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Trade, price and quality upgrading effects of agri-food standards

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Abstract

This paper assesses how cross-country differences in public mandatory food standards affect trade, prices and product quality upgrading in the agri-food sector. We estimate different gravity-type models that exploit the bilateral difference in maximum residue limits (MRLs) over the period from 2005 to 2014 for 145 products across 59 countries. Our findings show that cross-country differences in MRLs restrict trade. However, conditional on trading, they increase product prices—even when we adjust prices for quality—with null effects on estimated product quality. These effects are pronounced for South–North trade but not for exports to the South.

Keywords: agricultural trade, trade margins, NTMs, maximum residue limits, product quality

JEL classification: F14, Q17, Q18

1. Introduction

How standards affect bilateral trade flows is topical in the agricultural trade literature. As many countries have reduced their use of tariffs and other quantitative restrictions, standard-like non-tariff measures (NTMs) have become important alternative trade policy instruments. In agricultural markets, food safety standards shape trade flows and determine who is successful in many high-value export markets. As a result, they are often seen as non-tariff barriers to trade, with different political economy implications (Swinnen, 2016).

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Unlike tariffs that operate as pure taxes on imports, standards affect both imports and domestic production.[1] Hence, they can have positive (negative) effects on trade depending on whether their demand-enhancing effects, if any, dominate (falls short of) their trade-cost effect (Xiong and Beghin, 2014). Empirical findings depict standards as either catalysts or barriers to trade (Disdier, Fontagné and Mimouni, 2008; Maertens and Swinnen, 2009; Disdier and Marette, 2010; Peterson *et al.*, 2013; Curzi *et al.*, 2018; Fiankor *et al.*, 2020). But they may also have no effects on trade (Xiong and Beghin, 2012; Schuster and Maertens, 2015). Thus, despite the increasing number of empirical studies, the effect of standards on agri-food trade remains ambiguous and heterogeneous (Santeramo and Lamonaca, 2019).

A limitation in this literature is the almost exclusive focus on the direct trade effects of standards while ignoring other welfare effects (Olper, 2016). For example, in agricultural markets, standards address market failures (Beghin, Maertens and Swinnen, 2015) and reduce the incidence of acute illnesses among farmers (Asfaw, Mithöfer and Waibel, 2010). Standards are linked to quality upgrading in the food industry (Gaigné and Larue, 2016), yet empirical evidence is rather rare in the agricultural trade literature. With growing interest, recent studies are either regional (Olper, Curzi and Pacca, 2014; Raimondi *et al.*, 2019) or use firm-level data for specific countries (Curzi *et al.*, 2020; Movchan, Shepotylo and Vakhitov, 2020). Moreover, the standards and trade literature has failed to assess the existence and magnitude of any such quality upgrading effect of regulatory heterogeneity (i.e. different country-specific standards for the same product) on trade.[2] Our paper contributes to filling this research gap.

In agriculture, chemical use is important to protect crops and enhance yields. But, depending on exposure levels chemicals can pose unacceptable health risks. As such, many governments and the Codex Alimentarius Commission (Codex for short), have established maximum residue limits (MRLs) to regulate their use. Besides, MRLs on chemicals substances (e.g. pesticides) are becoming crucial in the debate on the environmental sustainability of food systems. The use of chemical pesticides in agriculture contributes to pollution (soil, water and air) and biodiversity loss and can harm non-target plants, insects and birds (European Union [EU] Commission, 2020). As a result, the restrictiveness of this type of food standards can only increase in the near future, calling for a better understanding of their trade and economic effects.[3]

1 To ensure consistency with the General Agreement on Tariffs and Trade (GATT) Article III on national treatment, public regulations on food safety must apply to both imports and domestic production. Nevertheless, importing countries imposing the standard may do so only when domestic producers have achieved compliance or find it easier than foreign exporters to comply. In which case, the standard will still be biased towards domestic production.

2 The first attempt is made at the firm level by Fernandes, Ferro and Wilson (2019) who proxy quality with prices measured as unit values. But, as we will discuss later in the empirical framework, prices may not proxy quality perfectly.

3 In the recent publication on 'Farm to Fork Strategy', the EU Commission announced the introduction of new restrictive regulation on the use of pesticides with the aim to improve the environmental sustainability of food systems.

This paper assesses how differences in country-specific MRLs affect trade, prices and product quality upgrading. We estimate unobserved product quality at the country–product–year level following Khandelwal, Schott and Wei (2013).[4] This approach follows the idea that conditional on price, a variety imported in higher volumes is assigned higher quality. That is, if varieties of a product from countries i_1 and i_2 sell at the same price p, the country that offers a higher quality faces a higher demand from importing country j. To achieve our objectives, we exploit the bilateral difference in the MRLs set by 59 countries for 145 agri-food products over the period from 2005 to 2014. In doing so, we provide new insights into other welfare effects of MRLs, but also further clarity on their direct trade effects.

