Doctoral Dissertation

Study on Trade Effects of Food Safety Standards: Export Promotion, Measure Protection and Trade Duration

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Hiroshima University

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Abstract

This thesis studies the food safety standards that need to be complied in international trade, e.g. maximum residue limits for pesticides (MRLs), and their effects on food trade exports, trade protectionism and trade duration, thus enriching the understanding of international trade effects.

Chapter 2: Are China's food safety standards driven by trade protectionism? - Empirical analysis of maximum residue limits

Mandatory food safety standards, including maximum residue limits, may be used to replace substantially reduced agricultural tariffs as new non-tariff measures in international trade. China is the world's largest importer of agricultural products, and there is a question whether the maximum residue limits promulgated and implemented over the years have led to protectionism. Scholars have proposed "protectionism indices" to quantify the trade protectionism of non-tariff measures. This thesis collects and collates a relatively new and complete data set of maximum residue limits in China and the Codex Alimentarius Commission. This is used to demonstrate the evolution of China's maximum residue limits, and measure their protectionism indices relative to international standards. Regression analysis shows that China's maximum residue limits have tended not to replace tariffs as a new tool for trade protection. The motivation for the rise of protectionism indices appears to stem from public demand for improved food safety and the government's active response to food safety incidents. There may be some misleading implications to using the term "protectionism indices" in relation to maximum residue limits. The use of the term "stringency indices" may be more neutral and objective.

Chapter 3: Influence of maximum residue limits for pesticides on agricultural food exports: analysis based on a quality heterogeneous firms trade model

Some studies suggest that maximum residue limits (MRLs) discourage imports by increasing compliance costs for exporters, similar to other non-tariff measures. This study analyzes the impact of MRLs on trade by constructing a quality heterogeneous firms trade model, with data of agricultural food products exported from China to the European Union (EU) from 2008 to 2020. The results show that the trade impact depends on the comprehensive effects of three factors: demand, variable cost,

and fixed cost. Heterogeneity indexes, which combine the standard quantity and level, are used to measure the difference in MRL standards between China and the EU. The Poisson pseudo maximum likelihood fixed-effect estimator is applied in the regression to investigate the impact of MRLs on the exports of agri-food products. The results indicate that more stringent MRLs, whether formulated by the EU or China, promote China's agri-product exports to the EU. When China (the exporter) actively raises its MRL standards, there is an even more significant promotion effect on its exports than when China only follows the strict MRLs of the EU (the importer). The results are consistent with the rapid development of China's food safety standards and significant improvement in food safety levels over the past decade.

Chapter 4: Influence of the exporter's food safety standards on trade duration: An empirical study of agricultural food products from China

Previous studies have revealed the duration of most international trade combinations is unexpectedly short. Focusing on improving the trade duration may be more critical than simply exploring diversified markets to boost trade. Based on a set of export data from 2008 to 2019, the trade survival analysis shows the average trade duration of China's agri-food export is 3.5824 years. To further understand the trade duration, this thesis introduces the heterogeneity indices of Maximum Residue Limits for pesticides (MRLs) between China and Codex Alimentarius Commission (CAC), aiming to quantitatively measure the strictness level of China's MRLs standards, and adopts the discrete-time hazard model (Cloglog) to examine the impact of food safety standards on the duration of agri-food export. The regression results illustrate the upgrading of MRLs standards in exporter (China) have contributed to prolong the trade duration and stabilize bilateral trade relations. In addition, the capacity of agri-food production is also an emphasis factor affecting the stability of export trade.

Contents

Chapter 1 Introduction

Food safety is the fundamental right of human safety and health, and ensuring food safety is one of the essential functions of governments. In the past two decades, the media worldwide, including China, have continuously exposed food safety incidents, which has exposed the long-standing problem of pesticide and veterinary drug abuse in food production and has aroused great attention to food safety worldwide. It makes governments issue more stringent food safety regulations, reform food safety regulatory agencies, establish and improve the national Maximum Residue Limit for Pesticide (MRLs) to regulate the use of pesticides strictly.

As the international food trade increasing exponentially in the past few decades, pesticide residues are widely regarded as one of the important factors affecting the quality and safety of agricultural products. Maximum residue limits (MRLs) for pesticides is the maximum concentration of legally allowable pesticide residues in or on food commodities and animal feeds (expressed in mg/kg), recommended by the Codex Alimentarius Commission (CAC). Food safety incidents around the world have triggered extensive reports in the local media, exposing long-standing problems such as excessive pesticides in imported or domestic foods and illegal use of unregistered pesticides. Enhanced public awareness of food safety and pressure from public opinion prompt governments to formulate more extensive and stringent MRL standards for pesticides as mandatory food import standards. Japan introduced the "The Japanese Positive List System for Agricultural Chemical Residues in Foods" in 2003, which was implemented in May 2006. The European Union (EU) member states have adopted unified EU MRLs since 2008. In the same year, Canada passed new MRLs. From 2010 to 2019, Australia, Hong Kong, and South Korea successively announced their new MRLs. Based on the consideration of domestic dietary habits, politics, economy and other factors, the MRLs of some developed countries and regions deviated from the CAC international standard advocated by the Agreement of Sanitary and Phytosanitary Measures (SPS) of the World Trade Organization, which led to the continuous reduction of the coordination of MRLs among countries, and the related agricultural trade disputes continued to rise. The international community is concerned about whether MRLs have replaced gradually reduced tariffs promised by countries and become a new form of trade protection policy tool? This has triggered many empirical studies on the impact of MRLs on trade.

Chapter 2:

The question of whether specific food safety standards can become non-tariff trade barriers has been the subject of considerable research. Scholars in food policy believe that food safety standards, unlike other non-tariff barriers, have dual effects on agricultural trade. They may increase compliance costs, hinder trade and cut social welfare. However, they may also reduce information asymmetry or negative externalities, promote trade and improve social welfare.

China is now the world's leading net importer of agricultural products. Large-scale agricultural imports threaten agricultural employment and farmers' income and bring new challenges to food security and trade disputes. With the loss of comparative advantage in agricultural products and the continuous expansion of the trade deficit, the question of whether Chinese government agencies will use trade protection tools other than import tariffs has attracted much attention. Scholars have examined the adjustment of China's trade policy following tariff reduction. One study found that China actively uses other policy tools to replace tariffs and extend the protection for domestic producers. Current research on food safety standards mainly focuses on the formulation of standards in developed countries and their impact on global trade. Few studies have examined the changes in China's agricultural products import trade policy. Scholars in China also tend to focus on the impact of developed countries' MRLs on China's agricultural exports. There is therefore very little research on China's own MRLs. The MRLs database of the US Department of Agriculture (USDA) is widely used in research, but this only includes the MRLs of pesticides prescribed by the United States. There is therefore no way of assessing the rapid development of MRLs in China. This thesis considers the following questions:

- What is the trend in MRLs in China?
- What are the main factors affecting the evolution of MRLs in China?
- Will MRLs replace decreasing import tariffs in China as a new tool in trade protection policy?

To obtain more objective and complete data for analysis, we drew on historical documents to establish an MRLs database for China and the CAC, and analyzed the evolution of China's MRLs compared with CAC standards. We found that MRLs have not replaced tariffs as a new trade protection policy tool. There may also be some misleading implications from using so-called protectionism indices to measure the use of MRLs.

Chapter 3:

In empirical studies of international trade, gravity model is mostly used. Most research focuses on whether the MRLs of importing countries hinder the imports of agri-products. Apart from the various countries, agri-products, and time periods, the main difference lies in the quantification of core explanatory variable. Early scholars used MRLs of important pesticides in import countries as explanatory variable, and later scholars almost used bilateral heterogeneity (similarity) indices of MRLs in import and export countries as explanatory variable, considering that bilateral divergence, not only the MRLs of importing countries, is the fundamental factor affecting trade. These indices integrate the number and level of MRLs standards, thus can comprehensively reflect the relative stringency of MRLs in import and export countries.

Existing empirical studies mainly focus on the impact of MRLs in developed countries on trade, rather than the relativity of standards between importer and exporter. The outdated time and limited samples do not timely and comprehensively reflect the rapid development of food safety standards in developing countries. Considering that the export of agri-food products accounts for a large proportion in the trade share of developing countries, the food safety standards will have a profound impact on the industry and trade of agri-food products, and then have a social and systematic influence on the development of rural areas, agriculture and farmers. As a developing country, China is the world's second importer and fourth exporter of agricultural products in 2020. From 2010 to 2021, China updated the national mandatory MRLs standard – "National Standard for Food Safety - Maximum Residue Limits of Pesticides in Food" for five times. The actual MRLs items specified in the standard increased from 873 in 2008 to 10092 in 2021, nearly twice that of CAC in 2020. The items of agri-food products had increased from 88 to 377, including 119 of agri-products unique to China. The items of pesticides had added from 138 to 564, basically realizing that all registered pesticides had standards to follow. The standard also stipulates the MRLs of 87 pesticides that are not prohibited but have not been approved for use in China. The principles, methods and data requirements of dietary risk assessment of pesticide residues adopted in China's MRLs are gradually in line with Codex Alimentarius Commission (CAC) and developed countries after more than a decade of development. The EU is recognized to have the most stringent MRLs standards, and its MRLs are regarded as an important obstacle to the export of agri-food products. Studying the impact of MRLs differences between China and the EU on the export of agri-products will help to enrich the understanding of food safety on trade effects and have certain guiding significance.

This thesis attempts to make contributions in both theoretical and empirical analysis. In theoretical analysis, we construct a concise QHFT model. The trade effect of MRLs is extended from two factors of demand and cost to three factors of demand, variable cost and fixed cost. On this basis, a reasonable gravity model that effectively handles the zero value is obtained. In empirical analysis, the heterogeneity indices are used to measure the bilateral relative stringency of MRLs between China and the EU. A relatively complete industry-level database of agri-food products in China and the EU is used to analyze the comprehensive effects of MRLs standards on trade. To make up for the data deficiency in previous studies, we have expanded the investigation for time, products and pesticides. This thesis finds that the current MRLs standards of the EU are still much more stringent than China, but the gap is narrowing, and even some MRLs in China have exceeded those in the EU. The EU's more stringent EU MRLs did not curb food exports from China to the EU, and when China's MRLs is more stringent, it shows a certain signal effect (quality upgrade), which plays a strong role (demand enhancing) in promoting China's food exports to the EU.

Chapter 4:

In the research on the trade effect of MRLs standards, scholars mainly focus on the impact of the improvement of food safety standards in developed countries, and these studies involve relatively early years. Most scholars focus more on the impact of developed countries' MRLs standards on their imports. Their research suggests that strict MRLs forces producers to bear additional production and compliance costs, and other costs come from the extension of delivery time in customs inspection and even refusal of entry, thus MRLs is used by importing countries to hinder the import of agricultural products and considered a protectionist measure. On the contract, other empirical studies suggest that seemingly strict MRLs standards can promote trade because they reduce the risk of information asymmetry and ease consumers' concerns, thus transmitting the signal of quality improvement in exporter and strengthening consumer demand.

Different from previous studies that focus on the impact of gross trade, this thesis focuses on the impact of MRLs standards on the duration of exports. Previous trade theory assume that trade relations will remain unchanged and continue for a long time after relationship are established, but this is not the case. Export duration plays an important role in the improvement of a country's export volume. If the trade duration is too short, it is difficult to maintain the sustained trade growth even if there are many trading partners.

The possible marginal contribution of this thesis is mainly in following aspects: First, different from previous studies focusing on the direct impact of food safety standards on gross trade, this thesis focuses on the implicit factor of the upgrading food safety standards on the trade duration of agricultural export. Second, based on the empirical data of China, this thesis explores the enhanced food safety standards such as MRLs on the export trade of developing countries. Thirdly, extend the research year to 2019 as to better conform to the rapid changes of MRLs standards in international trade since 2010. This thesis is dedicated to further improve the current research on the trade effect of food safety standards, and provide reflections for the agricultural industry upgrading of developing countries and the sustainable development of global agri-products trade.

The organizational structure of this thesis is summarized as follows：

Section 2.2 is the description of data sources. Section 2.3 analyzes the evolution characteristics of MRLs in China based on our database, and introduces the relative stringent index. Section 2.4 discusses the basic motivation of the changing MRLs in China by applying the regression model proposed. Section 2.5 is the conclusion and prospect.

Section 3.2 of this thesis is the theoretical model of QHFT, Section 3.3 is the empirical model, Section 3.4 is the data source, focusing on the explanation of the heterogeneity indices, and Section 3.5 is the methods and results of estimation. Section 3.6 is the conclusion and future research.

Section 4.2 is literature review, Section 4.3 is the estimation of trade duration, Section 4.4 is the empirical research on the influencing factors of trade duration, and Section 4.5 is the conclusion.

Chapter 2 Are China's food safety standards driven by trade protectionism? - Empirical analysis of maximum residue limits

2.1 Introduction

Food safety is a fundamental human right, part of both safety and health. Ensuring food safety is therefore one of the essential functions of governments. In the past two decades, the media worldwide, including in China, have exposed many food safety incidents (Swinnen, 2018). This, in turn, has exposed a long-standing problem of pesticide and veterinary drug abuse in food production and has focused attention on food safety worldwide. Governments have issued more stringent food safety regulations, reformed food safety regulatory agencies, and established and regulated the use of pesticides through improved national maximum residue limits (MRLs) for these chemicals (Swinnen, 2018).

The World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures recommends that member states formulate MRLs following the international standards of the Codex Alimentarius Commission (CAC). This standard is not mandatory, thus countries develop their MRLs in line with national practice. This behavior intensifies the inconsistency of MRLs between countries. There are concerns that the increasing number of trade disputes about agricultural products mean that food safety standards, including MRLs, may be used by some countries to replace substantially reduced tariffs as new non-tariff trade measures.

The question of whether specific food safety standards can become non-tariff trade barriers has been the subject of considerable research. Scholars in food policy believe that food safety standards, unlike other non-tariff barriers, have dual effects on agricultural trade (Swinnen, 2018; Yeung et al., 2017). They may increase compliance costs, hinder trade and cut social welfare. However, they may also reduce information asymmetry or negative externalities, promote trade and improve social welfare.

Scholars in international trade research have analyzed the trade effect of food safety standards from multiple angles and levels. The results vary between countries and products. Some studies found that food safety standards hindered trade (Ferro et al., 2015; Hejazi et al., 2016; Seok et al., 2018), while others found a promotion effect (Shingal et al., 2021; Xiong & Beghin, 2012; Xiong & Beghin, 2014). One study argued that countries with relatively low food safety standards import from countries with higher standards (Sun et al., 2014). Changes in standards in the importing country therefore do not have a significant impact on international trade.

Other studies on trade policy issues have introduced negative externality to the political economy model of trade policy-making and explored the political economy factors that lead to MRLs being too high or too low (Marette & Beghin, 2010; Swinnen & Vandemoortele, 2011). Another study used ordered logit and Probit regressions to examine whether MRLs have become trade protection policy tools (Farnsworth, 2012). It found that MRLs showed no overall protective tendency at the national or industrial level, but might be used to protect individual products. Li and colleagues proposed "protectionism indices" to measure the degree of protection of MRLs (Li & Beghin, 2014). They used these indices to construct a political economy model and investigate the substitution of MRLs for tariffs (Li et al., 2017). They believe that MRLs have become a trade protection policy tool to replace tariffs. A case study on China's dairy import standards found that China's domestic import rules affected the development of global norms for food safety (Augustin-Jean & Xie, 2016). As a policy response to a problem with milk in 2008, China has improved the standards of dairy products to enhance the competitiveness of its domestic industries and maintain social stability. This has also reshaped the international market at the advantage of its own producers.

China achieved its tariff reduction target and joined the WTO in 2001, committing to ongoing reductions in agricultural tariffs and non-tariff measures (NTMs). China's move from being a net exporter of agricultural products to a net importer in 2004 was attributed to both food demand growth and low tariffs. The average import tariff rate on agricultural products has fallen to about 15%, about one-quarter of the global average, and remains at that level. In early 2009, China comprehensively fulfilled its import tariff reduction commitments. In the same year, it established a food safety law, which defines the food governance system, including MRLs. During 2009–2019, China issued four new standards for MRLs. The number of standard items increased from 873 in 2008 to 7107 in 2019. The pace of internationalization of China's MRLs is also accelerating, as it moves from a position of receiving international standards to being a critical participant and leader. It became the chair of the Codex Committee on Pesticide Residues (CCPR) in 2006, and has hosted 14 CCPR conferences until 2021[1] . Several experts from China represent the Asia–Pacific region in the United Nations Food and Agriculture Organization, which is responsible for pesticide management and setting standards. The principles, methods, and data requirements of pesticide residue dietary risk assessment in China are in line with CAC international standards. In total, 11 MRLs from China have been adopted as CAC international standards. The number of MRLs in China exceeds the CAC international standard, and 90% of the standards there are equal to or stricter than the CAC international standard (Jiang et al., 2018).

[1] Sourced from official report: *The 52nd annual meeting of the Codex Alimentarius Committee on Pesticide residues was held online*.

China is now the world's leading net importer of agricultural products. Large-scale agricultural imports threaten agricultural employment and farmers' income and bring new challenges to food security and trade disputes (Zhu et al., 2018). With the loss of comparative advantage in agricultural products and the continuous expansion of the trade deficit, the question of whether Chinese government agencies will use trade protection tools other than import tariffs has attracted much attention. Scholars have examined the adjustment of China's trade policy following tariff reduction. One study found that China actively uses other policy tools to replace tariffs and extend the protection for domestic producers (Garred, 2018). Current research on food safety standards mainly focuses on the formulation of standards in developed countries and their impact on global trade. Few studies have examined the changes in China's agricultural products import trade policy. Scholars in China also tend to focus on the impact of developed countries' MRLs on China's agricultural exports. There is therefore very little research on China's own MRLs. The MRLs database of the US Department of Agriculture (USDA) is widely used in research, but this only includes the MRLs of pesticides prescribed by the United States (Li & Beghin, 2014). There is therefore no way of assessing the rapid development of MRLs in China. This thesis considers the following questions:

- What is the trend in MRLs in China?
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To obtain more objective and complete data for analysis, we drew on historical documents to establish an MRLs database for China and the CAC, and analyzed the evolution of China's MRLs compared with CAC standards. We found that MRLs have not replaced tariffs as a new trade protection policy tool. There may also be some misleading implications from using so-called protectionism indices to measure the use of MRLs.

Section 2.2 is the description of data sources. Section 2.3 analyzes the evolution characteristics of MRLs in China based on our database, and introduces the relative stringent index. Section 2.4 discusses the basic motivation of the changing MRLs in China by applying the regression model proposed. Section 2.5 is the conclusion and prospect.

