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Trade efficiency under FTA for Thailand's agricultural exports: copula-based gravity stochastic frontier model

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Abstract

This study investigated the trade efficiency and trade effects under Free Trade Agreements for Thailand's agricultural exports. There are five main trading partners comprising China, Japan, Australia, New Zealand, and India. The important agricultural commodities of rubber, cassava, fruits, vegetables, and herbs were assessed from 1998 to 2019. In a traditional stochastic frontier model the two error components of symmetric noise (v_j) and a non-negative inefficiency (u_j) are assumed to be independent. This may result in invalid inferences due to misspecification. To address this obstacle, copula-based Gravity Stochastic Frontier Models (GSFM) using panel criteria were constructed to estimate trade efficiency. Empirically, the Student-*t* copula-based SFM minimizes both AIC and BIC. According to their mean TE, China (0.48) and Japan (0.48) had the highest export efficiencies followed by India (0.41), New Zealand (0.39), and Australia (0.33) in rank order. Hence, Thailand should pursue more FTA negotiations with the trading partners. Moreover, they should promote miscellaneous behind-the-border barriers to stimulate flows of goods to enhance the country's trade efficiency substantially.

Keywords: Trade efficiency, Free trade agreements, Autocorrelated inefficiency component, Copula-based gravity stochastic frontier model, Thailand's trade potential

JEL Classification: F02, F13, F15, F41

1 Introduction

Thailand is an export-oriented economy with exports accounting for approximately 65% of the gross domestic product (GDP). Manufactured goods contribute 86% of total export, and the rest is agricultural goods 14%. Despite that small fraction, the agricultural sector remains a great stimulation to the Thai economy and contributes to the convergence in levels of wealth. World Trade Organization (WTO) is a body designed to stimulate free trade by organizing trade regulations. FTAs or Regional Trade Agreements (RTAs) have been massively negotiated. Principally, FTA is a pact between two or more nations to eliminate barriers (tariffs and duties) to imports and exports among them. Under a free trade policy, people can trade in goods and services across the global market with little or no government measures in terms of tariffs, quotas, subsidies, or prohibitions to inhibit its exchange.

Several FTAs among trading partners have entered into force since the late 1990s. Because of these, the average tariffs on industrial commodities have decreased from 40 to 4% from Uruguay to Doha: Agricultural Trade Negotiations (WTO 2003). Also, the average tariffs seem to lack uniformity with a specific duty adopted for each commodity group. The WTO reports that tariffs on agricultural products range from 0 to 171% (WTO 2019). The main purpose of FTAs/RTAs is explicit: amplifying bilateral trade and multilateral trade by eliminating economic or institutional barriers and eliminating fortress effects. Indeed, FTAs/RTAs appear to essentially affect export performance (Santosa 2018; Janas et al. 2020; Harada and Nishitateno 2021; Kuroiwa 2021). The obliteration of imported duties on several commodities leads to price reductions across the FTA partners.

Due to the negotiations of WTO, they have significantly eliminated tariffs and fostered global trade, the rank of non-tariff measures (NTMs) has kept high and increased over time indeed. This leads to negative effects on the trade performances of the world economy, in particular developing countries (Harvey 1994; Santeramo and Lamonaca 2019). The NTMs can take many different forms such as subsidies, technical barriers to trade, sanitary and phytosanitary measures, etc. The NTMs impose additional costs for enforcement, sourcing, and process adaptation to the agricultural sector as well as food and beverage (F&B) manufacturing businesses), constrain to access the global market, and may reduce productivity and competitiveness. With this, NTMs also undermine food security (Felippa 2021).

Thailand purposely advocates negotiating with several trading partners both bilateral and multilateral FTAs. Thailand is a member of ASEAN, which was established in 1967. Recently, it has 14 FTAs with 18 countries (bilateral FTAs comprising Thailand–Australia FTA, Thailand–New Zealand Closer Economic Partnership, Japan–Thailand Economic Partnership Agreement, Thailand–India FTA, Thailand–Chile FTA, Thailand–Peru FTA; Multilateral-FTAs comprising ASEAN FTA, ASEAN–China FTA, ASEAN–India FTA, ASEAN–Japan Comprehensive Economic Partnership, ASEAN–Korea FTA, ASEAN–Australia and New Zealand FTA, ASEAN–Hong Kong). The Regional Comprehensive Economic Partnership, which came into force in early 2022, is the latest trade pact (Ministry of Foreign Affairs 2022). In this study, we focus on the five major trading nations consisting of China, Japan, Australia, New Zealand, and India. By the end of 2003, the Thai government signed FTAs with China and India. By mid-2004 there treated Japan, Australia, and New Zealand.

Agriculture contributes largely to Thailand's economic growth. Thailand has considerably competitive, diversified, and specialized in agriculture and its exports are very successful internationally. For over a decade, rubber is one of the major important crops. Thailand is the world's top producer and exporter of natural rubber, accounting for around a third of global rubber production each year. Likewise, Thailand is the second largest cassava producer at 10.7% of global output and its production is targeted for export. Hence, Thailand is among the world's top five exporters of cassava products between 2018 and 2022 (Sowcharoensuk 2020). Moreover, Thailand is well-known for its natural products and gastronomy, with fruits being one of the best-selling products. Thai fruits take a great place in the international markets. For example, Thai durian is the most popular (76% market share of global durian imports), as longan, mangosteen, etc. Other agricultural commodities produced in significant amounts include vegetables and herbs. Consequently, we focus on the main agricultural commodities rubber, cassava, fruits, vegetables, and herbs, with the five nations China, Japan, Australia, New Zealand, and India in this study. Recently, there is no consensus regarding the consequences of growth effects on trade openness. This evokes advantages dependent on certain complementary domestic transforms in terms of deregulation of commerce, financial development, rule of law, etc. Otherwise, international trade constrains long-term growth (Freund and Bolaky 2008; Chang et al. 2009; Hur and Park 2012).

