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Pesticide Residue Control and the Role of Regulatory Cooperation: Evidence from Fruit Exports in Southeast Asia

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Sanitary and Phytosanitary measures are the predominant non-tariff measures for agricultural products. In response to safety concerns, governments and international bodies have set Maximum Residue Limits (MRLs) for pesticide residues on agricultural products. However, variation in MRL standards across countries creates obstacles to agricultural trade. This study explores how the regulatory heterogeneity of MRLs and regulatory cooperation affect fruit exports from ASEAN countries. The findings indicate that regulatory heterogeneity generally hinders fruit exports from ASEAN countries, with the effects varying across major markets; The regulatory heterogeneity restricts fruit exports to South Korea but seldom affects exports to Australia, China, and Japan. Furthermore, the negative impact of regulatory heterogeneity can be partially mitigated through regulatory cooperation under the regional trade agreement framework while maintaining required safety standards, highlighting the importance of regulatory cooperation.

Keywords: Maximum Residue Limitation, Non-Tariff Measures, regulatory cooperation, fruit exports, agricultural trade

JEL classification: F13, F15, Q17

1. Introduction

Over the past three decades, through multiple rounds of World Trade Organization (WTO) negotiations and the proliferation of Regional Trade Agreements (RTAs), tariff rates on agricultural products have been substantially reduced globally. The adoption of non-tariff measures (NTMs) is becoming more prevalent, with Sanitary and Phytosanitary (SPS) regulations emerging as a key instrument in agricultural trade (Stone and Casalini, 2020).

SPS measures serve the dual purposes of safeguarding consumer health and preventing the transmission of pests and diseases that threaten plant and animal populations. Such regulations

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encompass a range of requirements, including sourcing products from disease-free regions, conducting inspections, and establishing permissible Maximum Residue Limitations (MRLs) in food (WTO 2010, p. 9). As defined by the Food and Agriculture Organization (FAO), MRLs represent the maximum level of pesticide residue allowed in food, with the prerequisite that pesticides should be properly adopted in accordance with Good Agricultural Practice (GAP).

Examining the impact of these standards on trade, prior research has primarily discussed two types of problems: the *level* of standards and their *regulatory heterogeneity*. Studies assessing the impact of *level* of standards have dominated the literature in this area. These studies assessed the impact of MRL standards using the actual MRL values of specific chemicals, concluding that stringent standards generally hinder agricultural trade (Wilson, Otsuki, and Majumdar, 2003; Wilson and Otsuki, 2004; Tran, Nguyen, and Wilson, 2014). This negative impact is particularly pronounced in developing countries, where stringent standards often create substantial barriers to market entry thus limiting participation in global agricultural trade (Shepherd and Wilson, 2013). However, a major problem with these studies is that they only focused on specific chemicals. In practice, several pesticides are applied during the production process, and analyses based on specific chemicals might over-estimate the trade impact.

Another problem is the *regulatory heterogeneity* of standards, where variations in MRL standards between countries create inconsistencies in MRL values for the same chemical across different markets. Drogué and DeMaria (2012) highlight that harmonization of MRL regulations has never been achieved at a global level. Although the WTO encourages member countries to use international standards (i.e., the standard developed by CODEX Alimentarius), WTO members are also allowed to adopt their own national standards. Therefore, some countries develop more stringent national MRLs, while many developing countries maintain international standards or do not develop national standards at all. Consequently, these legal regulations differ across countries, which can pose a serious problem for international trade.

Despite recognizing this issue, the impact of regulatory heterogeneity on standards have yet to be properly explored. Various methodologies have been proposed to quantify the regulatory heterogeneity of MRLs; however, many share fundamental limitations. Existing indices assume a linear relationship between regulatory heterogeneity and harmonization costs (e.g., Drogué and DeMaria, 2012; Winchester et al., 2012; Ferro, Otsuki, and Wilson, 2015). Harmonizing stringent

standards requires additional inputs in the production process and greater heterogeneous stringency leads to escalating marginal costs. Thus, a more realistic cost function is required to properly assess the impact of the regulatory heterogeneity of MRLs.

A recent development in this area is a contribution by Li and Beghin (2014), who overcame this shortcoming in their study, constructing an index that compared regulatory heterogeneity between a given exporting country and international standards. However, a comparison with international standards is less realistic because most countries have established their own national MRL standards and operate accordingly. In addition, the CODEX standard covers a restricted range of pesticides, which may introduce bias by overlooking other widely used pesticides that are not included. Peng (2023) revised Li and Beghin's (2014) method by substituting the international benchmark with the MRL standards of importing countries, allowing for direct comparisons between trading partners. In addition, Peng (2023) expanded the index to incorporate unregistered pesticides omitted from the original framework, providing a more comprehensive reflection of the regulatory heterogeneity between given country pairs.

Although these studies have enhanced our understanding, further improvements are required in three aspects: perspective, methodology, and policy. First, the long-term effects of standards on trade are unclear. The regulatory heterogeneity of MRLs increases compliance costs, which are fixed costs for exporters (Ferro, Otsuki, and Wilson, 2015). Although not always, the existence of fixed costs hinders firms from responding immediately because it may take time to assure a certain volume of exports that will cover fixed costs. However, in the long run, once these barriers are cleared, regulations may not significantly obstruct trade (Ferro, Otsuki, and Wilson, 2015; Peterson et al., 2013). Hence, the long-run impact may be less pronounced than that of short-run disruptions. Addressing this empirical question requires long-term analysis.

Second, many studies have struggled to solve the endogeneity issue, which is an inherent problem in trade analysis. Trade policies, such as the establishment of RTAs, are not purely exogenous; countries tend to establish RTAs with their main trading partners (Trefler, 1993). Many previous studies have not effectively addressed this issue, potentially leading to biased results. Therefore, following Baier and Bergstrand's (2007) approach, we introduced pair-specific fixed effects to address the endogeneity issue. This method also accounts for the bilateral, time-invariant determinants of trade (Agnosteva, Anderson, and Yotov, 2019).