Our empirical analyses are set within a product-level structural gravity framework. Consistent with the heterogeneous firms literature (Melitz, 2003; Helpman, Melitz and Rubinstein, 2008), we find that regulatory heterogeneity hinders trade at the extensive and intensive margins and reduces conditional export sales. In a second step, we show that conditional on exporting, standards increase product prices and quality-adjusted prices but have null effects on estimated product quality. Hence, our paper decomposes for the first-time observed product price changes induced by MRLs into quality and quality-adjusted price components. We also explore the heterogeneity of these effects across different trade routes. The trade-reducing and the price-raising effects are strongest for South–North trade, followed by North–North trade, but do not matter for exports to the South.

Our work extends the existing literature in three ways. First, using MRL data to study the price and quality upgrading effects of standards adds to existing works that measure standards using notifications to the World Trade Organisation (WTO) on Sanitary and Phyto-Sanitary (SPS) measures (Curzi *et al.*, 2020; Movchan, Shepotylo and Vakhitov, 2020). Using these notifications to construct frequency indices, coverage ratios or define standard dummies have limitations (Peterson *et al.*, 2013). For instance, these counts of notifications (i) do not always allow the researcher to identify product-specific regulations, (ii) are unilateral which makes it difficult to compare stringency of standards between countries[5] and (iii) only capture the prevalence of standards but fail to measure their strictness. Using MRL data, we overcome these limitations. MRLs are continuous measures of relative stringency set on specific products and thus comparable across country pairs.[6] For instance, if two

4 Quality is estimated as the residual from a demand-side ordinary least squares (OLS) regression that controls for product characteristics, the elasticity of substitution between products and the incomes and price indices of the importing countries. Quality is considered any attribute that raises consumer demand other than price.

5 Indeed, MRLs are also country-specific measures and by construction do not have a bilateral dimension. However, the stringency levels across country–pairs can be compared easily resulting in a bilateral measure.

6 By focusing on MRLs, we provide precise estimates on the effects of a specific standard but lose the generality of studies using counts of SPS notifications, which cover a broad range of policy instruments. However, many notifications in these databases are also related to MRLs.

countries i and j set an MRL of 0.01 and 0.50 parts per million (ppm), respectively, on product k, then it is clear that standards in i are stricter than in j. MRLs are also typical of most food quality standards and fundamental to both public and private standards. The limits set for product–pesticide pairs also vary across countries (see Table 1). Thus, another novelty of our paper is that while the existing literature focuses on how unilateral measures imposed either by the importer or the exporter affect product quality upgrading, we consider a case where for the same product both countries set standards that differ from each other.

Second, standards may be endogenous to trade volumes. A specific case is made for MRLs in Shingal, Ehrich and Foletti (2020). But, many empirical exercises carried out within gravity-type models ignore the problem (e.g. Tran, Wilson and Anders, 2012; Winchester *et al.*, 2012; Arita, Beckman and Mitchell, 2017; Kareem, Martínez-Zarzoso and Brümmer, 2018). Following Baier and Bergstrand (2007), we minimise endogeneity concerns by including in our estimations a host of country–product–time and country–pair fixed effects. The latter are better measures of bilateral trade costs than the standard set of bilateral varying gravity variables (Egger and Nigai, 2015; Agnosteva, Anderson and Yotov, 2019). Our empirical estimates also show that failing to control for this source of endogeneity overestimates the trade effects of MRLs.

Third, many countries in the South are tropical and suffer from severe pest and disease pressure. As such, the average effects we estimate across all countries may hide interesting heterogeneous effects. We explore how the estimated effects vary across different trade routes, i.e. South–South, North–North, South–North and North–South. There is limited evidence on trade route-specific effects of standards. Known exceptions include Disdier, Fontagné and Cadot (2015) who considers only South–South and North–South trade and Xiong and Beghin (2014) who consider only South–North and North–North trade. We consider all four trade routes (see also Ferro, Otsuki and Wilson, 2015; Santeramo and Lamonaca, 2019).

The rest of the paper proceeds as follows. Section 2 reviews the related literature. Section 3 discusses the different pathways through which MRLs may affect trade, product prices and product quality upgrading and highlights the necessary theoretical predictions needed to interpret our empirical findings. In Section 4, we discuss our empirical strategy and describe in detail how we measure our dependent variables. A detailed description of the data is in Section 5. We present our results in Section 6. Section 7 discusses our main findings and offers policy recommendations. Section 8 concludes.

