promoting access to green technologies (Halim & Moudud-Ul-Huq, 2024). In contrast, other studies emphasize that excessive trade expansion may intensify environmental pressure, increase carbon emissions, and heighten exposure to external shocks, thereby constraining long term sustainable development (Pham & Nguyen, 2024). These challenges have become even more pronounced in the context of major global shocks, such as the aftermath of the COVID 19 pandemic, supply chain disruptions, and rising geopolitical instability, which

have made the role of trade in sustainable development increasingly uncertain (Kindo et al., 2024). Recent research shows that both excessive trade expansion and abnormal trade contraction can weaken economic resilience and reduce the probability of achieving sustainable development goals, particularly in developing countries (Dou et al., 2023; Wang et al., 2024). Although a growing body of literature has examined the impact of trade openness on individual pillars of sustainable development, most studies have not sufficiently addressed this issue from the perspective of the probability of achieving sustainable development, especially when distinguishing between normal levels of trade openness and abnormal states of trade expansion or contraction. Therefore, this study aims to model the probability of achieving sustainable development under different levels of trade openness. By doing so, it contributes new empirical evidence and offers policy relevant insights for the design of trade strategies that support long term sustainable development. Specifically, this study seeks to address two main research questions: (1) How does trade openness affect the probability of achieving sustainable development when both trade expansion and trade contraction are taken into account? (2) Which trade related policies should countries prioritize in the current era of sustainability?

2 THEORETICAL AND LITERATURE REVIEW

2.1 Theoretical foundation

The theoretical links between trade openness and sustainable development can be explained through the following frameworks.

Institutional theory and sustainable development, initiated by North (1990), emphasizes the role of governance quality, the rule of law, and policy effectiveness in transforming economic forces into sustainable development outcomes. In the context of trade openness, strong institutions help create a transparent environment, protect property rights, limit opportunistic behavior, and regulate negative externalities arising from economic activities. As a result, the benefits of trade integration can be allocated more efficiently and aligned with long term development goals. In contrast, under weak institutional conditions, trade openness may worsen environmental degradation, income inequality, and dependence on natural resource exports. Institutions therefore act as a filtering mechanism that determines whether trade becomes a driver or an obstacle to

sustainable development. Strengthening institutional capacity not only reduces the risks associated with trade integration but also enables trade to support green growth, social inclusion, and economic stability over time.

Endogenous growth theory, developed by Romer (1990) and Aghion and Howitt (1992), argues that long run economic growth is driven by internal factors such as technological innovation, knowledge accumulation, and human capital development. Within this framework, trade openness is viewed as a key channel for technology and knowledge diffusion across countries. By reducing trade barriers and increasing flows of goods, services, and capital, economies gain access to advanced technologies, modern production processes, and higher production standards. Trade openness not only raises productivity and improves resource efficiency but also facilitates the adoption of cleaner technologies and better energy efficiency. Through these mechanisms, trade supports the transition from resource based growth toward growth driven by knowledge and innovation. However, the effectiveness of this process depends on a country's ability to absorb technology, which is shaped by human capital quality, financial development, and governance capacity. When these conditions are met, trade openness can contribute positively to green economic growth and sustainable development in the long run.

The Environmental Kuznets Curve theory, introduced by Grossman and Krueger (1995) and rooted in the work of Kuznets (1955), suggests that the relationship between economic growth and environmental degradation is nonlinear and varies across development stages. In the context of trade openness, this theory implies that increasing trade may intensify environmental pressure in the early stages of integration due to expanded production scale and higher resource extraction. However, at more advanced stages of development, trade openness can promote structural change toward higher value added and less polluting sectors, while encouraging the adoption of stricter environmental standards. From this perspective, both excessive trade expansion and unreasonable trade restriction may divert economies from a sustainable development path. The Environmental Kuznets Curve framework therefore provides a basis for examining the regulatory role of trade policy in balancing economic growth and environmental protection.