Third, the extent to which regulatory cooperation affects the regulatory heterogeneity of MRLs remains unclear. Regulatory cooperation is an important part of the RTA framework, which comprises several independent chapters designated for different NTMs, such as SPS and Technical Barriers to Trade (TBT), which aim to mitigate the negative impact of NTMs. SPS-related chapters typically contain several clauses to achieve this objective. For instance, standard harmonization clauses promote the establishment of international or regional standards and improve market access by allowing products that comply with these standards to enter the domestic market. Transparency clauses require member countries to provide timely updates on new regulations or amendments to existing regulations, thereby minimizing information asymmetry. Despite these possible influences, research on regulatory cooperation is limited owing to data constraints. A related study by Santeramo and Lamonaca (2022) estimated how regulatory cooperation affects trade flows between RTA signatories. Specifically, they estimated the impact of specific provisions (standard harmonization/equivalence, risk assessment, etc.) embedded in the RTAs related to regulatory cooperation, finding that establishing a committee on SPS coordination tends to increase bilateral trade by more than 20% and that actively working on technical cooperation boosts trade two folds. Building on the definition of regulatory cooperation established by Santeramo and Lamonaca (2022), this study investigates the impact of regulatory cooperation on international trade.

Incorporating these three new aspects, this study estimates a structural gravity model to identify the impact of the regulatory heterogeneity of MRLs and the role of regulatory cooperation on international trade using country-level data from 2008 to 2020. This study focuses on Association of Southeast Asian Nations (ASEAN) countries' fruit exports for three reasons: (i) tropical fruits are more likely to suffer from the regulatory heterogeneity of MRLs; (ii) ASEAN countries hold a prominent position in the global fruit trade, contributing approximately 10% to global fruit exports in 2020; and (iii) the production of these cash crops makes a significant contribution to ASEAN's economic development.² Our results show that the regulatory heterogeneity of MRLs generally

² There are two essential factors that make the issue of regulatory heterogeneity of MRLs more pronounced in the context of fruit exports. The first comes from the nature of the tropical area. Tropical climates promote the spread of pests and diseases that threaten the harvest. To combat this issue, farmers use various pesticides, making it more difficult to meet MRL standards set by importing countries. Second, tropical fruits are considered minor crops due to their smaller

hinders fruit export from the ASEAN; however, the effects differ across major markets. Regulatory heterogeneity restricts fruit exports to South Korea but seldom affects exports to Australia, China, and Japan. Furthermore, the negative impact of the regulatory heterogeneity of MRLs can be partially mitigated through regulatory cooperation under the RTA framework, while maintaining its original purpose of setting safety standards, highlighting the importance of regulatory cooperation on SPS measures.

The remainder of this paper is organized as follows. Section 2 discusses ASEAN's MRL policy and regulatory cooperation on SPS measures. Section 3 outlines the theoretical framework, empirical specifications, and data sources utilized in this study. Section 4 presents the findings on how the regulatory heterogeneity of MRLs affects trade, along with an analysis of the role played by regulatory cooperation. Finally, Section 5 provides concluding remarks and outlines the policy implications.

2. The MRL policy in the ASEAN and regulatory cooperation on SPS measures

Controversy over the use of pesticides remains unsolved; however, its impact is undeniable. Over the past half century, the increased adoption of pesticides has significantly boosted the productivity of agricultural products worldwide. However, the use of pesticides is associated with persistent concerns regarding safety risks, because some of these chemicals are toxic to humans. A notable example is Paraquat, a widely used herbicide that has been confirmed to be linked to the development of Parkinson's disease. Consequently, Paraquat has been banned in several countries, and even in countries where its use remains legal, Paraquat's MRL is strictly regulated.

In response to these health concerns, and to enhance the competitiveness of agricultural products, the ASEAN established a regional MRL standard modeled after the EU's framework (hereafter referred to as the "ASEAN standard"). However, unlike the EU's harmonized regulatory system, ASEAN standards have not been uniformly adopted by all member countries. Most ASEAN members (Indonesia, Malaysia, Singapore, Thailand, Philippines, and Vietnam in this

cultivation areas compared to major crops like grains and soybeans. Some countries lack the specific MRL regulations for these tropical fruits, largely because they are not grown in that area. This vacuum in MRL policies creates uncertainties for ASEAN's fruit exports.

study) maintain their own national MRL standards. Some countries, such as Malaysia and Singapore, defer to the ASEAN standard when a given pesticide is not registered in the national MRL database. In contrast, Cambodia, Lao PDR, and Myanmar, which have not developed a national standard, have fully adopted the ASEAN standard. In these countries, ASEAN standards serve as a substitute for the absence of domestic MRL regulations.

Moreover, the ASEAN has sought economic cooperation through RTAs to enhance regulatory alignment. While traditional RTAs focus on facilitating trade flow by eliminating tariffs levied on products, recent agreements emphasize regulatory cooperation with NTMs. Such cooperation typically takes the form of independent chapters within the RTA framework that address specific types of NTMs, such as SPS and TBT, to mitigate their negative impact. Each chapter contains several clauses, such as the mutual recognition of international standards and conformity assessment procedures and transparency clauses, which go beyond the WTO's requirements and play crucial roles in mitigating the negative impact caused by NTMs. Empirical evidence suggests that incorporating specific clauses into RTAs can significantly enhance trade flows. For example, Disdier, Stone, and van Tongeren (2019) provide empirical evidence that RTAs incorporating SPS and TBT measures have a significant positive effect on trade flows, with the enforceability of regulatory cooperation mechanisms exerting the strongest and most robust impact. Similarly, Santeramo and Lamonaca (2022) estimated the effects of regulatory cooperation on trade flows between RTA signatories, finding that establishing a committee for SPS coordination increases bilateral trade by more than 20%, while actively pursuing technical cooperation doubles this effect. These findings underscore the critical role of regulatory cooperation in enhancing the effectiveness of RTAs and fostering deeper economic integration.