Conventional global trade studies principally describe bilateral trade flows between two countries using a gravity model initially introduced by Tinbergen (1962). The basic concept of the gravity model involves Newton's Law of Gravitation. The volume of bilateral trade is derived from a proportion of physical masses, which are represented by GDP, with geographical distance measured by transaction costs for a pair of countries. However, this model possibly supports an argument of approximating the trade potential through ordinary least squares regression, which would describe the central values of the data set. Conceptually, the potential trade indicates the maximum feasible trade to achieve between any two countries that have liberalized their mutual trade restrictions. Instead, the copula-based GSFM can manipulate technical efficiency coincident with the upper bound imposed on trade data. Furthermore, the GSFM comes up with two error components: a non-negative error (μ), indicating trade inefficiency, and asymmetric noise (ν), indicating country-specific circumstances. The Copula-based GSFM overcomes the strong assumption of independence between these two errors through a large variety of joint distributions accompanied by marginal distributions and copula functions. Accordingly, this approach can be used to examine international trade efficiency under FTA Preferences for Thai agricultural exports.

Every country seeks to achieve its full trade potential through engagement in international trade. Understanding the efficiency levels of Thailand's exports with its major FTA trading partners and the rules of origin on export can help policymakers to manipulate the existing restrictive measures on trade growth. In this paper, the GSFM is augmented with several copulas including Gaussian, Student-*t*, and Farlie–Gumbel–Morgenstern (FGM) copulas, to explore the dependence structure of error components. Furthermore, a panel data framework is adopted to evaluate trade efficiencies. The rest of the paper is organized as follows: Section II highlights the background incidence of FTAs and Section III details the methodology. Section IV presents the dataset and empirical results. Section V concludes and provides policy inferences.

2 Literature review

In 1990, several bilateral FTAs have risen dramatically. The trade promotions from the FTAs occur after many countries entered into such agreements. Many studies regarding the degree of openness and the correlation between an individual country's growth have been examined. The impacts of FTAs can be investigated by considering whether both countries will be better off or worse off when they remove their trade barriers. The evidence of a positive effect of free trade on economic growth had been supported by Dollar (1992), Sachs et al. (1995), Edwards (1998), Frankel and Romer (1999), Dollar and Kraay (2004), Romyen, et al. (2019) by utilizing various methods. Moreover, the insignificant or negative impact of free trade on economic growth had been reported by Harrison (1996), Rodriguez and Rodrik (2000), Rodrik et al. (2004), Wacziarg and Welch (2008).

However, Freund and Bolaky (2008) found that the growth impact of trade openness is importantly positive only when accurate complementary domestic amends are undertaken which include the rule of law, better education, deregulations of business, labor market flexibility, even financial developments, etc. Contrarily, the trade would not relate to long-run growth in such an economic system. Additionally, Hur and Park (2012) pointed out that FTAs may insignificantly impact total growth in one to ten periods after launch while detecting a significant upward in the gap between GDP per capita and growth rates for a bilateral FTA. Tai Hsieh et al. (2020) postulated that it is possible to incur negative new gains from liberalization since several domestic disadvantages and productivity are opposed by import productivity losses. Free trade may cause subordinate selection impacts across domestic producers and foreign exporters. Ultimately, this leads to disadvantages to any within-firm productivity effects. Thus, the uneven FTA impacts across nations had been implied within an FTA.

3 Research methods and materials

3.1 The gravity model

Tinbergen (1962) initially applied Newton's universal law of gravitation to explain patterns of bilateral trade flows between two countries i and j as proportional to the economic sizes (generally represented by the GDP and inversely proportional to the geographic distance between them. The so-called gravity equation of bilateral trade flow is expressed by:

$$Trade_{ij} = \frac{(GDP_i)^{\alpha}\left(GDP_j\right)^{\beta}}{\left(Dist_{ij}\right)^{\delta}}. \tag{1}$$

The role of economic sizes (α, $\beta \approx 1$) is positively related to trade flows, while the role of distance (δ) remains diverse across different countries and the vast choice of econometric methods (Chaney 2011). Taking the logarithm to linearize the gravity model provides the elasticity with the following form:

$$lnTrade_{ij} = \theta + \alpha lnGDP_i + \beta lnGDP_j - \delta lnDist_{ij} + \varepsilon_{ij}, \tag{2}$$

where $Trade_{ij}$ informs about the bilateral trade between countries i and j. GDP_i and GDP_j stand for the national outputs by countries i and j, $Dist_{ij}$ measures the distance between the two nations. θ is a constant from taking a log of a conversion factor, and α, β, and δ are the estimated parameters.

3.2 The stochastic frontier model

The standard form of the stochastic frontier model (SFM) is defined as:

$$Y_i = f(X_{ik'}\beta).TE_i, i = 1, \ldots, N, \tag{3}$$

$$\text{or} lnY_i = X_{ik}\prime\beta + \varepsilon_i, \tag{4}$$

$$\varepsilon_i = V_i - U_i, \tag{5}$$

where Y_i is the output, $X_{ik}\prime\beta$ represents an N^*K matrix with various K inputs, and β denotes an N^*K matrix of estimated parameters. The function $f(\cdot)$ refers to the stochastic frontier form. The TE indicates technical efficiency and the ε_i is an error component comprising noise V_i as well as inefficiency U_i. Fundamentally, the V_i is assumed to be normally distributed. The U_i are non-negative half-normal aspects assumed continuous and independent with several factors.

3.3 The gravity with SFM

The bilateral trade potentials and efficiency levels can be determined by the GSFM. Particularly, the trade inefficiency from (2.3) can be decomposed into the V_i with the two-sided random term and the U_i with the one-sided random term, indicating trade inefficiency. To inspect the principal determinants of the trade treaties between Thailand and its trading partners, the augmented GSFM is as follows:

$$\begin{aligned} lnTrade_{ij} = \beta_0 + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnPop_i + \beta_4 lnPop_j \\ + \beta_5 lnEx_i + \beta_6 lnEx_j - \beta_7 lnDist_{ij} - \mu_{ij} + \nu_{ij}, \end{aligned} \tag{6}$$

where Pop_i, Pop_j stand for a population in a country i and j. The population is relevant to global trade since they can be consumers, laborers, or entrepreneurs. Ex_i, Ex_j represent exchange rates of a country i and j. If exchange rates change, the prices of imported goods will change in value, including domestic products that depend on imported parts and raw materials.

Fundamentally, the μ_{ij} and ν_{ij} are supposed to be identical and independent. The μ_{ij} indicates the failure levels compared to the frontier. Nevertheless, a country having a low technical efficiency will have certain trades below optimal.

