The Effect of Maximum Residue Limits on Agri-Food Trade: Evidence from Chinese Exports to the EU

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Abstract

There is debate about whether maximum residue limits (MRLs) for pesticides act as a catalyst or barrier to trade. By constructing a trade model based on heterogeneous firm quality and productivity, we show that MRLs' net effects on total export value, the number of exporting firms, and the average export value per firm depend on the interplay between the effect on import demand and that on variable and fixed compliance costs. We employ firm-level transaction data for agri-food products exported from China to the European Union (EU). We use heterogeneity indices that combine the number and level of MRLs to measure MRL stringency between China and the EU; a Poisson pseudo-maximum-likelihood estimator with fixed effects is used for estimation. We find that stricter MRLs, whether imposed by China or the EU, promote China's agri-food exports to the EU. However, such promotion effects are heterogeneous across agri-food-exporting firms. In China, updates to MRL standards improve agri-food-exporting firms' ability to comply with stricter MRLs. Public investment and services help reduce compliance costs. Our findings provide new evidence that MRLs are not new non-tariff measures adopted to replace reduced import tariffs.

Keywords

agri-food export; maximum residue limit; heterogeneity index; quality-based heterogeneous firm trade model

1 Introduction

Pesticides are needed to protect crops and enhance yield. Yet, depending on exposure levels, pesticides can pose health risks, increase pollution (soil, water, and air), and result in biodiversity loss. The Codex Alimentarius Commission (Codex)[1] defines the maximum residue limit (MRL) as the maximum legally allowable concentration of pesticide residue in or on food commodities and animal feed (expressed in mg/kg).

Media reports on food safety incidents around the world have exposed long-standing problems, such as the abuse of pesticides in imported food and the illegal use of unregistered pesticides in production. Heightened social awareness of food safety has prompted developed economies to set more extensive and stringent MRL standards (SWINNEN, 2018). Japan, for example, announced the "Japanese Positive List System for Agricultural Chemical Residues in Foods" in 2003 and implemented it in 2006. Canada set a new MRL standard in 2008. The same year, the European Union (EU) set a unified EU MRL standard. Others, such as Australia and South Korea, similarly announced new MRL standards between 2010 and 2019.

Although the Codex has developed international MRL standards to minimize the impact of MRLs on international trade, they are not statutory. Based on national dietary habits and political and economic factors, various developed economies have deviated from the Codex standard recommended in the WTO's "Agreement on the Application of Sanitary and Phytosanitary Measures" when setting their own national MRL standards.

Increasing trade disputes related to heterogeneous MRLs among different countries have raised concerns about whether MRLs act as new trade protection instruments used to replace tariffs. Accordingly, various studies have investigated the effect of MRLs on agri-food trade. Some use a few specific MRLs to represent the stringency of MRLs imposed by importing countries. Others, who believe that trade is affected by

[1] The Codex Alimentarius Commission (Codex) is the international food standards–setting body established by the United Nation's Food and Agriculture Organization and the World Health Organization. Codex develops international food standards, guidelines, and codes of practice for an international food code that contributes to the safety, quality, and fairness of food trade.

DOI: 10.30430/gjae.2023.0328

the relative stringency of MRLs between countries, construct various heterogeneity (similarity) indices to compare the MRLs of importing countries with those of exporting countries or of the Codex. The findings are inconsistent. Some find that stricter MRLs set by importing countries inhibit imports (CHEN et al., 2008a; DROGUÉ and DEMARIA, 2012; WINCHESTER et al., 2012; FERRO et al., 2015; HEJAZI et al., 2016; KAREMERA et al., 2020; FIANKOR et al., 2021; HEJAZI et al., 2022). Others, meanwhile, find that they do not hinder imports and can even promote them (XIONG and BEGHIN, 2012, 2014; ISHAQ et al., 2016; SHINGAL et al., 2021). Three studies have focused on whether the MRLs set by exporting countries play an active role in trade; their findings suggest that relatively stringent MRLs set by exporting countries can significantly promote agri-food exports (DOU et al., 2015; SEOK et al., 2018; SHINGAL et al., 2021).

The dual effect of MRL standards—comprising the demand-enhancing effect and the trade-cost effect—has been identified as key to understanding these divergent findings (XIONG and BEGHIN, 2014; SWINNEN, 2018; SHINGAL et al., 2021). The demand-enhancing effect refers to the fact that compliance with MRLs promotes trade by reducing information asymmetry and/or negative externalities. The trade-cost effect refers to the fact that MRL compliance impedes trade by increasing compliance costs. Whether MRLs hinder or promote trade depends on the net effects of these two opposing effects, which can vary according to the countries or products included in the sample.

The first contribution of the present study is that we develop a novel quality-based heterogeneous firm trade (QHFT) model[2] to examine the abovementioned dual effect of MRL standards. We assume that compliance with stringent MRLs will not only raise variable and fixed costs but also enhance consumers' import demand for high-quality products. The interaction of these two effects influences the export behavior of firms with heterogeneous productivity. Thus, we investigate the effect of MRLs on aggregate export performance including total export value as well as the number of exporting firms (the extensive margin) and average export value per firm (the intensive margin). Three studies have theoretically examined this dual effect of food safety standards. CHEN et al. (2008b) analyzed the dual effects on export probability, export quantity, and export products using a perfect competition model. Using a monopoly competition model, XIONG and BEGHIN (2014) analyzed and verified the demand-enhancing and trade-cost effects but did not consider their interactions and net effects. In addition, these two studies did not account for firm heterogeneity and did not properly address the large number of zero values in trade data. MEDIN (2019) analyzed the abovementioned dual effects on the number of export firms, average exports per firm, and total exports using a different QHFT model.[3] That study separately investigated the interaction between demand and variable cost and between demand and fixed cost owing to MRL compliance, thus ignoring the interaction between variable cost and fixed cost.

Our second contribution is that we examine the effect of MRLs on agri-food exported from China to the EU. The EU's MRL standard covers the most extensive range of products and pesticides and sets the most stringent MRL values. As a result, it has been viewed as an obstacle to agri-food exports from developing countries such as China. As the world's largest developing country, China has been trying to catch up with the MRL standards of developed economies and of the Codex. Between 2005 and 2021, China published 10 new versions of its national MRL standard. The number of specific MRLs increased from 2,359 in 2005 to 43,027 in 2021; the number of covered agri-food products increased from 146 to 418; and the number of regulated pesticides increased from 138 to 564. The latest MRL standard, released in 2021, specifies 428 pesticides that are approved for registration in China, 49 that are banned or restricted, and 44 that are exempt from regulation[4].

China is the world's second-largest importer and fourth-largest exporter of agri-food products; thus, agri-food exports play an important role in farmers' incomes and the development of China's rural regions. Examining how differences in MRLs between China and the EU affect agri-product trade—

[2] The quality-based heterogeneous firm trade (QHFT) model is based on the heterogeneous firm trade (HFT) model proposed by MELITZ (2003). BALDWIN and HARRIGAN (2011) have pointed out that the difference between enterprises lies not only in productivity but also in quality; hence, the influence of quality on firms' export decisions should be considered.

[3] MEDIN (2019) assumed that product quality is a function of variable and fixed costs which by their own are related to food safety standards. In contrast, we assume that product quality is a direct function of food safety standards.

[4] MINISTRY OF AGRICULTURE AND RURAL AFFAIRS OF THE PRC (2021): Maximum Residue Limits of Pesticides in Food (2021 Edition). https://www.sdtdata.com/fx/fmoa/tsLibCard/183688.html.

especially whether China's updated MRL standard promotes firms' ability to comply with stringent MRLs—will improve our understanding of the effect of food safety standards on trade and offer policy guidance.

We use firm-level transaction data for agri-food exports from China to the EU to explore the intensive margin of trade (the number of exporting firms) and the extensive margin (exporting firms' average export value), along with total export value. Further, by using heterogeneity indices to separately measure the relative stringencies of China's and the EU's MRLs, we cover a longer time period, more products, and more pesticides in our sample.

We find that stricter MRLs imposed by the EU do not hinder agri-food exports from China. Rather, they significantly promote agri-food exports in both the extensive and intensive margins. Stricter MRLs set by China significantly boost its agri-food exports by signaling improvements in quality. Previous Chinese studies have focused on the restrictiveness of MRLs set by developed economies and ignored the promotion effect of China's MRLs. Our findings indicate that stricter MRLs, whether imposed by China or the EU, have a strong demand-enhancing effect and benefit exporting firms with higher levels of productivity more so than those with less productivity.

The next section presents the theoretical model. The third section introduces the empirical model. Then, we present the variables and data sources, focusing on the explanation of the heterogeneity indices. The fifth section presents the methods and results of the estimation. The final section concludes and discusses directions for future research.