In our dataset, 11 out of 18 RTAs involving ASEAN countries contained a chapter designating SPS, reflecting ASEAN's commitment to addressing NTMs through cooperative frameworks. Such regulatory cooperation focuses not only on facilitating trade, but also on building trust in the safety and quality of agricultural products.

3. Methodology and data

3.1 Calculating the Bilateral Heterogeneity Index (BHI)

Building on Li and Beghin's (2014) approach, we constructed our core indicator—the bilateral

heterogeneity index (BHI)—to capture the regulatory heterogeneity between ASEAN member countries and importers. This index accounts for two key dimensions: the number of registered pesticides (n) in one country and the MRL levels assigned to each pesticide (Peng, 2023). Let MRL_{ipt}^k denote the legal MRL (in ppm) of pesticide p for product k in country i at year t . A lower MRL value reflects more stringent standards adopted by the respective country. The fundamental assumption is that if the MRL regulation in the importing country j is more stringent than the domestic regulation in the exporting country i ($MRL_{ipt}^k - MRL_{jpt}^k > 0$), it constitutes a trade barrier. The BHI is defined in Equation (1).

$$BHI_{ijt}^k = \frac{1}{n} \sum_{p=1}^n \exp\left(\frac{MRL_{ipt}^k - MRL_{jpt}^k}{MRL_{ipt}^k}\right) \quad (1)$$

The first step in the calculation is to measure how different importer j 's MRL from those of exporter i . This difference can be positive (when importers' requirements are more stringent) or negative (when exporters' requirements are more stringent). Existing studies often posit a linear relationship between regulatory heterogeneity and harmonization costs. However, satisfying stringent standards requires additional inputs in the production process (e.g., alternative pesticides with higher costs); the greater the gap in stringency, the higher the resulting marginal costs in the production process. To address this issue, we followed the exponential function proposed by Li and Beghin (2014), which maps the observed values within the range of 0–2.72. Finally, the aggregation process depicts the average disparities in MRL policies for product k between a given country pair in year t . A BHI score close to 1 indicates that the stringency of the existing MRL policy of a given country pair is at a highly similar level, whereas higher scores reflect more stringent standard requirements in the importing country than in the exporting country.

In certain cases, MRL_{ipt}^k (or MRL_{jpt}^k) is missing from the database when pesticide p is unregistered in country i (or j). These occurrences are common when countries i and j have different levels of economic development. Addressing unregistered pesticides represents a crucial improvement over previous studies and ensures that our index accurately reflects the actual extent of regulatory heterogeneity. Therefore, following Peng (2023), we refer to the national regulations of MRL deferral policies, detailed in Appendix 1. These policies may include outright bans on

unregistered pesticides, the application of default MRLs (e.g., zero tolerance or 0.01 ppm), or the recognition of international standards, such as CODEX, EU, or ASEAN standards. Although MRL deferral policies help address missing values, many developing countries lack such a framework and do not restrict the use of unregistered pesticides. In these cases, a common maximum MRL value of 50 ppm is assigned.

3.2 Model specification and data source

We adopted the structural gravity model developed by Anderson and Van Wincoop (2003) as the theoretical framework for the econometric analysis. It is one of the most well-known and effective frameworks in the international trade literature for quantifying the impact of trade policies (Yotov et al., 2016). The structural gravity model is expressed in Equation (2), as follows:

$$X_{ij} = \frac{Y_i E_j}{Y} \left(\frac{t_{ij}}{\pi_i P_j} \right)^{1-\sigma} \quad (2)$$

Time indices are ignored for simplification. X_{ij} represents country j 's imports from country i . The right-hand part in this equation consists of a size term $\frac{Y_i E_j}{Y}$ and a trade cost term $\frac{t_{ij}}{\pi_i P_j}$. The intuitive interpretation of the size term is as the hypothetical level of frictionless trade between countries i and j if there were no trade costs, where Y_i is the value of total exports in country i ($Y_i \equiv \sum_j X_{ij}$), Y is the total output for all exporters, (i.e., $Y \equiv \sum_i Y_i$) and E_j is the total expenditure in country j . The trade cost term captures the total effects of trade costs that drive a wedge between realized and frictionless trade. Specifically, t_{ij} denotes the bilateral trade cost ($t_{ij} \geq 1$) and π_i and P_j are defined as the inward and outward multilateral resistance terms representing i and j 's ease of market access, respectively (Yotov et al., 2016). Anderson and van Wincoop (2003) determined that multilateral resistance terms are necessary for the accurate estimation of the gravity equation.

The empirical model for the baseline estimation is presented in Equation (3). The dependent variable X_{ijt}^k , denotes the import value of product k from country i , as reported by country j in year t (measured in millions of US dollars). Import value data were collected from the United Nations Commodity Trade Statistics Database (UN Comtrade; United Nations Statistics Division, 2020). These specifications include three independent variables. $tariff_{ijt}^k$ is the tariff rate at the HS 6-digit level (simple average), obtained from the United Nations Conference on Trade and

Development (UNCTAD, 2022).³ RTA_{ijt} is a binary variable equal to one when the given trading pairs i and j are RTA signatories in year t . Detailed information on RTAs was obtained from the WTO RTA Database (WTO, 2022).

$$X_{ijt}^k = \exp \left(tariff_{ijt}^k + BHI_{ijt}^k + RTA_{ijt} + \varphi_{ij} + \mu_{it} + \tau_{jt} + \vartheta^k \right) \times \varepsilon_{ijt}^k \quad (3)$$