2. Literature review

In this section, we review the empirical literature on MRLs and agricultural trade with a focus on studies that use the gravity model. Our review covers the various indices that have been used in the literature to measure regulatory

Table 1. Comparison of maximum residue limits on selected products in 2014

		Countries						
Chemical	Fruit	EU	USA	Canada	Japan	Vietnam	China	Codex
Carbaryl	Citrus	0.01	10	10	1	7	—	15
Methidathion	Citrus	0.02	5	2	5	5	2	5
Captan	Apple	3	25	5	5	25	1	15
Fenbutatin-Oxide	Apple	2	15	3	5	5	5	5
Acetamiprid	Apple	0.80	1	1	2	—	0.8	0.80
Bifenthrin	Tea	5	30	—	30	—	—	30
Endosulfan	Tea	30	24	—	30	30	—	10
Fenpropathrin	Tea	2	2	2	25	—	5	2
Chlorpyrifos	Wheat	0.05	0.50	—	0.5	0.50	0.50	0.50
Chlorpyrifos	Banana	3	0.10	—	3	2	—	2
Chlorothalonil	Cranberries	0.67	5	2	5	—	—	5

Source: Homologa dataset.
Notes: Implies that there are no residue limits set by that country on the given product–pesticide pair. All residue limits are measured in ppm.

heterogeneity of MRLs. We then review the standards and product quality-upgrading literature.

The first group of studies on the MRL-trade effect considers how importer-specific MRLs affect imports from other countries. For example, Otsuki, Wilson and Sewadeh (2001) estimate the effects of changes in aflatoxin standards on groundnut trade from 1989 to 1998. They find that a 10 per cent tighter aflatoxin standard in Europe will reduce edible groundnut imports from Africa by 11 per cent. A decade later, Xiong and Beghin (2012) use a theory consistent version of the gravity model and find no evidence that EU MRLs reduce groundnut exports from Africa. Tran, Wilson and Anders (2012) find negative effects of chloramphenicol standards set by Canada, the EU15, Japan and the USA on the probability of trade and the volume of trade for third countries.

The second group of studies compare standards in an importing country to an international benchmark. In 2014, Li and Beghin proposed an exponential aggregation index to quantify protectionism in NTMs. An importer's MRL is deemed protectionist if its stringency exceeds the corresponding science-based limit established by the Codex. Since then many studies have used the Li and Beghin (2014) index to assess how national MRLs relative to the Codex affect trade. Xiong and Beghin (2014) find that MRLs imposed by high-income Organisation for Economic Co-operation and Development (OECD) and developed countries enhance import demand but hinder foreign export supply. Kareem, Martínez-Zarzoso and Brümmer (2018) find that tomato—but not lime, lemon and orange—exports from Africa are negatively affected by EU MRL regulations. Curzi *et al.* (2018) find that EU MRLs affect in particular imports from developing countries, while they facilitate EU exports.

The last group of studies measure relative stringency of MRLs between countries. Winchester *et al.* (2012) define a dissimilarity index such that if standards in the exporting country are stricter than those in the importer, the index takes the value of zero. This reflects that the dissimilarity does not represent a barrier to the exporter. Their results show that stricter pesticide limits for plant products in one country relative to other countries reduce exports to the country maintaining the standard. Drogué and DeMaria (2012) consider the specific case of apples and pears to show that differences in MRLs between countries can hinder trade. They used a similarity index, first proposed by Vigani, Raimondi and Olper (2012), defined as a distance associated with Pearson's correlation coefficient. In Ferro, Otsuki and Wilson (2015), country-level restrictive MRLs decrease trade at the extensive margin, but often do not affect the intensive margin. Their bilateral asymmetry measure simply normalises a country's MRL regulation for a product–pesticide pair in year t to be between 0 and 1 relative to the maximum and minimum MRLs for that same product–pesticide pair in all other countries. In a follow-up application of the index using firm data, Fernandes, Ferro and Wilson (2019) find that an increase in the stringency of importer standards, relative to the exporter, lowers firms' probability of exporting, deters exporters from entering new markets, and induces market exit. Hejazi, Grant and Peterson (2018) adapted the Li and

Beghin (2014) exponential index to measure standards relative to other countries that set their own MRLs. Their results suggest significant reductions in bilateral fresh fruit and vegetable trade.