2.2 Data descriptions

To obtain complete historical data about Chinese MRLs, we collected and reviewed the four versions of MRLs issued by the government from 2005 to 2019. They were "The National Standard for Food Safety—Maximum Residue Limits of Pesticides in Food (GB 2763-2012), (GB 2763—2014), (GB 2763—2016) " and " National food safety standard Maximum residue limits for 43 pesticides in food (GB 2763.1—2018)"[2] . Each new standard replaced the previous version. The standards in the four documents were classified by product, pesticide and year to give a complete MRLs Database of China (2008–2019), with a total of 20396 MRLs.

Relevant data about CAC standards were obtained from the Codex pesticides residues in food online database[3]. However, this database only provides the most recent annual list of MRLs. To obtain complete historical data from 2008 to 2019, we used the 2008 CAC international standards from the "Residue limits for pesticides and veterinary drugs in foods of major trading countries and regions (in Chinese)", and sorted them by product and pesticide (Wang, 2010). We then used the updated versions for each year after that to provide a new list. This gave a database of MRLs set by the CAC (2008–2019), which includes 40555 MRLs.

To compare the differences and stringency between Chinese and CAC standards, we matched the food names and pesticide names of the two standards. The food names in the CAC standard are in the Codex Classification of Foods and Animal Feeds[4], and those in the Chinese standard are in Appendix A - Food Category and Testing Site (in Chinese) of The National Standard for Food Safety-Maximum Residue Limits of Pesticides in Food (GB 2763) . We used these to match the food names in the two standards. To match the pesticide names, we modified some pesticide items in the Chinese MRLs based on CAC standard. For example, the pesticides Fenvalerate and Esfenvalerate are combined in the China list and separated in the CAC list. We modified China's pesticide items into separate ones in accordance with the MRLs of CAC. The reverse approach is taken with some other items.

Both Chinese and CAC standards have repetitive MRL items. For the same pesticide, different MRLs may be specified for major and subordinate categories of a food product. We selected the MRL value of sub-categories of food as representatives. For example, for the pesticide dichlorvos, the MRL in 2018 in China was 0.1 mg/kg for grains, but 0.2 mg/kg for corn. We used the MRL for corn as representative.

For some pesticides, MRLs may only stipulate the standards for major categories of products but not sub-categories. To supplement the missing data, we applied the MRLs for the major categories downwards to the products in the sub-categories. Take Endrin as an example. China stipulates Endrin MRLs of cucurbitaceous vegetables are 0.05mg/kg, and this MRLs should be

[2] Sourced from government standards: *National food safety standard—Maximum residue limits for pesticides in food (GB 2763-2012); (GB 2763-2014); (GB 2763-2016); National food safety standard Maximum residue limits for 43 pesticides in food (GB 2763.1-2018))*

[3] Sourced from online database: *Codex Pesticides Residues in Food Online Database*

[4] Sourced from CAC standards: *Codex Classification of Foods and Animal Feeds (CAC/MISC 4–1993).*

added to the zucchini and other products included in cucurbitaceous category. A similar operation is performed on the CAC data. This increased the number of standard items in both Chinese and CAC standards (Table 2.1).

2.3 Stringency of MRLs

2.3.1 Evolution of MRLs in China

From 2008 to 2019, China issued three new sets of MRL standards, in 2013, 2014, and 2018. We selected these three years as the observation years. The document “National food safety standard Maximum residue limits for 43 pesticides in food (GB 2763.1—2018)” is the supplementary version of “National food safety standard—Maximum residue limits for pesticides in food (GB 2763—2016)”. We integrated the two versions into a complete Chinese MRL standard for 2018 and compared with the CAC international standard for the same year. Taking 2008 as the reference year, we summarized the changes in MRLs across the three aspects of food category, pesticide category, and pesticide functions.

2.3.1.1 Food category

The number of food categories in China’s MRLs has increased steadily over time. The number of food classifications has increased from less than 60 in 2008 to 219 in 2018, narrowing the gap to the CAC standard (307 in the same period). The food category names in China also tend to be in line with the CAC, with some revision of food category names especially in the “National Standard for Food Safety - Maximum Residue Limits of Pesticides in Food (GB 2763-2012)”. For example, “unprocessed grain” was changed to “cereal grains”, “cabbage vegetables” to “brassica vegetables”, and “small fruits” to “berries and other small fruits”.

The number of new food categories included in the standards also continues to rise. For instance, nuts, edible fungi, seasonings, and beverages were added in (GB 2763-2012). (GB 2763-2014) added fruit juices, dried fruit, and medicinal plants, and dried vegetables were added by (GB 2763-2016). Food classification has also been refined to reflect Chinese culture. For example, the addition of medicinal plants as a primary classification reflects the fact that medicinal plants are widely used in traditional Chinese medicine. Beans are classified as cereals and vegetables in China. In contrast, they are classified as leguminous vegetables in CAC, because beans are a staple food in China, and account for a considerable proportion of food consumption there.

2.3.1.2 Pesticide category

MRLs in China were not revised regularly, and the highest average annual increase of 64 pesticide categories was between 2014 and 2018. By contrast, the CAC standard is revised every year, with an average of 6.4 new pesticide categories added each time. In 2013, there was considerable development of China's MRLs, and the largest increase (171 pesticides, 126%) occurred in this period. Since then, the growth rate has begun to decline. The number of pesticides in China's MRLs exceeded the CAC list in 2013, and the gap has continued to widen. By 2018, there were 187 more pesticide categories in China's MRLs than in the CAC standards. There were 185 shared pesticide categories, 80% of the CAC pesticides, and 232 pesticide categories unique to China, or 56% of China's pesticide categories. This shows that China's MRLs first followed the CAC standards for pesticide categories, but then supplemented this information to provide standards suitable for national conditions. China's standards show significant "localization" characteristics while maintaining the "internationalization" direction (Table 2.1).

Table 2.1 Number of pesticide categories in Chinese and CAC standards

Categories	**2008**	**2013**	**2014**	**2018**
China	136	307 (34.2)	371 (64)	417 (11.5)
CAC	166	194 (5.6)	201 (7)	230 (7.25)
Both	83	122 (7.8)	164 (42)	185 (5.25)
Unique to China	53	185 (26.4)	207 (22)	232 (6.25)
Unique to CAC	83	72 (−2.2)	37 (−35)	45 (2)

Note: The number in brackets is the average annual increase of pesticide categories compared with the previous observation year.

2.3.1.3 Pesticide functions

The functional composition of pesticides has also changed over time, reflecting national conditions. Like the CAC standard, the pesticides in China's MRLs are divided into four main categories by function: herbicides, acaricides, fungicides, and insecticides, which together cover nearly 95% of the total pesticides. Table 2.2 shows that the increase in pesticide items in China was mainly from three categories: herbicides, fungicides, and insecticides. These all exceed the numbers in the CAC standard and show steady growth. There are slightly fewer acaricide items in the Chinese standard than in the CAC standards, and the gap is the smallest for this category. There are more herbicide items in China than the CAC standards, mainly because herbicides are used more than other categories. Since the early 2000s, China has become one of the world's most important producers and exporters of herbicides. The continuing decline in herbicide prices has encouraged farmers to use more chemical herbicides (Huang et al., 2017). The differences also show that the agriculture sector in China faces constraints from rising labor costs because of the massive loss of agricultural population. Crop field management is developing to become labor-saving, and herbicides are frequently applied as an alternative to traditional manual weeding.

Table 2.2 Number of pesticides by function in Chinese and CAC standards

Category	both China and CAC				Unique to China				Unique to CAC			
	2008	**2013**	**2014**	**2018**	**2008**	**2013**	**2014**	**2018**	**2008**	**2013**	**2014**	**2018**
Herbicide	5	7	12	21	20	83	90	99	7	9	7	9
Acaricide	10	13	14	14	0	5	7	7	10	8	8	9
Fungicide	20	34	58	57	7	43	49	60	29	26	4	8
Insecticide	45	62	73	78	24	51	53	53	26	22	12	14
Other	3	6	7	15	2	3	8	13	11	7	6	5

2.3.2 Stringency indices of MRLs

2.3.2.1 Definition of stringency indices

We used the protectionism indices proposed by Li et al. to measure the stringency of China's MRLs standards relative to CAC international standards, and explore comparative trends (Li & Beghin, 2014). These indices have the properties of invariance to scale and regulation, convexity in protectionism, monotonicity in MRL stringency, and boundedness. The index is also relatively objective. The calculation formula is:

$$S_{qt} = \frac{1}{N}\sum_{k=1}^{N} exp\left(\frac{MRLs_{CAC,kqt} - MRLs_{CHN,kqt}}{MRLs_{CAC,kqt}}\right) \tag{2.1}$$

$MRLs_{CAC,kqt}$, and $MRLs_{CHN,kqt}$ are the MRLs of pesticide k in product q in either the CAC or Chinese standards in year t. Stringency indices are $S_{qt} \in [0, e \approx 2.72]$. When the index $S_{qt} > 1$, the MRL for product q is more stringent in China than the CAC. A value closer to 2.72 is stricter. When the index $S_{qt} = 1$, the MRL of product q is the same level of stringency in China and the CAC. When the index $S_{qt} < 1$, the MRL of product q is looser in China than the CAC standard. A value closer to 0 is looser.

Equation (2.1) means that the MRLs databases for China and the CAC can be used to calculate the stringency indices of each food. No direct comparison can be made for pesticides that are only regulated by the CAC, or by China. To maintain the integrity and comparability of the results, we therefore drew on previous methods to deal with this problem. If there were no data for a particular food in the Chinese MRLs standard database in year t, we selected other MRLs in the database that were closest to that food in the year t as an alternative. Previous studies have suggested that the appropriate MRL value should be the maximum MRL of the main classification group to which the food belongs. For pesticide items unique to China, this method can therefore be used to fill the gaps in the MRL database of CAC (Hejazi et al., 2016; Seok et al., 2018; Shingal et al., 2021).

2.3.2.2 Stringency indices for food categories

The stringency indices of the four major food categories (cereal grains, oil, vegetables, and fruit) all indicated a consistent trend from 2008 to 2018 (see Table 2.3). Since 2014, the categories of food with a stringency index of $S_{qt} > 1$ have been increasing year on year, and categories with an index $S_{qt} < 1$ have continued to decrease, indicating that China's MRLs standards are becoming more stringent than CAC international standards. In 2018, 52% of oils had an index of $S_{qt} > 1$, as did more than 80% of foods in the remaining three categories. It is worth noting that grains and oilseeds are land-intensive products, and China has lost its comparative advantage in these products. In contrast, vegetables and fruit are labor-intensive products, and China still maintains a specific comparative advantage. This demonstrates that the overall stringency of China's MRLs has increased.

Table 2.3 Distribution of stringency indices in the four categories of food

Year	**Cereal grains**		**Oil**		**Vegetables**			**Fruit**	
	S_{qt}<1	S_{qt}>1	S_{qt}<1	S_{qt}>1	S_{qt}<1	S_{qt}=1	S_{qt}>1	S_{qt}<1	S_{qt}>1
2008	14 (63.6%)	8 (36.4%)	13 (72.2%)	5 (27.8%)	34 (68.0%)	2 (4.0%)	14 (28.0%)	28 (87.5%)	4 (12.5%)
2013	12 (46.2%)	14 (53.8%)	13 (61.9%)	8 (38.1%)	30 (39.5%)	0	46 (60.5%)	17 (37.8%)	28 (62.2%)
2014	5 (17.9%)	23 (82.1%)	10 (45.5%)	12 (54.5%)	11 (13.9%)	0	68 (86.1%)	8 (15.4%)	44 (84.6%)
2018	6 (19.4%)	25 (80.6%)	11 (47.8%)	12 (52.2%)	15 (16.9%)	0	74 (83.1%)	10 (17.5%)	47 (82.5%)

Note: The value in brackets is the percentage of items in each category of stringency indices values for the food classification in that year. Where no values are given for S_{qt} = 0, there were no items in that category.

The stringency indices of the four main food categories all rose sharply in 2014 and then stabilized (see Figure 2.1). However, the stringency of each category of food varied. That for oil was slightly higher than one, but the increase was less than for the other three food categories. This indicates that the overall stringency of oil is lower than that of the other three categories of food. The stringency indices for cereal, vegetables, and fruit are all slightly higher than 1.50 but lower than 1.70, which is far lower than the upper bound of 2.72. The stringency of MRLs in China therefore shows an overall upward trend, but its overall level is not high.

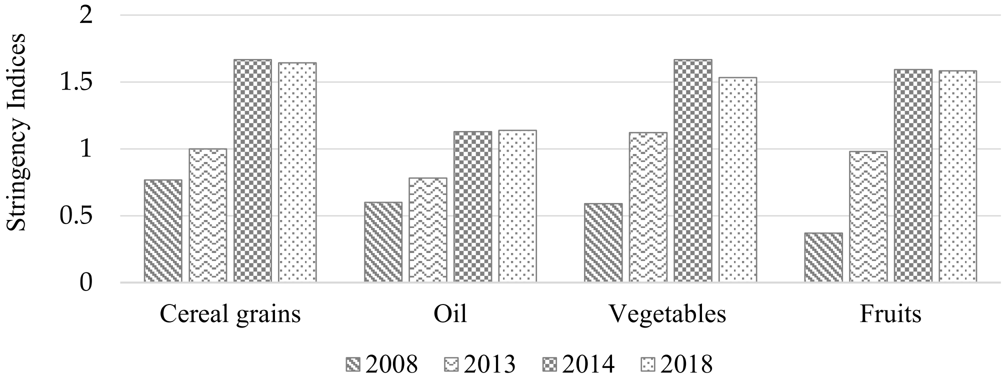

Figure 2.1 Distribution of the stringency indices for selected four products

2.4 Motivation of China's changing MRLs

We wanted to assess whether differences in stringency meant that China is using MRLs as a form of trade protection. The alternatives are that increased per capita income means that the Chinese public has higher requirements for food safety, or that the Chinese government is determined to address food safety issues more strictly. We used regression analysis to assess these issues.

2.4.1 Theoretical analysis

The political economy model for MRLs provides an analytical framework for our empirical analysis (Li et al., 2017). In this model, more stringent MRLs will directly increase the costs of food producers while reducing the social cost of negative externality. The goal of government agencies is to determine the optimal level of MRLs by maximizing social welfare. This consists of the weighted sum of food consumer surplus, food producer profit, and negative externality. We can use the first-order conditions for maximizing the objective function to derive the final impact of import tariffs, comparative advantages, market size, and other factors on MRLs. We also further identified the influencing factors into three categories: trade protectionism, demand upgrade, and crisis response. The next few paragraphs describe each of these in turn.

As the national economy continues to grow, a country's agricultural and food industry will gradually lose its comparative advantage. Food imports will expand, and the income and profits of food producers will therefore decline. The reduction of import tariff leads to a further decrease in food producers' profit compared with consumer surplus, reducing social welfare. However, the political pressure of food producers for protection will lead to an increase in the weight of their profits in social welfare. To maximize social welfare, government agencies may use more stringent non-tariff measures to replace import tariffs. This should alleviate the competition from imported food and improve the profits of domestic food producers. When China joined the WTO, it promised to reduce tariffs. This has gradually happened over time, and China now has a relatively low tariff level. As agriculture sectors continues to open up to the world market, China has become the world's leading net importer of agricultural products, and the deficit continues to increase. Large-scale agricultural imports threaten agricultural employment and farmers' incomes, bringing new challenges to food security and trade disputes (Zhu et al., 2018). China therefore has motivation to use MRLs as a new trade protection tool instead of import tariffs, and we considered three hypotheses.

Hypothesis 1: The gradual loss of food comparative advantage may encourage China to keep strengthening MRLs, resulting in rising stringency indices and the tendency of MRLs to support trade protectionism.

Hypothesis 2: The expansion of food imports may encourage China to keep strengthening MRLs, resulting in rising stringency indices and the tendency of MRLs to support trade protectionism.

Hypothesis 3: The reduction of food import tariffs may encourage China to keep strengthening MRLs, resulting in rising stringency indices and the tendency of MRLs to support trade protectionism.

The second possible motivation is demand upgrade. When the scale of the food market represented by per capita income in a country expands, the absolute scale of consumer surplus and reduced negative externalities will increase. They will therefore make up a greater proportion of social welfare. Government agencies aiming to maximize social welfare will pay more attention to consumers' food safety and thus develop more stringent MRLs. The past four decades have been a period of rapid income growth in China, during which the country has moved from middle-income to upper-middle-income status. The sustained growth of food demand (market size) is accompanied by increased demand from the public for food safety (reduction of negative externalities). We therefore proposed:

Hypothesis 4: With the increase in per capita income, the domestic demand upgrade encourages China to keep strengthening MRLs, resulting in rising stringency indices to meet the higher demand from the domestic public for food safety.

Finally, we considered crisis response as a motivation. The expansion of commercial media will lead to increased coverage of food safety issues and lower the threshold for public access to information (Swinnen, 2018). This effectively increases public interest in food safety and improves knowledge about the issue, which in turn increases public demand for better food safety (reduction of negative externalities). Media reports will create public opinion pressure that reflects the public's food safety demands, which will in turn drive government agencies to formulate more stringent MRLs to elevate the weight of consumer surplus and negative externalities in social welfare. Government agencies may also consider adopting more stringent or even over-stringent standards following the principle of "political precaution", the principle that politicians are forced to act in response to public perceptions, even if the actual risk is very low (Yeung et al., 2017). Food safety incidents have occurred frequently in China over the past two decades, and these have been extensively reported by both the official and commercial media. Chinese government agencies comprehensively strengthened food safety control after a problem with tainted powdered milk in 2008 (Augustin-Jean & Xie, 2016). Public demand for food safety and the pressure of public opinion could therefore force the Chinese government to resolve the food safety crisis and strengthen food safety governance. We therefore hypothesized:

Hypothesis 5: The occurrence of food safety incidents and related media reports may force the Chinese government to improve the stringency of MRLs and strengthen food safety governance, resulting in rising stringency indices.

2.4.2 Regression model

Based on the hypothesis above, the regression model is constructed as:

$$S_{qt} = a_0 + b_1 \ln(PERGDP_t) + \ln(Report_{t-1}) + b_3 \ln(Tariff_{qt} + 1) \\ + b_4 \ln(RCA_{qt}) + b_5 \ln(IMV_{qt}) + \lambda_t + \lambda_q + \varepsilon_{qt} \qquad (2.2)$$

S_{qt} is the stringency index of Chinese product q in year t, derived from the previous calculations. a_0 is a constant term, b_1 to b_5 are regression coefficients, λ_t is the fixed effect of year, λ_q is the fixed effect of product, and ε_{qt} is the random error. $PERGDP_t$ is China's per capita GDP in year t, representing the level of per capita income, which is taken from the World Development Indicators (WDI) database[5]. $Report_{t-1}$ is the number of Chinese media reports on domestic food safety issues in year $t-1$. It expresses the time lag between media attention or reports on food safety incidents and the development of substantial public opinion pressure. Data were taken from Liu et al. (Liu & Ma, 2016), but the website of database has not been updated since 2016[6]. The observations included in the analysis were therefore from 2008 to 2016. $Tariff_{qt}$ is the import tariff rate imposed by China on product q in year t, taken from WTO tariff database[7] and World

[5] Sourced from online database: *World Development Indicators (WDI) database*

[6] Sourced from online database: *Food scandal database of Chinese provinces*

[7] Sourced from online database: *WTO tariff database*

Integrated Trade Solution (WITS)[8] . The tariff data used the simple average tariff rate of the food name corresponding to the HS-6 code, which is mainly based on the WTO tariff database. Missing data were supplemented by applying tariff data from the WITS, and some countries have import tariffs of zero. RCA_{qt} is the comparative advantage index of product q in year t, calculated using the UN Comtrade Database[9]. IMV_{qt} is China's food imports of product q in year t, taken from the UN Comtrade Database. The data for the above variables between 2008 and 2016 constitutes an unbalanced panel dataset. Table 2.4 demonstrates the descriptive statistics for the variables used in the regression analysis.