2 Theoretical Model

Here, we present the theoretical foundation for the dual effect of MRLs by extending the heterogeneous firm trade (HFT) model proposed by LAWLESS (2010)[5]. Based on MELITZ (2003) and CHANEY (2008), Lawless deconstructed total export value into the number of exporting firms (the extensive margin) and the average export value (the intensive margin). We introduce the dual effect of MRL standards into Lawless's model, assuming that compliance with stricter MRLs not only increases firms' variable and fixed exporting costs but also enhances consumers' demand for imported high-quality agri-food products. Since stricter MRLs can be imposed by either the importing or exporting country, we establish two submodels to deal with these two situations.[6] We examine under which circumstances compliance with stricter MRLs will promote or hinder exports, which are measured by total export value, the extensive margin, and the intensive margin.

2.1 A Model with Stricter MRLs Imposed by Importing Countries

We assume M importing countries and one exporting country[7]. The number of exporting firms is exogenously given and denoted by N. Labor is the only factor used in production, and it moves freely among sectors; hence, the wage rate can be set as equal to 1.

2.1.1 Import Demand

Consumers in each importing country j have a constant elasticity of substitution utility function:

$$U_j = \left\{\int_0^{\Omega} \theta\,(v)_j^{\beta} q\,(v)_j^{\frac{\epsilon-1}{\epsilon}}\, dv\right\}^{\frac{\epsilon}{\epsilon-1}}, \tag{1}$$

where Ω represents the varieties of agri-food products consumed in importing country j; q denotes the (demand) quantity of agri-food product v; $\epsilon>1$[8] is the substitution elasticity between horizontally differentiated agri-food products; $\theta\,(v)_j^{\beta}$ is the quality-shift parameter related to $\theta\,(v)_j$, a measure of MRLs specified for agri-food product v[9,10]; and $\beta>0$ measures

[5] LAWLESS (2010) assumes the number of exporting firms is given exogenously and omits the free-entry condition in the Melitz model, thereby focusing on the zero-profit condition to analyze firms' export behavior.

[6] The difference between these two submodels lies in the compliance costs of MRLs. When MRLs imposed by the exporting country are stricter than those imposed by importing countries, exporting firms who follow the domestic MRLs can more easily meet the looser MRLs imposed by importing countries without incurring compliance costs.

[7] In the empirical analysis, we use trade data for agri-food exported from China to the EU. China is the only exporting country, and the EU member states are the importing countries. The assumption of a single exporting country is justified, and the exporting country subscript can be suppressed for simplification.

[8] It is assumed that the elasticity of substitution ϵ is constant.

[9] Here, $\theta\,(v)_j$ is a scalar or index that embodies specific MRLs.

[10] The similar utility functions are commonly used in the literature on QHFT models, such as HALLAK (2006), Johnson (2012), FEENSTRA and ROMALIS (2014), and GERVAIS (2015). In our study, we use the same formula-

consumers' perceptions and acceptance of agri-food product v owing to the imposition of MRLs. Since MRLs imposed by the importing country are stricter, exporting firms must comply but have no motivation to exceed them. Consumers believe the quality of imported agri-product v is much higher than that of products subject to looser MRLs in the home market (FERNANDES et al., 2019; FIANKOR et al., 2021). Therefore, compliance with stricter MRLs enhances consumers' preference for, and thus the import demand of, agri-food products. Accordingly, parameter β captures the demand-enhancing effect of stricter MRLs.

Consumer expenditure on all agri-food products is given by $E_j = \int_0^{\Omega} p_j(v) q_j(v)\, dv$. Maximizing the utility function subject to agri-food expenditure gives the demand for agri-food product v, as:[11]

$$q_j = \theta_j^{\beta\epsilon} p_j^{-\epsilon} P_j^{\epsilon-1} E_j, \quad (2)$$

where p_j is the price of agri-food product v; and $P_j = [\int_0^{\Omega} p_j(v)^{1-\varepsilon}\, dv]^{\frac{1}{1-\epsilon}}$ is the price index of all agri-food products sold in importing country j.

2.1.2 Export Supply

Each firm's cost function for exporting agri-food product v to country j is defined as:

$$c_j = \frac{\tau_j \theta_j^{\alpha}}{\varphi} q_j + \frac{\theta_j^{\eta}}{\eta}, \quad (3)$$

where φ is each firm's productivity randomly drawn from distribution $g(\varphi)$ with a probability density function over $[0, +\infty)$; τ_j is the variable trade costs of exporting to country j, including import tariffs and transport costs; θ_j^{α} and $\frac{\theta_j^{\eta}}{\eta}$ are, respectively, the variable and fixed costs incurred by firms to meet stricter MRLs imposed by importing country j (e.g., the adoption of new technologies or labor training). Parameters $\alpha>0$ and $\eta>0$ measure the amount of the variable and fixed costs of compliance, respectively, under stricter MRLs. These two parameters capture the variable trade-cost effect and fixed trade-cost effect. The sum of the variable trade-cost effect and fixed trade-cost effect is defined as the trade-cost effect.

Then, the profit of each firm can be expressed as

$$\pi_j = \left(p_j - \frac{\tau_j \theta_j^{\alpha}}{\varphi}\right) q_j - \frac{\theta_j^{\eta}}{\eta}. \quad (4)$$

As in all HFT and QHFT models, firms are assumed to engage in monopolistic competition, which means firms are free to enter or exit exporting, and they independently choose prices to maximize profits. The price of agri-food product v can be derived from the first-order condition of the firm's profit maximization:

$$p_j = \frac{\epsilon}{\epsilon-1} \frac{\tau_j \theta_j^{\alpha}}{\varphi}. \quad (5)$$

From Eq. (5), we can see that the price of agri-food product v depends on the substitution elasticity between agri-food products, firms' productivity, and variable costs. Since the price is the product of marginal cost $\frac{\tau_j \theta_j^{\alpha}}{\varphi}$ multiplying a constant $\frac{\epsilon}{\epsilon-1}$, it is a markup over the marginal cost.

Using Eqs. (2) and (5), each firm's export revenue and export value in relation to importing country j can be given by

$$r_j = p_j q_j = \left(\frac{\epsilon}{\epsilon-1}\right)^{1-\epsilon} \left(\frac{\tau_j}{\varphi}\right)^{1-\epsilon} \theta_j^{\beta\epsilon-\alpha(\epsilon-1)} P_j^{\epsilon-1} E_j. \quad (6)$$

The elasticity of r_j with respect to θ_j is given by

$$\mathrm{E}_{\theta_j}(r_j) = \beta\epsilon - \alpha(\epsilon - 1). \quad (7)$$

From Eq. (7), we can find that the effect of stricter MRLs on firms' export value depends on whether the demand-enhancing effect or the variable trade-cost effect dominates, which are captured by the magnitudes of parameters α and β. If α is large enough, such as $\beta\epsilon > \alpha(\epsilon - 1)$, the variable trade-cost effect dominates. The imposition of stricter MRLs leads to an increase in firms' export value. On the contrary, if β is large enough, such as $\beta\epsilon < \alpha(\epsilon - 1)$, the demand-enhancing effect dominates. The imposition of stricter MRLs leads to a decrease in firms' export value.

2.1.3 Cutoff Productivity

Under the assumption of free entry and exit, a firm's profit in Eq. (4) is equal to 0. Using Eqs. (2), (3), and (5), the cutoff productivity that each firm needs to achieve when exporting to country j is given by

$$\underline{\varphi} = \left(\frac{\eta}{\epsilon-1}\right)^{\frac{1}{1-\epsilon}} \left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{\epsilon}{\epsilon-1}} \theta_j^{\frac{[\eta+\alpha(\epsilon-1)]-\beta\epsilon}{\epsilon-1}} \tau_j P_j^{-1} E_j^{\frac{1}{1-\epsilon}}. \quad (8)$$

The elasticity of $\underline{\varphi}$ with respect to θ_j is given by

$$E_{\theta_j}\left(\underline{\varphi}\right) = -\frac{\beta\epsilon - [\eta + \alpha(\epsilon-1)]}{\epsilon-1}. \quad (9)$$

tion of the utility function as in GAIGNÉ and LARUE (2016) to study the effect of MRL standards on demand in agri-food trade.

[11] To simplify the notation, we suppress the subscript for agri-food product v in the following analysis.

From Eq. (9), we can see that the effect of stricter MRL imposition on the cutoff productivity depends on whether the demand-enhancing effect or the trade-cost effect dominates. If β is sufficiently large, such that $\beta\epsilon > \alpha(\epsilon-1)+\eta$, the demand-enhancing effect dominates. The imposition of stricter MRLs leads to an increase in cutoff productivity. On the contrary, if α and η are sufficiently large, such that $\beta\epsilon < \alpha(\epsilon-1)+\eta$, the trade-cost effect dominates. The imposition of stricter MRLs leads to a decrease in cutoff productivity.