2.2 Literature review

The relationship between trade openness (TRADE) and sustainable development has become a central topic in development economics, particularly as countries strive to achieve the Sustainable Development Goals (SDGs). However, empirical evidence suggests that the effects of trade liberalization are not uniform, but instead depend strongly on national context, economic structure, and development level. Pham and Nguyen (2024) analyze a sample of developing countries using advanced econometric techniques to examine the impact of trade openness on environmental quality. Their findings indicate that trade liberalization can improve environmental outcomes by promoting technology transfer and enhancing production efficiency, but these benefits materialize only under appropriate institutional and policy conditions. This study highlights that trade does not automatically lead to sustainable development and must be supported by effective regulatory frameworks (Pham & Nguyen, 2024). More directly linked to the SDGs, Halim and Moudud-Ul-Huq (2024) investigate BRIC and CIVETS countries to assess the role of trade openness in promoting green economic growth aligned with sustainable development objectives. Their results show that trade openness contributes positively to green growth, yet the magnitude of this effect varies substantially across countries, reflecting the presence of thresholds and country-specific conditions in the trade–sustainability nexus. The nonlinear and heterogeneous nature of this relationship is further emphasized in the global study by Dou et al. (2023). By re-estimating the link between trade openness and carbon emissions while accounting for nonlinear, mediating, and heterogeneous effects, the authors demonstrate that the impact of trade depends on both the degree of openness and country-specific economic characteristics. Their findings support the argument that both excessive trade expansion and extreme trade restriction may generate adverse consequences for sustainable development. At a broader scale, Wang et al. (2024) provide evidence from 114 countries, showing that trade openness can facilitate progress toward carbon neutrality, particularly through improvements in energy efficiency and the diffusion of clean technologies. However, the study also stresses that these benefits are unevenly distributed and depend on factors such as energy structure, industrial composition, and governance capacity. Evidence at both group and country levels continues to underline the diversity of trade effects. Papadas (2024), focusing on the N11 countries, finds that the relationship between

trade openness, economic growth, and environmental quality is strongly shaped by the service sector structure and energy mix. Similarly, Kindo et al. (2024), using Ghana as a case study, conclude that trade can simultaneously stimulate growth and intensify environmental pressure, highlighting the need to balance trade liberalization with sustainable development objectives.

From this review of the literature, several research gaps emerge:

First, there remains a lack of comprehensive studies that evaluate the impact of trade openness on the likelihood of achieving sustainable development. Most existing research focuses on linear relationships or average effects of trade openness on individual dimensions of sustainability, such as economic growth, carbon emissions, or environmental quality. This approach does not fully capture the reality that the effects of trade may be heterogeneous and dependent on the level of openness itself. In particular, excessively high or unusually low levels of trade openness may generate different outcomes for sustainable development. As a result, an important gap persists in understanding how trade openness influences the probability of achieving sustainable development, rather than merely its average impact.

Second, unlike previous studies that rely primarily on frequentist regression frameworks, this study adopts a Bayesian logistic regression approach to directly estimate the probability that a country achieves sustainable development under different levels of trade openness. One major challenge in analyzing the effects of trade openness lies in the complex and potentially nonlinear nature of the relationship, which often leads to issues such as multicollinearity and unstable estimates in traditional models. This partly explains why earlier studies rarely examine trade effects in probabilistic terms. The Bayesian logistic framework offers a flexible approach to address these challenges while allowing the incorporation of prior information to enhance the reliability of the estimates (Kruschke, 2015; McElreath, 2020).

Moreover, conventional estimation methods typically provide point estimates and pay limited attention to parameter uncertainty. In the context of sustainable development research, this may result in conclusions that fail to fully reflect the inherent variability of economic, social, and environmental factors. In contrast, Bayesian logistic regression represents each parameter as a probability distribution, enabling not only the identification of the direction of TRADE effects but also the quantification of estimation uncertainty (Le Quoc, 2024). This approach is particularly suitable given that sustainable

development is influenced by many unobservable and time-varying factors, such as changes in trade policy, global supply chain disruptions, and macroeconomic shocks.

Overall, this study contributes to the literature in three main ways. First, it clarifies the role of trade openness in shaping the probability of achieving sustainable development, thereby enriching empirical evidence related to theories of trade and sustainability. Second, it pioneers the application of Bayesian logistic regression to model sustainable development outcomes in the context of trade openness, allowing for a comprehensive treatment of uncertainty and heterogeneity. Finally, the findings provide important policy implications by helping policymakers identify appropriate levels of trade openness that can support sustainable development in the long run.