Table 2.4 Descriptive statistics for regression variables

Variable	Observations	Min.	Max.	Median	Mean	Standard Deviation
$ln(Tariff_{qt}+1)$	1672	0	4.19	2.64	2.51	0.72
$ln(RCA_{qt})$	1723	−16.5	3.07	0.1	−0.8	2.98
$ln(IMV_{qt})$	1532	−6.21	17.51	6.68	6.85	4.38
$ln(Report_{t-1})$	1596	3.81	6.58	5.2	5.44	0.91
$ln(PERGDP_t)$	1824	8.15	8.99	8.69	8.63	0.29

2.4.3 Results and discussion of regression

We used the panel data with fixed effects in Stata15 to estimate, and select robust standard errors. We considered that there might be multicollinearity among import tariffs, food imports, and comparative advantages. We therefore first performed a basic regression excluding the two explanatory variables of revealed comparative advantage index and food imports, and then a complete regression that included these two explanatory variables. The results showed no significant difference between the two, indicating no apparent multicollinearity between the explanatory variables. The regression results were therefore considered robust, and we used the complete regression for further analysis (Table 2.5). Columns (1) to (4) are the individual regression results of the selected products in the four food categories. Because of the high homogeneity of products within the same food category, product fixed effect was not adopted to avoid inconsistent estimates and include more information. Column (5) is the regression results of the mixed products in the four categories, and the products fixed effect of the is added in the

[8] Sourced from online database: *World Integrated Trade Solution (WITS) database*

[9] Sourced from online database: *UN Comtrade Database*

regression.

Table 2.5 Regression results

Explanatory variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
	Cereal Grains	**Oil**	**Vegetables**	**Fruit**	**Mixed**
$ln(Tariff_{qt}+1)$	0.5078	0.1971	−0.2104**	−0.0416	−0.1125
	(0.634)	(0.575)	(0.0813)	(0.102)	(0.0789)
$ln(RCA_{qt})$	0.0609	−0.0150	−0.0969**	0.0018	0.0127
	(0.0392)	(0.0842)	(0.0474)	(0.0275)	(0.0272)
$ln(IMV_{qt})$	−0.1707**	0.0184	0.0001	−0.0586	−0.0227
	(0.0804)	(0.0359)	(0.0175)	(0.0429)	(0.0176)
$ln(Report_{t-1})$	0.3381**	0.1587*	0.2345***	0.2431***	0.2182***
	(0.154)	(0.0831)	(0.0444)	(0.0736)	(0.0332)
$ln(PERGDP_t)$	12.9900**	7.0371**	7.9214***	10.7579***	8.6702***
	(5.894)	(3.247)	(1.267)	(2.843)	(1.131)
_cons	−206.0034**	−112.0096**	−124.7086***	−169.5371***	−136.6386***
	(95.71)	(52.09)	(20.31)	(45.66)	(18.14)
Products Fixed Effect					yes
Time Fixed Effect	Yes	yes	yes	yes	yes
Observations	138	124	398	308	968
R^2	0.448	0.258	0.598	0.633	0.513

Notes: Robust standard error is in parentheses. *, **, *** show significance of 10%, 5%, and 1%.

The regression coefficient of the revealed comparative advantage index (RCA_{qt}) and food imports (IMV_{qt}) were similar, but the coefficients of the RCA_{qt} were not uniform. Except for vegetables, they were also not statistically significant. The coefficient of IMV_{qt} is also not uniform, except for grain, which is also not statistically significant. This means that the improvement in the stringency of China's MRLs is not directly related to the loss of food comparative advantages and the expansion of imports. It also suggests that the fundamental purpose of setting stringent MRLs in China is not to protect the domestic food industry.

Except for cereal grains and oil, the coefficient of tariffs ($Tariff_{qt}$) is negative, and apart from vegetables, not statistically significant. This means that whether we look at the four categories of food as a whole or individually, China's MRLs generally do not show a tendency towards protectionism. This suggests that MRLs have not replaced tariffs as a new trade protection policy tool. As a labor-intensive product, vegetables are the second-largest agricultural product exported by China and have obvious comparative advantages. Chinese government agencies therefore have no motivation to use MRLs as a trade protection tool. However, with the general reduction of import tariffs in WTO member countries and intensified competition in the international market for high-value products such as vegetables, China is actively participating in the formulation of international standards to improve product quality and enhance the international competitiveness of vegetables by strengthening its own MRLs (Augustin-Jean & Xie, 2016).

The coefficient of per capita GDP ($PERGDP_t$) was also positive, in line with expectations. Except for cereal grains, the $PERGDP_t$ coefficients were all statistically significant. This shows that as China's per capita income level increases, and especially as China transitions from being a middle-income country to an upper-middle-income country, the number of food imports have increased. As a result, public awareness of food safety and health has also significantly increased, and they prefer high-quality and safe food, requiring lower MRLs.

The coefficient of the number of media reports on food safety issues ($Report_{t-1}$) was positive and statistically significant. It can therefore reasonably be inferred that the frequent occurrence of food safety incidents and ongoing media reports on food safety issues have aroused public interest and caused the government's focus on food safety. The government is therefore likely to be responding to public demands for improved food safety by issuing ever-more stringent MRLs and strengthening food safety governance (Swinnen, 2018). In China, in response to people's concerns about food safety, the government has specially established the only official food safety media to publicize food safety policies and administrative law enforcement, popularize scientific awareness of food safety, and timely disclose or clarify food safety incidents and their response measures[10].

The regression results do not support Hypotheses 1 to 3 about the motivation of protectionism. Instead, they support Hypothesis 4 about demand upgrade and Hypothesis 5 about crisis response. This means that the primary goal of China's MRLs is to deal with food safety problems, curb food safety incidents and ensure public safety, rather than reducing food imports or protecting the domestic food industry, even though this is gradually losing its comparative advantage. We suggest that the fundamental reason for this is that the policy objectives of the Chinese government focus more on consumers' demand for food safety than food producers' income. This conclusion is consistent with previous studies that used the standard policy preference function to measure the weight of import policy preference of primary agricultural products (Mao et al., 2019). That study found that the priority of import trade policy is consumers, producers, traders, and government, in that order. Import policies focus on the interests of consumers rather than other economic agents, whose welfare may even be reduced. In other words, Chinese government agencies give much more weight to consumer surplus and negative externalities than to the income of food producers when setting MRLs. The stringency of MRLs

[10] Sourced from official website: *China Food Safety Net*, https://www.cfsn.cn/

is not directly related to the sharp decline in import tariffs and comparative advantages or the continuing increase in food imports. However, it appears to be related to the level of per capita income and media coverage of food safety incidents.

2.5 Conclusion and prospect

By collecting and processing the data of previous studies and official updates on China's MRLs standards, we obtained a relatively new and complete database of Chinese MRLs, and used it to analyze the evolution of these standards. The MRLs developed rapidly in China from 2008 to 2019, and the food and pesticide items covered maintained a sustained and rapid expansion. The variety of foods included has increased from less than 60 to 219, and the gap with CAC international standards has narrowed. The types of pesticides increased to 417, exceeding the CAC international standard of 187. The actual number of items has increased from 859 to 8388, an increase of 933%, which is the same as in the CAC international standard. The revision of China’s MRLs has drawn on the CAC international standard, reflecting a growing trend towards internationalization. The adjustment of food and pesticide items unique to China reflects the distinct characteristics of Chinese localization, such as agricultural production, food security requirements, and the change of food consumption structure.

We measured the stringency of the Chinese MRLs compared with the CAC standards using Stringency Indices. The stringency indexes of about 80% of China’s MRLs were greater than one, indicating higher stringency than the CAC standards. However, the high stringency indices do not prove that China is using MRLs as non-tariff measures or for trade protectionism. The regression results indicate that the factors driving the rise in stringency indices are actually public demand for higher food safety and the government’s positive response to food safety incidents. We therefore conclude that China’s MRLs have not become a new trade protection policy tool, and are not being used as an alternative to a tariff. In the long run, the growth in China’s demand for food and the constraints of agricultural resources determine that the trends in food import and MRL development is irreversible.

We cannot ignore the role of media reports in reflecting public food safety demands, increasing public food safety awareness, and promoting the revision of food safety standards. Government agencies should take the initiative to use media channels to guide public participation in the supervision and formulation of food safety standards, so that relevant government departments improve their governance. In the era of rapid information dissemination via the internet, timely and transparent disclosure of food safety incidents, and scientific popularization of food safety knowledge is helpful in avoiding irrational public focus on food safety, which drives politicians to take excessive action as a result of “political precaution”, resulting in unreasonably high food safety standards.

Our study shows that the so-called “protectionism indices” can only measure the relative stringency of MRLs and the CAC standards (Li & Beghin, 2014). We have shown that differences may have other causes. Using these indices as a proxy for protectionism may therefore be misleading. The use of the term “stringency indices” may be more neutral and objective, as well as more accurate. We believe that the impact of MRLs on international food trade requires comprehensive research into its effects on food imports and exports, price, quality, and even social welfare, which will be the focus of our future research.

Chapter 3 Influence of maximum residue limits for pesticides on agricultural food exports: analysis based on a quality heterogeneous firms trade model

3.1 Introduction

With the exponential increase in international food trade of the past few decades, pesticide residues have become widely regarded as an important factor affecting the quality and safety of agricultural products. Maximum residue limits (MRLs) for pesticides are defined as the maximum concentration of legally allowable pesticide residues in or on food commodities and animal feeds (expressed in mg/kg) recommended by the Codex Alimentarius Commission (CAC). Food safety incidents around the world have triggered extensive media reports, exposing long-standing problems, such as excessive pesticides in imported or domestic foods and illegal use of unregistered pesticides. Enhanced public awareness of food safety and public pressure has prompted governments to formulate more extensive and stringent MRL standards for pesticides as mandatory food import standards (Swinnen, 2018). Japan announced the "Japanese Positive List System for Agricultural Chemical Residues in Foods" in 2003 and implemented the system in May 2006. European Union (EU) member states have adopted unified EU MRLs since 2008. In the same year, Canada passed new MRLs. Australia, Hong Kong, and South Korea successively announced new MRLs from 2010 to 2019. Based on the consideration of domestic dietary habits, politics, economy, and other factors, the MRLs of some developed countries and regions deviate from the CAC international standard of the Agreement of Sanitary and Phytosanitary Measures of the World Trade Organization, which has led to a continuous reduction of coordination of MRLs among countries, and related agricultural trade disputes have continued to rise. The international community is concerned about whether MRLs have in effect replaced gradually reduced tariffs promised by countries and become a new form of trade protection policy tool. This issue has triggered a large body of empirical research on the impact of MRLs on trade.

The gravity model is mostly used in empirical studies on international trade. Most research focuses on whether the MRLs of importing countries hinder imports of agri-products. The main difference in the research results lies in the quantification of the core explanatory variable but others include differences in the various countries, agri-products, and time periods. Early scholars used the MRLs of important pesticides in importing countries as the explanatory variable, and later scholars mostly used bilateral heterogeneity (similarity) indexes of MRLs in importing and exporting countries as the explanatory variable, considering that bilateral divergence, and not the MRLs of importing countries only, is the fundamental factor affecting trade. These indexes integrate the number and level of MRL standards and thus, can comprehensively reflect the relative stringency of MRLs in importing and exporting countries.

Although some scholars have found that more stringent MRLs in importing countries inhibit imports (C. L. Chen et al., 2008; Drogué & DeMaria, 2012; Ferro et al., 2015; Fiankor et al., 2021; Hejazi et al., 2016; Winchester et al., 2012), whereas others have found that they do not hinder or even promote trade (Ishaq et al., 2016; Shingal et al., 2021; Xiong & Beghin, 2012; Xiong & Beghin, 2014). In addition, some scholars have found that more stringent MRL standards in exporting countries promote exports (Seok et al., 2018; Shingal et al., 2021), which is attributed to the signaling effect of conveying product quality. Regarding the divergence in empirical studies, scholars have identified dual effects; that is, food safety standards, including MRLs (Shingal et al., 2021; Swinnen, 2018; Xiong & Beghin, 2014), not only increase compliance costs that impede trade, but also promote trade by reducing information asymmetry or negative externalities. The impact of food safety standards on trade depends on the comprehensive effect of these two factors and varies by country or product. Dual effects have been introduced into the empirical trade model to analyze their impact on trade, but there are fewer theoretical analyses amid the rich empirical literature.

Chen et al. analyzed the comprehensive influence of dual effects on export probability, export market quantity, and export product category margin in a perfect competition model (M. X. Chen et al., 2008). Xiong and Beghin used the monopoly competition model to analyze and verify the existence of demand-enhancing and trade-cost effects (dual effect) but did not consider their comprehensive influence (Xiong & Beghin, 2014). These two studies did not properly account for the large number of zero-trade values in trade data at the industrial and product levels, which can be addressed by introducing firm heterogeneity and analyzing the intra-industry adjustment caused by food safety standards. Medin used the heterogeneous firms trade (HFT) model to analyze the impact of food safety standards on the number of export firms, average exports of firms, and total industrial exports (Medin, 2019). However, a limitation of their study is the function setting of the variable cost and fixed cost, which means that the dual effect can be divided only in two independent ways: demand and variable cost, and demand and fixed cost. The comprehensive influence of the three factors cannot be considered.

Existing empirical studies mainly focus on the impact of MRLs in developed countries on trade rather than on the relativity of standards between importers and exporters. Outdated time and limited samples do not reflect the rapid development of food safety standards in developing countries in a timely manner. Considering that exports of agri-food products account for a large proportion of the trade share of developing countries, food safety standards will have a profound impact on the industry and trade of agri-food products, which would have a social and systematic influence on the development of rural areas, agriculture, and farmers. As a developing country, China was the world’s second largest importer and fourth largest exporter of agricultural products in 2020. From 2010 to 2021, China updated the national mandatory MRLs standard, the "National Standard for Food Safety—Maximum Residue Limits of Pesticides in Food," five times. The MRLs items specified in the standard increased from 873 in 2008 to 10092 in 2021, nearly double that of the CAC in 2020. The number of agri-food products increased from 88 to 377, including 119 agri-food products unique to China. The items of pesticides increased from 138 to 564, and standards for all registered pesticides are expected to follow. The standard also stipulates MRLs for 87 pesticides that are not prohibited but have not been approved for use in China[11]. After more than a decade of development, the principles, methods, and data requirements of dietary risk assessment of pesticide residues adopted in China's MRLs have gradually aligned with those of the CAC and developed countries. The EU is recognized as having the most stringent MRL standards; its MRLs are regarded as an important obstacle to exports of agri-food products. Studying the impact of MRL differences between China and the EU on exports of agri-products would help enrich understanding of food safety on trade effects and provide rich implications.

The quality heterogeneous firms trade (QHFT) model is based on the HFT model proposed by Melitz (Melitz, 2003). Some scholars have considered that the difference between enterprises lies not only in productivity, but also in quality; therefore, the influence of quality on the export decisions of enterprises should be considered (Baldwin & Harrigan, 2011). This study contributes to both theoretical and empirical analyses on the topic of MRLs for pesticides. For the theoretical analysis, we construct a concise QHFT model. We extend the trade effect of MRLs from two factors (demand and cost) to three factors (demand, variable cost, and fixed cost). Based on this model, a reasonable gravity model that can effectively treat zero-trade values is obtained. For the empirical analysis, heterogeneity indexes are used to measure and compare the stringency of MRLs between China and the EU. A relatively complete industry-level database of agri-food products in China and the EU is used to analyze the comprehensive effects of MRL standards on trade. To compensate for the data deficiency in previous studies, we expand the analysis of time, products, and pesticides. This study finds that the current MRL standards of the EU are still much more stringent than those of China, but the gap is narrowing, and some MRLs in China even exceed those in the EU. The EU's more stringent MRLs have not curbed food exports from China to the EU, and for cases in which China's MRLs are more stringent, there is a signal effect (quality upgrade), which plays a strong demand-enhancing role in promoting China's food exports to the EU.

Section 3.2 of this thesis is the theoretical model of QHFT, Section 3.3 is the empirical model, Section 3.4 is the data source, focusing on the explanation of the heterogeneity indices, and

[11] Sourced from official report: *Analysis of the National Standard for Food Safety - Maximum Residue Limits of Pesticides in Food (2021 Edition)*

Section 3.5 is the methods and results of estimation. Section 3.6 is the conclusion and future research.

3.2 Theoretical model

The Chaney model is a simplified Melitz model that is widely used in trade-margin analysis (Chaney, 2008). It assumes that the number of exporting companies is given exogenously and omits the free-entry condition in the Melitz model, thereby focusing on the analysis of the export behavior of a company and its zero-profit condition (ZPC). This study sets up a concise QHFT model by introducing the dual effects of MRLs on trade into the Chaney model. The difference in MRLs between importers and exporters affects consumers' preferences, variable cost, and fixed cost. We find that the overall impact of MRLs on agri-food trade depends on the three factors mentioned above. The model can be further divided into two cases, in which the MRLs of the importer or exporter are more stringent. Stricter MRLs in the importing country are more complicated, and the following derivation is mainly based on this case, which can be easily extended to the more stringent case of MRLs in the exporting country.

3.2.1 Stricter MRLs in importer

3.2.1.1 Import demand

We assume that there are N importers. The consumers in each importer j have a constant elasticity of substitution (CES) utility function,

$$U=\left\{\int_{0}^{\Omega}\theta(v)^{\beta}q(v)^{\frac{\epsilon-1}{\epsilon}}\,dv\right\}^{\frac{\epsilon}{\epsilon-1}} \tag{3.1}$$

where Ω represents the available varieties of agri-food products in importer j; q and θ denote the quantity and quality of agri-food product v consumed, respectively; ϵ is the substitution elasticity between agri-food products with horizontal differentiation; and $\epsilon>1$. Vertical differentiation also exists between the same agri-food products, which have a different quality θ. Assuming that the importer has formulated the mandatory MRL standard θ_j, all product v in the importer market must meet this standard. Hence, the MRL standard θ_j determines the quality θ of agri-products in the importer market. Consumers can perceive this quality difference and react accordingly, and firms are not motivated to exceed the standard because of additional costs. Specifically, when the MRL standards of the importing country are more stringent, the exporting firms must comply with the more stringent MRLs to produce, which convinces consumers in the importing country that the quality of imported agri-products has improved compared with that produced according to the MRLs of the exporting country (Fiankor et al., 2021). More stringent MRLs enhance consumers' preferences for the quality of imported agri-products and increase their consumption demand, which is the demand-enhancing effect of MRLs. $\beta > 0$ indicates consumers' perception and acceptance of the quality represented by MRLs by the importer.