3.4 A panel data copula-based stochastic frontier model with correlated noise and inefficiency

One problem of the panel SFM is the endogeneity problem. This problem is relatively serious since it affects varying estimates and wrong inferences. Fallacious conclusions and inappropriate theoretical interpretations are a consequence. Tran and Tsionas (2015) showed that both endogenous regressors and heterogeneity can be relaxed. Paul and Shankar (2018) considered the exogenous effects in the inefficiency effects. The inefficiency effects model can be categorized into two groups.

The estimation of the production frontier can be achieved by using the first group which is the two-step procedure. Then, the TE score can be obtained by regression against a set of variables that are hypothesized to affect the inefficiency of production. However, the lack of consistency can be considered a technical problem because SFM's assumption assumes that the statistical error term and the inefficiency error term are independent with identical and independent distribution assumptions. However, in the application of the SFM estimation, the assumption of inefficiency that it is identically distributed cannot be met. The correlation between the efficiency effect variable and the production function variable can be another significant problem concerning the model. This is because the first step of the two-step estimation faces the problem of omitted variable bias. The second model for inefficiency effects is to estimate the inefficiency scores and exogenous effects in one step.

The panel data methodology provides explicit economic advantages. This can deal with the relationships among variables across time and can track unobservable incidents between trading partner pairs. Moreover, the panel data approach can manipulate the multi-collinearity among the explanatory variables in the model (Baltagi 1995). For a panel data copula-based stochastic frontier model, the dependence structures are reckoned through marginal probability densities associated with the copula function. Then, we receive the joint probability distribution of inefficiency and noise. A panel GSFM has the general form:

$$y_{ij,t} = f_\beta\left(x_{ij,t}\right)\exp\left(v_{ij,t} - u_{ij,t}\right), \varepsilon_{ij,t} = v_{ij,t} - \mu_{ij,t}, \tag{7}$$

where $y_{ij,t}$ denotes the volume of bilateral trade between country i and country j at a certain time t and $i = 1, \ldots, n, j = 1, \ldots, n, t = 1, \ldots, T$. $f_\beta(\cdot)$ refers to the deterministic trade frontier respecting the error efficiency, and $x_{ij,t}$ informs on relevant bilateral trade factors. Regarding the error components, v_{ij} is the statistical noise and u_{ij} is the inefficiency. The deterministic frontier is subject to noise $f_\beta^S\left(x_{ij,t}\right) \equiv f_\beta\left(x_{ij,t}\right)exp$ is called the stochastic frontier. The distributions of $v_{ij,t}$ and $u_{ij,t}$ are $v_{ij,t} \sim N(0, \sigma_v^2), -\infty < v_{ij,t} < \infty$ and $\mu_{ij,t} \sim N^+\left(0, \sigma_\mu^2\right), 0 < u_{ij,t} < \infty$. This provides the maximum capacity output from a certain input bundle $x_{ij,t}$ without random residual judgment. Theoretically, finite production $y_{ij,t}$ is ordinarily underneath its potential production in such a way that $y_{ij,t} \leq f_\beta^S\left(x_{ij,t}\right)\forall_{ij,t}$. The deficiency of the real output concerning the potential production is assessed by

$$e^{-\mu_{ij,t}} = \frac{y_{ij,t}}{f_\beta^S\left(x_{ij,t}\right)}, \tag{8}$$

$$0 \leq \frac{y_{ij,t}}{f_\beta^S\left(x_{ij,t}\right)} \leq 1. \tag{9}$$

Since $u_{ij,t}$ is non-negative, the parameters of the probability distribution of $u_{ij,t}$ are then taken into account in the inference of the stochastic frontier analysis.$D_{\pi it}(v_{ij,t})$, $G_{\eta it}(\mu_{ij,t})$ are the distribution functions and$d_{\pi ij,t}(v_{ij,t})$,$g_{\eta ij,t}(\mu_{ij,t})$ are the probability density functions of noise and inefficiency, accompanied by the countries i and j at time t. $\pi_{ij,t}$ and $\eta_{ij,t}$ denote the parameter vectors of v_{ij} andμ_{ij}. These notations are defined as$\mu_{ij} = (\mu_{ij,1}, \ldots, \mu_{ij,T})\prime$, $v_{ij} = (v_{ij,1}, \ldots, v_{ij,T})\prime$, $\eta_{ij} = (\eta_{ij,1}, \ldots, \eta_{ij,T})\prime$ and $\pi_{ij} = (\pi_{ij,1}, \ldots, \pi_{ij,T})\prime$. We assume that a 2 T-variate copula can properly estimate the dependency of $\mu_{ij,t}$ and$v_{ij,t}$. The joint probability density function of $(\mu_{ij,t} and v_{ij,t})$ is expressed by:

$$h_{\gamma_{ij}}(\mu_{ij,t}, \nu_{ij,t})) = \left(\prod_{t=1}^{T} g_{\eta ij,t}(\mu_{ij,t}) d_{\pi ij,t}(\nu_{ij,t})\right) c_{\alpha_{ij}}\left(G(\mu_{ij,1}), \ldots, G(\mu_{ij,T}), D(\nu_{ij,1}), \ldots D(\nu_{ij,T})\right), \tag{10}$$

where $\gamma_{ij} = (\pi_{ij}, \eta_{ij}, \alpha_{ij})$, and α_{ij} denotes the vector of copula parameters. It can be assumed that the temporal dependencies among residual and inefficiency procure the joint density function and the dependence structure at a certain unit *ij*. In this study, it is a fixed effect since the same set of units is tracked throughout the study.

3.5 Correlated noise and inefficiency modeling using normal and T copula

The SFM has two strong assumptions. Firstly, in general, the two error terms are assumed to be independent. Consequently, this paper will apply the copula function to join two error terms that are allowed to have a relationship with any distribution. Secondly, in general, the SFM assumes that inefficiency is constant indicating that there is no correlation between its inefficiency terms. According to the work of Das (2015), the inefficiency term should have a relationship with itself. Thus, he relaxed this assumption by allowing the inefficiency in one period can correlate with its past level. This paper will follow Das's work which seems to be more realistic. For that reason, the copula-based GSFM should improve the result of the estimated parameters of the potential of Thailand's Agricultural Exports.