On the effects of standards on product quality-upgrading, very few studies exist in the agricultural trade literature. With increasing interest, recent studies focus on the EU or use firm-level data for specific countries. Olper, Curzi and Pacca (2014) investigate the relationship between the diffusion of EU standards and product quality upgrading in the food industry. They replicate the procedure in Khandelwal (2010) to estimate quality and show that the diffusion of EU voluntary standards boosts the rate of quality upgrading. Using a dataset of EU geographical indications (GIs), Raimondi *et al.* (2019) find that GIs increase export prices. This is consistent with the idea that consumers perceive GI products as higher quality. But, using prices as a proxy for quality, Fernandes, Ferro and Wilson (2019) find a negative but statistically insignificant effect of MRL dissimilarity. This was contrary to their a priori expectation that more stringent MRLs in the destination country will lead to the import of higher quality products. Curzi *et al.* (2020) focus on Peruvian firms and how specific trade concerns raised on NTMs affect their product quality upgrading. They find that only the most restrictive standards result in product quality upgrading. Movchan, Shepotylo and Vakhitov (2020) introduce NTMs into a model with heterogeneous firms and test their model predictions on food-processing firms in Ukraine from 2008 to 2013. More regulations on inputs in upstream industries lead to exports of higher quality products while mandatory certifications affect quality negatively. Both Curzi *et al.* (2020) and Movchan, Shepotylo and Vakhitov (2020) measure quality following Khandelwal, Schott and Wei (2013). Except for Fernandes, Ferro and Wilson (2019), all these studies focus on country-specific standards and do not consider regulatory heterogeneity between countries.

3. Conceptual and theoretical discussion

3.1. Maximum residue limits and trade

Following Krugman (1980) more recent theoretical models (e.g. Melitz, 2003; Helpman, Melitz and Rubinstein, 2008) have incorporated firm heterogeneity to show that productivity differences across firms are an additional source of comparative advantage. The theoretical predictions of these models imply that the introduction of a food safety standard imposes extra costs that affect trade at the intensive and extensive margins.[7] The fixed cost component of the standard is expected to affect mainly the extensive margin since only productive firms that meet the fixed costs imposed by the standard would export. As predicted by the Abel-Koch (2013) model, this prohibitive nature of fixed costs will lead to zero trade between some country pairs. The variable cost component would affect both extensive and intensive trade margins. When variable costs are low,

7 Note that in the Krugman (1980) model, all export variations are on the intensive margin because all firms export to all destinations.

each exporting firm exports more (i.e. the intensive margin) and new firms enter the market (i.e. the extensive margin), and vice versa. Thus, while we expect public standards to reduce the extensive margin, their impact on the intensive margin of trade is a priori ambiguous (Fontagne *et al.*, 2015).

Focusing on MRLs as a product standard, there are different sources of trade disruptions that can arise due to differing limits across countries. For instance, farmers producing according to good agricultural practices (GAP) approved for their domestic market—whether that is a national standard or the Codex—cannot be sure that their GAP compliant and domestically legal products will be granted access to other countries (Yeung *et al.*, 2018). This is because different countries set national residue limits with varying stringencies for same product–pesticide pairs (see Table 1). To guarantee market access, producers incur information costs to acquaint themselves with standards in their target markets. Depending on how dissimilar standards are between countries, producers will have to invest in improved infrastructure, research and development, use higher-quality inputs, or change freight modes. The associated costs can increase remarkably depending on how many markets the producers intend to export to or how often the destination country changes their tolerance levels.

The number of MRLs regulated also varies across countries. What happens when an MRL is missing from a national list. For example, in 2014, Canada had no established residue limits for Bifenthrin and Endosulfan use in tea production (Table 1). In such cases, does the importer have a default tolerance level that applies, or does the importing country reject shipments that contain these residues (Yeung *et al.*, 2018)? Such a lack of transparency increases the cost of trading; even more so for developing country producers because they are mainly located in tropical areas with high pest and disease pressure and have weaker institutional capacities to set standards. Nevertheless, developed countries are not spared the trade effects of regulatory heterogeneity. American exports of pears and apples to the EU declined when the EU introduced lower standards for chemicals applied to preserve their appearance in 2008 (Hejazi, Grant and Peterson, 2018).

To meet stricter importing country MRLs, producers face sunk costs and higher marginal costs. As a result, we expect differences across national residue limits to affect both trade margins. The introduction of a new limit on a particular pesticide or the tightening of an existing limit will impose extra costs for producers, especially in countries where existing public regulations are weak. This includes fixed costs of investing in new production techniques or adjustments to existing ones. Only firms with productive capacities to overcome this fixed cost will export to the market imposing the standard. Thus, in line with the predictions of the heterogeneous firm literature, we expect stricter MRLs to affect the extensive margin and induce market exit. The standard will also impose higher variable costs (e.g. costly inputs, recurrent costs of quality control and product testing), which will affect export volumes and varieties to the product-destination market maintaining the stricter standard.

3.2. Maximum residue limits, product quality and prices

3.2.1. Standards, competition and product quality

Traditional theories of international trade neglect the existence of product quality differences across countries, but extensions of the firm heterogeneity literature incorporate horizontal and vertical quality differentiation across firms as a key driver of firms' export performance (Hallak, 2006; Kugler and Verhoogen, 2011; Crozet, Head and Mayer, 2012). Successful exporters use higher-quality inputs and more skilled workers to produce higher-quality output that sell at higher prices. Since standards define product characteristics and specify a level of quality, they are features of differentiated product markets.