The key variable, BHI_{ijt}^k , measures the regulatory heterogeneity of any given country pair, i and j . MRL data is collected from the HOMOLOGA (2022) crop protection database. We expect the coefficient of BHI_{ijt}^k to be negative, as a higher score reflects a more stringent MRL policy adopted by the importing country (i.e., higher heterogeneity between importing and exporting countries), which might increase compliance costs or even trade restrictions (Peng 2023). To further explore the impact of regulatory cooperation on SPS measures, we introduce a new dummy variable in Equation (4): $SPS\ cooperation_{ijt}$. This variable takes a value of 1 if RTA includes a dedicated chapter on SPS. The interaction term of $SPS\ cooperation_{ijt} \times BHI_{ijt}^k$ captures the additional impact of countries with regulatory cooperation on SPS measures within the framework of RTAs.⁴

$$X_{ijt}^k = \exp \left(tariff_{ijt}^k + BHI_{ijt}^k + SPS\ cooperation_{ijt} \times BHI_{ijt}^k + \varphi_{ij} + \mu_{it} + \tau_{jt} + \vartheta^k \right) \times \varepsilon_{ijt}^k \quad (4)$$

Several challenges arise when the estimation methods are considered. One primary concern is the zero-trade issue. The conventional log-linear ordinary least squares (OLS) approach, widely used in trade analysis, has struggled to address this issue. Moreover, log-linear OLS models may yield biased elasticity estimates (Silva and Tenreyro, 2006). Therefore, we applied the Poisson pseudo-maximum likelihood (PPML) estimation, as suggested by prior studies. The Poisson model provides a natural way to incorporate zero observations and can also address the heteroskedasticity issue.

³ Treatment for tariff: $\log(\text{tariff rate} + 1)$.

⁴ Given that the SPS chapter's clauses mainly stress cooperation on the principles of SPS measures, but not directly aim at MRLs. We do not examine the impact of cooperation on the main principles in this study.

Despite these advantages, the PPML method also has certain limitations. Burger, Van Oort and Linders (2009) argue that the PPML method is vulnerable to overdispersion and excessive zeros in the dependent variable. Within the context of trade analysis, zero observations may result from rounding errors, the absence of bilateral trade, or stringent MRL regulations imposed by importing countries. We address the issue of excessive zeros by applying Greene's (1994) zero-inflation negative binomial (ZINB) model.⁵

Another challenge is endogeneity, an inherent problem in trade analysis. Countries are more likely to establish RTAs with their main trading partners (Trefler, 1993), creating potential correlations between endogenous trade policies and unobserved trade costs across countries (Yotov et al., 2016). To mitigate this issue, we included country-pair fixed effects (FEs, ϕ_{ij}), as suggested by Baier and Bergstrand (2007). These FEs also absorb the time-invariant bilateral determinants of trade (Agnosteva, Anderson and Yotov, 2019). In addition, exporter-year (μ_{it}) and importer-year (τ_{jt}) FEs are introduced to control for the size variables (i.e., the total expenditure in country j and the value of production in country i) and unobservable multilateral resistances, as argued by Yotov et al., (2016).

The dataset comprises six exporting countries from the ASEAN region, 15 importing countries that are the main trading partners, and 12 fruit products, covering 2008 to 2020. Detailed information is provided in Appendix 2. The dataset includes 9759 observations,⁶ of which 4028 are zero observations and 5731 are nonzero.

4. Empirical results

4.1 Overview of BHI score

⁵ Another similar method for handling excessive zero observations is the Zero-Inflated Poisson (ZIP) method, developed by Lambert (1992). The ZIP model consists of two components: a Poisson regression to estimate elasticities, and a logit regression to model the probability of zero observations. Since the PPML method is also based on a Poisson distribution, the results of the PPML method are generally consistent with those of the ZIP method. In this study we primarily report results using the PPML and ZINB method, while employing ZIP as an alternative when the ZINB estimation fails to concave.

⁶ This is an unbalanced dataset. Due to data availability, some crop-level and year-level MRL data are missing.

Table 1 Number of registered pesticides for selected countries

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Exporter													
Indonesia	-	29	29	29	29	29	29	29	66	66	66	66	66
Myanmar	26	29	30	31	31	31	39	39	39	39	42	41	42
Malaysia	67	67	67	67	68	68	68	70	70	70	70	77	77
Philippines	-	-	-	-	-	-	-	50	50	50	50	50	50
Thailand	16	16	16	16	37	37	37	37	37	55	55	55	56
Vietnam	70	70	70	70	70	70	70	70	70	70	145	145	171
Importer													
Australia	154	158	163	166	166	152	152	166	172	181	209	232	241
Canada	43	49	52	55	65	83	94	109	117	125	129	135	137
China	31	54	54	54	41	89	125	127	127	143	143	164	201
CODEX	75	79	101	97	106	116	118	123	151	151	166	181	163
EU	459	462	471	498	510	526	533	568	572	606	618	855	827
Hong Kong SAR, China	75	79	101	97	106	116	156	158	158	158	164	164	164
India	74	50	50	50	50	50	50	50	50	50	50	80	80
Japan	414	414	429	395	394	402	416	528	451	452	465	529	459
Korea, Rep.	197	217	238	250	251	251	271	462	468	472	477	290	296
Singapore	49	49	49	49	49	49	49	49	49	49	57	59	59
USA	142	146	152	157	160	169	181	191	189	192	228	234	238

Data source: HOMOLOGA (2022)