According to the noise-inefficiency dependence and temporal dependence of the inefficiency assumption, the temporal dependence among residuals principally disappears for each trading partner country along with three assumptions. Firstly, the stochastic dependences of the noise and the inefficiency accompanied by any trading partner country are identical across times such as$Corr(\mu_{ij,t}, \nu_{ij,t}) = \rho, \forall ijandt$. There is no time dependence of order one or more between the noise and inefficiency so$Corr(\mu_{ij,t}, \nu_{ij,t-s}) = Corr(\nu_{ij,t}, \mu_{ij,t-s}) = 0, \forall s = 1, \ldots, T$. Secondly, the time dependence of inefficiency is order one and identical for the *ij*th trading partner nations at any two coherent periods so that $Corr(\mu_{ij,t}, \mu_{ij,t-1}) = \psi$ and there is no time dependence of order two or more among inefficiencies so that $Corr(\mu_{ij,t}, \mu_{ij,t-s}) = 0, \forall s = 2, \ldots, T$. Finally, the time dependence of order one or more among the noise does not exist so that $Corr(\nu_{ij,t}, \nu_{ij,t-s}) = 0, \forall s = 2, \ldots, T$ (Das 2015). Consequently, the joint density function of $\mu_{ij,t}$ and $\nu_{ij,t}$ respecting the normal copula is expressed by:

$$f_{\gamma_{ij}}(\mu_{ij,t}, \nu_{ij,t})) = \left(\prod_{t=1}^{T} \frac{1}{\sigma_\nu}\phi\left(\frac{\nu_{ij,t}}{\sigma_\nu}\right)\frac{1}{\sigma_\mu}\phi\left(\frac{\mu_{ij,t}}{\sigma_\mu}\right)\right)\frac{1}{|R|^{\frac{1}{2}}} exp\left[-\frac{1}{2}\varsigma'\left(R^{-1} - I\right)\varsigma\right], \tag{11}$$

$$where\ \varsigma = \left(\Phi^{-1}(2\Phi)\left(\frac{\mu_{ij,1}}{\sigma_\mu}\right) - 1\right), \ldots, \Phi^{-1}\left(2\Phi\left(\frac{\mu_{ij,T}}{\sigma_\mu}\right) - 1\right),$$

$$\Phi^{-1}\left(\Phi\left(\frac{\nu_{ij,1}}{\sigma_\nu}\right)\right), \ldots, \Phi^{-1}\left(\Phi\left(\frac{\nu_{ij,T}}{\sigma_\nu}\right)\right),'$$

$$R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix},$$

$$R_{11} = \begin{pmatrix} 1 & \psi & 0 & \cdots & 0 \\ \psi & 1 & \psi & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 1 \end{pmatrix},$$

$$R_{12} = R_{21} = \begin{pmatrix} \rho & 0 & \cdots & 0 \\ 0 & \rho & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \rho \end{pmatrix}$$

$$and\, R_{22} = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & \rho & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \rho \end{pmatrix},$$

where ρ denotes a copula parameter associated with joint dependence between noise and inefficiency independence. ψ refers to a copula parameter associated with lagged dependence within inefficiency. Rewriting $v_{ij,t} = \varepsilon_{ij,t} + \mu_{ij,t}$ in Eq. (3.6) and integrating over μ_{ij}, t, the density function of ε_{ij} is expressed by:

$$h(\varepsilon_{ij}) = \int_0^\infty \cdots \int_0^\infty \left(\prod_t f(\varepsilon_{ij,t} + \mu_{ij,t})\right) C_{\alpha_{ij},t} \left(\prod_t g(\mu_{ij,t})\right) d\mu_{ij,t}, \tag{13}$$

where

$$C_{\alpha_{ij}} = C_{\alpha_{ij}}(G(\mu_{ij1}), \ldots, G(\mu_{ijT}), F(\varepsilon_{ij1} + \mu_{ij1}), \ldots F(\varepsilon_{ijT} + \mu_{ijT})).$$

For the tail dependence property, the multivariate T copula can deal with this dependence on Thai export volumes. Given that ρ is asymmetric, positive definite with diagonal ρ and$T_{\rho,v}$, the standardized Student's distribution with v degrees of freedom and correlation matrixρ, the joint density function of μ_{ij}, v_{ij} under T copula is calculated as follows:

$$f_\gamma(\mu_{ij,t}, v_{ij,t}) = |\rho|^{-\frac{1}{2}} \frac{\Gamma\left[\frac{v_{ij,t}+T}{2}\right]\left[\Gamma\left(\frac{v_{ij,t}}{2}\right)\right]^T \left[1 + \frac{1}{v_{ij,t}}\xi^T \rho^{-1}\xi\right]^{\frac{-v_{ij,t}+T}{2}}}{\left[\Gamma\left[\frac{v_{ij,t}+T}{2}\right]\right]^T \left[\Gamma\left(\frac{v_{ij,t}}{2}\right)\right] \prod_{t=1}^T \left[1 + \frac{\xi_T^2}{v_{ij,t}}\right]^{\frac{-v_{ij,t}+T}{2}}}, \tag{14}$$

where $\xi_n = t_v^{-1}(\mu_n), t_v^{-1}$ is the inverse of the univariate Student's distribution.

According to the Jondrow et al. (1982) estimator of technical inefficiency, the SFM accompanied by the correlated error element through copula criteria can be written as:

$$TIE_i = E[\mu_{ij}|\varepsilon_{ij}] = \frac{1}{h(\varepsilon_{ij})}\int_0^\infty \mu_{ij} f_\gamma(\mu_{ij}, \varepsilon_{ij}) d\mu_{ij} \tag{15}$$

$$= \frac{1}{h(\varepsilon_{ij})}\int_0^\infty \mu_{ij}\left(\prod_t f(\varepsilon_{ij} + \mu_{ij})\right) C_{\alpha_{ij}} \left(\prod_t g(\mu_{ij})\right) d\mu_{ij}.$$