3 METHODOLOGY

3.1 Research data

The dataset covers 73 countries worldwide and is selected based on data availability for the period from 2002 to 2020. Data on sustainable development (SD) are obtained from the Sustainable Development Goals Transformation Center (sdgs.un.org), while data for the remaining variables are collected from the World Development Indicators (WDI) published by the World Bank.

Based on these considerations, the empirical model examining the impact of TRADE is specified as follows:

$$SD_{i,t} = \beta_0 + \beta_1 TRADE_{i,t} + \beta_x X_{i,t} + \varepsilon_{i,t} \quad (1)$$

In this study, SD is initially measured as a continuous variable reflecting a country's overall achievement of sustainable development goals. However, to model the probability of attaining sustainable development, SD is transformed into a binary variable based on the sample median. Specifically, a dummy variable (SDbin) is constructed, taking the value of 1 if a country's SD exceeds the sample median, indicating a relatively high level of sustainable development, and 0 otherwise, reflecting a lower level relative to the sample. The use of the median threshold rather than the mean helps reduce the influence of outliers and skewed distributions, which are common in composite

sustainability indicators. This approach allows countries to be clearly classified into two states—achieving and not achieving sustainable development—thereby aligning well with the Bayesian logistic regression framework (Dinh, 2025a, 2025b, 2025c, 2025d).

Through this coding strategy, the analysis focuses on how trade openness affects the probability that a country achieves sustainable development, while maintaining estimation stability and interpretability in the presence of uncertainty and cross-country heterogeneity (Kim & Quoc, 2024; Khoi & Dinh, 2025; Huy & Dinh, 2025a, Huy & Dinh, 2025b; Huy & Loan, 2022; Le Quoc, 2024; Le Quoc et al., 2025; Nguyen Quoc et al., 2025).

Based on the above arguments, the following hypothesis is proposed:

H1: Trade openness (TRADE) has a positive effect on the probability of achieving sustainable development.

In addition to the main variable of interest, the model includes five control variables: foreign direct investment (FDI), urbanization rate (UR), economic growth (GDP), inflation rate (INF), and unemployment rate (UNE). These variables are incorporated to reduce omitted variable bias and improve the accuracy of the estimates.

To examine whether excessively high or unusually low levels of trade openness affect sustainable development, two additional dummy variables are constructed: TRADE_H and TRADE_L. Specifically, TRADE_H equals 1 if TRADE exceeds the mean plus 1.5 standard deviations, indicating an abnormally high level of trade openness, and 0 otherwise. Conversely, TRADE_L equals 1 if TRADE falls below the mean minus 1.5 standard deviations, representing an abnormally low level of trade openness, and 0 otherwise. Interaction terms between TRADE and these dummy variables (TRADE×TRADE_H and TRADE×TRADE_L) are then introduced to capture the effects of trade openness at unusually high or low levels.

This approach allows for the examination of nonlinear effects of trade openness and provides policy-relevant insights into optimal trade intensity. The analysis offers valuable implications for policymakers by clarifying how different levels of trade openness influence the probability of achieving sustainable development, thereby supporting the design of more effective trade strategies.

Accordingly, the following hypotheses are formulated:

H2a: When trade openness exceeds its normal level, the positive effect of TRADE on the probability of achieving sustainable development weakens or reverses.

H2b: When trade openness is abnormally low, TRADE reduces the probability of achieving sustainable development.

3.2 Bayesian logistics regression method

The models are estimated using Bayesian logistic regression. Logistic regression is particularly appropriate for this study because it is commonly applied when the dependent variable is binary, meaning that it takes only two possible values. In this study, the sustainable development variable (SD) is constructed as a binary indicator. In addition, the Bayesian logit approach offers important advantages by allowing the incorporation of prior distributions and explicitly accounting for uncertainty in the estimation process, thereby improving the accuracy and interpretability of the empirical results (Quoc et al., 2025a, Quoc et al., 2025b, Quoc et al., 2025c; Quoc & Quoc, 2025; Van & Quoc, 2024; Van et al., 2025a; Van et al., 2025b, Tuyet & Dinh, 2025).