We assume that the total expenditure on agri-food products of consumers in importer j is given by $E_j = \int_0^{\Omega} p(v)q(v)\,dv$. Consumers maximize the utility function subject to total expenditure. Then, the equilibrium demand for the agri-food product v produced by country i is given by

$$q_{ij} = \theta_j^{\beta\epsilon} p_{ij}^{-\epsilon} P_j^{\epsilon-1} E_j \tag{3.2}$$

Where p_{ij} is the price of agri-food product v from exporter i to importer j. $P_j = [\int_0^{\Omega} p(v)^{1-\varepsilon}\,dv]^{\frac{1}{1-\epsilon}}$ is defined as the price index of all agri-food products v in importer j.

3.2.1.2 Export supply

Assume that an exogenous variable n_i denotes the number of producers of agri-products v in exporting country i. Production technology increases returns to scale. Labor is the only factor of production and it moves freely among the differentiated sectors. The wage rate can be set equal to one. The cost function for an enterprise to produce and export agri-food products v is

$$C_i(v) = \frac{\tau_{ij}\theta_j^{\alpha}}{\varphi} q_{ij} + f_{ij} \tag{3.3}$$

where φ is productivity, which obeys the Pareto distribution on [1, +∞) with the parameter γ, and γ is positively correlated with the mean and variance of enterprise productivity. We assume that the lower bound of productivity is φ_{min}, and the density function is $g(\varphi) = \gamma\varphi_{min}^{\gamma}\varphi^{-\gamma-1}$. If the lower bound of productivity is normalized to unity, the density function is simplified to $g(\varphi) = \gamma\varphi^{-\gamma-1}$. $\frac{\tau_{ij}\theta_j^{\alpha}}{\varphi} q_{ij}$ is the variable cost, $f_{ij} = \frac{\theta_j^{\eta}}{\eta} D_{ij}$ is the fixed cost, where τ_{ij} is the ad valorem (variable) trade cost from exporter i to importer j, that is, the "iceberg cost," including tariffs. D_{ij} is the trade cost resulting from the differences in distance, language, religion, and so on between importers and exporters. θ_j^{α} is the additional input of production factors generated by satisfying the quality standard of country j, and $\frac{\theta_j^{\eta}}{\eta}$ represents the incremental fixed costs incurred by exporters to operate in country j of stricter MRL standards, such as new technologies applied or labor training, assuming that both are specific to the quality level θ embodied in the standard. Specifically, when the importing country's MRLs are more stringent, the exporter must fully comply with the importer's stricter MRLs. This incurs additional compliance costs θ_j^{α} and $\frac{\theta_j^{\eta}}{\eta}$ over production complying with the MRLs of the exporting country; these are the variable and fixed trade-cost effects of MRLs, respectively. $\alpha > 0$ and $\eta > 0$ indicate the impact of the MRLs of the importing country on variable cost and fixed cost, respectively.

$$\pi_i = \left(p_{ij} - \frac{\tau_{ij}\theta_j^{\alpha}}{\varphi}\right) q_{ij} - f_{ij} \tag{3.4}$$

The firm chooses a price to maximize its profit. The first-order condition is

$$\frac{\partial \pi}{\partial p_{ij}} = q_{ij} - \frac{\tau_{ij}\theta_j^{\alpha}}{\varphi}\frac{\partial q_{ij}}{\partial p_{ij}} = 0 \Rightarrow p_{ij} = \frac{\epsilon}{\epsilon - 1}\frac{\tau_{ij}\theta_j^{\alpha}}{\varphi} \tag{3.5}$$

It can be seen from (3.5) that the price of agri-food products v is set equal to the mark-up over the marginal cost. p_{ij} depends on the firm's productivity and the impact of the importing country's MRLs on the variable costs. According to (3.2) and (3.5), the exports of each firm can be given by:

$$p_{ij}q_{ij} = \theta_j^{\beta\epsilon} p_{ij}^{1-\epsilon} P_j^{\epsilon-1} E_j = (\tfrac{\epsilon}{\epsilon-1})^{1-\epsilon} (\tfrac{\tau_{ij}}{\varphi})^{1-\epsilon} \theta_j^{\beta\epsilon - \alpha(\epsilon-1)} P_j^{\epsilon-1} E_j \tag{3.6}$$

It can be seen from (3.6) that the impact of MRLs on the firm's exports depends on whether $\beta\epsilon - \alpha(\epsilon - 1) > 0$ or $\beta\epsilon - \alpha(\epsilon - 1) < 0$, In other words, whether the demand-enhancing effect or the variable trade-cost effect dominates. Assuming that the elasticity of substitution ϵ is constant, if α is large enough, the variable trade-cost effect dominates, and the firm's exports decrease with stricter MRLs. On the contrary, if β is sufficiently large, the demand-enhancing effect dominates and the firm's exports increase. Moreover, firms productivity φ is positively related to the firm's exports.

3.2.1.3 Total exports of agri-food products

By setting the firms' ZPC in (3.4) and using (3.2), (3.3), and (3.5), we can obtain the cut-off productivity for exporting (*cpe*) that the firms of country *i* need to achieve when exporting to country *j*:

$$\underline{\varphi} = (\frac{\eta}{\epsilon-1})^{\frac{1}{1-\epsilon}}(\frac{\epsilon}{\epsilon-1})^{\frac{\epsilon}{\epsilon-1}}\theta_j^{\frac{[\eta+\alpha(\epsilon-1)]-\beta\epsilon}{\epsilon-1}}\tau_{ij}D_{ij}^{\frac{1}{\epsilon-1}}P_j^{-1}E_j^{\frac{1}{1-\epsilon}} \tag{3.7}$$

From (3.7), we know that *cpe* increases with ad valorem (variable) trade costs, such as import tariffs, and fixed trade costs, such as languages, and decreases with the income of importer j. The impact of MRLs on *cpe* is uncertain, depending on whether $[\eta+\alpha(\epsilon-1)]-\beta\epsilon>0$ or $[\eta+\alpha(\epsilon-1)]-\beta\epsilon<0$, that is, whether the demand-enhancing or trade-cost effects dominate. Assuming that the substitution elasticity ϵ is constant, if α and η are sufficiently large relative to β, the trade-cost effect dominates, and *cpe* increases with the MRLs. This means that the threshold of exports increases with the MRLs, some export firms exit, and the number of export firms decreases. Conversely, if β is sufficiently large, the demand-enhancing effect dominates and *cpe* decreases with the MRLs. The threshold for exports decreases with the MRLs, some non-exporting firms enter, and the number of export firms increases. The MRLs lead to adjustments within the firms by affecting the entry or exit choices of the firms, which is the fundamental difference between the QHFT and the monopoly competition model.

Integrating (3.6), that is, adding up the exports of all export firms, the total exports of agri-food products v exported by exporter i to importer j can be obtained as

$$EXP_{vij} = \int_{\underline{\varphi}}^{\infty} n_j p_{ij} q_{ij} g(\varphi) d\varphi =$$

$$\frac{\gamma}{\gamma-\epsilon+1}(\frac{\eta}{\epsilon-1})^{\frac{\epsilon-\gamma-1}{1-\epsilon}}(\frac{\epsilon}{\epsilon-1})^{\frac{\epsilon-\epsilon\gamma-1}{\epsilon-1}} n_j\theta_j^{\frac{\beta\epsilon-[\alpha(\epsilon-1)+\eta(\gamma-\epsilon+1)]}{\epsilon-1}}\tau_{ij}^{-\gamma}D_{ij}^{-\frac{\gamma-\epsilon-1}{\epsilon-1}}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}} \tag{3.8}$$

According to (3.8), the elasticity of the total exports of agri-food products v with respect to the MRLs is given by

$$\frac{\partial EXP_{vij}}{\partial\theta_j}\frac{\theta_j}{EXP_{vij}} = \beta\epsilon-[\alpha(\epsilon-1)+\eta(\gamma-\epsilon+1)] \tag{3.9}$$

For formulas (3.7) and (3.8) to be valid, it is generally assumed $\epsilon>1$ and $\gamma-\epsilon+1>0$. Comparing (3.6) and (3.8), and reminding (3.7), the meaning of (3.9) is clear. The importer's MRLs affect the exports of each firm, as well as the behavior of entering or exiting the export, which will result in an increase or decrease in the export firms, eventually affecting the total exports of agri-products v.

Specifically, due to the presence of fixed costs, exporting firms with a productivity lower than *cpe* will exit; thus, the number of export firms decreases. If $\beta\epsilon-\alpha(\epsilon-1)<0$, both the number of exporting firms and the exports of remaining firms reduce, resulting in total exports drop of the entire industry. If $\beta\epsilon - \alpha(\epsilon - 1) > 0$, the exports of each existing export firm increase, but when $\beta\epsilon - \alpha(\epsilon - 1) < \eta(\gamma - \epsilon + 1)$, which means the demand-enhancing effect is larger than the variable trade-cost effect but smaller than the fixed trade-cost effect. Accordingly, the decreased exports generated by exiting firms are greater than the increased exports of the remaining high-productivity firms, comprehensively showing a decline in the total exports of the industry. Conversely, when $\beta\epsilon - \alpha(\epsilon - 1) > \eta(\gamma - \epsilon + 1)$, that is, the demand-enhancing effect is larger than the sum of the variable trade-cost effect and the fixed trade-cost effect. The decreased exports resulting from exiting firms are smaller than the increase in the remaining firms, which leads to an increase in total exports.

3.2.2 Stricter MRLs in exporter

When exporters' MRLs are more stringent, exporting firms comply with the public quality standards θ_i given by native country i for production. Consumers believe that the quality of agri-products produced according to MRL standards in the exporting country is higher than that in importing countries, thus generating higher consumption demand. Similar to the first-order condition of maximizing consumer utility, the demand of consumers in importing country j for agri-food products v is given as follows:

$$q_{ij} = \theta_i^{\beta\epsilon} p_{ij}^{-\epsilon} P_j^{\epsilon-1} E_j \tag{3.10}$$

However, when the exporter's MRLs are more stringent, there is no additional compliance cost for export firms of country i in trading with country j, namely, no trade-cost effect. The cost function of export firms is simplified as

$$C_i(v) = \frac{\tau_{ij}}{\varphi} q_{ij} + D_{ij} \tag{3.11}$$

According to the first-order condition of profit maximization, the following equations are obtained:

$$p_{ij} = \frac{\epsilon}{\epsilon - 1} \frac{\tau_{ij}}{\varphi} \tag{3.12}$$

$$p_{ij} q_{ij} = \left(\frac{\epsilon}{\epsilon-1}\right)^{1-\epsilon} \left(\frac{\tau_{ij}}{\varphi}\right)^{1-\epsilon} \theta_i^{\beta\epsilon} P_j^{\epsilon-1} E_j \tag{3.13}$$

Let the profit of firm be 0 and the cut-off productivity that all firms in country *i* must achieve when exports to country *j* are given by

$$\underline{\varphi}=(\frac{\eta}{\epsilon-1})^{\frac{1}{1-\epsilon}}(\frac{\epsilon}{\epsilon-1})^{\frac{\epsilon}{\epsilon-1}}\theta_i^{\frac{-\beta\epsilon}{\epsilon-1}}\tau_{ij}D_{ij}^{\frac{1}{\epsilon-1}}P_j^{-1}E_j^{\frac{1}{1-\epsilon}} \tag{3.14}$$

The total exports of agri-food product v from country i to country j were obtained by integration.

$$EXP_{vij}=\frac{\gamma}{\gamma-\epsilon+1}(\frac{\eta}{\epsilon-1})^{\frac{\epsilon-\gamma-1}{1-\epsilon}}(\frac{\epsilon}{\epsilon-1})^{\frac{\epsilon-\epsilon\gamma-1}{\epsilon-1}}n_j\theta_i^{\frac{\beta\epsilon}{\epsilon-1}}\tau_{ij}^{-\gamma}D_{ij}^{-\frac{\gamma-\epsilon-1}{\epsilon-1}}P_j^{\gamma}E_j^{\frac{\gamma}{\epsilon-1}} \tag{3.15}$$

By comparing the above equations, the difference between the two cases with more stringent MRLs for the importer or exporter lies in the presence of the trade-cost effect. Exporting firms do not incur additional compliance costs by complying with stricter domestic MRLs, and stricter MRLs of exporting countries signal improved product quality to consumers in importing countries.

3.2.3 Hypothesis

The MRLs of importers and exporters directly affect the total exports of agri-products by quality θ, and indirectly affect exports by the demand-enhancing effect (β), variable trade-cost effect (α), and fixed trade-cost effect (η). The changes in β, α, and η can be attributed to the public's awareness of safety standards and government investment, such as improving quarantine capacity.

Hence, we propose the following testable hypothesis.

If the MRLs between importing and exporting countries have a demand-enhancing effect, a variable trade-cost effect, and a fixed trade-cost effect, then:

(1) when MRLs are more stringent in an importing country, their impact on total exports of agri-food products is uncertain, depending on the combined effects of the above three (total exports increase only when the demand-enhancing effect is greater than the sum of the variable and fixed trade-cost effects); and

(2) when MRLs are more stringent in an exporting country, there is only a demand-enhancing effect, which promotes exports of agri-food products.

3.3 Empirical model

Take the logarithm of equation (3.8) and (3.15) to derive the gravity equations：

$$lnEXP_{vij}=\phi_0+\phi_1+\phi_2+\frac{\beta\epsilon-[\alpha(\epsilon-1)+\eta(\gamma-\epsilon+1)]}{\epsilon-1}\ln\theta_j-\gamma\ln\tau_{ij}-\frac{\gamma-\epsilon-1}{\epsilon-1}lnD_{ij}+\frac{\gamma}{\epsilon-1}lnE_j \tag{3.16}$$

$$lnEXP_{vij} = \phi_0 + \phi_1 + \phi_2 + \frac{\beta\epsilon}{\epsilon-1}\ln\theta_i - \gamma\ln\tau_{ij} - \frac{\gamma-\epsilon-1}{\epsilon-1}lnD_{ij} + \frac{\gamma}{\epsilon-1}lnE_j \qquad (3.17)$$

where $\phi_0 = \ln\frac{\gamma}{\gamma-\epsilon+1} + \frac{\epsilon-\gamma-1}{1-\epsilon}\ln\frac{\eta}{\epsilon-1} + \frac{\epsilon-\epsilon\gamma-1}{\epsilon-1}\ln\frac{\epsilon}{\epsilon-1}$ is a constant term. $\phi_1 = \gamma lnP_j$ is the price index of agri-food products, which is controlled by the fixed effect for the importer in our study. $\phi_2 = lnn_j$ is the number of firms in the exporter country, which is replaced by the gross agri-food output of China based on data availability[12]. $\frac{\gamma}{\epsilon-1}lnE_j = \frac{\gamma}{\epsilon-1}lnGDP_{jt}$ is the total expenditure of agri-food products, depending on the GDP of the importer. $\gamma\ln\tau_{ij} = \gamma\ln(1 + Tariff_{vijt})$ is the ad valorem (variable) trade cost, including import tariffs. $\frac{\gamma-\epsilon-1}{\epsilon-1}lnD_{ij} = \frac{\gamma-\epsilon-1}{\epsilon-1}\delta lnDIST_{ij}$ denotes the fixed trade cost, including the transportation cost represented by the distance between the importer and exporter[13]. As more than 70% of EU agri-product trade is intra-EU, this study also considers the impact of the supply capacity of agri-products among EU member states on external imports. As panel data are used for the estimation, the gravity model is given by

$$lnEXP_{vijt} = \beta_0 + \beta_1\theta_{ij} + \beta_2 lnGDP_{jt} + \beta_3 lnPRO_{vit} + \beta_4 lnPRO_{vjt}$$

$$+\beta_5 lnDIST_{ij} + \beta_6\ln(1 + Tariff_{vijt}) + \kappa_{vt} + \mu_{jt} + \varepsilon_{ijt} \qquad (3.18)$$

where EXP_{vijt} represents exports of China's agri-product *v* to EU member states in year *t*. To avoid the bias caused by the single use of importers' MRLs in previous studies, this study adopts the relative stringency θ_{ij} of MRLs in importer and exporter countries, which can be measured by the heterogeneity indexes. GDP_{jt} is the GDP of EU member states. PRO_{vit} is the total production of China's agri-products *v* in year *t*, PRO_{vjt} is the total production of EU agri-products in year *t*[14]. $DIST_{ij}$ is the geographical distance between China and EU members, and is multiplied by the West Texas Intermediate oil price in the regression to reflect the yearly impact of geographical

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[12] It is generally assumed that the number of exporting firms is directly proportional to the income or labor of the exporter, but in the case of incomplete data of the gross value of agricultural output and labor, the gross yield of agricultural production related to the above two is used instead.

[13] Since the exporter is China and the importer is the EU members, this study does not include the fixed trade cost terms, such as common boundary, common language, and common religion, in the general gravity model.

[14] The varieties of agri-products included in this study are not produced in every EU member state, and thus, some production data are missing. The total production of EU member states is used to represent their supply capacity, which reflects the reality of intra-EU trade and retains as many observations as possible.

distance[15]. $Tariff_{vijt}$ is the average tariff rate of customs duties charged by the EU on China's agri-products v in year t. β_0 is a constant. β_1–β_6 are parameters to be estimated. κ_{vt} is the fixed effect of product-year. μ_{jt} is the fixed effect of EU member states-year[16]. ε_{ijt} is the error term and is normally distributed.

3.4 Data sources

3.4.1 Dependent variable

The dependent variable is China's food exports to EU members, derived from the EU Eurostat database[17]. This study selects 67 representative agri-food products, which are identified by the HS6 Codes (Harmonized System). These products belong to the eight plant-based categories in the HS2 code: vegetables (HS07), fruits (HS08), tea and spices (HS09), cereals (HS10), flour (HS11), oil seeds (HS12), vegetable oil (HS15), and fruit juices (HS20). The exporting country i is China, and the importing country j is the 28 EU member states. The study period is from 2008 to 2020. Thus, the sample consists of panel data of 13 (year) × 28 (country) × 67 (product)[18].

3.4.2 Explanatory variable

To investigate the influence of the relative stringency θ_{ij} of MRLs between China and the EU on China's food exports, this study draws on the heterogeneity indexes proposed by Shingal et al. (Shingal et al., 2021). They averaged the sum of the stringency indexes of each pesticide by the total number of pesticides and made the heterogeneity indexes a stable characteristic invariant to the regulation intensity. Using a simple average method can avoid simply assigning higher values to certain products, which are usually specified by different types of pesticides.