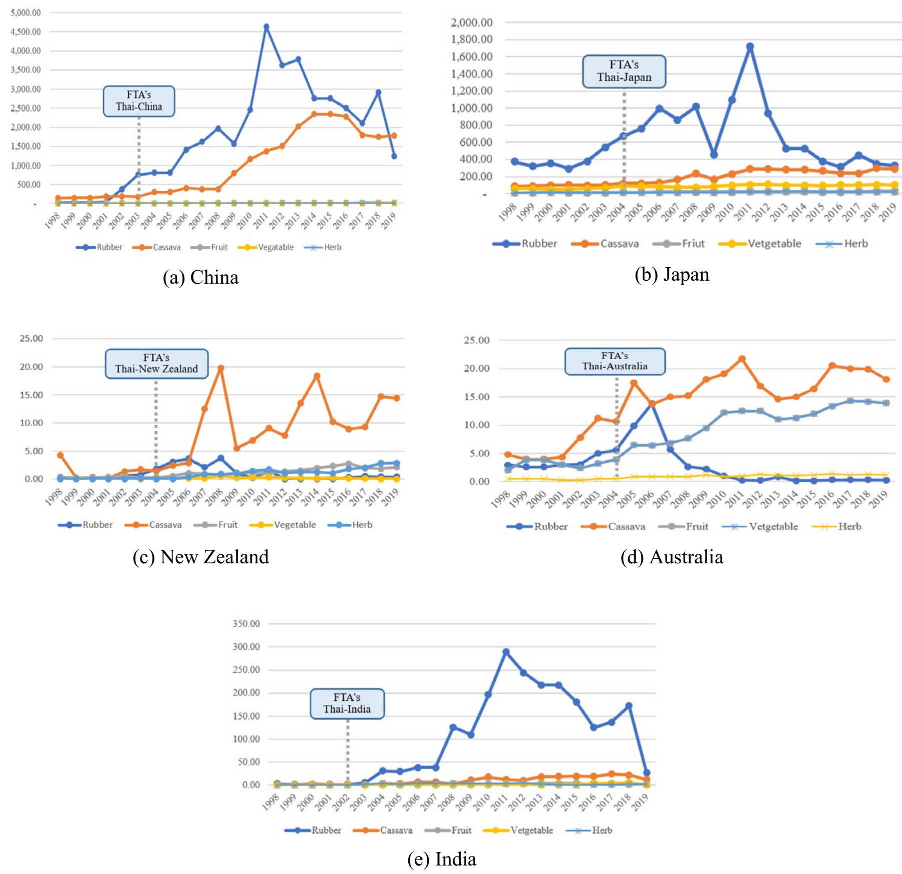

Fig. 1 The volumes of five agricultural commodities exported to Thailand's FTA trading partners. Source: Office of Agricultural Economics (2019)

4 Empirical results

4.1 Dataset

The panel data consisting of the five bilateral trading partners with Thailand for the agricultural commodities rubber, cassava, vegetables, fruits, and herbs were taken from the Information Technology and Communication Center, Ministry of Commerce. One of the advantages of utilizing the panel data is that it can deal with the behavior of technical inefficiency across time. The data on the *GDP*, which is a proxy for the size of the economy, population (*POP*) the exchange rate (*EX*) were collected from the World Development Indicators (WDI) over the period from 1998 to 2019. The distance data are received from the CEPII Geodist dyadic dataset. Then, the variables were transformed into logarithms. Figure 1(a to e) shows the five agricultural commodity volumes (million US$) of Thailand with the FTA trading partners China, Japan, New Zealand, Australia, and India. In this study, the products of rubber, cassava, fruits, and herbs are utilized as proxies representing the agricultural commodities, since they regularly make up a large share of export to these destinations. The FTAs have generally been established since 2003 for each trading partner. Afterward, the volumes of agriculturities greatly expanded but possibly fluctuate over time.

4.2 Empirical findings

To emphasize the incidences of noise-inefficiency dependence and temporal dependence among the model's error components, we augment the standard frontier model associated with the gravity model using the copula criteria. The standard GSFM is assumed to have independent error components. Moreover, the Gaussian copula, the Student-*t*, and the multivariate multiparameter FGM copulas-based GSFMs were constructed to measure the trade technical efficiency. For model selection, we determine Akaike's information criterion (AIC) and Bayes information criterion (BIC) to compare the candidate models. Akaike's information criterion (AIC) is an estimator to measure the performance of statistical model fitting, which pree relative quality of a statistical model to each of the other models.

The AIC and BIC methods offer significant advantages in reality. This is because the estimator cooperates with a model's maximum likelihood estimation (log-likelihood) to represent the performance of quantifying how close predictions are to the actual outcomes. A variety of researchers have applied the AIC estimator to offer a means for model selection (Stoica and Selen 2004; Richard 2016; Matt 2019). Moreover, Tharmaratnam and Claeskens (2011) confirmed that the AIC-based estimator plays an important role and provides quantitative pee robustness. Table 1 summarizes the estimated results for standard GSFM and copulas-based GSFM.

The results indicate that the Student-*t* copula-based GSFM in every part of agriculture commodity offers minimized both AIC and BIC for rubber (AIC = 796.600 and BIC = 852.198), cassava (AIC = 633.073 and BIC = 688.671), fruits (AIC = 677.982 and BIC = 733.580), vegetables (AIC = 676.152 and BIC = 749.725), and herbs (AIC = 648.123 and BIC = 760.190). Generally, the Student-*t* copula can capture and characterize the covariant structure of tail dependencies. In this study, the Student-*t* copula-based GSFM performs best in simulating the occurrence of extreme events due to its strong tail dependence both upper and lower tail dependence.

Accordingly, the Student-*t* copula-based GSFMs are utilized to estimate technical efficiency. Empirically, the Thai GDP, partner GDP, partner's population, and exchange rates are positively significant at the 1% level of significance in promoting Thai exports. For instance, a 1% growth in Thai and partner GDPs are associated with increases in Thai rubber export by 1.039% and 1.898%, respectively. A 1% growth in the partner's population stimulates rubber export by 0.817%, etc. It is verified that bilateral trade expands when the GDPs of both trading partners rise, which is consistent with the studies of Anderson (2014) and Boonyakunakorn et al. (2018).