Table 2 Econometric results estimating the impact of BHI on ASEAN's fruit trade

Estimation method	Column (1)	Column (2)		Column (3)	Column (4)	
	PPML	ZINB		PPML	ZIP	
		Negative Binomial	Logit		Poisson	Logit
Variable						
$tariff_{ijt}^k$	-0.19** (0.08)	-0.16*** (0.03)		-0.21** (0.08)	-0.23*** (0.01)	
BHI_{ijt}^k	-0.68*** (0.21)	-0.14** (0.07)	1.59** (0.50)	-0.22 (0.30)	-0.36*** (0.02)	0.18** (0.08)
$BHI_{ijt}^k \times Australia$				0.89 (0.74)	1.26*** (0.12)	0.25*** (0.09)
$BHI_{ijt}^k \times China$				-0.42 (0.41)	0.26*** (0.03)	0.36*** (0.08)
$BHI_{ijt}^k \times EU$				-0.49 (0.51)	-0.09 (0.07)	0.11* (0.06)
$BHI_{ijt}^k \times Japan$				0.81 (0.66)	2.16*** (0.13)	0.29*** (0.09)
$BHI_{ijt}^k \times Korea$				-1.86*** (0.66)	-1.19*** (0.04)	0.40*** (0.07)
RTA_{ijt}	-0.02 (0.71)	-0.01 (0.29)	16.44 (771.836)			
Fixed effect	Yes	Yes		Yes	Yes	
Observation	9759	9759		9759	9759	

Note: dependent variable is the import value at product level (unit: million US dollars). ***, **, and * indicate the significance level at 1%, 5%, and 10% respectively. Standard errors are presented in parentheses. Constants included but not reported. Importer-time, exporter-time, country-pair and crop-specific FEs are included in all regressions. The estimated alpha in Column (2) is 1.69 (95% confidence interval: 1.62~1.75). ZINB estimation fails to concave in Column (4), we employ ZIP method as an alternative.

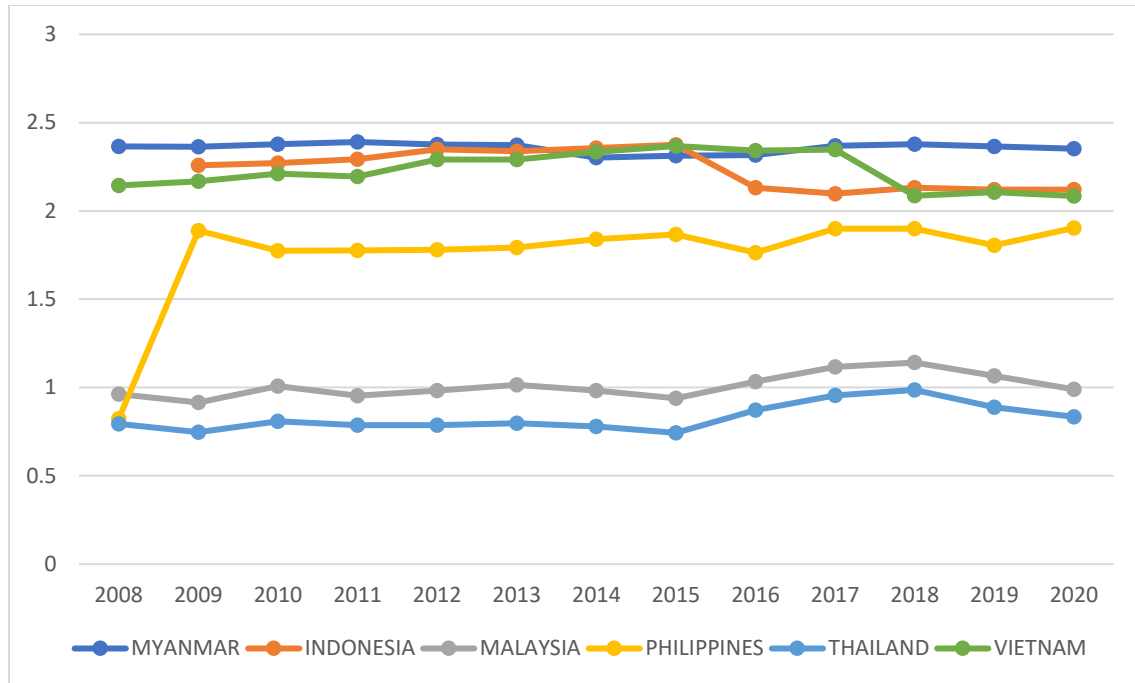


Fig. 1 Simple average BHI score aggregated by exporters, 2008 ~ 2020

Note: Indonesia started national standard of MRL since 2009, thus there is no data before 2009; it is the same situation for Philippines before 2015, given that Philippines recognizes CODEX standard, we use CODEX standard to substitute the missing values.

Before delving into the econometric results, we explore the BHI scores in our dataset. The average BHI score was 1.65, indicating that importers' MRL standards were more stringent than those of exporters. This disparity reflects the significant differences in regulatory policies.

A major source of disparity arises from the number of registered pesticides. As shown in Table 1, ASEAN countries register fewer pesticides than the major importing economies. Even for the same pesticide, the MRLs set by importers are often lower than those set by exporters. For example, in 2020, the MRL for Chlorothalonil on bananas was 15 ppm under the ASEAN standard, CODEX, and Vietnam's national regulation, while it is set at 0.2 ppm in China, Japan, and Malaysia, and 0.5 ppm in the US. These differences contribute to higher BHI scores.

Nevertheless, disparities in MRL regulations between trading partners do not necessarily translate into uniformly high BHI scores across all country pairs. There was notable heterogeneity in the aggregate BHI scores at the export level, as shown in Figure 1. This variation was largely driven by the adoption of MRL deferral policies, which prevent high BHI scores due to unregistered pesticides. In our dataset, Malaysia and Thailand, who follow the same MRL deferral

policy (default value of 0.01 ppm) as several importing countries, achieved relatively low average BHI scores in 2020—0.99 for Malaysia and 0.83 for Thailand. Despite having fewer registered pesticides, their deferral policies have mitigated regulatory disparities. Similarly, the Philippines defers to the CODEX standard to enhance its national MRL database. This policy significantly reduced the disparity in MRL policies, resulting in an average BHI score of 1.90 in 2020. In contrast, other ASEAN member countries who have not adopted MRL deferrals have considerably higher BHI scores, often exceeding 2.1. These findings highlight the importance of MRL deferrals in reducing disparities in the stringency of national standards among trading partners.