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[15] Sourced from online database: *West Texas Intermediate (WTI) crude oil prices*

[16] By introducing product-year fixed effect and importer-year fixed effect to control factors of product-time and importer-time respectively, the endogeneity caused by omitted variables can be addressed.

[17] Sourced from online database: *EU Eurostat database*

[18] For ensuring the continuity and reducing the outliers, the observations used meet the following conditions simultaneously: (1) the gross food output data of 28 EU member states for more than 10 consecutive years from 2008 to 2020 can be obtained; (2) the gross food output data of China for more than 10 consecutive years from 2008 to 2020 can be obtained; and (3) the data of food import tariffs levied by the EU on China for more than 10 consecutive years from 2008 to 2020 can be obtained.

3.4.2.1 Heterogeneity indices

First define two indices for relative stringency of MRLs:

$$f_{vkt} = \begin{cases} \frac{MRL_{CHNvkt} - MRL_{EUvkt}}{MRL_{CHNvkt} + MRL_{EUvkt}} & \text{if } MRL_{CHNvkt} > MRL_{EUvkt} \\ 0 & otherwise \end{cases} \tag{3.19}$$

$$m_{vkt} = \begin{cases} \frac{abs(MRL_{CHNvkt} - MRL_{EUvkt})}{MRL_{CHNvkt} + MRL_{EUvkt}} & \text{if } MRL_{CHNvkt} \leq MRL_{EUvkt} \\ 0 & otherwise \end{cases} \tag{3.20}$$

where MRL_{CHNvkt} is the MRL of product *v* and pesticide *k* in China in year *t*. MRL_{EUvkt} is the MRL of product *v* and pesticide *k* in the EU in year *t*. f_{vkt} (m_{vkt}) indicates that for agri-food products *v*, the MRL standard of the EU (China) for pesticide *k* is more stringent than that of China (EU).

Then f_{vkt} and m_{vkt} are respectively simple average to obtain the corresponding heterogeneity indices of product *v*:

$$F_{vt} = \frac{1}{K}\sum_{k=1}^{K} f_{vkt} \tag{3.21}$$

$$M_{vt} = \frac{1}{K}\sum_{k=1}^{K} m_{vkt} \tag{3.22}$$

where *K* is the total type of pesticide specified for product *v* in the MRLs, that is, the number of MRL items of product v. The range of F_{vkt} (M_{vkt}) is [0, 1]. The closer the value is to 1, the more stringent the EU (China) MRL regulation for agri-food products *v*.

3.4.2.2 Description of MRLs data

For China's MRL data, this study collects 10 versions of "National food safety standard—Maximum residue limits for pesticides in food" implemented in China from 2005 to 2020[19]. Each new version clearly specifies updates to the old standard. The prescribed items in the above 10 documents are sorted according to products-pesticides-years. Then, a database of China's MRL standards from 2008 to 2020 is established. The database of EU MRL standards comes from the EU Pesticides Database[20].

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[19] Sourced from online database: *National food safety standard-Maximum residue limits for pesticides in food*

[20] Sourced from online database: *EU Eurostat database for pesticide*

Due to the differences in item names and food classifications between MRLs of China and the EU, this study unifies the diverse names of products and pesticides, and reclassifies the foods according to the abovementioned eight categories of the HS2 code. As shown in Table 3.1, the categories of pesticides jointly regulated by China and the EU are increasing. Although the total number of pesticides regulated by the EU is greater than that of China, the number of pesticides exclusively regulated by the EU is gradually decreasing, whereas that of China is increasing rapidly.

Table 3.1 The number of prescribed pesticides of MRLs in China and EU

Year	China	EU	China and EU	China only	EU only
2008	138	442	104	34	338
2011	161	453	122	39	331
2012	219	458	160	59	298
2013	323	465	219	104	246
2015	387	480	263	124	217
2017	433	504	286	147	218
2019	434	518	288	146	230
2020	483	521	315	168	206

Note: All the years in the table are the implementation years of the new standard except 2008.

The MRL standards of China and the EU have specified some pesticide items separately, resulting in missing MRL data for these pesticides. The EU clearly stipulates that the default value of MRLs for pesticides not specified in its MRLs is 0.01 mg/kg, while China does not specify the default value of MRLs. This study draws on relevant studies and adopts the maximum score in China's MRLs of that year to supplement the default, which represents low stringency for pesticide residues (Hejazi et al., 2016; Seok et al., 2018; Shingal et al., 2021).

3.4.2.3 Variation of heterogeneity indices

We use (3.19), (3.20), (3.21), and (3.22) to calculate the heterogeneity indexes of each agri-food product in our data set. Then, we simply average the heterogeneity indexes contained in a category of agri-food products to obtain the heterogeneity indexes of the category. The variation in the heterogeneity indexes of the eight categories over time is shown in Figure 1. The left (right) axis represents the value of F_{vt} (M_{vt}).

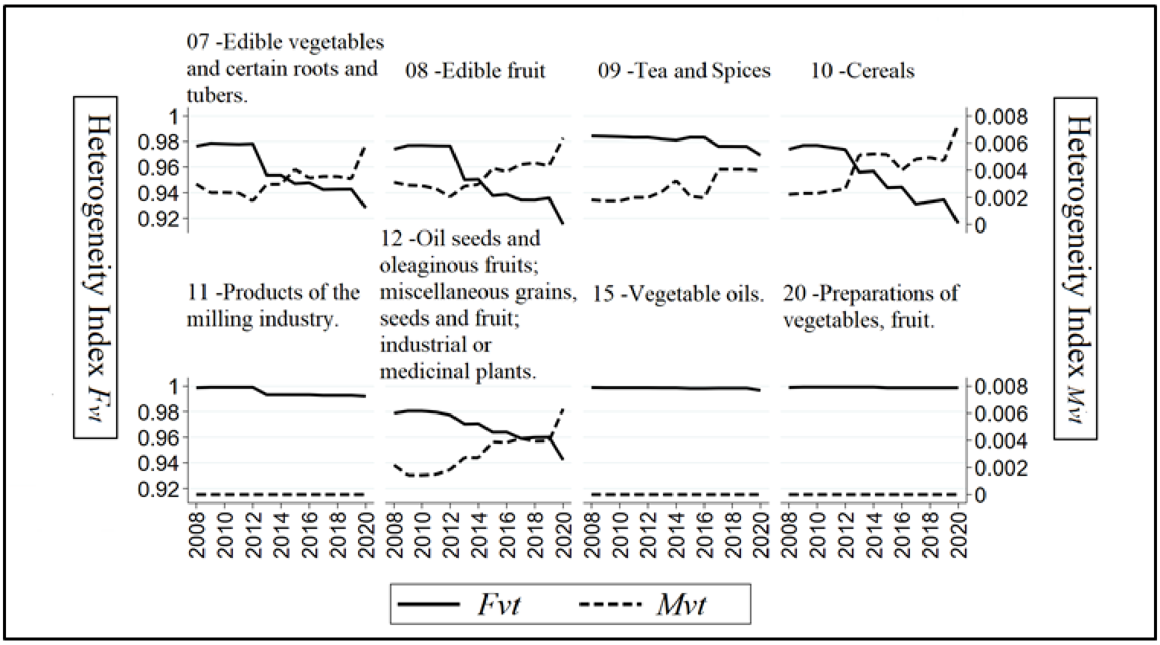

Figure 3.1 Variation of F_{vt} and M_{vt} values with years

F_{vt} exceeds 0.91, and M_{vt} is less than 0. 008.The value of F_{vt} is much higher than that of M_{vt}, indicating that the MRLs of the EU are much more stringent than those of China in general; however, the gap is gradually narrowing. There are no significant changes in vegetable oils (HS15) and fruit juices (HS20). By contrast, the F_{vt} of vegetables (HS07), fruits (HS08), cereals (HS10), and oil seeds (HS12) all show a notable decrease, while the decline of tea and spices (HS09) and flour (HS11) is relatively gentle, maintained above 0.97. The change in M_{vt} is basically opposite to that in F_{vt}, showing an obvious upward trend, but the increase is much smaller. This result demonstrates that the stringency of some MRL items in China has gradually exceeded that of the EU and has maintained an increasing trend.

3.4.3 Data description

For the 67 agri-food products selected in this study, there is a data shortage (N/A) of agri-product output and import tariffs with regard to the EU. The data used in the estimation consist of four sets of panel data. The first set comprises unbalanced panel data, including all control variables. It comprises 43 agri-products from 2008 to 2020 and 13 agri-products from 2008 to 2017. The observations are 19292 (13 years × 28 countries × 43 products + 10 years × 28 countries × 13 products), with an observed value of zero of 16359 exports from China to EU members, giving a zero frequency of 84.8%. The second set also comprises unbalanced panel data, but the controlled variables do not include the import tariff rate of the EU. This data set comprises 52 agri-products from 2008 to 2020 and 15 agri-products from 2008 to 2017. The sample observations are 23128 (13 years × 28 countries × 52 products + 10 years × 28 countries × 15 products), with an observed value of zero of 19584 exports from China to EU members. The frequency of zeros is 84.68%. The third data set consists of balanced panel data. The controlled variables do not contain the output of EU agricultural food products. The sample observations are 20384 (13 years × 28 countries × 56 products), with an observed value of zero of 17148 exports from China to EU members, giving a zero frequency of 84.12%. The fourth data set comprises balanced panel data from 2008 to 2017, including all control variables. The sample observations are 15680 (10 years × 28 countries × 56 products), with an observed value of zero of 13185 exports from China to EU member states, giving a zero frequency of 84.09%.

Table 3.2 Statistical characteristics of variables

	Unit	Obs.	Mean	St.Dev	Min.	Max.
$lnEXP_{vit}$	Euro	24,388	1.6478	3.9889	0	17.7165
$F_{vt\text{-}all}$		24,388	96.4183	3.0980	83.5722	99.9334
$M_{vt\text{-}all}$		24,388	2.9353	2.9650	0	18.0746
$F_{vt\text{-}both}$		24,388	94.0488	5.6493	68.5654	99.9678
$M_{vt\text{-}both}$		24,388	5.5462	6.5487	0	39.5489
$lnGDP_{jt}$	Euro	24,388	25.8883	1.5524	22.5488	28.8761
$lnPRO_{it}$	Tonne	24,388	15.0022	2.7512	7.8047	19.3958
$lnPRO_{jt}$	Tonne	23,128	13.9707	2.8222	4.0431	18.8983
$lnDIST_{ij}$	km.	24,388	12.8121	0.6115	11.0277	13.7866
$ln(1+Tariff_{vit})$	%	20,384	1.3764	1.0567	0	3.2581

The statistical characteristics of all the variables are shown in Table 3.2. $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ are the heterogeneity indexes calculated from the MRLs of all relevant pesticides in China and the EU, respectively. $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$ are the heterogeneity indexes calculated for pesticide MRLs jointly prescribed by China and the EU. To avoid bias in the Poisson pseudo maximum likelihood (PPML) estimation results due to the large numerical difference between variables, this study expands the heterogeneity indexes *F* by 100 times and *M* by 1000 times. Some tariff data are not recorded and, therefore, there are fewer observations, but the missing data have little significant impact on the regression results.

The GDP of EU member states derived from the EU Eurostat database[21]. The food production data of China and EU are from the Food and Agriculture Organization (FAO) of the

[21] Sourced from online database: *EU Eurostat database*

United Nations[22]. Bilateral distance data comes from CEPII[23]. EU import tariffs are derived from the World integrated Trade Solutions[24].

3.5 Methods and results of estimation

3.5.1 Estimation method

Zeros are heavily present in export data on agri-food products of China to the EU. The frequency of zeros exceeds 80%, which leads to biased estimates and therefore, needs to be effectively treated. Silva and Tenreyro pointed out that the PPML estimator can effectively solve heteroscedasticity and zeros, and is relatively robust to various forms of heteroscedasticity and measurement errors (Silva & Tenreyro, 2006). Assuming that the conditional variance is proportional to the conditional mean (not necessarily equal), the PPML estimator is optimal; the PPML estimation results are consistent even when the two are not proportional. Silva and Tenreyro further pointed out that PPML is still a well-behaved estimator, even if the frequency of zeros is large (Santos Silva & Tenreyro, 2011). Thus, PPML is an appropriate estimator of the gravity equation. The estimation in this study adopts PPML with fixed effects and cluster-robust standard errors for importing countries (28 EU member states), which can properly treat overdispersion.

3.5.2 Estimation result analysis

The baseline estimate uses the first set of panel data, including all controlled variables. The estimation results are shown in column (1) of Table 3.3. Because the exports of agri-food products (dependent variable) take a logarithmic value, while the heterogeneity indexes (explanatory variable) do not, the regression coefficient of the heterogeneity indexes is semi-elastic. The regression coefficients of the other logarithmic control variables are elastic.

The coefficient of $F_{vt\text{-}all}$ is positive and statistically significant. This indicates that although there is still a certain gap between China's MRL standards and those of the EU in terms of stringency, with the upgrading of China's MRs standards, the demand-enhancing effect is higher than the variable and fixed trade-cost effect. Therefore, when EU MRLs are more stringent, they do not restrain China's agri-food product exports to the EU; on the contrary, they play a role in

[22] Sourced from online database: *FAOSTAT database*

[23] Sourced from online database: *CEPII database*

[24] Sourced from online database: *World Integrated Trade Solution (WITS) database*

promoting trade. When the stringency indexes of the EU MRLs exceed those of China by 1%, exports of agri-products from China to the EU increase by 37.3%. In the case in which the MRL gap is narrowing year by year, the influence of EU MRL standards on China's agri-food product exports continues to weaken.

Table 3.3 Results of PPML estimation - unbalanced panel

	(1)	**(2)**	**(3)**	**(4)**
$F_{vt\text{-}all}$	0.3730***	0.3896***		
	(7.5865)	(11.7035)		
$M_{vt\text{-}all}$	0.1612***	0.1571***		
	(4.6324)	(6.7490)		
$F_{vt\text{-}both}$			0.1839***	0.1993***
			(7.3495)	(11.9979)
$M_{vt\text{-}both}$			0.0703***	0.0703***
			(4.4171)	(6.4334)
$lnGDP_{jt}$	0.3130***	0.3434***	0.3131***	0.3434***
	(5.8501)	(6.4406)	(5.8727)	(6.4107)
$lnPRO_{it}$	0.2257***	0.2392***	0.2327***	0.2436***
	(14.9480)	(15.1427)	(14.9936)	(16.1930)
$lnPRO_{jt}$	-0.1286***	-0.1687***	-0.1343***	-0.1692***
	(-8.3734)	(-8.1642)	(-8.0400)	(-8.0439)
$lnDIST_{ij}$	-0.4584	-0.8509***	-0.4731	-0.8594***
	(-1.4550)	(-3.8512)	(-1.6070)	(-4.1946)
$ln(1+Tariff_{vit})$	-0.8694***		-0.8819***	
	(-16.1476)		(-16.4023)	
Constants	-39.6979***	-37.5995***	-20.6895***	-18.5832***
	(-5.9066)	(-8.7411)	(-4.7552)	(-6.8171)
Product-Year FE	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes
Observations	15402	18611	15402	18611
R^2	0.4900	0.4216	0.4841	0.4167

Note: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, Within the brackets are the cluster-robust standard error of the importers. Due to the applying of fixed effect, some observations were dropped out in the estimation process of PPML.

The coefficient of $M_{vt\text{-}all}$ is also positive and statistically significant. More stringent Chinese MRL standards have enhanced EU consumers' cognition and preference for the quality of Chinese agri-food and play a role in signaling product quality, which reflects a significant demand-enhancing effect and effectively promotes exports of Chinese agri-food products. For every 1% increase of the stringency of China's MRL standards compared to those of the EU, there is an increase of 16.12% in China's exports of agri-products to the EU. Thus, increasingly stringent MRLs in China further promote exports of agri-food products from China to the EU. By comparing the coefficients of $M_{vt\text{-}all}$ and $F_{vt\text{-}all}$, export promotion of agri-food produced by following China's stricter MRL standards is more effective than that of following the EU. This also means that actively raising China's MRL standards would generate an even more significant promotion effect on its exports than following only the strict MRLs of the EU.

The regression results are in accordance with the expectations of hypotheses (1) and (2) based on the QHFT model. Stricter MRL standards, whether formulated by the EU or China, promote China's exports to the EU. The difference between our results and those of previous studies lies in the coefficient of $F_{vt\text{-}all}$, which indicates that more stringent MRLs in the EU do not hinder exports of agri-products from China. This result is similar to that reported by Shingal et al. (Shingal et al., 2021). When the MRLs of importing countries (EU) are more stringent, using only the MRLs of importers as the explanatory variable leads to the traditional conclusion that MRLs act as trade barriers to exporting countries (in our case, China). However, as analyzed in this study, if the demand-enhancing effect exceeds the trade-cost effect of MRLs, it can be concluded that MRLs promote trade. The application of heterogeneity indexes compensates for the deficiency of using only the MRLs of the importer, and the PPML with fixed effects can effectively solve the endogeneity problem.

The coefficients of other controlled variables are consistent with expectations and statistically significant, indicating that the EU's demand for high-quality agri-products is the "pull" factor of imports, and the production capacity of Chinese agri-products is the "push" factor for China's exports to the EU. Geographical distance and tariffs still have no negligible trade costs for China's agri-product trade.

In addition, the public investment and services of the exporting country can help enterprises reduce the compliance cost of MRLs, thereby reducing the trade-cost effect and synthetically promoting product exports. For example, Chinese government agencies have increased investment in export quarantine facilities and capabilities, strengthened the collection and sorting of EU MRLs and quarantine early warning, established national and provincial demonstration zones for the quality and safety of exported agri-food products, and helped enterprises learn and adapt to the MRLs of developed countries, such as those of the EU[25]. This is in line with

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[25] Sourced from government document: *Opinions on improving the quality and safety risk early warning and rapid response supervision system*

continuous improvements in food safety in China in the past decade. As Yuan and Chen pointed out, the notification of food imported from China by the Rapid Alert System for Food and Feed of the EU has decreased year by year in terms of quantity and proportion of the total notification (Yuan & Chen, 2019). Among these notifications to China, pesticide residue notifications, which ranked second in the food safety crisis, demonstrated a significant decline annually. The impact of MRLs on China's agri-product trade has presented new characteristics with the rapid development of MRLs.

3.5.3 Robustness check

3.5.3.1 Dealing with MRL default values

To investigate whether the treatment of MRL default values would affect the regression results, we select the pesticide items jointly stipulated by China and the EU to calculate another set of heterogeneity indexes. $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$ are heterogeneity indexes that include only the pesticide items jointly specified in the MRLs of China and the EU. $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ are heterogeneity indexes that include all regulated pesticides in China and the EU. In Tables 3, 4, 5, and 6, the regression coefficients of $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ are larger than those of $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$, while the coefficients of the other variables change little, which shows that the treatment of MRL default values does not affect the basic conclusions of this study.