4.3 Thailand's agricultural export efficiency

The technical efficiency (TE) in terms of trade efficiency belonging to an individual country is determined as the ratio of the observed agricultural commodities with the corresponding gravity model properties such as economic mass, geographic distance, and other relevant global trade elements utilized by the trading partners. Hence, Thai export efficiency levels under the FTA schemes are estimated using the copula-based GSFM for each of the trading countries and their frontier specifications. Export potential conceptually imposes either a country's trade performance at the optimum frontier with frictionless trade regimes, or it is the maximum level of trade at certain determinants

Table 1 The estimated results of standard GSFM and the copulas-based GSFM

Variable	**Standard GSFM**		**Gaussian copula-based GSFM**		**Student-*t* copula-based GSFM**		**FGM copula-based GSFM**	
	Coefficient	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
Rubber								
Constant	− 0.694	0.096	0.173	1.246	0.458	0.851	0.619	0.520
$lnGDP_i$	0.107***	0.027	1.122***	0.017	1.039***	0.003	0.806***	0.099
$lnGDP_j$	1.829***	0.071	0.870***	0.045	1.898***	0.015	0.654***	0.042
$lnPOP_i$	− 1.802	0.050	− 0.438	0.034	− 2.075	0.035	− 3.265	0.135
$lnPOP_j$	0.674**	0.063	1.667**	0.045	0.817*	0.081	9.953*	0.246
$lnDist_{ij}$	− 8.220	0.215	− 3.029	0.129	− 9.654	0.168	− 13.639	0.164
$lnEX_i$	0.381**	0.015	0.153**	0.008	0.464**	0.036	0.620	0.058
$lnEX_j$	− 2.555	0.011	− 1.330	0.034	− 3.637	0.058	− 2.897	0.440
σ_μ	0.471***	0.336	0.056***	0.013	0.878*	0.223	0.371**	0.234
σ_ν	0.299*	0.065	0.836**	0.011	0.199**	0.046	0.169*	0.294
ρ_1			− 0.319	0.098	0.934***	0.053	− 0.990	0.177
ρ_2			0.252**	0.051	0.990***	0.001	− 0.053	0.268
ρ_3			–	–	0.720**	0.029	–	–
ρ_4			–	–	0.410*	0.064	–	–
AIC	1526.374		1466.382		**796.600**		1386.497	
BIC	1627.396		1514.035		**852.198**		1434.152	
Cassava								
Constant	0.59	0.192	0.101***	0.651	0.615**	0.139	0.627	2.886
$lnGDP_i$	1.23***	0.063	1.752***	0.001	1.188***	0.051	1.232	0.054
$lnGDP_j$	0.03	1.882	0.483***	0.054	0.062**	0.029	− 0.459	1.953
$lnPOP_i$	− 3.32***	0.155	0.415*	0.010	3.172**	0.006	− 3.069	0.141
$lnPOP_j$	8.73	0.184	0.404***	0.022	0.244	0.072	9.137	0.055
$lnDist_{ij}$	− 12.92***	0.627	− 0.945*	0.024	− 12.477	0.030	− 12.117	0.553
$lnEX_i$	0.02	0.043	− 0.784***	0.007	0.023**	0.027	0.031***	0.036
$lnEX_j$	− 2.36***	0.845	− 0.109***	0.112	− 1.782	0.041	− 2.367	0.655
σ_μ	0.456**	0.195	0.035***	0.005	0.647**	0.033	0.489	0.041
σ_ν	0.691***	0.013	0.324***	0.016	0.541*	0.077	0.324	0.163
ρ_1			0.568***	0.084	0.653***	0.049	0.990	0.492
ρ_2			− 0.104***	0.068	0.790***	0.001	− 0.084	0.268
ρ_3			–	–	0.471*	0.015	–	–
ρ_4			–	–	0.054*	0.043	–	–
AIC	1425.386		1392.558		**633.073**		1247.293	
BIC	1528.394		1440.216		**688.671**		1294.948	
Fruits								
Constant	0.971	0.099	0.161***	0.791	0.106*	0.171	0.130	0.687
$lnGDP_i$	1.371	0.088	1.493***	0.074	1.325***	0.064	0.730	0.100
$lnGDP_j$	− 6.968	0.042	1.191***	0.141	0.920**	0.026	− 0.649	3.605
$lnPOP_i$	− 1.129	0.017	− 1.127	0.204	− 0.579	0.150	− 0.245	0.262
$lnPOP_j$	5.837	0.062	1.737**	0.200	0.5412*	0.091	0.449	0.120
$lnDist_{ij}$	− 3.631	0.074	− 3.032	0.818	− 1.120*	0.074	− 0.458	1.020
$lnEX_i$	− 2.611	0.053	− 0.249**	0.052	− 0.218***	0.030	− 0.042	0.068
$lnEX_j$	1.207	0.071	0.010***	0.095	− 0.413	0.035	0.292	1.206
σ_μ	0.598	0.018	0.472***	0.070	0.627**	0.056	0.896	0.077
σ_ν	0.364	0.845	0.147*	0.104	0.644*	0.011	0.572	0.259
ρ_1			0.833**	0.154	0.790***	0.048	0.990	0.596
ρ_2			− 0.096*	0.268	0.490***	0.001	− 0.089	0.268

Table 1 (continued)

Variable	Standard GSFM		Gaussian copula-based GSFM		Student-*t* copula-based GSFM		FGM copula-based GSFM	
	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
ρ_3			–	–	0.500***	0.020	–	–
ρ_4			–	–	0.620	0.043	–	–
AIC	1437.306		1338.892		**677.982**		1380.869	
BIC	1527.359		1386.557		**733.580**		1428.524	
Vegetables								
Constant	− 3.940	1.156	0.206***	1.285	0.210	1.055	0.313**	0.2987
$lnGDP_i$	2.288***	0.083	2.295***	0.084	2.332**	0.073	0.414***	0.092
$lnGDP_j$	− 0.719	0.158	− 0.786**	0.213	− 0.785	0.024	− 0.213	0.682
$lnPOP_i$	− 1.352	0.212	− 1.386	0.211	− 1.416	0.096	− 1.754	0.573
$lnPOP_j$	4.502***	0.711	2.176*	0.646	2.2198***	0.022	3.701*	0.173
$lnDist_{ij}$	− 1.966	0.831	− 2.099	0.824	− 2.146***	0.063	− 4.929	0.929
$lnEX_i$	0.270**	0.056	0.268**	0.054	0.264***	0.047	0.751**	0.626
$lnEX_j$	− 2.439	1.002	− 2.105	0.983	− 2.016	0.090	1.629***	0.110
σ_μ	0.611***	0.216	0.656***	0.111	0.815*	0.078	0.768	0.522
σ_ν	0.343**	0.399	0.648***	0.246	0.404**	0.033	0.008***	0.524
ρ_1			0.732**	0.307	0.677***	0.068	0.594	0.280
ρ_2			− 0.080*	0.268	0.990*	0.001	− 0.046	0.380
ρ_3			–	–	0.063***	0.017	–	–
ρ_4			–	–	0.137**	0.035	–	–
AIC	1426.396		1335.973		676.152		1358.847	
BIC	1493.472		1383.636		749.725		1406.502	
Herbs								
Constant	− 5.853	0.091	0.2483***	5.468	0.197**	4.568	0.323	0.743
$lnGDP_i$	4.532***	0.053	0.389***	0.056	0.375**	0.047	0.101**	0.096
$lnGDP_j$	− 3.046	0.415	0.867***	0.231	1.222***	0.163	− 1.085	0.348
$lnPOP_i$	− 1.008	0.191	− 1.399	0.142	− 1.169	0.114	− 1.251	0.244
$lnPOP_j$	3.584	0.582	3.633	0.384	2.705**	0.629	3.632*	0.243
$lnDist_{ij}$	− 3.167***	0.764	− 4.943*	0.564	− 4.206***	0.456	− 4.281	0.958
$lnEX_i$	5.823*	0.053	0.559**	0.037	0.544**	0.032	0.544***	0.063
$lnEX_j$	− 3.184	0.081	− 1.112	0.611	− 0.148	0.499	− 0.062	0.144
σ_μ	0.295***	0.193	1.175**	0.235	0.505**	0.259	0.841**	0.139
σ_ν	0.475*	0.222	3.182*	0.338	1.927**	0.386	0.500	0.456
ρ_1			0.369***	0.012	0.087***	0.116	0.990	0.352
ρ_2			− 0.523	0.089	0.190*	0.001	− 0.092	0.268
ρ_3			–	–	0.320**	4.199	–	–
ρ_4			–	–	0.020***	0.643	–	–
AIC	1472.386		1367.127		**648.123**		1339.762	
BIC	1496.364		1414.773		**760.190**		1387.417	