2.1.4 The Extensive Margin

Aggregating all exporting firms, we obtain the extensive margin (the number of firms exporting to country j):

$$N_j = N\int_{\underline{\varphi}}^{\infty} g(\varphi)d\varphi. \quad (10)$$

The elasticity of N_j with respect to θ_j is given by

$$E_{\theta_j}(N_j) = -\frac{N}{N_j}\underline{\varphi}g\left(\underline{\varphi}\right)E_{\theta_j}\left(\underline{\varphi}\right). \quad (11)$$

Since $E_{\theta_j}(N_j)$ has the opposite sign of $E_{\theta_j}\left(\underline{\varphi}\right)$, the effect of stricter MRLs on the extensive margin depends on whether $E_{\theta_j}\left(\underline{\varphi}\right) > 0$ or $E_{\theta_j}\left(\underline{\varphi}\right) < 0$. If $E_{\theta_j}\left(\underline{\varphi}\right) < 0$, the trade-cost effect dominates. Then, the increased cutoff productivity for exporting forces firms with the lowest productivity to exit exporting, leading to a decrease in the extensive margin. If $E_{\theta_j}\left(\underline{\varphi}\right) > 0$, the demand-enhancing effect dominates. The decreased cutoff productivity encourages new firms to export, leading to an increase in the extensive margin.

2.1.5 Total Export Value

Adding up the export value of all exporting firms, the total export value of agri-food products to importing country j is

$$R_j = N\int_{\underline{\varphi}}^{\infty} r_j(\varphi)g(\varphi)\,d\varphi. \quad (12)$$

The elasticity of R_i with respect to θ_j is given by

$$E_{\theta_j}(R_j) = \frac{N}{R_j}\left[\theta_j\left(\int_{\underline{\varphi}}^{\infty}\frac{r_j(\varphi)g(\varphi)}{\theta_j}d\varphi\right)E_{\theta_j}(r_j) - r_j\left(\underline{\varphi}\right)g\left(\underline{\varphi}\right)\underline{\varphi}E_{\theta_j}\left(\underline{\varphi}\right)\right]. \quad (13)$$

From Eq. (13), we can see that the effect of stricter MRL imposition on total export value depends on the signs and magnitudes of the two parts within the square brackets in Eq. (13). The first part has the same sign as $E_{\theta_j}(r_j)$ and represents the change in total export value owing to the export value of incumbent firms. The second part has the opposite sign as $E_{\theta_j}\left(\underline{\varphi}\right)$ and represents the change attributable to the export value of firms that enter or exit exporting.

If $E_{\theta_j}(r_j) < 0$ and $E_{\theta_j}\left(\underline{\varphi}\right) > 0$, the trade-cost effect dominates in both parts. The decreases in both the number of exporting firms and the export value of incumbent firms tend to reduce the total export value. If $E_{\theta_j}(r_j) > 0$ and $E_{\theta_j}\left(\underline{\varphi}\right) < 0$, the demand-enhancing effect dominates in both parts. The increases in both the number of exporting firms and the export value of incumbent firms tend to increase the total export value. The case of $E_{\theta_j}(r_j) > 0$ and $E_{\theta_j}\left(\underline{\varphi}\right) > 0$ is complicated. The demand-enhancing effect dominates in the first part, and the trade-cost effect dominates in the second part. Therefore, the effect on total export value is indeterminate. The total export value increases (decreases) only if the increased export value of incumbent firms is greater (smaller) than the decreased export value caused by exiting firms.

2.1.6 The Intensive Margin

Dividing total export value by the number of exporting firms, the intensive margin (average export value per firm) can be obtained as

$$I_j = \frac{R_j}{N_j}. \quad (14)$$

The elasticity of I_j with respect to θ_j is given by

$$E_{\theta_j}(I_j) = E_{\theta_j}(R_j) - E_{\theta_j}(N_j) = \frac{N}{R_j}\left[\theta_j\left(\int_{\underline{\varphi}}^{\infty}\frac{r_j(\varphi)g(\varphi)}{\theta_j}d\varphi\right)E_{\theta_j}(r_j) - \left(N_j r_j\left(\underline{\varphi}\right) - R_j\right)\frac{g\left(\underline{\varphi}\right)\underline{\varphi}}{N_j}E_{\theta_j}\left(\underline{\varphi}\right)\right]. \quad (15)$$

The fact that the product of the number of exporting firms multiplied by the export value of firms with cutoff productivity must be smaller than the total export value implies $\left(N_j r_j\left(\underline{\varphi}\right) - R_j\right) < 0$. The first part within the square brackets in Eq. (15) has the same sign as $E_{\theta_j}(r_j)$ and denotes the change in the intensive margin owing to the export value of incumbent firms. The second part has the same sign as $E_{\theta_j}\left(\underline{\varphi}\right)$ and denotes the change in the intensive margin owing to export value of firms entering or exiting exports.

Therefore, the effect of stricter MRLs on the intensive margin also depends on the signs and magnitudes of $E_{\theta_j}(r_j)$ and $E_{\theta_j}(\underline{\varphi})$.

If $E_{\theta_j}(r_j) > 0$ and $E_{\theta_j}(\underline{\varphi}) > 0$, the demand-enhancing effect dominates in the first part, and the trade-cost effect dominates in the second part. Each incumbent firm exports more, and the low-productivity firms exit exporting. The increase in total export value and the decrease in the number of exporting firms tend to jointly raise the intensive margin. If $E_{\theta_j}(r_j) < 0$ and $E_{\theta_j}(\underline{\varphi}) >0$, the trade-cost effect dominates in both parts. The decrease in total export value tends to reduce the intensive margin while the decrease in the number of exporting firms tends to raise it. The opposite applies to the case of $E_{\theta_j}(r_j) > 0$ and $E_{\theta_j}(\underline{\varphi}) < 0$. Therefore, the effect of stricter MRLs on the intensive margin is indeterminate.

2.2 A Model with Stricter MRLs Imposed by the Exporting Country

When the exporting country sets stricter MRLs than the importing countries, exporting firms can more easily meet the looser MRLs of the importing countries without incurring additional compliance costs. The imposition of stricter MRLs enhances consumer demand for imported agri-food products. Therefore, there is only the demand-enhancing effect and no trade-cost effect.

As demonstrated in Eq. (2), the demand of agri-food product v can be obtained by the maximization of consumer utility. Even if exporting firms choose to comply with stricter domestic MRLs, they incur no additional compliance costs for exporting. The cost function of the exporting firm can be simplified as

$$C_j(v) = \frac{\tau_j}{\varphi} q_j. \tag{16}$$

From the first-order condition of the firm's profit maximization, the export revenue and export value of each firm are obtained as

$$r_j = p_j q_j = \left(\frac{\epsilon}{\epsilon-1}\right)^{1-\epsilon} \left(\frac{\tau_j}{\varphi}\right)^{1-\epsilon} \theta_i^{\beta\epsilon} P_j^{\epsilon-1} E_j. \tag{17}$$

The elasticity of r_j with respect to θ_j is given by

$$\mathrm{E}_{\theta_j}(r_j) = \beta\epsilon > 0. \tag{18}$$

The cutoff productivity all firms must achieve when exporting to country j is given by

$$\underline{\varphi} = \left(\frac{\eta}{\epsilon-1}\right)^{\frac{1}{1-\epsilon}} \left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{\epsilon}{\epsilon-1}} \theta_j^{\frac{-\beta\epsilon}{\epsilon-1}} \tau_j P_j^{-1} E_j^{\frac{1}{1-\epsilon}}. \tag{19}$$

The elasticity of $\underline{\varphi}$ with respect to θ_j is given by

$$E_{\theta_j}(\underline{\varphi}) = -\frac{\beta\epsilon}{\epsilon-1} < 0. \tag{20}$$

Based on the discussion of Eq. (11), we know that $E_{\theta_j}(\underline{\varphi}) < 0$ leads to $E_{\theta_j}(N_j) > 0$. The imposition of stricter home MRLs encourages new firms to export. Hence, the effect of stricter home MRLs on the extensive margin is positive. $\mathrm{E}_{\theta_j}(r_j) > 0$ implies that incumbent firms export more when complying with stricter MRLs at home. Consequently, the effect of stricter home MRLs on the total export value is positive. While an increased number of exporting firms tends to reduce the intensive margin, the increased export value of incumbent firms tends to raise it. As a result, $E_{\theta_j}(I_j)$ will go in either direction, leaving the effect of stricter domestic MRLs on the intensive margin indeterminate.

2.3 Brief Summary

Table 1[12] summarizes the net effect of stricter MRLs as the result of interactions among the demand-enhancing and (variable and fixed) trade-cost effects. Given the assumption of β>0, α>0, and η>0, the results listed in columns (1) – (3) correspond to the discussion in section A. When the trade-cost effect dominates, the effects on both total export value and the extensive margin are negative, and the effect on the intensive margin is ambiguous (see column (1)). When the demand-enhancing effect dominates the viable trade-cost effect but is dominated by the trade-cost effect (the sum of variable trade-cost and fixed trade-cost effects), the effect on the extensive margin is negative, the effect on the intensive margin is positive, and the effect on total exports is ambiguous (see column (2)). When the demand-enhancing effect dominates, the effects on total export value and the extensive margin are opposite to column (1), and the intensive margin is ambiguous (see column (3)). On the assumption of β>0, α=0, and η=0, the results listed in column (3) correspond to the discussion in section B, in which only the demand-enhancing effect exists.