The gap in the regression coefficients between $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ is greater than that between $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$, which is due to the introduction of the default values of the MRLs. For pesticide items regulated only by the EU, China does not specify the corresponding default value of the MRLs. This study uses the maximum of China's MRLs in that year as the default value. Although the stringency of the MRL levels is higher, it is still lower than that of the EU and has a moderate impact on the heterogeneity indexes. This is because the default value of the MRLs regulated by the EU is 0.01 mg/kg, which is much more stringent than that of China. For pesticide items regulated only by China, the corresponding heterogeneity indexes also show that the EU is more stringent. When all pesticides are included in $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$, the pesticide item K in agri-product v increases, $F_{vt\text{-}all}$ increases, and $M_{vt\text{-}all}$ drops, with the gap between $F_{vt\text{-}all}$ and $M_{vt\text{-}all}$ being obviously wider than that between $F_{vt\text{-}both}$ and $M_{vt\text{-}both}$, leading to a larger gap in the regression coefficients.

3.5.3.2 Test of multicollinearity

Li et al. considered that MRLs are replacing import tariffs as a new trade protection measure (Li et al., 2017). We examined the multicollinearity between MRLs and import tariffs and their impact on the estimation results. The Pearson correlation test demonstrates a significant negative correlation between import tariffs and F_{vt}. We use the second set of panel data excluding the EU's import tariff rate for the estimation, as shown in columns (2) and (4) in Table 3.3. Compared with columns (1), (2), (3), and (4) in Table 3.3, the regression coefficient of the heterogeneity indexes changes slightly, but the sign and significance does not change, indicating no serious multicollinearity problem. Some scholars have pointed out that MRLs tend to protect the safety and health of domestic food consumers (Yeung et al., 2017). Even if they show some trade distortion, they cannot be classified as a non-tariff measure deliberately designed to replace import tariffs.

3.5.3.3 Sample observations

To investigate whether the unbalanced panel data used in the basic estimation affect the regression results, the third and fourth sets of balanced panels are used for the estimation. As mentioned earlier, the two balanced panels differ in the studied years and the controlled variable of EU agri-product output. The results are shown in Table 3.4. The coefficients and statistical significance of $F_{vt\text{-}all}$, $M_{vt\text{-}all}$, $F_{vt\text{-}both}$, and $M_{vt\text{-}both}$ demonstrate little difference to the results in Table 3.3, except for a slight change in geographical distance ($lnDIST_{ij}$).

3.5.3.4 Check for overdispersion

There are many methods for dealing with overdispersion and inflated zero-trade values. Considering heteroscedasticity and the panel data used, this study applies negative binomial regression for panel data to test whether the inflated zero-trade values and overdispersion affect the estimation results. First, NBREG in STATA 15 is used for the regression (Table 3.5), where the coefficient of overdispersion (lnα) shows the existence of overdispersion. Then, XTNBREG with random effects and fixed effects are used for the regression. Both the likelihood ratio test and Hausman test indicate that random effects should be adopted. The estimation results for XTNBREG with random effects are shown in Table 3.6.

In Table 3.6, the absolute regression coefficient of geographical distance decreases obviously, while the absolute value of the regression coefficient of heterogeneity indexes and other controlled variables increases obviously, but the expected sign and significance do not change. Thus, the problem of overdispersion does not affect the basic conclusion of this study.

Table 3.4 Results of PPML estimation - balanced panel

	2008-2020		**2008-2017**	
	(1)	**(2)**	**(3)**	**(4)**
$F_{vt\text{-}all}$	0.3726***		0.3379***	
	(8.8249)		(8.1539)	
$M_{vt\text{-}all}$	0.1176***		0.1829***	
	(4.1675)		(6.5210)	
$F_{vt\text{-}both}$		0.1733***		0.1583***
		(8.1343)		(7.6078)
$M_{vt\text{-}both}$		0.0342**		0.0850***
		(2.6880)		(6.5411)
$lnGDP_{jt}$	0.3240***	0.3266***	0.3171***	0.3188***
	(6.1571)	(6.2244)	(5.7464)	(5.7853)
$lnPRO_{it}$	0.1871***	0.1935***	0.2186***	0.2213***
	(17.8760)	(17.2541)	(15.4015)	(15.6604)
$lnPRO_{jt}$			-0.1312***	-0.1423***
			(-9.1400)	(-9.1857)
$lnDIST_{ij}$	-0.8410**	-0.9365***	-0.5964	-0.6644
	(-3.2453)	(-3.8836)	(-1.4173)	(-1.6308)
$ln(1+Tariff_{vit})$	-0.8527***	-0.8489***	-0.8469***	-0.8528***
	(-14.9737)	(-15.8284)	(-16.0151)	(-16.3236)
Constants	-36.1183***	-15.2468***	-34.5547***	-15.7320**
	(-6.5908)	(-4.4273)	(-5.0079)	(-3.1314)
Product-Year FE	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes
Observations	16427	16427	12663	12663
R^2	0.4848	0.4796	0.4818	0.4767

Note: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, Within the brackets are the cluster-robust standard error of the importers. Due to the applying of fixed effect, some observations were dropped out in the estimation process of PPML.

Table 3.5 NBREG estimation results

	(1)	(2)	(3)	(4)
$F_{vt\text{-}all}$	0.4730***	0.5731***		
	(5.6895)	(8.2620)		
$M_{vt\text{-}all}$	0.1396*	0.2337***		
	(2.0907)	(5.2044)		
$F_{vt\text{-}both}$			0.2505***	0.3062***
			(5.7383)	(8.9340)
$M_{vt\text{-}both}$			0.0771*	0.1170***
			(2.4891)	(5.3649)
$lnGDP_{jt}$	0.5233***	0.4076***	0.5247***	0.4080***
	(4.8066)	(5.8707)	(4.7006)	(5.8251)
$lnPRO_{it}$	0.2985***	0.3008***	0.3078***	0.3184***
	(10.2722)	(13.7125)	(9.9983)	(13.4004)
$lnPRO_{jt}$	-0.1436***	-0.1319***	-0.1494***	-0.1392***
	(-7.6286)	(-7.7364)	(-7.6332)	(-8.1524)
$lnDIST_{ij}$	-1.1555*	-1.8908***	-1.2857**	-2.1745***
	(-2.5346)	(-4.4807)	(-2.8449)	(-4.7047)
$ln(1+Tariff_{vit})$	-1.1845***		-1.2069***	
	(-10.2796)		(-10.3541)	
Constants	-46.5644***	-45.5906***	-22.8450***	-15.5590**
	(-4.3326)	(-5.3408)	(-3.3419)	(-2.7409)
lnalpha	1.8366***	1.9846***	1.8433***	1.9902***
	(17.6481)	(15.9288)	(17.6638)	(15.8824)
Product-Year FE	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes
Observations	19292	23128	19292	23128

Note: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, Within the brackets are the cluster-robust standard error of the importers.

Table 3.6 XTNBREG-RE estimation results

	(1)	(2)	(3)	(4)
$F_{vt\text{-}all}$	0.4442***	0.4333***		
	(9.6908)	(11.1146)		
$M_{vt\text{-}all}$	0.2968***	0.2267***		
	(7.7109)	(6.9709)		
$F_{vt\text{-}both}$			0.1473***	0.1993***
			(5.4731)	(8.9817)
$M_{vt\text{-}both}$			0.0627**	0.0745***
			(3.1300)	(4.7185)
$lnGDP_{jt}$	0.4363***	0.4077***	0.4175***	0.3981***
	(11.7636)	(11.1494)	(10.9320)	(10.6829)
$lnPRO_{it}$	0.2559***	0.2220***	0.2484***	0.2148***
	(13.0587)	(11.3290)	(12.2977)	(10.9160)
$lnPRO_{jt}$	-0.2679***	-0.3230***	-0.2550***	-0.3139***
	(-15.5163)	(-18.2159)	(-13.5811)	(-16.6255)
$lnDIST_{ij}$	-0.1622	-0.5548+	-0.4712	-0.6894*
	(-0.5097)	(-1.9408)	(-1.4525)	(-2.3904)
$ln(1+Tariff_{vit})$	-1.1662***		-1.1554***	
	(-21.6815)		(-21.2635)	
Constants	-54.1792***	-47.0990***	-20.1606***	-21.7856***
	(-8.5336)	(-8.5246)	(-3.9828)	(-4.9844)
ln_r	-0.4289***	-0.4940***	-0.4501***	-0.5017***
	(-7.8178)	(-10.4495)	(-8.2899)	(-10.6458)
ln_s	-0.3380**	-0.4420***	-0.4008***	-0.4607***
	(-3.1333)	(-4.8849)	(-3.7766)	(-5.1161)
Product-Year FE	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes
Observations	19292	23128	19292	23128

Note: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, Within the brackets are the cluster-robust standard error of the importers.

3.6 Conclusion and future research

Growing public concern about food safety has caused governments to actively formulate their own food safety standards, and the impact of these different but mandatory safety standards on trade has been widely discussed. Previous empirical studies have mainly focused on the impact of MRLs in developed countries on trade rather than on the relativity of standards between importers and exporters. Outdated time and limited samples do not reflect the rapid development of food safety standards in developing countries in a timely manner. This study attempts to reveal the comprehensive impact of MRLs on agricultural food industry trade based on theoretical and empirical analyses.

This study constructs a QHFT model to explain the influence of MRLs on exports and derives an appropriate empirical model. The basic logic is that, on one hand, when the MRLs in an importing country are more stringent than those in an exporting country, firms in the exporting country must comply with the stricter MRLs of the importing country. Goods produced according to the MRLs of importing countries can enhance product quality compared with the relatively loose MRLs of exporting countries. Consumers in importing countries with quality preference perceive the improvement in product quality, which increases consumer demand. However, the relative improvement in quality requires input, resulting in additional costs for firms (products). On the other hand, when the MRLs in an exporting country are more stringent than those in an importing country, the products produced in the exporting country make a high-quality impression on consumers, and the firms do not input additional trade costs in this case. The comprehensive impact of MRLs on trade should be determined by three effects: demand-enhancing, variable trade-cost, and fixed trade-cost effects.

We employ a relatively new and complete MRL database for China and the EU from 2008 to 2020 for the empirical analysis. The heterogeneity indexes integrate the quantity and level of standards to measure the relative stringency of MRLs between China and the EU. The PPML fixed-effect model is used to treat heteroscedasticity, inflated zero-trade values, and endogeneity in the trade data. Finally, the robustness of some key influencing factors is tested. We find that more stringent EU MRLs do not curb food exports from China to the EU. A more plausible explanation is that the stricter MRLs signal to consumers that the quality of products has improved, thereby generating a demand-enhancing effect that can boost the consumption demand of importing countries. The demand-enhancing effect plays a leading role in promoting agri-food exports from China to the EU. Meanwhile, the EU MRLs are still more stringent than those of China in general, but the gap continues to narrow, and the stringency of certain MRLs for pesticides in China exceeds that of the EU. The rapid upgrading of China's food safety standards can dynamically adjust the domestic agricultural industry to a high quality and efficiency. China's efforts to adopt more stringent domestic MRL standards has boosted exports over and above passively complying with EU MRLs.

The results illustrate that MRL standards are not intentionally designed as non-tariff measures, and their impact on trade depends on the combined effect of demand and cost. MRLs as a food safety standard and their impact on trade also show phased characteristics with development. For example, as China's economy has grown and production capacity for agri-products increased, public attention has shifted from food security to a healthy diet. The impact of stricter MRLs in developed countries and regions on China's exports has shifted from being a barrier to trade between high-income countries and a low-income country to one of mutual promotion between high-income countries. Owing to the significant differences in productivity and quality of enterprises, an in-depth understanding of the impact of MRLs on quality improvement, imports and exports, and other micro behaviors of agri-food enterprises would help to comprehensively and accurately evaluate the impact of MRL standards on trade and welfare. The QHFT model proposed in this study provides an analytical basis. Customs and enterprise data could be used to conduct empirical research of various trade margins, which is a direction for further research.

Chapter 4 Influence of the exporter's food safety standards on trade duration: An empirical study of agricultural food products from China

4.1 Introduction

Despite long-standing debate, mainstream discourse continues to suggest that free trade in agricultural and food products can strengthen global food security and sustainable development; typically, the rationale is that such free trade will enable people living in poverty to live healthier lives and thus have access to higher return on non-agricultural activities. In developing countries, where agriculture accounts for a relatively large share of the economy, the potential benefits of agricultural trade liberalization will be greater. In 2020, during the COVID-19 pandemic, agricultural growth in developing countries was dynamic and significantly helped to stabilize the world's food trade (notably, during this same period, exports declined in developed countries)[26].

The SPS[27] Agreement guarantees trading countries sovereignty in adopting restrictions on imported animal and plant trade products to protect national health and sustainable development. In addition, to promote international trade, it coordinates the quarantine of animals and plants in international trade and offers guidelines for resolving disputes between nations. To ensure a strong balance between scientific rationality and fair trade, the SPS Agreement encourages nations to adopt the principles, guidelines, and recommended technical standards developed by the CAC[28], including MRLs[29] for pesticides. However, the CAC standards are not mandatory. In practice, participating countries have formulated different mandatory technical standards, including MRL standards, based on their complex national conditions. Owing to the heterogeneity

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[26] Sourced from FAO report: *FAO's Food Outlook: Developing countries buoy global food trade*

[27] The Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) is a multilateral trade agreement under the jurisdiction of the World Trade Organization (WTO).

[28] The Codex Alimentarius Commission (CAC) is an intergovernmental organization established by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) in 1963 to coordinate intergovernmental food standards and establish an international food standards system.

[29] The maximum residue limit for pesticides (MRL) is the maximum concentration of a pesticide residue (expressed as mg/kg) the CAC recommends nations should legally permit in or on food commodities and animal feeds. MRLs are based on GAP data. Foods derived from commodities that comply with the respective MRLs are viewed as toxicologically acceptable.

of standards and the popular trend of annually reducing international trade tariffs, sanitary and quarantine measures based on these standards are often considered non-tariff measures with strong concealment.

Existing research on how MRL standards may affect trade mainly focuses on the impact of improved food safety standards in developed countries; notably, these studies are relatively old and mostly focus on how developed countries' MRL standards impact their imports (Curzi et al., 2018; Fernandes et al., 2019; Kareem et al., 2018; Xiong & Beghin, 2012). Generally, this research suggests that strict MRLs force producers to bear additional production and compliance costs (C. L. Chen et al., 2008; Otsuki, 2001), and that other costs emerge if customs extends delivery times or refuses entry (Xiong & Beghin, 2014). Thus, MRLs are used by importing countries to hinder the import of agri-products and are considered a protectionist measure (Ferro et al., 2015). In contrast, other empirical studies suggest that seemingly strict MRL standards can promote trade because they reduce the risk of information asymmetry and ease consumer concerns, thus signaling quality improvement to exporters and strengthening consumer demand (Ishaq et al., 2016; Li et al., 2017; Seok et al., 2018; Shingal et al., 2021).

Unlike previous studies, which focused on the impact of gross trade, this study focused on the impact of MRL standards on the duration of exports. Previous trade theory assumes that trade relations remain unchanged and continue for a long time after the relationship is established, but this is not the case (Brenton et al., 2010). Export duration plays an important role in improving a country's export volume. If the trade duration is too short, it is difficult to maintain sustained trade growth even if there are many trading partners (Besedes & Blyde, 2010).

Some domestic Chinese scholars have discussed various factors affecting trade duration; however, they primarily explore MRL standards in importing countries and fail to reflect the rapid development of China's MRL standards in recent years. The latest version of China's National Food Safety Standard containing the nation's MRL standards—"Maximum Residue Limits for Pesticides in Food" (GB2763–2021)—was formally implemented on September 3, 2021. This document presents 10092 MRL standards, involving 564 pesticides and 376 foods. Compared to the 2019 version, these standards cover 81 new varieties of pesticides (an increase of 16.7%) and 2985 new MRLs (an increase of 42%)—ultimately, they cover nearly twice the number of pesticide varieties and MRLs as the CAC standards[30]. In 2020, China was the world's second largest importer and fifth largest exporter of agri-products; additionally, it had the world's second highest gross trade value. However, from 2000 to 2020, China's agri-food imports grew faster than its exports. When China joined the WTO in 2004, it quickly shifted from having an

[30] Sourced from official report: *China's pesticide residue limit standard exceeded 10000 items, fully covering the approved pesticide varieties and main plant-derived agricultural products in China*

agricultural trade surplus to an agricultural trade deficit (Han et al., 2021). Therefore, China is a useful sample for an export duration study because it may serve as a good reference for developing countries transitioning from agricultural to non-agricultural economies.

This study contributes to existing literature in the following ways. First, unlike previous studies focusing on the direct impact of food safety standards on gross trade, this study focused on how the implicit factor of upgraded food safety standards impacts the trade duration of agricultural exports. Second, based on empirical data from China, this study explored how enhanced food safety standards, such as MRLs, impact exports in a developing country. Third, this study's sample period extended to 2019, which better reflects the rapid changes in MRL standards in international trade since 2010. This paper is dedicated to further improving current research on how food safety standards impact trade and to offering useful insights on the agricultural upgrading of developing countries and the sustainable development of the global agri-product trade.

The remainder of the paper unfolds as follows. Section 4.2 is literature review, Section 4.3 is the estimation of trade duration, Section 4.4 is the empirical research on the influencing factors of trade duration, and Section 4.5 is the conclusion.

4.2 Literature review

This thesis focuses on the influence of MRLs standards on the duration of agricultural exports. The relevant literature mainly includes the impact of MRLs on agricultural trade and trade duration.

4.2.1 MRLs impact on agricultural trade

Otsuki et al. studied the impact of the EU's aflatoxin standard on Africa's exports using the gravity model (Otsuki, 2001). They found that Africa's exports decreased by 11% for every 10% increase in the EU's standard. Meanwhile, Xiong and Beghin used the same method to study the impact of the EU's aflatoxin standard on African exports and found that the standard had no significant impact on the exports of African countries (Xiong & Beghin, 2012). Recently, scholars have studied trade effects by comparing the heterogeneity of standards in different countries and organizations. Xiong and Beghin found that strict MRL standards in high-income countries increased demand for imports but hindered foreign exports (Xiong & Beghin, 2014). Kareem et al. also pointed out when the EU's MRL standards became more comprehensive than the CAC standards (Kareem et al., 2018), Africa's tomato exports to the EU gradually decreased. Additionally, Curzi et al. measured the standard stringency of the EU and its major trading partners using the CAC standard as a baseline (Curzi et al., 2018). They found that the EU's stringent MRLs hindered the agri-product exports of developing countries but promoted EU member state exports. Last, using firm-level data, Fernandes et al. found that when importers have stringent MRLs, exporters are less likely to enter their markets and existing enterprises are more likely to exit their markets; notably, this effect was stronger for relatively small enterprises (Fernandes et al., 2019).