Calculation, significance codes: * = 0.1, ** = 0.05, *** = 0.01 and the best models, denoted by the lowest AIC and BIC values, were represented in bolditalic

in case of the least restrictions and trade barriers within the global market. If a country virtually merchandizes its commodities to the global market at the trading frontier, it can achieve economic efficiency. This status indicates a country reaches its technical and allocative efficiency (Kaliraja and Shand 1999; Roperto and Edgardo 2014).

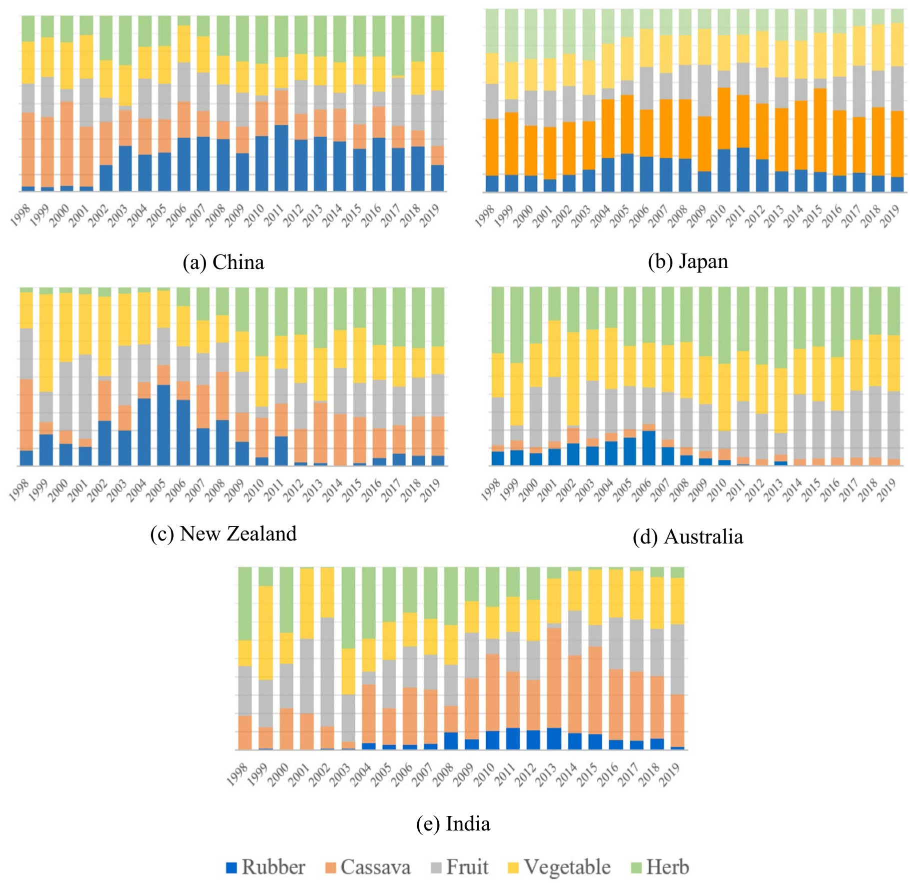

Fig. 2 The TE scores from 1998 to 2019

In this study, if Thailand reaches an efficient level of exports to the FTA trading partners, this indicates that Thai export performance approaches its maximum potential with that nation. On the other hand, an inefficient position in exports is suggested by poorer actual data than the plausible trade potential. The Thai FTA partner countries in this study were China (CHN), Japan (JPN), New Zealand (NZL), Australia (AUS), and India (IND). The higher TE scores of Thai agricultural exports convey that the export performance to a partner country virtually reached its maximum export potential. For China, Thailand can gain considerably from rubber compared to the other commodities, but recently this export has been down for a while, as seen in Fig. 2a. For Japan in Fig. 2b, cassava and vegetables have been exported consistently to Japan, which is one of the main cassava importers from Thailand. In New Zealand shown in Fig. 2c, fruits and vegetables have performed continuously, while herbs have remarkably increased lately. For Australia in Fig. 2d, the trends are similar to New Zealand. For India in Fig. 2e, cassava, fruits, and vegetables have performed steadily in trade efficiency, while rubber and herbs appear to be vulnerable.