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12 Since $\beta\epsilon<\alpha$ (ϵ-1) implies $\beta\epsilon<\alpha$ (ϵ-1)+η, we do not demonstrate the assumption of $\beta\epsilon<\alpha$ (ϵ-1)+η in Table 1. All net effects are achieved without specifying an assumption about the distribution of firms' productivity. As discussed in appendix B, under the assumption of Pareto distribution, the opposing effects of variable trade cost cancel each other; the effect on the intensive margin can only be expressed as a function of the fixed trade cost.

Table 1. Net effects of stricter MRLs on exports

	$\boldsymbol{\beta\epsilon < \alpha(\epsilon-1)}$ (1)	$\boldsymbol{\alpha(\epsilon-1)+\eta > \beta\epsilon > \alpha(\epsilon-1)}$ (2)	$\boldsymbol{\beta\epsilon > \alpha(\epsilon-1)+\eta}$ (3)
Total export value	−	+/−	+
Extensive margin	−	−	+
Intensive margin	+/−	+	+/−

Source: authors' construction

Our proposed QHFT model can be extended to examine the effects of food safety standards on trade margins under various assumptions. Given the assumption of β=0, α>0, and η>0, food safety standards, including MRLs, are viewed as non-tariff barriers; this demonstrates the trade-cost effect as seen in LAWLESS (2010). The effects correspond to column (1), except for the effect on the intensive margin being definitely negative. Given the assumptions of β>0, α=0, and η>0 or β>0, α>0, and η=0, the variable trade-cost effect and the fixed trade-cost effect can be considered independently, as in MEDIN (2019). The net effects correspond to columns (1) and (3), except for the effect on the intensive margin being definitely positive when the fixed trade-cost effect is dominant[13].

3 The Empirical Model

As shown in Eqs. (6) and (8), each firm's export value r_j and cutoff productivity $\underline{\varphi}$ can be expressed as explicit functions of food expenditure E_j, price index P_j, import tariff τ_j, and MRLs θ_j. Inserting Eqs. (6) and (8) into Eqs. (10), (12), and (14) allows us to express total export value, the number of exporting firms, and average export value per firm as implicit functions of food expenditure E_j, price index P_j, import tariff τ_j, and MRLs θ_j.[14,15] We construct a reduced form of the gravity equation corresponding to our theoretical models:

$$Y_{vjt} = \beta_0 + \beta_1 H\_Index_{vjt} + \beta_2 FOODE_{vjt} + \beta_3 Tariff_{vjt} + \varepsilon_{vjt}, \tag{21}$$

where Y_{vjt} represents the total export value ($EXPORT_{vjt}$), the number of exporting firms ($EXTENSIVE_{vjt}$), and the average export value ($INTENSIVE_{vjt}$) of agri-food product v from China to the EU in year t. H_Indexe_{vjt} refers to the heterogeneity indices used to measure the relative stringency of MRLs between China and the EU. $FOODE_{vjt}$ is food expenditure per capita in the EU member states. $Tariff_{vjt}$ is the simple average of tariffs applied by EU member states to China's agri-food product v in year t. ε_{vjt} is the error term following a normal distribution.[16]

Introducing the EU member state-year fixed effect μ_{vjt} in equation (21), we obtain a more simplified gravity equation for estimation[17]:

$$Y_{vjt} = \beta_0 + \beta_1 H_{Index_{vjt}} + \beta_2 Tariff_{vjt} + \mu_{vjt} + \varepsilon_{vjt}. \tag{22}$$

4 Data and Variable Description

We draw on two novel datasets to investigate the effect of heterogeneous MRLs between China and the EU on China's agri-food exports to the EU. The first is a collection of MRL data for China and the EU, and the second is a compilation of firm-level trade data for agri-food products exported from China to EU countries. Given that the EU unified MRLs in 2008, and

[13] Since MEDIN (2019) treats the variable trade-cost effect and fixed trade-cost effect separately, that study ignores the interaction of the demand-enhancing effect, the variable trade cost, and the fixed trade cost, which is shown in Table 1, column (2).

[14] Just as in submodel A, the total export value, the number of exporting firms, and average export value per firm in the submodel B can also be expressed as implicit functions of food expenditure E_j, price index P_j, import tariff τ_j, and MRLs θ_j.

[15] As shown in appendix B, assuming that firm productivity φ follows a specific distribution, Pareto distribution allows us to express the total export value, the number of exporting firms, and the average export value per firm as explicit functions of food expenditure E_j, price index P_j, import tariff τ_j, and MRLs θ_j.

[16] Without specific data, the price index is included in the error term and controlled by the fixed effect.

[17] Following a reviewer's suggestion, we omit food expenditure per capita after introducing the EU member state–year fixed effect. However, we still include tariffs as a control because statistically significant negative correlations between tariffs and heterogeneity indices suggest a degree of substitution across the two trade policy measures.

firm-level trade data are not available after 2016, the datasets cover the period 2008–2016.

4.1 Data on MRLs

4.1.1 Heterogeneity Indices

To avoid the bias caused by using a few specific MRLs in previous studies, we need a measure to compare the relative stringency of MRLs between China and the EU. We draw on the heterogeneity indices proposed by SHINGAL et al. (2021).

First, we define two relative stringency indices:

$$f_{vkt} = \begin{cases} \frac{MRL_{CHNvkt} - MRL_{EUvkt}}{MRL_{CHNvkt} + MRL_{EUvkt}} & \text{if } MRL_{CHNvkt} > MRL_{EUvkt} \\ 0 & otherwise \end{cases}, \quad (23)$$

$$m_{vkt} = \begin{cases} \frac{abs\,(MRL_{CHNvkt} - MRL_{EUvkt})}{MRL_{CHNvkt} + MRL_{EUvkt}} & \text{if } MRL_{CHNvkt} \leq MRL_{EUvkt} \\ 0 & otherwise \end{cases}, \quad (24)$$

where MRL_{CHNvkt} is the MRL for pesticide k on product v in China in year t, and MRL_{EUvkt} is the MRL for pesticide k on product v in the EU in year t. The relative stringency index f_{vkt} corresponds to the MRL for pesticide k on agri-food product v in the EU being more stringent than that in China; m_{vkt} corresponds to the MRL for pesticide k on agri-food product v in China being more stringent than that in the EU.

Then, we average each relative stringency index over the number of pesticides specified for agri-food product v to obtain heterogeneity indices:

$$F_{vt} = \frac{1}{K}\sum_{k=1}^{K} f_{vkt}, \quad (25)$$

$$M_{vt} = \frac{1}{K}\sum_{k=1}^{K} m_{vkt}, \quad (26)$$

where K is the total number of pesticides specified for agri-food product v; that is, the number of MRLs for product v. The value of both F_{vt} and M_{vt} is over [0, 1]. The closer the value is to 1, the more stringent the EU (China) MRLs for agri-food product v.

These two heterogeneity indices have four advantages.

- For every product, we include all pesticides regulated in China and the EU. This is in contrast to the limited set of pesticides used in previous studies on China (DOU et al., 2015; ISHAQ et al., 2016; GAO, 2018).
- They combine into one measure the number of specific MRLs and MRL values, indicating the stringency of MRLs.
- We make the indices invariant to regulation intensity by averaging the sum of the relative stringency index of each pesticide by the total number of pesticides. Using the simple average avoids assigning higher values to certain products simply because more pesticides are commonly applied to them.
- The heterogeneity index M_{vt} measuring the stringency of China's MRLs relative to the EU's allows us to test the effects of stricter MRLs imposed by China. This distinguishes our study from those that simply ignore heterogeneity when the exporter is stricter and from those that assume that heterogeneity always imposes compliance costs for the exporter in the importing country.