Standards may also affect product quality and prices through their effects on industry structure. For instance, the theoretical model of Abel-Koch (2013)—who considers the economic effects of NTMs in a Melitz (2003) framework—predicts that standards reduce competition and product variety in the destination market imposing the standard. Due to the increased production costs—e.g. associated costs of meeting the standards in a target importing country, or segregating crops for different markets—standards will induce market-exit for lower quality firms. Surviving exporters may exploit the reduced competition in this new market environment and pass on the extra costs of production to consumers as higher product prices. But the investments and quality improvements required to comply with stricter standards may be rewarded with increased consumer willingness to pay a 'quality premium'. The theoretical literature on minimum quality standards offers further insights into the underlining mechanisms. The models of Leland (1979) and Shapiro (1983) suggest that standards will induce price increases due to the increased costs of producing higher quality products. But there is a second possibility. By excluding low-quality exports, standards may limit the scope for product quality differentiation, but instead, induce an increase in price competition. This will occur if mandatory compliance with the public standard induces firms that until the introduction of the standard were producing 'low-quality' to improve their quality. In this case, the difference in quality between surviving firms reduces after the introduction of the standard. This will cause an increase in price competition and, as a consequence, a reduction in quality-adjusted prices. This mechanism is consistent with the theoretical model of Ronnen (1991).

3.2.2. Maximum residue limits, trade and product quality

SPS measures, which are rife in the agri-food sector, are less about protecting domestic producers and more about ensuring product quality and consumer health (Murina and Nicita, 2017). Thus, the proliferation and the increasing relevance of agri-food standards imply that farmers have to decide the quality and not just the quantity they produce (Korinek, Melatos and Rau, 2008). As such recent work has extended the quality upgrading literature to the agri-food sector (Curzi and Olper, 2012; Movchan, Shepotylo and Vakhitov, 2020). Following Fernandes, Ferro and Wilson (2019), we extend this nascent literature to MRLs.

The level of residues in a food crop determines its quality in terms of pesticide contamination. Thus, citrus fruit with a residue limit of 8 ppm of carbaryl may be considered high quality in the USA, Canada, and by the Codex but low quality in Vietnam, Japan and the EU (see Table 1).[8] Food crops that are produced under strict MRLs may indicate a higher level of sophistication of the production process and, hence, higher product quality.[9] Theoretical models (see, e.g. Kugler and Verhoogen, 2011) typically treat product quality as an outcome of conscious investment decisions. This is true also for agricultural production where standards can be seen as a ban on cheaper technology (Vandemoortele and Deconinck, 2014). To meet the higher quality levels imposed by stricter MRLs, farmers need to upgrade their farm-level production technologies to include *inter alia* expensive inputs and specialised human capital. For instance, they must avoid using some pesticides completely and determine correct pre-harvest intervals. Thus, meeting importer-specific MRLs will reduce information asymmetries, which in turn enhance quality claims (Fernandes, Ferro and Wilson, 2019).[10] The differences in MRL regulations across destination markets will also affect the final marketing options for producers and may lead to a redistribution of market shares among surviving exporters in certain sectors. For instance, Gaigné and Larue (2016) are theoretical model studies how restrictive (quality) standards affect firms' export behaviour and market structure. Introducing vertical differentiation in a firm heterogeneity trade model, they show that as quality standards proliferate, some domestic and foreign firms will exit the market, which leads to reallocation of market shares towards more productive firms.

Yet, unlike the effect on trade, theoretical expectations on the effects of standards on quality and (quality-adjusted) prices are less definite and often

8 The 8-ppm limit falls below the maximum allowable limit required in the USA, Canada and the Codex but falls above the maximum allowable range in Vietnam, Japan and the EU.

9 Whether these differences in residue limits across countries imply higher food safety and better health outcomes is contested. Winter and Jara (2015) argue that divergence in limits across countries does not necessarily lead to improvements in food safety. Handford, Elliott and Campbell (2015) also argue that because agricultural and food safety policies diverge across countries, MRLs will differ for different pesticides and markets although these limits are still safe. Chemical use is core to agricultural production but their use must be regulated. However, the standard set by the public regulator may be stricter than needed to counteract the externality, thereby disguising protectionist intents (Fischer and Serra, 2000). Winter and Jara (2015) argue that this is the case for MRLs as violative residue limits are rarely of health significance.