In addition, the Bayesian method also removes model problems such as endogeneity, heteroscedasticity and autocorrelation (Thach, 2020). In the Bayesian view, we build the linear regression by using the probability distribution as follows:

$$P(\beta|y,X) = \frac{P(y|\beta,X)(P(\beta|X)}{P(y|X)} \qquad (2)$$

In there:

P(β/y,X): Posterior distribution of model parameters given inputs and outputs
P(y/β,X): Likelihood of the data
P(β/X): Prior probability distribution
P(y/X): Normalizing constant that can be ignored
As a result, equation (2) is frequently reduced to:

$$P(\beta|y,X) = P(y|\beta,X)(P(\beta|X) \qquad (3)$$

Bayesian regression was used in the procedure to evaluate through a specific three-step process: First, to ensure the recorded estimates tend toward zero rather than away from it, and to avoid biasing the analysis in a positive or negative direction, prior

distributions for the regression coefficients were established with a mean assumption of zero. For the next step of the process, based on the parameters extracted from the equation, the distribution for the likelihood functions of the coefficients was determined. The final step was to obtain the posterior distribution of the coefficients by applying Markov Chain Monte Carlo (MCMC) and Gibbs Sampler techniques. This was done through a process of estimating and simulating 30,000 samples based on the posterior distribution, with the first 5,000 samples removed. MCMC techniques are widely applied to refine complex models in various fields (Levy & Mislevy, 2017; Huy et al., 2024; Huy et al., 2023a, Huy et al., 2023b; Nga et al., 2024a; Nga et al., 2024; Huy & Tam, 2025a, Huy & Tam, 2025b; Huy & Tam, 2025c).

4 RESEARCH RESULTS

4.1 Overview of descriptive statistics

Descriptive statistics indicate that the variable SD has a mean value of 69.35, reflecting a relatively high level of sustainable development, with a standard deviation of 9.99, suggesting a moderate degree of dispersion across observations. In contrast, the TRADE variable has a mean value of 79.84 and a much larger standard deviation of 37.97, indicating substantial variation in trade openness across countries. The wide range of TRADE values, from 20.45 to 250.11, further highlights significant differences in the degree of trade integration. Overall, TRADE exhibits greater dispersion than SD, suggesting that the impact of trade openness on sustainable development may not be uniform across countries.

Notably, Table 1 highlights two key issues. First, there is concern regarding cross sectional dependence, which is an important issue that must be examined prior to panel data analysis. Ignoring this aspect may lead to biased estimation results and misleading policy implications. To address this issue, this study applies the Pesaran (2021) cross sectional dependence test. The results show that all variables are statistically significant at the one percent level, indicating the presence of cross sectional dependence. Second, the normality of the data distribution is examined using the Jarque Bera test. The results indicate that none of the variables follows a normal distribution at conventional significance levels. This reflects the presence of skewness or excess kurtosis, implying

asymmetric distributions and the potential existence of outliers or heavy tails. Given these data characteristics, the choice of an appropriate empirical model is critical. Conventional approaches such as OLS, fixed effects, or structural equation models may yield biased or inefficient estimates under cross sectional dependence and non normality. Therefore, this study employs a Bayesian logistic regression framework, which allows inference based on probability distributions. Bayesian inference incorporates prior distributions into the estimation process, thereby improving the robustness and accuracy of the empirical results in the presence of complex data features.

Table 1

Descriptive statistics for variables

Biến	Mean	Std. Dev	Minimum	Maximum	Pesaran CD Test	Jarque-Bera Test
SD	69.3473	9.9858	38.5818	86.8687	207.012***	73.210***
TRADE	79.8362	37.9668	20.4471	250.1085	44.149***	139.46***
GDP	3.2238	4.0708	-17.8212	34.4662	114.404***	159.19***
FDI	5.7517	23.1148	-296.013	431.7885	20.981***	0.0000***
UR	64.5896	18.9647	16.2080	98.0790	148.231***	58.590***
UNE	7.3653	4.7713	0.3160	29.2170	19.511***	305.41***
INF	4.5789	6.2295	-18.8992	84.6834	36.866***	942.59***

Note: *** indicates a significance level of 1%.
Source: Authors' calculations

In addition, a correlation matrix analysis is conducted to examine the relationships among variables in the dataset and to assess the presence of multicollinearity. The results of the correlation matrix, presented in Table 2, summarize the main insights. The findings indicate that the correlation coefficients among the explanatory variables are generally low to moderate, and no pair of variables exhibits a correlation exceeding the threshold of 0.8, which is commonly associated with severe multicollinearity. This implies that the dataset does not suffer from serious multicollinearity issues, and all variables can be appropriately included in the empirical model.