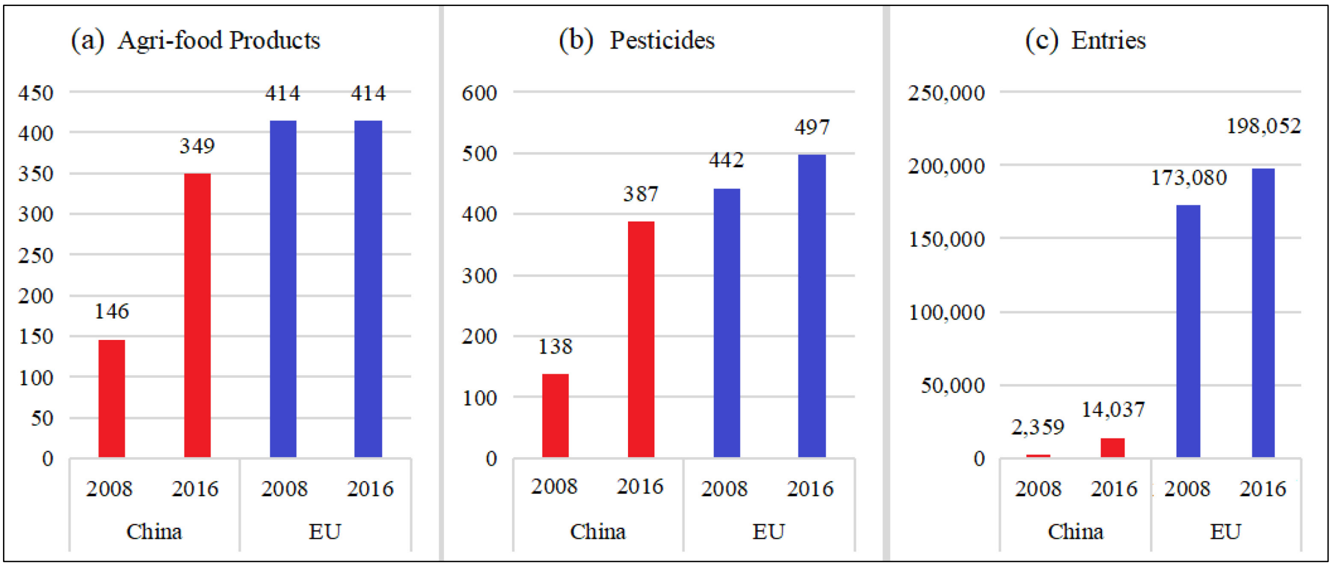
4.1.2 Data Sources

China's first national MRL standard of the twenty-first century was released in 2005. China updated its MRL standards irregularly before 2008. From 2008 to 2016, China released new national MRL standards biannually, officially termed the "National Food Safety Standard-Maximum Residue Limits for Pesticides in Food." Each new MRL standard replaced or supplemented the old one, clearly specifying product coverage, pesticide coverage, and product–pesticide specific MRLs. We collected all entries of MRLs recoded in China's national MRL standards, including GB2763-2005, GB2763-2005 Amendment No.1, GB2763-2010, GB25193-2010, GB26130-2010, GB28260-2011, GB2763-2012, and GB2763-2014. Since some MRL values apply to all products belonging to the same variety, we assign variety-specific MRL values to every product to obtain specific MRLs for all regulated products. Therefore, our database contains many more entries for specific MRLs than in the original official documents. We sort all specific MRLs into product–pesticide–year pairs for comparison. The EU has been updating MRLs annually since it announced the first unified MRL standard in 2008. In a similar way, we compile a database of EU MRLs based on historical records found in an official online database called the EU Pesticides Database. Since there are differences in the names of agri-food products and pesticides, as well as in agri-food classifications, between MRL standards in China and the EU, we reclassify agri-food products according to the HS2 digit codes and unify the diverse names of products and pesticides in our database of MRLs.

4.1.3 Heterogeneity in MRLs

Although the number of pesticides and products regulated by China has been increasing rapidly since 2008,

Figure 1. Number of agri-food products, pesticides, and entries in Chinese and EU MRLs



Source: Author's calculations from Chinese and the EU MRLs databases.

the EU still regulates more agri-food products and pesticides in its MRL standard. As shown in Figure 1 (a), the number of agri-food products regulated by the EU has remained at 414 while that in China increased from 146 in 2008 to 349 in 2016. During the same period, the number of pesticides regulated by China increased sharply from 138 to 387 while that of the EU increased gradually from 442 to 497 (see Figure 1 (b)). However, pesticides exclusively regulated by the EU have been gradually decreasing, leading to an increase in pesticides regulated by both China and the EU. As shown in Figure 1 (c), the EU has established more specific MRLs than China. Although the specific MRLs set by China increased from 2,359 in 2008 to 14,037 in 2016, those set by the EU were more than fourteen times those set by China in 2016. This implies that the EU has regulated many more pesticides per product and set more specific MRLs per product than China.

In addition to wider coverage of products and pesticides, the EU has also set generally stricter MRLs than China, as shown in Table A.4. From 2008 to 2016, the minimum value of MRLs set by China fell from 0.005 mg/kg to 0.002 mg/kg, and the maximum value increased from 20 mg/kg to 90 mg/kg, with the average MRL value decreasing from 1.0271 mg/kg to 0.9595 mg/kg. For the EU, the minimum and maximum values of MRLs were 0.0008 mg/kg and 500 mg/kg, respectively, with average value increasing from 0.4979 mg/kg to 0.6491. While most MRLs set by the EU are stricter than those set by China, a small proportion of MRLs set by China are as strict as or stricter than those set by the EU. Among the 8,620 specific MRLs established by both China and the EU in 2016, 2,311 share the same MRL value while 994 have a lower value set by China.

4.1.4 Default Value

One challenge for computing heterogeneity indices is that for pesticides regulated exclusively by either the EU or China, the corresponding specific MRLs in China or the EU are missing. Since the EU states that the default MRL value for unspecified pesticides is 0.01 mg/kg, we replace missing MRLs with this default value. However, since China does not set a default value, we use the maximum MRL value in a given year as the default value for missing MRLs; this represents the lowest stringency level for all MRLs regulated by China (HEJAZI et al., 2016; SEOK et al., 2018; SHINGAL et al., 2021).

4.2 Data on Trade

From the Chinese Custom Trade Statistics we collected firm-level transaction records of Chinese agri-food products exported to EU member states. Each record contains the firm's Chinese name and its unique 10-digit harmonized-system (HS) identifier, the destination country, the eight-digit HS product code, the export value in current US dollars (USD), and the export quantity before 2016. Data for the simple-average applied tariff rate at the HS six-digit level are sourced from the WITS (World Integrated Trade Solutions)–TRAINS database.

Table 2. Descriptive statistics

	Unit	Obs.	Mean	St. Dev	Min.	Max.
$EXPORT_{vjt}$	Million USD	16,380	0.2100	2.1367	0.0000	86.8807
$EXTENSIVE_{vjt}$	Piece	16,380	0.7212	3.7103	0.0000	98.0000
$INTENSIVE_{vjt}$	Million USD/piece	16,380	0.0261	0.1736	0.0000	6.2760
$F_{vt\text{-}all}$		16,380	9.5562	0.3081	8.5019	9.9900
$M_{vt\text{-}all}$		16,380	0.3907	0.3173	0.0000	2.0911
$F_{vt\text{-}both}$		16,380	9.5216	0.4035	8.0959	9.9900
$M_{vt\text{-}both}$		16,380	0.4294	0.5096	0.0000	2.9103
$Tariff_{vjt}$	%	16,380	4.4143	4.9203	0.0000	20.0000

Source: authors' calculations based on MRLs and trade databases.

We focus on agri-food products (i.e., those belonging to HS chapters 06–24, excluding HS chapters 15–16) for which MRLs are specified. First, we exclude processing firms that use agri-food products imported from other countries as intermediate inputs in production. Then, we sum the firm-level trade data into an annual series based on product–destination–year pairs. Aggregating these annul series at the HS six-digit level, we obtain the panel data for total export value.[18]Applying a similar procedure to the number of firms, we obtain panel data for the number of exporting firms. Dividing the total export value by the number of exporting firms, we obtain the panel data for the average export value per firm.

We matched export data with MRL data based on the HS six-digit code and name. Because of data availability for tariffs, our sample comprises 65 HS six-digit agri-food products belonging to one of five HS two-digit groups: HS07 (edible vegetables and certain roots and tubers), HS08 (edible fruit), HS09 (tea and spices), HS10 (cereals), and HS12 (oil seeds and oleaginous fruits; miscellaneous grains, seeds, and fruit).[19]

4.3 Descriptive Statistics

Table 2 summarizes the descriptive statistics of the dependent and control variables. There are 16,380 observations in our sample. Even though aggregated up to the HS six-digit level, zero values account for 85.60% of the observations in the export data. $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ are the heterogeneity indices containing all pesticides regulated in China and the EU, while $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$ are the heterogeneity indices containing pesticides regulated by both China and the EU.[20] Figure A.1 shows the $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ of the 65 agri-food products included in our sample.[21] The value of $F_{vt\text{-}all}$ is above 0.85, and that of $M_{vt\text{-}all}$ is less than 0.021. The large gap between $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ confirms that for every agri-food product, the EU sets much stricter MRLs on most pesticides while China sets stricter MRLs on only a few pesticides.

5 Estimation Methods and Results

5.1 Estimation Method

SILVA and TENREYRO (2006) note that the Poisson pseudo-maximum-likelihood (PPML) estimator can effectively address zero values and heteroscedasticity in the data for the dependent variable, and it is robust to various forms of heteroscedasticity and measurement errors. Under the assumption that the conditional variance is proportional to the conditional mean (not necessarily equal), the PPML is an optimal estimator. The estimates of the PPML estimator are consistent, even if conditional variance and conditional mean are not proportional. SILVA and TENREYRO (2011) further showed that the PPML is still a well-behaved estimator even if zero values account for a large share of observations. We use a PPML estimator with fixed effects and robust standard errors clustered around the EU member–year to estimate Eq. (22).[22]

[18] Aggregating original export data at the HS eight-digit level up to the HS six-digit level allows us to match the export data with MRL data and tariff data, which are available at the HS six-digit level.