4.2 Overall impact of BHI on trade flows

The results in Table 2 show how the regulatory heterogeneity of MRLs affects the ASEAN's fruit trade. Column (1) shows the baseline estimation using the PPML estimator. Overall, the estimated coefficients of tariff rates and the BHI were statistically significant with the expected sign, whereas the coefficient of RTA was insignificant. The negative coefficient of tariffs implies that although they are whittled down by emerging bilateral and preferential trade agreements, tariffs continue to restrain fruit exports.

The estimated coefficient of BHI was -0.68, with statistical significance at the 1% level. This implies that the greater regulatory heterogeneity of MRLs leads to a decrease in total trade flows. Such regulatory heterogeneity imposes compliance costs on producers who must meet varying import standards; the greater the heterogeneity, as indicated by a higher BHI score, the higher the compliance costs. These increased costs can erode the competitiveness of some producers, leading to reduced exports. This finding reinforces the notion that regulatory heterogeneity can act as a barrier to trade and is consistent with the results of Hejazi, Grant, and Peterson (2022), who similarly conclude that stringent MRLs by importing countries reduces the export of fresh fruits and vegetables from the US.⁷

⁷ An alternative perspective suggests that standards do not significantly impede trade flows, a view often supported by firm-level analyses (e.g., Peterson et al., 2013). Firm-level and country-level analyses often yield contrasting conclusions regarding the impact of standards on trade. The existence of private standards and certifications ensures that firms can meet importer's requirements regardless of national regulatory heterogeneity between trading partners. Consequently, firm-level studies typically find that the negative impact of regulatory heterogeneity is limited. In contrast, country-level analyses capture the broader disparities in national regulations,

To address excessive zero observations in the dataset, the model was re-estimated using the ZINB method. The ZINB model accounts for two latent groups within the population: that of strictly zero counts and that of non-zero probability of positive trade flows (Burger, Van Oort and Linders, 2009). Correspondingly, the estimation process of the ZINB model comprises two components: the first is a Negative Binomial regression, which estimates the elasticities for nonzero observations, and the second is a logit (or probit) regression, which models the probability of zero trade flows.

Column (2) presents the results of the ZINB estimation. The estimated coefficient of BHI in negative binomial regression is consistent with the PPML estimation, reaffirming the negative impact of BHI on positive trade flows. The estimated effect is -13.1%.⁸ In the logit regression, BHI had a positive and statistically significant coefficient at the 1% level. This finding indicates that greater regulatory heterogeneity, as captured by a higher BHI score, increases the likelihood of zero-trade observations. This finding is intuitive: Exporters are likely to withdraw from the market and seek alternative buyers if they cannot meet the destination country's stringent MRL requirements, resulting in zero trade flow. Consequently, regulatory heterogeneity in MRLs poses a potential threat to market access and affects firms' decisions in destination countries.

However, trade costs may not affect all trade flows in the same way (Chen and Novy, 2022). To examine potential heterogeneities in the impact across major trading partners, we interact BHI_{ijt}^k with several country dummies (Australia, China, the EU, Japan, and South Korea).⁹ Columns (3) and (4) of Table 2 present these results.

The estimated coefficients are insignificant in the PPML estimation, as shown in Column (3) of Table 2. Given that excessive zero observations can lead to biased results under the PPML estimation, we re-estimated the regression using the zero-inflated Poisson (ZIP) method with the results presented in Column (4). Notably, there is a clear distinction between the estimated coefficients of the interactions between the BHI and country dummies. South Korea showed a

highlighting how differences in MRL policies across countries create systemic trade barriers that individual firms cannot fully mitigate.

⁸ The estimation for binary variables: $(e^x - 1) \times 100\%$, where x is the estimated coefficient.

⁹ Australia, China, EU, Japan, and South Korea established RTA with the ASEAN or individual ASEAN members. Therefore, the RTA dummy is not included in Columns (3) and (4). The impact of RTAs is absorbed by country dummies.

negative and statistically significant result, indicating that regulatory heterogeneity poses a significant barrier to ASEAN fruit exports. In contrast, the coefficients for Australia, China, and Japan were positive and statistically significant, whereas the coefficient for the EU was insignificant. These results suggest that, while regulatory heterogeneity creates significant barriers for exports to South Korea, it has minimal or even favorable effects on exports to Australia, China, and Japan. This finding is consistent with that of Drogué and DeMaria (2012), who reported ambiguous results regarding the marginal effects of regulatory heterogeneity across countries. They attributed the positive coefficients for Japan and the US to cases in which standard harmonization can result in trade diversion, which may also apply here. Ferro, Otsuki, and Wilson (2015) emphasized that exporters facing multiple potential markets are more likely to choose countries with less stringent product standards, which could explain the favorable results for Australia, China, and Japan in this context.

Since the country dummies also absorb the impact of RTAs, disparities across countries may also reflect the heterogeneous impact of the different provisions contained within these agreements. For instance, RTAs with Australia, China, and Japan often include provisions for the mutual recognition of standards or equivalence agreements, which can lower compliance costs and create more predictable trade environments for exporters. In contrast, South Korea's regulatory framework may prioritize stricter standards and enforcement mechanisms, potentially limiting the effectiveness of similar provisions. The insignificant coefficient for the EU can be explained by the limited scope and timeline of its trade agreements, as the EU's agreement with Vietnam entered into force in 2020, the final year of the study period.

Overall, this divergence highlights the varying compliance costs that exporters face depending on the target market's regulatory framework and emphasizes the importance of understanding market-specific dynamics when assessing the impact of regulatory heterogeneity on trade.