4.2.2 Study on trade duration

Besede and Prusa introduced a survival analysis method from medical research to trade studies and found that the median trade duration of most imports in the US was only 2–4 years (Besedes & Prusa, 2006). Meanwhile, Nitsch and Hess and Persson compared the trade situations of Germany and the EU and arrived at similar conclusions (W. Hess & M. Persson, 2011; Nitsch, 2009). In a study on agri-products, Peterson et al. examined the phytosanitary measures and the import duration of fruits and vegetables in the US and found that phytosanitary measures had no significant impact on import duration (Peterson et al., 2017). Additionally, Straume studied the export of Norwegian salmon and found that enterprise- and market-level factors affect the stability of export duration (Straume, 2017). Zhang and Tveteras studied the influence of the generalized scheme of preferences (GSP) of the EU on the export of aquatic products from developing countries (Zhang & Tveterås, 2019). They found that this measure prolongs the export duration of aquatic products, but hinders the export of primary aquatic products.

In summary, most studies on food safety standards and agri-food trade have been based on the standards of northern countries (importers). Regarding the effect of MRL standards on trade, scholars mainly discussed the impact of MRLs on trade volumes, and some scholars extended the marginal impact to product quality. However, research on trade duration is limited. In recent years, the economic development of southern countries and the continuous reform of food safety standards have required timely attention. This study examined the drastic changes in China's MRLs and explored how its agri-food exports affect trade duration. Our findings offer insights that may be conducive to further studies into the effect of MRL standards on trade and serve as empirical references for southern countries seeking to catch-up.

4.3 Estimation on trade duration

4.3.1 Data preprocessing

Since 1989, most products in international trade flows have been classified as harmonized systems (HS). Based on the research subject and data availability, 113 product items specified by the HS 6-digit level were selected. These items belong to ten categories of agri-food products identified by the HS 2-digit code, namely: HS02, HS04, HS07, HS08, HS09, HS10, HS11, HS12, HS18, and HS20. In this study, the single exporter *i* is China, and importer *j* includes 155 importing countries participating in bilateral trade. The sample period was 2008–2019. These data constituted a panel dataset of 12 (years) × 155 (countries) × 113 (products).

"Trade duration" refers to the period or "spell" beginning when an exporter in a bilateral trade relationship enters the market and ending when it withdraws for any reason. Existing economic studies on trade duration mainly measure duration based on yearly product trade due to data availability and the ease of this approach. Defects in data censoring and multiple spells in statistical methodologies must be handled properly.

4.3.2 Multiple spells

In this study, a "spell" comprises the continuous years with non-zero trading between importers and exporters in the dataset. Multiple spells may occur in the sample; namely, trade relations restart after being interrupted during the observed period. To control for this phenomenon, Besedes and Prusa (2006a) advice regarding multiple spells as independent segments for analysis or situating the first spell of multiple spells as the observation (Besedes & Prusa, 2006; Molina & Fugazza, 2009). Neither approach qualitatively impacts the estimated results of trade duration. Considering the additional advantage of maximizing the sample size, this study treated multiple spells as independent fragments for analysis.

As shown in Table 4.1, the 4111 trade relations have only one spell, accounting for 37.8% of the total. Of the total trade relations, 51.8% of trade relations can only last for one year, 14.2% for five years or more, and 2.2% for 10 years or more. In terms of trade duration, the sample of only one spell recorded a maximum of 12 years, compared to 10 years for multiple spells. In addition, only 6.6% of the multiple spells had a duration of more than 5 years, compared with 16.2% in only one spell. China's agri-food exports are mainly short-term, and only one spell had a better trade duration performance than multiple spells. This can be explained by the heterogeneity or low substitution elasticity of product types in only one spell or the mutual trust and trade preference of bilateral traders, which results in less trade interruption.

Table 4.1 The number of spells and trade relationships

Duration (years)	Only One Spell		Multiple Spells		Total	
	Number of Spells	Trade Relationships	Number of Spells	Trade Relationships	Number of Spells	Trade Relationships
1	2394	2394 (22.0%)	5458	3247 (29.8%)	7852	5641 (51.8%)
2	518	518 (4.8%)	1810	1546 (14.2%)	2328	2064 (19.0%)
3	266	266 (2.4%)	901	827 (7.6%)	1167	1093 (10.0%)
4	149	149 (1.4%)	404	392 (3.6%)	553	541 (5.0%)
5	123	123 (1.1%)	317	314 (2.9%)	440	437 (4.0%)
6	96	96 (0.9%)	206	206 (1.9%)	302	302 (2.8%)
7	80	80 (0.7%)	121	121 (1.1%)	201	201 (1.8%)
8	167	167 (1.5%)	66	66 (0.6%)	233	233 (2.1%)
9	94	94 (0.9%)	37	37 (0.3%)	131	131 (1.2%)
10	85	85 (0.8%)	18	18 (0.2%)	103	103 (0.9%)
11	85	85 (0.8%)			85	85 (0.8%)
12	54	54 (0.5%)			54	54 (0.5%)
Total	4111	4111 (37.8%)	9338	6774 (62.2%)	13449	10885 (100.0%)

Note: The number in parentheses is the percentage of the trade relations in the total trade relations.

4.3.3 Data censoring

The sample data in this study span from 2008 to 2019; hence, the export status of the product level before 2008 and after 2019 is unknown. When bilateral trade is observed in 2008, the starting time of this trade is not included in the sample, giving rise to the problem of left censoring. In contrast, for the ongoing bilateral trade in 2019, the time of trade termination cannot be observed in the sample, leading to a right-censoring problem. To obtain unbiased parameters of estimation for the left-censoring problem, the left-censored observations were excluded from the data (Besedes & Prusa, 2006; Besedeš & Prusa, 2006). Notably, our sample only contained data on agri-food products that exporter i (China) did not trade in 2007 and only began to export to importer country j in 2008 and later. Thus, the longest duration of agri-product exports in our study was 12 years. Meanwhile, discrete-time hazard models can effectively solve the correct censoring problem (W. Hess & M. Persson, 2011).

4.3.4 Methodology of survival analysis

The survival (hazard) function is used to describe the characteristics of the survival (hazard) rate in the trade survival analysis. As mentioned above, survival analysis can effectively handle right censoring. We introduced a survival function to estimate the distribution of the trade duration for China's agri-food exports.

Let i denote the continuous trade duration (spell) of various trade relationship combinations (China's product=v; importer=j): i=1，2，3,…. Let T be a discrete random variable that denotes the length of spell i, reflecting the duration of the trade combination for China's agri-product, v, exported to importer j. T is taken as t = 1, 2, 3,..., (years) in this study. Therefore, the corresponding survival function is $S_i(t) = Pr(T_i > t)$, implying that the conditional probability of T_i exceeds year t given that the trade has survived to year t. Thus, the Kaplan-Meier estimator of the survivor function is given as:

$$\widehat{S_i}(t) = \prod_{k=1}^{t} \frac{n_k - d_k}{n_k} \tag{4.1}$$

where n_k refers to the number of spells that survived (but were at risk of trade interruption) in year k. Similarly, d_k denotes the number of spell-observed trade termination events in year k.

The hazard function expresses the conditional probability of export ending in year $t + \Delta t$ under the condition that the export of agri-products of China survived in year t.

$$h_i(t) = \Pr(T_i = t | T_i \geq t) = \frac{\mathrm{p}(t)}{S_i(t-1)} \tag{4.2}$$

The nonparametric estimation of the hazard function is as follow:

$$\widehat{h_i}(t) = \frac{d_k}{n_k} \tag{4.3}$$

The survival and hazard functions of the trade duration of the agri-food product exports in China were estimated based on the Kaplan-Meier estimator, as shown in Figure 4.1.

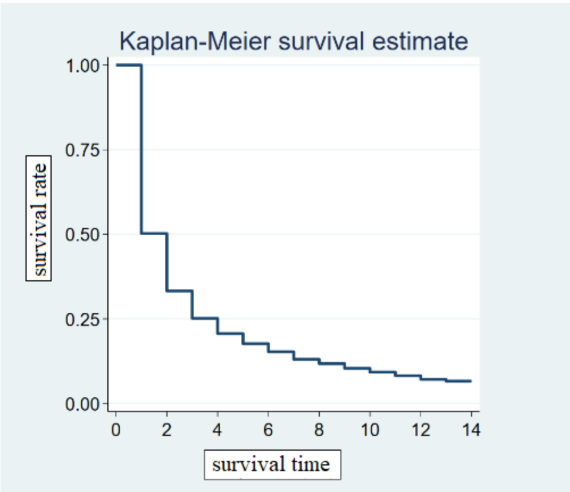

Figure 4.1 Estimation of survival rate

The duration of China's agri-food export is generally short, with an average of 3.58 years. As Shown in Figure 4.1, the survival rate of Chinese export firms dropped sharply in the early stage, and then decreased slowly and flattened. A nonparametric analysis of the survival rate and survival time demonstrated a significant negative duration dependence; this is consistent with the conclusions of most studies (Besedes & Prusa, 2006; W. Hess & M. Persson, 2011; Yang et al., 2021).

The negative duration dependence may be due to heterogeneous data clusters (destination markets, products, or enterprises) (Esteve-PÉRez et al., 2013), the sunk costs of market entry (Brenton et al., 2010), or the learning effect (experience accumulation) (Esteve-Pérez, 2021). Thus, the sustainable development of trade relations may be a determinant rather than a result of extensive margins in trade diversification.

4.4 Influencing factors of trade duration

4.4.1 Estimation model

4.4.1.1 Dependent variable

In the general trade duration model, food safety standards affect trade duration through the hazard/survival rate. Food safety standards partly increase trade costs, resulting in the withdrawal of existing exporters, that is, the interruption of trade relations. Meanwhile, food safety standards can discourage exporters from entering the market (non-exporters), thus strengthening the persistence of existing exporters and prolonging trade duration. Some scholars researching trade have adopted Cox proportional hazards models (Besedeš & Prusa, 2006; Molina & Fugazza, 2009; Nitsch, 2009), while others (Esteve-PÉRez et al., 2013; W. Hess & M. Persson, 2011; Peterson et al., 2017; Wang et al., 2019) have adopted discrete-time hazard models. Notably, the Cox model has the following defects: ① the model is applicable to continuous-time specifications, while observed time on trade duration studied is yearly discrete—"tied" duration times cause asymptotic bias in an estimation; ② it ignores unobserved heterogeneity and causes parameter and estimation biases in the survivor function; and ③ its assumptions of proportional hazards are rather restrictive—incorrectly imposing proportionality causes estimation bias in covariates. Discrete-time hazard models can effectively address the above three defects and can be used to estimate the base hazard in a nonparametric mode similar to the Cox model (Wolfgang Hess & Maria Persson, 2011). Accordingly, this study used a discrete-time hazard model to examine the influence of food safety standards on the export hazard rate of agri-products.

Discrete-time hazard models are used to study export duration because they can effectively estimate the "failure" probability of "spell" i in a specific trade relationship combination in discrete time, namely the discrete-time hazard rate, $h_i(t)$. The functional form of the hazard rate must be set before estimating parameters in the survival analysis model. The hazard rate distribution function in discrete-time hazard models typically follows normal, logistic, and extreme-value minimum distributions, corresponding to the probit, logit, and cloglog (complementary log-log) models, respectively (Sueyoshi, 1995). This study assumed that $h_i(t)$ yields the extreme-value minimum distribution. The cloglog estimator was applied in the benchmark regression. Subsequently, the logit and probit models were selected for robustness tests. The corresponding discrete cloglog model was as follows:

$$\text{Cloglog}[h_i(t,X)] = \log(-\log[1 - h_i(t,X)]) = X'\beta + \gamma_t + u \tag{4.4}$$

where $h_i(t,X)$ denotes the discrete-time hazard rate. The covariate X', which includes the explanatory variables, is the vector that embodies the characteristics of the impact factors. β is the regression coefficient vector to be estimated. γ_t is the baseline hazard, which integrates the time-varying risk faced by the samples; u is the error term normally distributed, which is used to control the individual unobservable heterogeneity affecting trade duration (individual random effect).

To examine the influence of food safety standards on the export duration of China's agri-food product exports, we referred to previous studies and carefully constructed the following basic empirical model:

$$\begin{aligned} fail_{vijt} = \beta_0 + \beta_1 \Delta MRLs_{vijt} + \beta_2 \ln gdp_{jt} + \beta_3 \ln counnum_{ijt} + \beta_4 contig \\ + \beta_5 comlang + \beta_6 \ln pro_{vit} + \beta_7 \ln pro_{vjt} + \beta_8 \ln dist_{ij} \\ + \beta_9 \ln(1 + tariff)_{vijt} + \alpha_t + \alpha_v + \mu_0 \end{aligned} \tag{4.5}$$

where $fail_{vijt}$ is a binary dependent variable that represents the outcome of each trade relationship. $fail_{vijt}$=1 represents a "fail" and the interruption of trade duration; the "fail" does not occur when $fail_{vijt}$=0. $\Delta MRLs_{vijt}$ is the gap in MRL stringency between importers and exporters, GDP_{jt} is the GDP of importer *j* in year *t*, and $counnum_{ijt}$ is the total number of importers for a product in year *t*, indicating market diversification. *contig* is the adjacency between the importer and exporter; *comlang* indicates whether the importer and exporter have a common language; PRO_{vit} is the exporter's total production of product *v* in year *t*; PRO_{vjt} is the importer's total production of product v in year t[31]; $DIST_{ij}$ is the geographical distance between the exporter and importer; $Tariff_{vijt}$ is the average tariff rate levied by the importer on export product v in year t; β_0 is a constant term; and β_1–β_9 are the parameters to be estimated. α_t is the fixed effect of the year, α_v is the fixed effect of the product. The year fixed effect and product fixed effect enable the proper handling of the endogeneity caused by omitted variables. ε_{ijt} is the normally distributed error.

4.4.1.2 Core explanatory variable

The framework of the WTO's SPS Agreement situates CAC food safety standards, including MRLs, as the only international standards jointly recognized by the FAO and the WTO. This study introduces heterogeneity indices between China and the CAC, which concisely and reasonably reflect the relative strictness of China's MRL standards compared to the CAC standards. Furthermore, it can be used to measure the influence of the relative strictness of China's MRL standards on the hazard rate of agri-food exports.

Li and Beghin argue that simply averaging the gap between the MRLs of importers and exporters means that the MRL stringency on trade is homogeneous (Li & Beghin, 2014). In contrast, the more stringent the MRLs, the greater the impact on trade. They reason that index weighting should be used to give more weight to stricter MRL standards in the process of index calculation and their advocated index is widely used in empirical research on MRL standards. Based on their views, new indices suitable for our study are presented below.

Firstly, we defined the indices measuring the gap of MRLs stringency as follows:

$$i_{vkt} = \exp\left(\frac{MRL_{CACvkt} - MRL_{CHNvkt}}{MRL_{CACvkt}}\right) \tag{4.6}$$

where MRL_{CACvkt} (MRL_{CHNvkt}) is the MRL of pesticide k in agri-products v specified by CAC (China) in year t. K denotes the number of pesticide items specified for agri-product v in MRLs, and the number of MRL items of agri-product v. The I_{vt} range is [0, 2.72]—if the value is closer to 2.72, then China's MRL regulation of agri-product v is more stringent; if the value is closer to 0, then the CAC's MRL regulation of agri-product v is more stringent; and if the value is closer to 1, then the CAC and China have the same level of MRL regulations for agri-product v.

[31] The outputs of agri-products v involved is not produced by each importing country and results in the missing data. This paper uses the gross outputs of agri-products exported by the importing country to the world in that year to represent its supply capacity and expand the observation.

In addition, this paper also introduces the heterogeneity indices proposed by Shingal et al. for a robustness test (Shingal et al., 2021). They simply averaged the relative stringency index of product items *v* by using the total pesticide items, *K*; thus, their heterogeneity indices have stable characteristics that do not vary with the intensity of the regulations. The simple averaging method prevents a certain product (v) from being given too much weight when there are many specified pesticide types.

Similarly, we defined the relative stringency indices as follows:

$$i_{vkt} = \frac{MRL_{CACvkt} - MRL_{CHNvkt}}{MRL_{CACvkt} + MRL_{CHNvkt}} \tag{4.7}$$

Then, we simply averaged i_{vkt} by using the total pesticide items, *K*. The heterogeneity indices were given as follows:

$$I_{vt} = \frac{1}{K}\sum_{k=1}^{K} i_{vkt} \tag{4.8}$$

where the range of I_{vt} is [-1, 1]— if the value is closer to -1, then the CAC's MRL regulation for agri-product *v* is more stringent; if the value is closer to 1, then China's MRL regulation for agri-product *v* is more stringent; and if the value is closer to 0, then the CAC and China have the same level of MRL regulations for agri-product *v*.

Due to the differences in the classifications and names of MRL items between China and CAC, this study unified the names of agri-products and pesticides and reclassified the foods of both entities according to customs-based HS-2 digit codes (see Table 4.2). Taken together, the MRLs of China and the CAC increased on an annual basis; this reflects an overall increase in pesticide residue control. However, the number of pesticides specified by China alone is increasing rapidly, whereas the number of pesticides specified by the CAC alone is gradually decreasing; this signifies that China is developing its pesticide regulations more rapidly than the CAC.

Table 4.2 The number of pesticides specified in the MRLs of China and CAC

Year	China	CAC	Both	China only	CAC only
2008	137	160	86	51	74
2013	322	189	127	195	62
2015	386	206	172	214	34
2017	432	218	188	244	30
2019	434	230	192	242	38

Notably, the pesticides collected under “both” in Table 4.2 comprise pesticide items specified by China but not by the CAC and vice versa, which led to missing data. Since neither China nor the CAC defined a default value for the MRLs, this study used the maximum values in their MRL databases as a supplement for their default values, which correspond to the minimum stringency of the MRLs in a given year.

4.4.1.3 Variable implication and data source

The meanings of the variables involved in the empirical model and the source of the sample data are summarized in Table 4.3. The Table 4.4 presents the statistical characteristics of the variables.

Table 4.3 Variable implication and data source

Variable	Definition	Implication	Data source
$fail_{vijt}$	"failure" event	Trade disruption	World Integrated Trade Solution (WITS) [32]
PRO_{vit}	Output of exporting country (China)	Supply capacity	
$counnum_{ijt}$	trade relations combinations	Product competitiveness and market diversification	
$Tariff_{vit}$	tariff	variable costs	
MRL_{CHNvkt}	MRLs standard of China	Core explanatory variable	National food safety standard—Maximum residue limits for pesticides in food[33]
MRL_{CACvkt}	MRLs standard of CAC	Core explanatory variable	CAC pesticide residue database[34]
GDP_{jt}	GDP of importing country	Consumption capacity	World Development Indicators (WDI)[35]

[32] Sourced from online database: *World Integrated Trade Solution (WITS) database*

[33] Sourced from online database: *National food safety standard-Maximum residue limits for pesticides in food*

[34] Sourced from online database: *CAC pesticide residue database*

[35] Sourced from online database: *World Development Indicators (WDI) database*

contig	contiguity	Trade convenience	
comlang	common language	Trade convenience	CEPII[36]
$DIST_{ij}$	Geographical distance	fixed cost	

4.4.2 Estimation results

The estimation results of the cloglog, probit, and logit models are shown in Tables 5 and 6, respectively. The core explanatory variables in columns (1), (3), and (5) are the heterogeneity indices $I_{vt\text{-}all}$, which includes all pesticides specified by China and the CAC. The explanatory variables in columns (2), (4), and (6) are the heterogeneity indices $I_{vt\text{-}both}$, which only include pesticides jointly specified by China and the CAC. Notably, while the dependent variable $fail_{vijt}$ is a binary variable, the heterogeneity indices of the core explanatory variables do not take logarithms; thus, the coefficient of the heterogeneity indices is semi-elastic and the coefficients of the other control variables are elastic. Moreover, all heterogeneity indices are negative, indicating that China's MRL regulation on agri-product *v* is higher than that of CAC. Therefore, in the regression process, this study took it as a positive number, situating a larger difference between the indices as indicating that China is stricter than the CAC.