[19] Among 65 HS six-digit agri-food products, 43 products are high-value agri-food products belonging to HS chapters 07–09, for which Chinese producers show comparative advantages.

[20] To avoid bias in the following PPML estimation owing to the large numerical differences in the values among variables, we expand the heterogeneity indices F_{vt} by 10 times and M_{vt} by 100 times. However, the heterogeneity indices shown in Figure A.1 are in the original values.

[21] The left axis represents the value of F_{vt}, and the right axis represents the value of M_{vt}.

[22] Stata 15.1 is used for the estimations.

5.2 Main Results

Columns (1), (3), and (5) in Table 3 show the main estimation results. Since the heterogeneity indices F_{vt} and M_{vt} are expanded by 10 times and 100 times in the estimation, respectively, we should take these expansions into account when interpreting the estimated coefficients.

The coefficients of $F_{vt\text{-}all}$ are all positive and statistically significant. When the EU sets more stringent MRLs, they do not restrain China's agri-food exports to the EU; on the contrary, they boost the exports. A 0.01 unit increase in the heterogeneous index leads to a 3.1116% increase in total export value. This promotion effect is attributable to the increases in both the extensive and intensive margins. A 0.01 unit increase in the heterogeneous index leads to a 1.2690% increase in the number of exporting firms and a 2.5396% increase in the average export value of each firm. Consequently, the demand-enhancing effect is overwhelmingly dominant in the dual effect of the EU's MRL standard on agri-food products exported from China.

The coefficient of $M_{vt\text{-}all}$ is also positive and statistically significant. When China sets more stringent MRLs, it sends a credible signal of improved product quality and enhances EU consumers' preference and demand for Chinese agri-food products. A 0.01 unit increase in the stringency of China's MRLs relative to the EU's raises the number of exporting firms by 0.2117% and the average export value of each firm by0.1495%, jointly raising the total export value by 0.0858%. The coefficient of *tariff* is negative and statistically significant, indicating that tariffs still pose substantial trade costs for China's agri-food exports to the EU.

Our findings on total export value comport with those of SHINGAL et al. (2021). Studies (CHEN et al., 2008a; WINCHESTER et al., 2012; XIONG and BEGHIN, 2012; FERRO et al., 2015; HEJAZI et al., 2016; KAREMERA et al., 2020; HEJAZI et al., 2022) that do not consider the demand-enhancing effect either expect more stringent MRLs imposed by importing countries to hinder exports, similar to other non-tariff barriers, or ignore the significant promotion effect of more stringent MRLs imposed by exporting countries.

Our proposed QHFT model provides reasonable explanations for these empirical findings regarding total export value as well as the extensive and intensive margins. The positive coefficients of $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ in the estimates of total export value and the extensive margins are consistent with the theoretical expectations listed in Table 1, column (3), demonstrating an overwhelmingly dominant and significant demand-enhancing effect. When MRLs set by the EU are more stringent, only if the demand-enhancing effect prevails over the trade-cost effect will the imposition of more stringent MRLs lead to an increase in both total export value and the number of exporting firms. When more stringent MRLs set by China signal the high quality of its agri-food products, the imposition of stringent MRLs will lead to increases in both

Table 3. Estimation results for PPML

	$EXPORT_{vjt}$		$EXTENSIVE_{vjt}$		$INTENSIVE_{vjt}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$F_{vt\text{-}all}$	3.1116***		1.2690***		2.5396***	
	(6.9180)		(9.5619)		(7.6471)	
$M_{vt\text{-}all}$	2.1171***		1.4953***		0.8584***	
	(9.1368)		(15.3192)		(5.1217)	
$F_{vt\text{-}both}$		3.3635***		1.3894***		3.0034***
		(7.6022)		(11.5053)		(9.6978)
$M_{vt\text{-}both}$		1.7627***		1.1692***		1.1310***
		(10.1574)		(15.0141)		(10.2991)
$Tariff_{vjt}$	−0.4195***	−0.4148***	−0.2789***	−0.2755***	−0.2516***	−0.2418***
	(−14.8769)	(−14.0909)	(−22.3373)	(−21.4632)	(−12.4992)	(−11.4414)
Constants	−32.1591***	−34.4313***	−12.6982***	−13.6851***	−28.5049***	−33.0893***
	(−7.2292)	(−7.8176)	(−9.5711)	(−11.1704)	(−8.6461)	(−10.6826)
Importer–year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15730	15730	15730	15730	15730	15730
Adjusted R^2	0.1725	0.1910	0.2837	0.2946	0.1427	0.1540

Note: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. Within brackets are the robust standard errors clustered around the EU member state–year. Some observations were dropped in the estimation process.
Source: estimation results

total export value and the number of exporting firms. However, the coefficients of $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ in the estimates of the intensive margin turn out to be positive only when the average export value of incumbent firms exceeds that of newly entering firms. Since the productivity of incumbent firms is higher than that of newly entering firms, our estimates of the intensive margin suggest that more stringent MRLs, whether imposed by the EU or China, benefit higher-productivity firms more than lower-productivity firms.

In addition to the endogenous trade-cost effect, MRL updates and public investment in China have exogenous and dynamic effects on compliance costs, which cannot be captured by the static parameters α and η. China's MRL updates lead to intra-industrial adjustments in the domestic agri-food industry. When China strengthens its MRL standards, the costs for firms to sell in the domestic market increase as they adjust their production techniques to comply with the more stringent MRLs. This raises the minimum productivity threshold for firms to sell profitably in the home market, forcing low-productivity firms to exit. The surviving firms with higher productivity are more capable of complying with the more stringent MRLs of developed economies. As shown in Eqs. (3), (6), (8), and (10), an increase in a firm's productivity level φ leads to a decrease in variable costs $\frac{\theta_j^\alpha}{\varphi}$, which would encourage incumbent firms to export more and new firms to export.

Meanwhile, China has been providing infrastructure and technology support to improve the safety of agri-food products, increasing investment in quarantine facilities and services for exporting, establishing surveillance and early-alert systems for MRL standards, and helping firms adapt to more stringent MRL standards through training. The reduced variable and fixed compliance costs stemming from these actions can be captured by the diminishing parameters α and η, respectively. Again, a decrease in fixed cost motivates new firms to export while a decrease in variable cost motivates new firms to export and incumbent firms to export more.

5.3 Robustness Check

5.3.1 Default Value of MRLs

To investigate whether the replacement of the default value of MRLs will affect the estimates, we re-estimate Eq. (22) using alternative heterogeneity indices of $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$, which comprise just the pesticides regulated by both China and the EU. The estimates presented in columns (2), (4), and (6) of Table 3 confirm that our findings remain qualitatively the same.

5.3.2 Outliers in Export Data

There are substantial differences in export value across agri-food-exporting firms. To investigate whether the outliers affect the estimates, we re-estimate using export data excluding firms whose export values are within the 1st and 99th percentiles. Table 4 presents the estimates. The coefficients of both $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ decrease somewhat but do not change our main findings.

Table 4. Estimation results for PPML excluding outliers

	$EXPORT_{vjt}$		$EXTENSIVE_{vjt}$		$INTENSIVE_{vjt}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$F_{vt\text{-}all}$	2.3928*** (6.6036)		1.2392*** (9.5126)		2.0537*** (6.1948)	
$M_{vt\text{-}all}$	1.9331*** (10.7837)		1.4880*** (15.2491)		0.7865*** (4.4791)	
$F_{vt\text{-}both}$		2.4662*** (8.2158)		1.3612*** (11.5000)		2.3582*** (8.9020)
$M_{vt\text{-}both}$		1.5198*** (11.2940)		1.1627*** (15.0320)		0.9416*** (8.8787)
$Tariff_{vjt}$	−0.4084*** (−19.2678)	−0.4065*** (−18.8658)	−0.2848*** (−22.4613)	−0.2816*** (−21.6536)	−0.2451*** (−13.6291)	−0.2369*** (−12.8516)
Constants	−25.2949*** (−7.0515)	−25.7991*** (−8.5694)	−12.4162*** (−9.5222)	−13.4198*** (−11.1591)	−23.8081*** (−7.2256)	−26.7998*** (−10.0854)
Importer–year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15730	15730	15730	15730	15730	15730
Adjusted R^2	0.2514	0.2648	0.2833	0.2937	0.1690	0.1744

Note: *p < 0.05, **p < 0.01, and ***p < 0.001. Within brackets are the robust standard errors clustered around the EU member state–year. Some observations were dropped in the estimation process.
Source: estimation results