4.3 The role of regulatory cooperation on SPS measures

The negative impact of the regulatory heterogeneity of MRLs suggests that reducing such heterogeneity between trading partners can inversely facilitate trade flows. This section discusses the role of regulatory cooperation in SPS measures and evaluates whether such cooperation mitigates the adverse effects of the BHI. Because regulatory cooperation is typically embedded within RTAs, we analyze a subsample comprising countries that have established an RTA with

the ASEAN or a single member country (irrespective of the year of RTA entry into force). Owing to the prevalence of excessive zero observations in the dataset, both the PPML and ZINB methods were applied. The results are summarized in Table 3.

Table 3 Econometric results explaining the impact of BHI and regulatory cooperation on ASEAN's fruit trade

Estimation method	Column (1)	Column (2)	
	PPML	ZINB	
		Negative Binomial	Logit
Variable			
$tariff_{ijt}^k$	-0.17** (0.08)	-0.14*** (0.03)	
BHI_{ijt}^k	-0.71*** (0.20)	-0.15** (0.07)	0.91*** (0.33)
$SPS\ cooperation_{ijt}$			17.32 (838.65)
$SPS\ cooperation_{ijt} \times BHI_{ijt}^k$	0.53* (0.28)	-0.01 (0.11)	
Fixed effect	Yes	Yes	Yes
Observation	8371	8371	

Note: dependent variable is the import value at product level (unit: million US dollars). ***, **, and * indicate the significance level at 1%, 5%, and 10% respectively. Standard errors are presented in parentheses. Constants included but not reported. Importer-time, exporter-time, pair-specific and crop-specific FEs are included in all regressions. The estimated alpha in Column (6) is 1.73 (95% confidence interval: 1.65~1.80).

Column (1) presents the results obtained using the PPML method. The estimated coefficients for the BHI and tariffs remain consistent with the previous results. Notably, the introduction of the interaction term $SPS\ cooperation_{ijt} \times BHI_{ijt}^k$, yields a positive and significant impact. This indicates that SPS cooperation mitigates the negative impact of the regulatory heterogeneity of MRL. Although the provisions in the SPS chapter under the RTA framework emphasizes cooperation on the principles of SPS measures rather than directly targeting MRL policies, countries engaged in regulatory cooperation experience a reduced negative impact from regulatory heterogeneity. Based on this finding, we recommend that ASEAN members incorporate regulatory cooperation on SPS measures into their RTA frameworks. Additionally, the technical cooperation clause in RTAs offers a promising avenue for the ASEAN to improve its poor MRL database.

Column (2) (Table 3) presents the results of the ZINB estimation. The estimated coefficient of the interaction term $SPS\ cooperation_{ijt} \times BHI_{ijt}^k$ is not significant in the negative binomial regression, whereas the coefficient of BHI shows positive and significant results in the Logit regression. This result is consistent with earlier findings indicating that greater regulatory heterogeneity increases the possibility of zero trade.

4.4 Robustness check

While trade value reflects the most direct impact of regulatory heterogeneity on trade, changes in market structure are often overlooked. To address this limitation, we conducted a robustness check by replacing the dependent variable with trade margins. Appendix 4 presents the calculation of trade margins, pioneered by Hummels and Klenow (2005). Two types of trade margins are analyzed: the extensive and intensive margins of trade. The extensive margin of trade refers to the variety or range of products that a country exports, reflecting the possibility of entering into a destination country. By contrast, the intensive margin of trade measures the value of goods exported within each product category, representing the market share of specific product groups at the country level, conditional on market access. The calculation of trade margins requires a change in the level of data aggregation, moving data from the HS 6-digit level to the 2-digit level. This aggregation process reduces the number of zero observations, enabling exclusive use of the PPML method in this section. The results are presented in Table 4.

Table 4 Econometric results explaining the impact of BHI on ASEAN's fruit trade margins

Dependent variable	Column (1)	Column (2)	Column (3)	Column (4)
	Extensive margin	Intensive margin	Extensive margin	Intensive margin
Variable				
$tariff_{ijt}^k$	-0.47*** (0.09)	-0.09 (0.07)	-0.41*** (0.09)	-0.13* (0.08)
BHI_{ijt}^k	-0.67*** (0.13)	-1.82*** (0.36)	-0.74*** (0.14)	-1.89*** (0.26)
RTA_{ijt}	-0.93*** (0.27)	-0.23 (0.51)		
$SPS\ cooperation \times BHI$			-0.20*** (0.08)	-0.19 (0.11)

Fixed effect	Yes	Yes	Yes	Yes
Observation	1116	1116	962	962

Note: ***, **, and * indicate the significance level at 1%, 5%, and 10% respectively. Standard errors are presented in parentheses. Importer-time, exporter-time, pair-specific, and year-specific FEs are included in all regressions. The estimation method is PPML.

Columns (1) and (2) of Table 4 examine the impact of the regulatory heterogeneity of MRLs on trade margins. The central finding is that BHI's negative impact on ASEAN fruit exports remains robust. The estimated coefficients for both the intensive and extensive margins were negatively significant, indicating that regulatory heterogeneity reduces not only the incentives for partners to trade more with each other (as reflected in the negative impact on intensive margin of trade) but also decreases the possibility of establishing new trade relationships (as seen in the negative impact on extensive margin of trade). Specifically, the estimated effect on the extensive margin was -48.8%, while the effect on the intensive margin was -84.7%. The relatively severe impact of the intensive margin suggests that for ASEAN countries, stringent MRL policies primarily result in decreased export values rather than complete withdrawal from one country. This finding is similar to that of Fontagné et al. (2015), who analyzed the export performance of French firms and found that restrictive SPS measures have a more pronounced impact on the intensive than on the extensive margin of trade.

Notably, the estimated coefficient of RTA is negatively significant in Column (1) (Table 4), which is contrary to expectations. A possible explanation is that certain partial scope agreements (PSAs) – such as the Global System of Trade Preferences (GSTP) among Developing Countries, which offer unilateral tariff reduction to specific countries – change comparative advantages, thereby affecting the impact of RTAs (Fugazza and Nicita 2013).