Table 2

Correlation Matrix

	SD	TRADE	GDP	FDI	UR	UNE	INF
SD	1.0000						
TRADE	0.3592	1.0000					
GDP	-0.2847	0.0417	1.0000				
FDI	0.0270	0.1823	0.0434	1.0000			
UR	0.6886	0.0378	-0.2753	0.0106	1.0000		

UNE	0.1592	0.0549	-0.1690	0.0305	0.2819	1.0000	
INF	-0.2286	-0.1152	0.1492	-0.0223	-0.1242	-0.0380	1.0000

Source: Authors' calculations

4.2 Logit Bayesian regression results

The Bayesian logit regression results reported in Table 3 show that trade openness has a positive and consistent effect on the probability of achieving sustainable development across all three model specifications. Specifically, in model (1), the mean coefficient of trade openness is 1.2036, indicating that an increase in TRADE significantly raises the likelihood of attaining sustainable development. This positive relationship remains robust in models (2) and (3), with estimated coefficients of 1.0623 and 1.2202, respectively, confirming the stability of the effect across alternative model specifications. Notably, when nonlinear effects are considered, the interaction term TRADE_TRADEH in model (2) exhibits a positive coefficient of 0.2763, suggesting that in countries with high levels of trade openness, the positive impact of trade on sustainable development is amplified. Similarly, the interaction term TRADE_TRADEL in model (3) is also positive, with a coefficient of 0.1006, implying that even in countries with relatively low trade openness, trade still contributes to improving the probability of achieving sustainable development, although the magnitude of the effect is smaller. Taken together, these findings provide clear empirical evidence that trade openness not only exerts a direct positive effect but also displays nonlinear characteristics, playing an important role in promoting sustainable development.

The tests with the Bayesian regression model show that the average acceptance rate of three-model, which lies in a stable range. The minimum efficiency of the MCMC chains is above the acceptable level of 0.01, showing that the sampling process is diverse enough to accurately estimate the target distributions. The posterior distribution built through the MCMC technique needs to ensure that the samples are representative of the target distribution. Therefore, MCMC diagnostic tools are required to test the convergence of the Markov chains and to determine the stopping point of sampling. In this study, the authors use the Gelman Rubin statistic (the Rc coefficient) to assess convergence and the efficiency index to check the quality of sampling. The results in Table 3 show that the Rc value is less than 1.1, meeting the convergence criteria given by Levy (2020). At the same time, all efficiency indices are above 0.01, proving the stability

and high reliability of the MCMC estimates. Different from traditional statistical methods such as OLS, FEM or REM, which often rely on the p value less than 0.05 to identify statistical significance, the Bayesian method uses the Monte Carlo Standard Error (MCSE) to assess the accuracy of the estimates. MCSE measures the error between the estimate from the MCMC chain and the true value of the target distribution, rather than relying only on the p value. According to Flegal & Jones (2011), when MCSE moves closer to zero, the stability of the MCMC chain becomes higher; MCSE below 6.5% of the standard deviation is considered acceptable, and below 5% is optimal. Based on the results in Table 3, all variables in the model meet this criterion. In this context, the MCMC diagnostic indices—acceptance rate, efficiency, Rc coefficient and MCSE—all exceed the required thresholds, confirming the strength and reliability of the Bayesian simulation results in this study.

Table 3

Logit Bayesian regression results

Dependent Variable: SD	(1)			(2)			(3)		
	Mean	Std. Dev.	MCSE	Mean	Std. Dev.	MCSE	Mean	Std. Dev.	MCSE
C	-0.1716	0.0758	0.0006	-0.1378	0.0781	0.0007	-0.1736	0.0762	0.0008
GDP	-0.6320	0.0843	0.0006	-0.6416	0.0854	0.0008	-0.6346	0.0849	0.0008
FDI	-0.0966	0.0723	0.0006	-0.1093	0.0743	0.0005	-0.0986	0.0729	0.0005
UR	1.7150	0.1130	0.0008	1.6968	0.1126	0.0010	1.7096	0.1128	0.0011
UNE	-0.2197	0.0726	0.0004	-0.2125	0.0732	0.0005	-0.2160	0.0724	0.0009
INF	-0.4916	0.0871	0.0005	-0.4912	0.0862	0.0007	-0.4978	0.0880	0.0009
TRADE	1.2036	0.0981	0.0006	1.0623	0.1179	0.0011	1.2202	0.0999	0.0008
TRADE_TRADEH				0.2763	0.1268	0.0014			
TRADE_TRADEL							0.1006	0.0682	0.0005
Observation		1,387			1,387			1,387	
Acceptance rate		0.7230			0.7221			0.7239	
Efficiency: min		0.0828			0.0473			0.0364	
Max Gelman–Rubin Rc		1.0000			1.0010			1.0010	