In columns (1)– (6) of Table 4.5, the heterogeneity indices of the core explanatory variables and coefficients of the control variables show unified characteristics.

The I_{vt} coefficients were all negative and statistically significant; this illustrates that the improvement of China's MRL standards helps stabilize the bilateral trade relations of agri-food products. Based on the regression results of the cloglog model, the stringency of China's MRLs is one percent higher than that of the CAC; that is, every one percent increase in I_{vt} will prolong the duration of China's agri-food product export by 0.32%–0.68%. The regression coefficient of the heterogeneity index $I_{vt\text{-}all}$ is significantly higher than that of $I_{vt\text{-}both}$, indicating that the pretreatment of pesticide types and the default value of MRLs in the sample data is meaningful. The high significance of both regression coefficients proves that data pre-processing did not affect our basic conclusions.

In terms of other controlled variables, $lnGDP_{jt}$, as a typical representative of the importer's consumption demand, has significant negative coefficients; this clearly indicates that higher import demand reduces the hazard of trade disruption.

Meanwhile, the regression coefficient of *lncounnum* is negative and highly significant.

[36] Sourced from online database: *CEPII database*

Notably, the exporter variable in year t was controlled to distinguish between heterogeneous products. Product types widely demanded by the markets were assumed to face less hazard because they are more competitive.

Table 4.4 Descriptive statistics of variables

	Unit	Obs.	Mean	St.Dev	Min.	Max.	VIF
$fail_{vijt}$		13,001	0.3483	0.4764	0.0000	1.0000	
$I_{vt\text{-}all\_Li}$		13,001	12.2456	2.0512	6.7521	16.6506	1.0510
$I_{vt\text{-}both\_Li}$		13,001	6.5644	1.4134	2.4306	9.6122	1.0451
$I_{vt\text{-}all\_Shingal}$		13,001	8.0206	4.2214	0.1090	16.6563	1.0830
$I_{vt\text{-}both\_Shingal}$		13,001	3.7610	2.7771	0.0149	9.6164	1.0860
$lnGDP_{jt}$	USD	13,001	25.6686	1.8445	19.5027	30.6569	1.4040
lncounnum		13,001	3.4316	0.5226	0.0000	4.3175	1.1330
contig		13,001	0.1095	0.3123	0.0000	1.0000	1.5064
comlang		13,001	0.0268	0.1614	0.0000	1.0000	1.1046
$lnPRO_{it}$	Tonne	13,001	9.3341	3.2682	-6.2146	14.4488	1.1550
$lnPRO_{jt}$	Tonne	13,001	4.5264	4.2485	-9.2103	17.3592	1.2150
$lnDIST_{ij}$	km.	13,001	8.9104	0.5041	6.8624	9.8677	1.5895
$ln(1+Tariff_{vit})$	%	13,001	1.6959	1.3523	0.0000	6.6174	1.1167

Note: $I_{vt\text{-}all}$ is the heterogeneity indices calculated by all pesticides including China and CAC, and $I_{vt\text{-}both}$ denote the heterogeneity indices calculated only for pesticides prescribed jointly by China and CAC. For avoiding bias in the estimation due to the large numerical difference between variables, this thesis expands the heterogeneity indices I for ten times.

The variable *contigs*, *comlang,* and $lnDIST_{ij}$ are considered important factors affecting costs in the general trade gravity model. Trade combinations with cultural proximity, a common language, and close distance share lower costs. In contrast, trade relationships with lower trade costs are better able to withstand the negative impact of the market and reduce the probability of trade interruption. Accordingly, the regression results show that *contig* and *comlang* have negative coefficients and $lnDIST_{ij}$ has positive coefficients.

Table 4.5 Estimation results by applying heterogeneity indices (Li Y)

	Cloglog		Probit		Logit	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$I_{vt\text{-}all\_Li}$	-0.6750***		-0.5527***		-0.8968***	
	(-4.6610)		(-5.1161)		(-5.0107)	
$I_{vt\text{-}both\_Li}$		-0.3263***		-0.2665***		-0.4321***
		(-4.9408)		(-5.4171)		(-5.3002)
$lnGDP_{jt}$	-0.1184***	-0.1184***	-0.0948***	-0.0949***	-0.1551***	-0.1553***
	(-12.2009)	(-12.2076)	(-12.5266)	(-12.5354)	(-12.4203)	(-12.4278)
lncounnum	-0.3834***	-0.3827***	-0.2998***	-0.2993***	-0.4946***	-0.4939***
	(-9.7941)	(-9.7773)	(-9.5591)	(-9.5426)	(-9.6063)	(-9.5910)
contig	-0.2820***	-0.2807***	-0.1975***	-0.1968***	-0.3392***	-0.3379***
	(-4.2773)	(-4.2564)	(-4.2141)	(-4.1993)	(-4.2882)	(-4.2723)
comlang	-0.4738***	-0.4738***	-0.3634***	-0.3638***	-0.6063***	-0.6067***
	(-3.9058)	(-3.9060)	(-4.4034)	(-4.4071)	(-4.2781)	(-4.2809)
$lnPRO_{it}$	-0.0280***	-0.0280***	-0.0235***	-0.0235***	-0.0378***	-0.0379***
	(-5.5516)	(-5.5576)	(-5.8710)	(-5.8789)	(-5.7695)	(-5.7761)
$lnPRO_{jt}$	0.0111**	0.0110**	0.0098**	0.0097**	0.0159**	0.0157**
	(2.7654)	(2.7366)	(3.1801)	(3.1491)	(3.1250)	(3.0943)
$lnDIST_{ij}$	0.1577***	0.1585***	0.1161***	0.1165***	0.1931***	0.1938***
	(3.9471)	(3.9667)	(3.9664)	(3.9801)	(3.9504)	(3.9639)
$ln(1+Tariff_{vit})$	0.1002***	0.1003***	0.0787***	0.0788***	0.1284***	0.1286***
	(8.0990)	(8.1102)	(8.4685)	(8.4834)	(8.3375)	(8.3501)
_cons	2.8923***	2.3076***	2.8753***	2.3982***	4.6799***	3.9040***
	(5.2468)	(4.3175)	(6.5561)	(5.6339)	(6.3715)	(5.4750)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Product fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observation	13001	13001	13001	13001	13001	13001

Note: $p < 0.05$, p ** < 0.01, p *** < 0.001, the brackets are robust standard error.

Table 4.6 Estimation results by applying heterogeneity indices (Shingal A)

	Cloglog		Probit		Logit	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$I_{vt\text{-}all\_Shingal}$	-0.9280^{***}		-0.7625^{***}		-1.2367^{***}	
	(-4.5052)		(-4.9400)		(-4.8414)	
$I_{vt\text{-}both\_Shingal}$		-0.5623^{***}		-0.4524^{***}		-0.7368^{***}
		(-5.5620)		(-6.0440)		(-5.9185)
$lnGDP_{jt}$	-0.1184^{***}	-0.1183^{***}	-0.0948^{***}	-0.0948^{***}	-0.1552^{***}	-0.1552^{***}
	(-12.2042)	(-12.1977)	(-12.5252)	(-12.5280)	(-12.4200)	(-12.4200)
lncounnum	-0.3891^{***}	-0.3821^{***}	-0.3049^{***}	-0.2986^{***}	-0.5028^{***}	-0.4927^{***}
	(-9.9576)	(-9.7621)	(-9.7347)	(-9.5201)	(-9.7779)	(-9.5667)
contig	-0.2820^{***}	-0.2783^{***}	-0.1976^{***}	-0.1950^{***}	-0.3392^{***}	-0.3349^{***}
	(-4.2764)	(-4.2204)	(-4.2172)	(-4.1587)	(-4.2888)	(-4.2328)
comlang	-0.4724^{***}	-0.4721^{***}	-0.3626^{***}	-0.3617^{***}	-0.6046^{***}	-0.6037^{***}
	(-3.8943)	(-3.8911)	(-4.3929)	(-4.3832)	(-4.2664)	(-4.2587)
$lnPRO_{it}$	-0.0273^{***}	-0.0276^{***}	-0.0228^{***}	-0.0232^{***}	-0.0369^{***}	-0.0375^{***}
	(-5.4147)	(-5.4896)	(-5.7118)	(-5.8107)	(-5.6150)	(-5.7092)
$lnPRO_{jt}$	0.0113^{**}	0.0107^{**}	0.0099^{**}	0.0094^{**}	0.0161^{**}	0.0153^{**}
	(2.8141)	(2.6547)	(3.2261)	(3.0626)	(3.1713)	(3.0065)
$lnDIST_{ij}$	0.1576^{***}	0.1603^{***}	0.1160^{***}	0.1178^{***}	0.1930^{***}	0.1961^{***}
	(3.9444)	(4.0115)	(3.9630)	(4.0234)	(3.9486)	(4.0086)
$ln(1+Tariff_{vit})$	0.1005^{***}	0.1014^{***}	0.0789^{***}	0.0798^{***}	0.1288^{***}	0.1301^{***}
	(8.1195)	(8.1943)	(8.4898)	(8.5822)	(8.3590)	(8.4422)
_cons	2.6601^{***}	2.3274^{***}	2.6860^{***}	2.4142^{***}	4.3723^{***}	3.9277^{***}
	(4.9106)	(4.3490)	(6.2247)	(5.6656)	(6.0487)	(5.5039)
year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Product fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observation	13001	13001	13001	13001	13001	13001

Note: $p^* < 0.05$, $p^{**} < 0.01$, $p^{***} < 0.001$, the brackets are robust standard error.

The terms $ln(1+Tariff_{vit})$ were highly significant in all the regressions. The sign of the coefficient illustrates that duties intensify trade interruptions and shorten trade durations, which is logically consistent with our expectations.

$lnPRO_{it}$ had a significant negative regression coefficient, indicating that the exporters' excellent supply capacity is an eventful aspect of reducing trade hazards, and numerous low-price and high-quality products will be sought by the market, thereby enhancing the stability of trade relations. However, the significance was weaker than that of $lnPRO_{it}$, perhaps due to the impacts of product diversification and complementarity. Considering that $lnPRO_{it}$ is the controlled variable in this study, this paper will not discuss this in more detail.

4.4.3 Robustness test

By applying heterogeneity indices of (Li Y) and (Shingal A) and using the log, probit, and logic models, six main groups of regression results were obtained. Columns (1) and (2) in Table 4.5 list the basic regressions; the other regression results were used as robustness tests. As can be seen from Table 4.5 and 4.6, the regression coefficients are all statistically significant. The coefficients of the heterogeneity indices $I_{vt\text{-}all}$ and $I_{vt\text{-}both}$ were similar. The sign and statistical significance of the variables did not change. Thus, the regression results are robust.

4.5 Conclusion

This study sought to examine the effect of food safety standards on trade duration. We used a set of Chinese data from 2008 to 2019 on agri-food product exports to 115 countries at the HS-6 level, and performed empirical description and analysis with a trade survival analysis. Using this data, we established the distribution of trade relations in China's agri-food product exports. Discrete-time hazard models (cloglog) were adopted to analyze the impact of food safety standards represented by MRLs on the export hazard rate of agri-food products in China.

We found that 51.8% of China's agri-food export trade relations can only last for one year, 14.2% can last for five years or more, and 2.2% can last for 10 years or more; the average trade duration was 3.85 years. As the world's fifth-largest exporter of agri-products, China’s short trade duration was unexpected. Notably, the survival rate also presents negative duration dependence.

In terms of parameter analysis, we constructed a trade gravity equation based on the log–log estimator in the survival analysis. We introduced a heterogeneity index for the core explanatory variable, which meaningfully quantified the stringency of food safety standards. The regression results confirm that upgrading China's MRLs can lower the hazard of trade interruption, thus stabilizing exports and extending trade duration. Each 1% increase in the relative stringency of China's MRL standards increases the duration of China's agri-food product export trade by 0.32%–0.68%. The remaining control variables are statistically significant, indicating that the variable settings of our model were appropriate. Regarding limiting the reduction of duties in international trade and other factors that cannot be controlled, we discovered that the agri-food production capacity of exporters is a crucial factor in stabilizing trade relations.

For many developing countries, the rapid loss of agri-food exports will create obstacles to export growth; thus, it is critical to study trade duration and influencing factors in such contexts.

The factors analyzed in this study may not be easily changed through policies. However, our study offers some insights on the Chinese context that may be worth applying to other developing countries. First, developing southern countries may improve their discursive power and the competitiveness of their products in the international market by accelerating their construction of MRL standards[37]; to date, northern countries still generally have the most stringent MRL standards. Second, increasing investment in their inspection institutions—specifically in research and detection[38]—may help nations control export quality, enhance their international images, and attract high premiums for their products. Customs will refuse agri-products with excessive pesticide residue, which can cause huge economic losses and resource waste. Meanwhile, using online marketplaces can strengthen the circulation of agri-products, reduce food waste, and increase agri-product yields[39]. In countries largely dependent upon agriculture, food security and national development depend on the tradable output of high-quality agri-food products. Subsequent studies may extend the work of this study to the firm-country or firm-product levels. To date, research on MRLs remains limited. The profound changes in food safety standards in recent years, such as MRLs and economic dynamics, can be clarified through studies that apply more recent and complete data.

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[37] Sourced from government document: *Reply - suggestions on strengthening the supervision of pesticide use*

[38] Sourced from government administration: *Carry out the verification of the technical ability of national agricultural product quality and safety inspection and testing*

[39] Sourced from official report: *Suggestions on the construction of agricultural products circulation system*

Chapter 5 Conclusion

In the study of measure protection, we measured the stringency of the Chinese MRLs compared with the CAC standards using Stringency Indices. The stringency indexes of about 80% of China's MRLs were greater than one, indicating higher stringency than the CAC standards. However, the high stringency indices do not prove that China is using MRLs as non-tariff measures or for trade protectionism. The regression results indicate that the factors driving the rise in stringency indices are public demand for higher food safety and the government's positive response to food safety incidents. We therefore conclude that China's MRLs have not become a new trade protection policy tool, and are not being used as an alternative to a tariff. In the long run, the growth in China's demand for food and the constraints of agricultural resources determine that the trends in food import and MRL development is irreversible.

We cannot ignore the role of media reports in reflecting public food safety demands, increasing public food safety awareness, and promoting the revision of food safety standards. Government agencies should take the initiative to use media channels to guide public participation in the supervision and formulation of food safety standards, so that relevant government departments improve their governance. In the era of rapid information dissemination via the internet, timely and transparent disclosure of food safety incidents, and scientific popularization of food safety knowledge is helpful in avoiding irrational public focus on food safety, which drives politicians to take excessive action as a result of "political precaution", resulting in unreasonably high food safety standards.

In terms of export promotion effect, this thesis constructs a Quality Heterogeneous Firm Trade (QHFT) model to explain the influence of MRLs on the exports and derives an appropriate empirical model. Its basic logic is: when the MRLs in importing country are more stringent, firms in exporting countries must comply with stricter MRLs. Compared with relatively loose MRLs of exporting countries, produced according to MRLs of importing countries can enhance product quality. Consumers in importing countries with quality preference perceive the improvement of product quality and increase consumer demand. But the relative improvement of quality requires input, resulting in additional costs for firms (products). When the MRLs in exporting country are more stringent, the products produced in the exporting country make a high-quality impression on the consumers, and the firms do not input additional trade costs in this case. The comprehensive impact of MRLs on trade should be determined by the demand-enhancing effect, variable trade-cost effect and fixed trade-cost effect.

We establish a relatively new and complete MRLs database of China and the EU from 2008 to 2020 for empirical analysis. The heterogeneity indices integrating quantity and level of standards to measure the relative stringency of MRLs between China and EU. PPML Fixed Effect (FE) model is used to handle the heteroscedasticity, inflated zeros and endogeneity in trade data.

Finally, the robustness of some key influencing factors is tested. We found more stringent EU MRLs did not curb food exports from China to the EU. A more plausible explanation is that the stricter MRLs signal to consumers that the quality of products has been improved, and thus generate the demand-enhancing effect that can boost consumption demand of importing countries. The demand-enhancing effect plays a leading role and promotes the agri-food exports from China to the EU. Meanwhile, the EU MRLs is still more stringent than China in general, but the gap continues to narrow and the stringency of certain pesticides MRLs in China has exceeded that of EU. The rapid upgrading of China's food safety standards can dynamically adjust the domestic agricultural industry to high quality and efficiency. China's (exporter) initiative to adopt more stringent domestic MRLs standards has led even more boost effect on exports than passively complying the EU (importer) MRLs.

Regarding trade duration analysis, the aim of this thesis is to carry forward the study of food safety standards on trade duration. We used a set of the China export data of agri-food products to 115 countries at the HS-6 level in 2008 to 2019, and performed empirical description and analysis by the trade survival analysis. With these data, we demonstrate the distribution of trade relations on China's agri-food products exports. The discrete-time hazard models (cloglog) are adopted to analyze the impact of food safety standards represented by MRLs on the export hazard rate of agri-food products in China.

For China's agri-food export, 51.8% of the trade relations can only last for one year, only 14.2% of the trade relations can last for 5 years or more, and only 2.2% of which can last for 10 years or more, with the average trade duration of 3.85 years. As the world's fifth largest exporter of agricultural products, the short trade duration of China seems unexpected, and the survival rate also presents a negative duration dependence.

In terms of parameter analysis, we constructed the trade gravity equation based on the cloglog estimator in survival analysis. As for the core explanatory variable, we introduce the heterogeneity index, which provides a fabulous method to quantify the stringency of food safety standards. The regression results confirm the upgrading of China's MRLs can lower the hazard of trade interruption, thus helping to stabilize the export and extend trade duration. Each 1% increase in the relative stringency of China's MRLs standards will increase the duration of China's agricultural food products export trade by 0.32% to 0.68%. The remaining control variables were statistically significant, indicating that the variable setting of our model is appropriate. For the limit reduction of duty in international trade and other factors that cannot be controlled, we discover the agri-food production capacity of exporter is also a crucial factor in stabilizing trade relations.

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