The results presented in Columns (3) and (4) of Table 4 show insignificant effects of regulatory cooperation on trade margins. There are two possible reasons for insignificance. First, although regulatory cooperation under the RTA framework primarily fosters a supportive trading environment by promoting standard harmonization and eliminating asymmetric information in national regulations, it does not directly address specific disparities in MRL policies between trading partners. The absence of a direct and explicit focus on harmonizing MRL standards limits the observable impact of such cooperation on trade margins. Second, the effectiveness of regulatory cooperation likely varies depending on specific provisions within RTAs, as well as the legal enforceability of those provisions (Disdier, Stone, and van Tongeren, 2019). Simply using a

dummy variable to evaluate the impact of regulatory cooperation masks the heterogeneity of provisions across agreements, potentially leading to insignificant results.

5. Conclusion

The relationship between safety standards and agricultural trade has garnered increasing interest in recent years. This study examines the debate surrounding “standards as barriers to trade” within the context of the ASEAN's fruit exports. Specifically, we adopted a structural gravity model to investigate the impact of the regulatory heterogeneity of MRLs and the role of regulatory cooperation on SPS measures. The dataset consists of six exporting countries, 15 importing countries (who are the main trading partners), and 12 fruit products, with data from 2008 to 2020.

Our results reveal a significant negative effect of BHI on total trade, indicating that the regulatory heterogeneity of MRLs generally impedes ASEAN's fruit exports. This impact manifests as both a reduction in total trade flows and a diminished likelihood of establishing new trade relationships. Additionally, trade effects vary across major markets. While the regulatory heterogeneity of MRLs significantly restricts fruit exports to South Korea, the effects on exports to Australia, China, and Japan are minimal.

These findings have important policy implications for the ASEAN and other developing countries facing similar challenges. They highlight the importance of improving MRL standards at both the regional (i.e., ASEAN standards) and national levels, which can help mitigate the negative impact of regulatory heterogeneity. Potential improvements include expanding the range of registered pesticides with more stringent residue controls and improving production practices such as providing farmers with training courses to acquire GAP certification and establishing food traceability systems. Effective implementation of such policies requires supervision; thus, robust national residue-monitoring programs are essential for enforcing MRL compliance. Although complying with higher MRL standards will inevitably result in higher production costs, in the long run, once these barriers are cleared, the regulations may not significantly obstruct trade. In summary, improving MRL standards can enhance competitiveness and facilitate better access to global markets in the long term.

Standard harmonization is another viable method for mitigating the negative impact of regulatory heterogeneity. For developing countries that do not establish national MRLs or maintain

loose standards, recognizing the CODEX standard or other regional standards offers a practical alternative. Furthermore, our results suggest that regulatory cooperation on SPS measures contributes to mitigating the negative impact of the regulatory heterogeneity of MRLs. Strengthening cooperation within the framework of RTAs can provide a platform for harmonizing standards and reducing trade barriers, thereby promoting deeper integration among trading partners.

A limitation of this study is its predominant focus on the direct impact of standards on trade flows, while ignoring the impact on domestic production and welfare. The ever-evolving requirements of importing countries force producers to allocate additional resources to meet new standards, which may adversely affect domestic supply and competition from imports by increasing marginal costs. The extent of this impact depends on the relative abilities of domestic and foreign suppliers to comply (Beghin and Schweizer 2021). However, improved product standards may shift consumer demand, further influencing domestic production. Future research can generate valuable insights by exploring these broader implications.

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Appendix 1: MRL deferrals for unregistered pesticides

Country	Regulation for unregistered pesticides
Australia	Zero-tolerance
Canada	Default limit of 0.01 ppm
China	CODEX
EU	Default limit of 0.01 ppm
Hong Kong SAR	-
India	Default limit of 0.01 ppm
Indonesia	-
Japan	Default limit of 0.01 ppm
Korea, Rep	Default limit of 0.01 ppm
Myanmar	-
Malaysia	1- CODEX 2- ASEAN standard 3- Default limit of 0.01 ppm
Philippines	CODEX
Singapore	1- CODEX 2- Zero-tolerance
Thailand	1- CODEX 2- Default limit of 0.01 ppm
United Kingdom	Default limit of 0.01 ppm
United States	Zero-tolerance
Vietnam	-

Appendix 2: formation of dataset

Exporters (6):

Indonesia, Malaysia, Myanmar, Philippines, Thailand, Vietnam

Importers (15):

Australia, Canada, China, Germany, Hong Kong SAR, India, Japan, Korea, Republic of Korea, Malaysia, the Netherlands, Singapore, Thailand, the United Kingdom, the USA, Vietnam

Crops (12):

080111, 080112, 080119, 080131, 080132, 080310, 080390, 080430, 080450, 080711, 081060, 081090

Period: 2008 ~ 2020

Appendix 3: statistical description

Variable	Observation	Average	Max	Min
X_{ij}	9759	9.58	2306	0
BHI_{ijt}^k	9759	1.65	2.72	0
$tariff_{ijt}^k$	9759	6.34	235.5	0
RTA_{ijt}	9759	0.56	1	0
$SPS\ cooperation_{ijt}$	8371	.22	1	0

Appendix 4: calculation of Extensive margin and Intensive margin of trade (Hummels and Klenow 2005)

Extensive Margin of Trade

$$EM_{ijt} = \frac{\sum_{k \in k_i} X_{jt}^k}{\sum_{k \in k_j} X_{jt}^k}$$

Intensive Margin of Trade

$$IM_{ijt} = \frac{\sum_{k \in k_i} X_{ijt}^k}{\sum_{k \in k_i} X_{jt}^k}$$

X denotes the trade value of different countries. X_{ijt}^k is the import value from country i . X_{jt}^k is country j 's imports from all trading partners.

k_i is the crop set (all crops) exported from country i to j .

k_j is the crop set (all the crops) imported by country j .