(Source: Authors' calculations)

4.3 Discussion

The Bayesian logit regression results reported in Table 3 provide clear evidence that trade openness is positively associated with the probability of achieving sustainable development. Across all model specifications, the coefficient of the trade variable remains positive and stable, indicating that greater integration into international trade increases the likelihood that a country attains sustainable development outcomes. This finding suggests that trade openness plays an important role not only in economic performance but also in shaping broader development paths that include social and environmental dimensions. The positive effect of trade openness is consistent with institutional theory and sustainable development as introduced by North (1990). According to this framework, institutions shape how economic activities translate into long term development outcomes. Greater trade openness often encourages improvements in institutional quality through increased transparency, stronger regulatory frameworks, and closer alignment with international standards. These institutional improvements can enhance the capacity of countries to manage economic growth in a way that supports sustainable development rather than short term gains. The results of this study suggest that trade openness may work through institutional channels to raise the probability of sustainable development. The findings are also in line with endogenous growth theory developed by Romer (1990) and Aghion and Howitt (1992). This theory emphasizes the role of knowledge spillovers, innovation, and technology diffusion in sustaining economic growth. Trade openness facilitates access to new technologies, production methods, and managerial practices, which can improve resource efficiency and productivity. As countries become more open to trade, they are better positioned to adopt cleaner technologies and more efficient production processes, thereby increasing their chances of achieving sustainable development. The positive coefficients of trade openness across all models support this mechanism. In addition, the results are consistent with the environmental Kuznets curve theory proposed by Grossman and Krueger (1995). This theory suggests that at higher levels of economic integration and development, environmental outcomes can improve as countries shift toward cleaner technologies and stronger environmental regulations. The positive impact of trade openness on sustainable development probability indicates that trade may help countries move beyond the stage where economic expansion leads to environmental degradation, toward a stage where

growth and environmental improvement coexist. Overall, the empirical evidence indicates that trade openness contributes to sustainable development through institutional improvement, knowledge diffusion, and structural transformation. These results support the theoretical expectation that trade, when accompanied by appropriate institutional and policy conditions, can enhance the likelihood of achieving sustainable development. The findings therefore provide empirical support for the role of trade openness as a key channel linking economic integration to sustainable development outcomes.

5 CONCLUSION

In the context of increasing global challenges related to climate change and environmental degradation, sustainable development has become a central objective in national development strategies. This study examines the impact of trade openness on the probability of achieving sustainable development using a Bayesian logit model applied to a multi country dataset over the study period. The empirical results show that trade openness has a positive and stable effect on the likelihood of achieving sustainable development, highlighting the role of trade integration in long term development processes. The findings indicate that international trade contributes to sustainable development by expanding market access, facilitating technology diffusion, and improving resource use efficiency. In addition, the effect of trade openness tends to be stronger in countries with higher levels of trade integration, suggesting that the depth of integration plays an important role in transforming trade benefits into sustainable development outcomes. This implies that trade is not only a driver of economic growth but can also support environmental and social objectives when properly guided. From a policy perspective, the results emphasize the importance of promoting trade integration alongside institutional reforms and environmental policies. Countries should focus on improving the quality of trade integration by strengthening participation in global value chains, enhancing compliance with environmental and social standards, and encouraging the transfer and adoption of cleaner technologies. For economies with relatively low levels of trade openness, gradual liberalization combined with policies that support firms and invest in human capital is essential to enhance competitiveness and the capacity to benefit from trade.

While this study provides meaningful empirical evidence, it has certain limitations related to the measurement of trade openness and differences in development contexts across countries. Future research may extend the analysis by incorporating broader dimensions of trade integration and institutional quality to further clarify the relationship between trade openness and sustainable development.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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