10 Consider the case of producers adopting higher importing country standards. This helps them to counter claims about the poor product quality that are typically associated with firms in their geographical locations (Fiankor, Martínez-Zarzoso and Brümmer, 2019). For example, through third-party certifications, suppliers must document their agricultural practices (e.g. how much, and which pesticide was applied and when), which serve as useful documentation to debunk claims of inferior quality by importers. Thus, even for producers in developing countries standards increase the credibility of their quality claims (Hatanaka, Bain and Busch, 2006; Fiankor, Martínez-Zarzoso and Brümmer, 2019).

ambiguous (Fontagne *et al.*, 2015; Curzi *et al.*, 2020). So, even though MRLs are fundamental to both public and private food standards, the extent to which consumers respond to them as a quality indicator is an empirical question.

4. Empirical framework

We study the standards, trade, price and quality relationship using structural gravity-type models. The gravity equation—one of the most successful empirical relationships in international economics—relates bilateral trade between exporting and importing countries to bilateral trade costs and exporting and importing country characteristics. In this section, we specify our econometric model and describe the different measures of the dependent variable.

4.1. Econometric specification and identification strategy

Our benchmark estimation model is the following product-level gravity equation, wherein we model bilateral trade costs as a constant elasticity of substitution (CES) function of the product and time-varying country–pair difference in MRLs (MRL_{ijkt}) and tariffs (Tariff_{ijkt}):

$$lnX_{ijkt} = \psi_{ikt} + \lambda_{jkt} + \alpha_{ij} + \beta_1 MRL_{ijkt} + \beta_2 ln\left(1 + Tariff_{ijkt}\right) + \varepsilon_{ijkt} \quad (1)$$

where i is the exporting country, j is the importing country, k is the product and t is time. Our parsimonious specification includes a host of exporter-product-time (ψ_{ikt}), importer-product-time (λ_{jkt}) and exporter-importer (α_{ij}) fixed effects. These fixed effects control for all country and product-specific time-varying effects (e.g. production, expenditure, incomes, population and other country-specific variables) and country–pair-specific time-invariant effects (e.g. bilateral distance, common language and contiguity). Hence, in principle, our model can only identify the effect of variables that are country–pair varying over time. Since these fixed effects eliminate many confounding factors as possible, we are confident our estimation captures a pure trade cost effect. In line with the structural gravity literature, ψ_{ikt} and λ_{jkt} also control for multilateral resistance (Anderson and van Wincoop, 2003). ε_{ijkt} is the error term, which we cluster at the country pair–product level. We are primarily interested in β_1, which reflects the effect of differences in product-specific MRLs between countries on different measures of trade, prices and quality. The inclusion of α_{ij} implies that identification of β_1 is achieved from changes in bilateral differences in MRLs over time.

4.2. Definitions of the different measures of X_{ijkt}

The dependent variable in equation (1) varies depending on the specific research question. It represents for each importer-exporter-product-time: the (i) extensive margin (ii) intensive margin (iii) product of both trade margins (iv) value of trade conditional on exports (v) import prices expressed as unit values (vi) quality and (vii) quality-adjusted prices. Here, we discuss these different measures.

5. Measures of the intensive and extensive trade margins

Although now armed with solid micro-foundations, estimating conventional gravity equations with total trade flows as the dependent variable may be misleading if the extensive and intensive trade margins respond differently to trade costs (Feenstra and Ma, 2014). Some studies in the literature have accounted for both trade margins using mainly the Heckman two-step procedure. However, this suffers two limitations; the incidental parameter problems of the first stage Probit equation in panel data contexts and the fact that the procedure only works well in bilateral trade equations when true exclusion restrictions exist (Helpman, Melitz and Rubinstein, 2008). Others have also used direct approaches to decompose the impact of trade policies on the extensive and intensive trade margins. These include measures such as the number of products exported within a certain industry, counts of categories that exceed a certain size, or exports concentration indices (see, e.g. Cadot, Carrere and Strauss-Kahn, 2011; Persson and Wilhelmsson, 2016). These simple counts, although transparent, are limited by the assumption that all products have the same economic weight.

Following Feenstra and Kee (2008), we use a theoretically founded decomposition of overall trade into the extensive and intensive margins considering the economic weight of the products. This measure is very similar to a count of the exported varieties within a certain industry, but appropriately weights categories of goods by their overall importance in exports to an importing country. The extensive margin (EM_{ijkt}) is the fraction of all products k exported from country i to country j, where each product is weighted by the importance of that product in total exports to j in year t. The intensive margin (IM_{ijkt}) is the bilateral trade flow from i to j relative to the average world export to j in the same product category. The product of the two margins equals the ratio of exports from i to j relative to country j's total imports, i.e. it measures the relative export performance of each exporter in sector k of the importing country in year t. We move to Appendix A, the detailed description of the methodology used to measure both trade margins. As a fourth measure of the dependent variable, we consider the absolute value of exports of product k from country i to j in year t.