A summary of TE scores for each agricultural commodity is listed in Table 2. The highest and the lowest TE levels from China are rubber (0.56) and fruits (0.41), from Japan, they are cassava (0.77) and rubber (0.34), from New Zealand, are vegetables (0.47) and

Table 2 The overall TE of Thai agricultural exports to FTA partner countries

Thai–FTAs partnerships	TE of Thai agricultural exports					
	Rubber	Cassava	Fruits	Vegetables	Herbs	Overall TE
CHN	0.56	0.48	0.41	0.45	0.50	***0.48***
JPN	0.34	0.77	0.41	0.48	0.42	***0.48***
NZL	0.30	0.39	0.42	0.47	0.39	***0.39***
AUS	0.11	0.07	0.44	0.48	0.54	***0.33***
IND	0.12	0.60	0.48	0.46	0.39	***0.41***

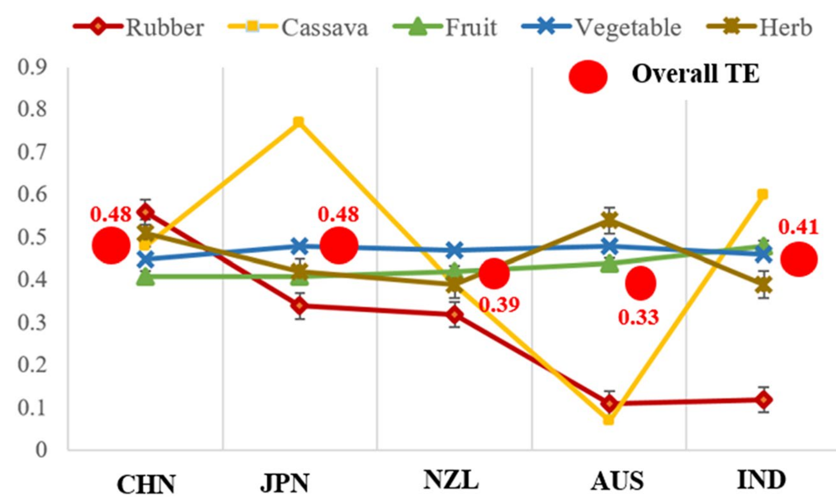

Fig. 3 TE scores of Thai agricultural exports to FTA partners

rubber (0.30), from Australia, are herbs (0.54) and cassava (0.07), and from India are cassava (0.60) and rubber (0.12).

The mean TE scores of Thai agricultural exports are shown in Fig. 3. Empirically, the TE levels of Thai agricultural exports to the FTA partners are far below their estimated efficient ranks. Among the Thai–FTA trading partners, China and Japan had the highest export efficiencies with the same average TE at 0.48. This is followed by India and New Zealand at 0.41 and 0.39. Australia had the lowest one at 0.33, in which rubber and cassava probably encountered certain burdens. The findings indicate that Thailand should adopt more FTA negotiations with the trading partners and support lenient rules of origin for export efficiency. Moreover, they should promote miscellaneous behind-the-border barriers to stimulate flows of goods that can improve the country's trade efficiency substantially.

There is no guarantee that an FTA would cause shifts in a particular direction of free trade. The effects rely substantially on the negotiations and agreements (Asian Development Bank 2008). In particular, Thailand operates with an outward-oriented strategy that engages in pro-free-market competition. Policymakers understand the comprehensive and complicated manners of agreements and attempt to foster advantages while minimizing the potentially negative impacts.

5 Conclusions and policy implications

This study investigated the international trade efficiency levels of Thai agricultural exports of rubber, cassava, fruits, vegetables, and herbs with FTA trading partners, namely China, Japan,

New Zealand, Australia, and India. We augmented the traditional GSFM by considering the dependency between two error elements: a non-negative error (μ), indicating the trade inefficiency, as well as asymmetric noise (v), indicating country-specific circumstances. The copulas including Gaussian, Student-*t*, and FGM were constructed to deal with dependency structures. Furthermore, we applied a panel data framework to estimate the trade efficiencies since this holds observations with diverse cross-sections and times. This method provides more information, more variability, and more efficiency during the studied period. The main findings can be summarized as follows:

- The aspect of "efficiency" is understood in common sense, it is fuzzy. Since several inputs are utilized using its technology to produce outputs and trade in global markets. For that, it is essential to measure it of a country or a firm. The Student-*t* copula-based SFMs offer the best model specification to precisely evaluate the trade efficiency levels for Thailand and its FTA trading partners because this produced lower AIC and BIC than the other copula families. Therefore, economists or policymakers can accurately measure the trade efficiency of a country through technical efficiency (TE), informing as "degrees of success to global trade" for a country.
- The Thai–Australia trading partnership retains some obstacles to the export of agricultural commodities, in particular rubber and cassava. Initially, they implemented very high tariff barriers (for some goods, up to 200%). On the date of entering into force of the Thai–Australia FTA, Australia eliminated more than 83% of tariffs on several goods imported from Thailand, covering fresh fruits and vegetables. However, the tariff on the remaining 17% of imports, including rubber and rubber products, textiles and apparel, etc., are deliberately eliminated between 2010 and 2015 (Chiasakul et al. 2008). Hence, Thailand has remaining unused trade potential in this context.
- The agricultural trade guidelines of Thailand are based on TE scores. Thailand should increase rubber trade to China, cassava should be expanded to Japan, vegetables should be raised to New Zealand, and herbs should be increasingly traded to Australia. However, Thailand needs to improve its technical efficiency in terms of trade with trading partners under the FTA. This is a guideline for a future study of what factors are contributing to the efficiency of Thai agricultural trade.
- Tariff rates on agricultural goods are ordinarily higher than non-agricultural goods since government rigorously protects domestic agriculture from foreign competition. For many countries, agricultural products are often set to be "sensitive-good", meaning they are important for national security reasons. For that, the competence of flexibility in trade negotiation, especially in sensitive agricultural products, is difficult to handle (Sébastien et al. 2010). From the overall point of view, the Thai's TE remains in the middle scoring between 0.33 and 0.48. These could be improved. Consequently, the Thai Government should intensively foster export

efficiency for agricultural commodities by stimulating structural reforms, as a comprehensive global resolution. It is not only the removal of tariffs and non-tariff barriers, but also FTA facilitation and negotiating agreements. Policymakers must understand the manifold natures of a treaty and try to pursue advantages while minimizing disadvantages.

– To improve trade efficiency, the Thai government should increase several agricultural instruments to diversify risks in the international market. Moreover, it should substantially promote collaboration between the private sector and the government. The private sector can predicate either distinct barriers or best practices from the engagement in each market. Also, the government should diagnose various recommendations received from the private sector. The government sets a priority for those issuers that will affect Thailand's economy. Ultimately, these collaborations may improve Thai competitiveness and trade efficiency.

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AR: conceptualization, methodology, data preparation, data curation, formal analysis, statistic program, investigation, writing, supervision. CN: statistic program, coding of the statistic software literature reviews. PN: coding of the statistic software, visualization. All authors have read and agreed to the published version of the manuscript.

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