Table 5. Estimation results for PPML excluding tariffs

	$EXPORT_{vjt}$		$EXTENSIVE_{vjt}$		$INTENSIVE_{vjt}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$F_{vt\text{-}all}$	3.6742***		2.3686***		3.1344***	
	(9.1669)		(21.8380)		(12.6442)	
$M_{vt\text{-}all}$	2.3186***		1.7517***		0.9543***	
	(11.1636)		(18.8044)		(5.5819)	
$F_{vt\text{-}both}$		3.7962***		2.3606***		3.3845***
		(10.9227)		(27.3443)		(15.1242)
$M_{vt\text{-}both}$		1.9149***		1.3907***		1.1649***
		(13.4075)		(20.2578)		(11.0303)
Constants	−38.3058***	−39.2610***	−23.9070***	−23.6246***	−34.7911***	−37.2543***
	(−9.8105)	(−11.5182)	(−23.1361)	(−28.0619)	(−14.1555)	(−16.7337)
Importer–year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	18711	18711	18711	18711	18711	18711
Adjusted R^2	0.1100	0.1283	0.1555	0.1729	0.1049	0.1168

Note: *p< 0.05, **p< 0.01, and ***p< 0.001. Within brackets are the robust standard errors clustered around the EU member state–year. Some observations were dropped in the estimation process.
Source: estimation results

5.3.3 Collinearity Test

Researchers debate whether MRL standards are used as a new measure of trade protection to replace tariffs (LI et al., 2017; YEUNG et al., 2017; JIANG & ZHANG, 2021; SHINGAL et al., 2021; KAREMERA et al., 2022). Since the Pearson's correlation test shows a significant negative correlation between tariffs and $F_{vt\text{-}all}$, we drop tariffs in the estimation.[23] As presented in Table 5, the coefficients of both heterogeneity indices change slightly, suggesting that collinearity between MRLs and tariffs does not have a substantial effect on the estimates. YEUNG et al. (2017) and JIANG and ZHANG (2021) noted that MRL standards aim to protect the safety and health of food consumers in the domestic market. Even if MRLs cause trade distortions, they should not be identified as a non-tariff measure designed to replace tariffs.

5.3.4 Endogeneity Test

The main estimates may suffer from endogeneity bias, either because of omitted variable bias or reverse causality. The former is considerably reduced by the EU member state–year fixed effect in Eq. (22). Reverse causality may occur if the EU adopts more stringent MRLs in response to high levels of agri-food exports as a consequence of reduced tariffs.

First, we re-estimate Eq. (22) using the year-lag of the heterogeneity indices. The estimates presented in Table 6 confirm our main findings.

Second, following FONTAGNÉ et al. (2015) and FERNANDES et al. (2019), we use the simple average of the heterogeneity index across agri-food products belonging to the same HS four-digit group as the instrumental variable. The IV estimates presented in Table 7 confirm our main findings.

6 Conclusion

We used a QHFT model to show that stricter MRLs set by importing countries affect agri-food trade through a dual effect—namely, the effect on import demand and that on variable and fixed compliance costs. However, when MRLs set by the exporting country are stricter, there is only a demand-enhancing effect. For the empirical analysis, we collected official records of MRLs and firm-level transactions of agri-food products exported from China to the EU to build two novel datasets for the period 2008–2016. We used heterogeneity indices integrating both the number and value of MRLs to measure the relative stringency of MRLs between China and the EU, and we applied the PPML estimator with fixed effects to treat zero values and heteroscedasticity in the export data. We also checked whether the main estimates are sensitive to the default value of MRLs, outliers, collinearity, and endogeneity.

We found that stricter MRLs, whether set by the EU or China, significantly promote China's agri-food

[23] Without being constrained by the availability of tariff data, the new sample comprises 77 agri-food products and 19,404 observations.

exports to the EU in the dimensions of total export value, the extensive margins, and the intensive margins. When the EU sets more stringent MRLs, it does not constrain China's agri-food exports to the EU. On the contrary, it boosts exports. When China sets more stringent MRLs, it signals product quality and enhances EU demand for Chinese agri-food products. Moreover, these promotion effects are heterogeneous across firms with different levels of productivity. Our findings confirm that MRL standards are not non-tariff measures intended to replace tariffs. Upgrading MRLs helps promote China's agri-food exports. China's updated MRL standards produce intra-industrial adjustments by raising the productivity threshold of the agri-food industry. Surviving agri-food firms with higher productivity can adjust to the more stringent MRLs set by developed countries such as those in the EU. In addition, public investments and services in China have helped reduce compliance costs.

These empirical findings are consistent with the theoretical expectations of our proposed QHFT model. By introducing the dual effect into the trade model based on heterogeneous firm quality and productivity, we provided reasonable explanations for the positive

Table 6. Estimation results for PPML with lagged indices

	$EXPORT_{vjt}$		$EXTENSIVE_{vjt}$		$INTENSIVE_{vjt}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$F_{v\ (t-1)\text{-all}}$	4.0579***		1.5610***		3.2054***	
	(6.6085)		(9.9767)		(6.6642)	
$M_{v\ (t-1)\text{-all}}$	2.4332***		1.6057***		0.9451***	
	(8.1446)		(13.7338)		(4.0636)	
$F_{v\ (t-1)\text{-both}}$		4.2343***		1.6722***		3.6961***
		(7.4374)		(11.5093)		(9.2438)
$M_{v\ (t-1)\text{-both}}$		2.0498***		1.2942***		1.3223***
		(9.3424)		(13.9254)		(9.5639)
$Tariff_{vjt}$	−0.4140***	−0.4089***	−0.2712***	−0.2670***	−0.2522***	−0.2428***
	(−13.2898)	(−12.7931)	(−19.5449)	(−18.5117)	(−11.5929)	(−10.8211)
Constants	−44.5355***	−46.1230***	−17.5406***	−18.4925***	−36.4385***	−41.3426***
	(−7.3708)	(−8.2108)	(−11.1151)	(−12.4639)	(−7.6719)	(−10.4580)
Importer–year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13910	13910	13910	13910	13910	13910
Adjusted R^2	0.1424	0.1677	0.2680	0.2859	0.1251	0.1355

Note: *p< 0.05, **p< 0.01, and ***p< 0.001. Within brackets are the robust standard errors clustered around the EU member state–year. Some observations were dropped in the estimation process.
Source: estimation results

Table 7. IV estimation results

	$LnEXPORT_{vjt}$		$LnEXTENSIVE_{vjt}$		$LnINTENSIVE_{vjt}$	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$F_{vt\text{-all}}$	1.3300***		0.1014***		1.2286***	
	(5.8183)		(3.7795)		(5.9385)	
$M_{vt\text{-all}}$	0.9766***		0.1282***		0.8484***	
	(5.5300)		(4.8329)		(5.3779)	
$F_{vt\text{-both}}$		1.5429***		0.1270***		1.4160***
		(7.3866)		(4.8163)		(7.5583)
$M_{vt\text{-both}}$		1.0782***		0.1230***		0.9552***
		(6.8565)		(5.2827)		(6.8647)
$Ln(1+Tariff_{vjt})$	−0.8515***	−0.8397***	−0.0938***	−0.0928***	−0.7577***	−0.7468***
	(−17.4395)	(−17.5301)	(−13.3209)	(−13.4094)	(−17.6647)	(−17.7609)
Constants	−10.8118***	−12.8409***	−0.8008**	−1.0383***	−10.0111***	−11.8026***
	(−4.7296)	(−6.1414)	(−2.9716)	(−3.9575)	(−4.8406)	(−6.2901)
Importer–year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16380	16380	16380	16380	16380	16380
Adjusted R^2	0.1889	0.1921	0.1374	0.1391	0.1838	0.1871

Note: *p< 0.05, **p< 0.01, and ***p< 0.001. Within brackets are the robust standard errors clustered around the EU member state–year.
Source: estimation results

effect of MRLs on Chinese agri-food exports to the EU and the heterogeneous effects across agri-food exporting firms. However, agri-food-exporting firms can be distinguished in terms of not only productivity and quality, but also by their product and market portfolios. Thus, an in-depth understanding of MRLs' effects on quality upgrading, market portfolios, product portfolios, and other micro-level behaviors among agri-food-exporting firms could help to better evaluate the effect of MRL standards on trade and welfare. In this regard, our proposed QHFT model provides a flexible theoretical framework that can be extended to studying the effect of MRLs on market portfolios, product portfolios, and the quality upgrading of agri-food exporting firms in future research.

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Acknowledgments

We thank anonymous reviewers for insightful suggestions. We also thank LetPub (www.letpub.com) for linguistic assistance. We gratefully acknowledge financial support from the National Natural Science Foundation of China (Grant No. 71463009) and the Center for Development and Application of Marxism Economics of Guizhou University (Grant No. 23GZGXRWJD021,23GZGXRWJD022).

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Appendix A

Table A.1 Number of agri-food products in MRL standards

Year	China	EU	China and EU	China only	EU only
2008	146	414	115	31	299
2009	150	414	119	31	295
2010	150	414	119	31	295
2011	171	414	125	46	289
2012	182	414	135	47	279
2013	279	414	216	63	198
2014	279	414	216	63	198
2015	349	414	254	95	160
2016	349	414	254	95	160

Source: authors' calculations based on the Chinese and EU MRL databases.