6. Measures of price, quality and quality-adjusted price

The final bit of our analyses relates the differences in national standards to prices and quality of imports. Critical to this part of the analyses is how we measure unobservable ‘product quality’. It is standard in the agricultural trade literature to use prices (measured as unit values) to proxy quality (Fernandes, Ferro and Wilson, 2019; Bojnec and Fertő, 2017). For each HS6 digit product k, the bilateral trade data records the total nominal value of imports in US dollars from a given exporter, as well as the quantity in tons. Taking the ratio of trade values and trade quantities, we obtain so-called unit values, i.e. $p_{ijkt} = v_{ijkt}/q_{ijkt}$. Information on unit values can be particularly noisy because the trade data may contain measurement errors at the disaggregated product level. Noise in the price data would also affect our quality estimates. To deal with potential outliers in the price and quality estimations, we exclude extreme unit values within the 1st and 99th percentiles. We also drop annual growth rates within the 1st and 99th percentiles. Finally, we drop the estimated quality values within the 5th and 95th percentiles. This data cleaning procedure eliminates 3 per cent of our observations. While unit values are available for a wide range of products and countries, they may not be precise proxies for quality. Prices may also reflect higher production costs, exchange rates or market power. Our approach follows Khandelwal, Schott and Wei (2013) and recovers quality directly from observed trade data.[11] The intuition behind the Khandelwal, Schott and Wei (2013) approach is simple: conditional on prices, varieties with higher quantities (market shares) are assigned higher quality.[12] We assume quality is any attribute that raises consumer demand other than price. After estimating quality $\hat{q}_{ijkt}$, we obtain the quality-adjusted price component as the observed log prices less estimated quality, i.e. $ln\hat{p}_{ijkt} = lnp_{ijkt} - ln\hat{q}_{ijkt}$. That is the difference in product prices for the same level of quality. See Appendix B for a detailed description of the quality estimation procedure.

As an initial exploratory analysis, we plot the Epanechnikov kernel density estimates of our quality estimates and unit values for the first and last years of our panel.[13] The results presented in Figure 1 reveal that the average quality and price of imports increased over the study period. Compared with prices, the average quality did not change by much. The extent to which this is driven by cross-country and product differences in MRLs over time is one goal of this paper.

6.1. Estimation procedure

We estimate the benchmark model in equation (1) using OLS.[14] Aggregating the unit of analysis from the HS6 to the HS2 digit level allows for enough variation in our dataset to compute the trade margins. And because the trade margins are defined conditional on trade, there are no zeroes in the trade matrix. Also, zero-value traded products do not have a price and are excluded from the price and quality estimations. To control for heteroskedasticity, we compute robust

11 While this method was originally applied at the firm–product–country–year level, subsequent applications have also been done at the product–country–year level, see e.g. Curzi and Pacca (2015), Breinlich, Dhingra and Ottaviano (2016). The limitation, however, is that different producers or firms may produce different qualities. Lack of farm/firm level trade data implies that our quality estimates reflect the average quality of exports from a country in a specific product.

12 For instance, suppose bananas from Ecuador and Colombia are equally priced, but Colombia's market share in destination market *j* is 20 per cent and Ecuador's is 10 per cent, the quality estimate for Colombia will be higher. If bananas from Colombia were more expensive, then we would need to control for the price difference and this would reduce the quality estimate for Colombia.

13 Here, we include only importer-product pairs that are present in both 2005 and 2014. We compare prices over time by regressing the log of unit values on country–product fixed effects before plotting the residuals.

14 To deal with the high-dimensional fixed effects in our model specifications, we use the user-written commands reghdfe and ppmlhdfe of Correia (2016) in Stata.

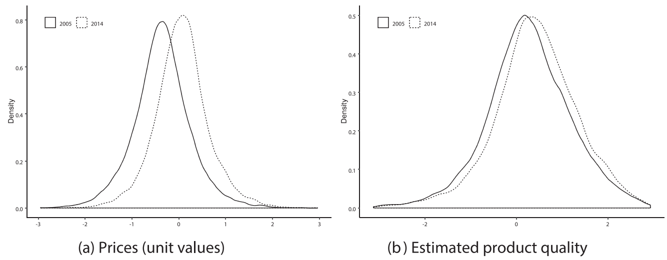

Fig. 1. Distribution of prices and estimated product quality of imports. (a) Prices (unit values). (b) Estimated product quality.

standard errors clustered at the importer-exporter-product level. For analysing observed trade values, controls for zeroes are important to avoid sample selection bias. Eighty-four per cent of our observed trade values at the HS6 digit level are zeroes. In this case, we use the Poisson-pseudo-maximum likelihood (PPML) estimator (Santos Silva and Tenreyro, 2006). This estimator's log-linear objective function allows us to specify equation (1) in its multiplicative form without log-transforming the dependent variable and accounts for heteroskedasticity. In all cases, we exclude singletons because maintaining them in linear regressions where fixed effects are nested within clusters might lead to incorrect inferences (Correia, 2016).