Table A.2 Number of pesticides in MRL standards

Year	China	EU	China and EU	China only	EU only
2008	138	442	104	34	338
2009	140	444	106	34	338
2010	140	449	106	34	343
2011	161	453	122	39	331
2012	219	458	160	59	298
2013	323	465	219	104	246
2014	323	473	219	104	254
2015	387	480	263	124	217
2016	387	497	264	123	233

Source: authors' calculations based on the Chinese and EU MRL databases.

Table A.3 Number of entries in MRL standards

Year	China	EU	China and EU	China only	EU only
2008	2,359	173,080	1,558	801	171,522
2009	2,604	174,381	1,809	795	172,572
2010	2,604	176,460	1,809	795	174,651
2011	2,739	178,593	1,890	849	176,703
2012	3,000	181,266	2,035	965	179,231
2013	9,616	184,646	5,597	4,019	179,049
2014	9,616	188,522	5,597	4,019	182,925
2015	14,037	191,459	8,649	5,388	182,810
2016	14,037	198,052	8,620	5,417	189,432

Source: authors' calculations based on the Chinese and EU MRL databases.

Table A.4 Average MRL value in MRL standards

Year	China				The EU			
	Obs.	Mean	Min	Max	Obs.	Mean	Min	Max
2008	2,359	1.0271	0.0050	20	173,080	0.4979	0.0008	500
2009	2,604	0.9739	0.0020	30	174,381	0.5912	0.0008	500
2010	2,604	0.9739	0.0020	30	176,460	0.6046	0.0008	500
2011	2,739	1.0486	0.0020	30	178,593	0.6062	0.0008	500
2012	3,000	1.0542	0.0020	30	181,266	0.6045	0.0008	500
2013	9,616	0.5419	0.0020	30	184,646	0.6104	0.0008	500
2014	9,616	0.5419	0.0020	30	188,522	0.6657	0.0008	500
2015	14,037	0.9595	0.0020	90	191,459	0.6773	0.0008	500
2016	14,037	0.9595	0.0020	90	198,052	0.6491	0.0008	500

Source: authors' calculations based on the Chinese and EU MRL databases.

Table A.5 List of agri-food products in our sample

HS2	HS6
07-Edible vegetables and certain roots and tubers	070190 (potatoes); 070200 (tomatoes); 070310 (onions and shallots); 070390 (leeks); 070410 (cauliflowers); 070420 (brussels sprouts); 070519 (lettuce); 070610 (carrots and turnips); 070810 (peas); 070820 (beans); 070920 (asparagus); 070930 (aubergine); 070940 (celery); 070951 (mushrooms); 070960 (capsicum and pimento); 070970 (spinach); 071310 (peas, dried); 071320 (chickpeas); 071331 (mungo); 071332 (adzuki); 071340 (lentils); 071350 (broad beans); 071420 (sweet potatoes);
08-Edible fruit	080212 (almonds); 080232 (walnuts); 080240 (chestnuts); 080250 (pistachios); 080260 (macadamia); 080300 (bananas); 080420 (figs); 080430 (pineapples); 080450 (mangoes); 080510 (oranges); 080520 (mandarins); 080550 (lemons and limes); 080610 (grapes); 080620 (grapes, dried); 080720 (papayas); 080910 (apricots); 080940 (plums and sloes); 081010 (strawberries); 081020 (raspberries, blackberries, and mulberries); 081050 (kiwifruit); 081320 (prunes, dried); 081340 (tamarind);
09-Tea and spices	090111 (coffee); 090300 (mate); 090700 (cloves); 090810 (nutmeg); 090920 (coriander seeds); 090930 (cumin seeds); 091010 (ginger); 091020 (saffron);
10-Cereals	100590 (maize); 100700 (grain sorghum);
12-Oil seeds and oleaginous fruits; miscellaneous grains, seeds, and fruit	120100 (soya beans); 120220 (ground-nuts); 120400 (linseed); 120510/120590 (rape or colza seeds); 120600 (sunflower seeds); 120740 (sesame seeds); 120750 (mustard seeds); 120791 (poppy seeds); 121010 (hop cones); 121120 (ginseng roots);

Source: authors' construction

Figure A.1 Variation in heterogeneity indices across products and over time

Source: authors' calculations based on the Chinese and EU MRL databases.

Appendix B Pareto Productivity Distribution Example

Following LAWLESS (2010) and GAIGNÉ and LARUE (2016), we assume firm productivity φ follows a Pareto distribution over [1, +∞) with a shape parameter γ (with $\gamma > \epsilon - 1$) and a lower bound φ_{min}. We further normalize the lower bound of productivity φ_{min} to 1, and the density function is simplified to $g(\varphi) = \gamma\varphi^{-\gamma-1}$. Based on the discussion of the theoretical model, we can express total exports, extensive margin, and intensive margin as explicit functions of food expenditure E_j, price index P_j, tariff τ_j, and MRLs θ_j.

A. A Model with Stricter MRLs Imposed by the Importing Country

The total exports R_j is given by

$$R_j = N\frac{\gamma}{\gamma-\epsilon+1}\left(\frac{\eta}{\epsilon-1}\right)^{\frac{\gamma-\epsilon+1}{\epsilon-1}}\left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{\epsilon-\epsilon\gamma-1}{\epsilon-1}}\theta_j^{\frac{\beta\epsilon\gamma-[\alpha(\epsilon-1)\gamma+\eta(\gamma-\epsilon+1)]}{\epsilon-1}}\tau_j^{-\gamma}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}}. \tag{B1}$$

The elasticity of R_{ij} with respect to θ_{ij} is given by

$$\mathrm{E}_{\theta_j}(R_j) = \frac{\beta\epsilon\gamma-[\alpha(\epsilon-1)\gamma+\eta(\gamma-\epsilon+1)]}{\epsilon-1}. \tag{B2}$$

The extensive margin N_j is given by

$$N_j = N\tau_j^{-\gamma}\left(\frac{\eta}{\epsilon-1}\right)^{\frac{\gamma}{\epsilon-1}}\left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{-\epsilon\gamma}{\epsilon-1}}\theta_j^{\frac{\beta\epsilon\gamma-[\eta+\alpha(\epsilon-1)]\gamma}{\epsilon-1}}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}}. \tag{B3}$$

The elasticity of N_j with respect to θ_j is given by

$$\mathrm{E}_{\theta_j}(N_j) = \frac{\beta\epsilon\gamma-[\eta+\alpha(\epsilon-1)]\gamma}{\epsilon-1}. \tag{B4}$$

The extensive margin I_j is given by

$$I_j = \frac{\gamma\epsilon\theta_j^{\eta}}{\eta(\gamma-\epsilon+1)}. \tag{B5}$$

The elasticity of I_j with respect to θ_j is given by

$$\mathrm{E}_{\theta_j}(I_j) = \eta. \tag{B6}$$

B. A model with Stricter MRLs Imposed by the Exporting Country

The total exports R_j is given by

$$R_j = N\frac{\gamma}{\gamma-\epsilon+1}\left(\frac{1}{\epsilon-1}\right)^{\frac{\gamma-\epsilon+1}{\epsilon-1}}\left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{\epsilon-\epsilon\gamma-1}{\epsilon-1}}\theta_j^{\frac{\beta\epsilon\gamma}{\epsilon-1}}\tau_j^{-\gamma}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}}. \tag{B7}$$

The elasticity of R_j with respect to θ_{ij} is given by

$$\mathrm{E}_{\theta_j}(R_j) = \frac{\beta\epsilon\gamma}{\epsilon-1}. \tag{B8}$$

The extensive margin N_j is given by

$$N_j = N\tau_j^{-\gamma}\left(\frac{1}{\epsilon-1}\right)^{\frac{\gamma}{\epsilon-1}}\left(\frac{\epsilon}{\epsilon-1}\right)^{\frac{-\epsilon\gamma}{\epsilon-1}}\theta_j^{\frac{\beta\epsilon\gamma}{\epsilon-1}}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}}. \tag{B9}$$

The elasticity of N_j with respect to θ_{ij} is given by

$$\mathrm{E}_{\theta_j}(N_j) = \frac{\beta\epsilon\gamma}{\epsilon-1}. \tag{B10}$$

The extensive margin I_j is given by

$$I_j = \frac{\gamma\epsilon}{\gamma-\epsilon+1}. \tag{B11}$$

The elasticity of I_j with respect to θ_{ij} is given by

$$\mathrm{E}_{\theta_j}(I_j) = 0. \tag{B12}$$

Based on the discussion of the theoretical model, we know that an increase (decrease) in the variable trade-cost of MRLs decreases (increases) the exports of incumbent firms but also eliminates (encourages) low-productivity firms. As LAWLESS (2010) showed, when productivity is drawn from a Pareto distribution, these two counteracting forces precisely offset each other. Therefore, the effect of the variable trade-cost effect on the intensive margin cannot be obtained in a tractable form.