The endogeneity of the standards–trade relationship is established, yet few studies address it empirically. Our approach improves upon the existing empirical strategy. Including the complete set of three-way fixed effects in equation (1) minimises endogeneity concerns arising from omitted variable biases, selection and initial conditions (Baier and Bergstrand, 2007). The dyadic fixed effects (α_{ij}) control for the unobserved heterogeneity that is specific to each trade flow, e.g. time-invariant observed and unobserved factors that drive both changes in MRL_{ijkt} and bilateral trade. This is important especially in cases where standards are set for political economy reasons; e.g. countries are more likely to set stringent standards to protect domestic sectors in which they face competition from cheaper imports. The country–product–time fixed effects capture (un)observable time-variant and invariant country-specific and product effects such as domestic institutions, comparative advantages, production and consumption patterns whose exclusion may bias β_1.

7. Data

MRLs are the highest level of a pesticide residue that is legally tolerated in or on food or feed when pesticides are applied correctly. To protect consumers from adverse health risks, governments set MRLs measured in ppm on pesticides and veterinary drugs. Each MRL addresses a specific substance (i.e. pesticides, fertilisers or certain chemicals) in a specific commodity in a specific country. They are mandatory regulations that condition market access. Non-compliance can lead to export rejections or complete import bans. As an international benchmark, the Codex sets MRLs that are considered in many studies (e.g. Li and Beghin, 2014; Curzi *et al.*, 2018) as the social optimum. However, the WTO agreement on SPS measures allows countries to deviate from this benchmark in the presence of scientific evidence based on risk assessments. Countries take advantage of this provision to set their own national MRLs. In some cases, the differences in the limits set across countries can be minor, but often, they vary substantially (Table 1). We show in Figure 2 the average MRL values set by different country groups across all products. Developed countries in the North set very stringent standards, relative to developing countries in the South. Of the countries in the North, the EU especially sets very low MRL values. These findings are expected; developing countries are usually standard-takers. MRLs have also become stricter over time. Across all country groups, established residue limits were higher in 2005 compared with 2014. This is further confirmed in Figure A1, which also shows substantial variation in MRLs across countries over the sample period. In our empirical analysis, we exploit these variations in MRLs across countries and products over time as a predictor of trade flows, product prices and estimated product quality.

Due to data availability, the MRL dataset we use covers the period from 2005 to 2014 for 59 countries and 145 agri-food products identified at the HS6

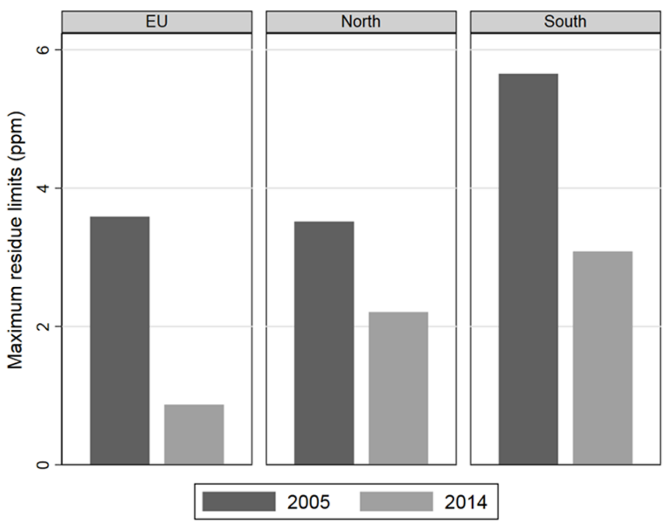

Fig. 2. Average MRLs by importing country groups in 2005 and 2014.
Source: Homologa database. *Notes*: Values are the average maximum residue limits set by the importing country in year *t*. An *MRL* value of 0 is the strictest. The values for the EU are the average across all EU Member States in 2005, but the harmonised value for the EU in 2014. The North is defined as all countries classified as high income by the World Bank income classifications, including the EU Member States.

digit level. We match the MRL data with HS6 digit trade data from United Nations (UN) Comtrade. The products include six-digit HS products under the following two-digit HS groups: HS07–10, HS12, HS14, HS17 and HS18 (Table A1). The sample of importers and exporters includes all countries that establish an MRL and are captured in the Homologa database (Table A2). However, our empirical analysis includes only countries that are present for more than half of the length of the panel. Thus, countries of the Gulf Cooperation Council are dropped since they only begin to appear in the dataset in 2012. There are differences in the MRLs for the EU Member States because until 2009 they set country-specific MRLs. Countries are heterogeneous in the products and pesticides they regulate. For products, this ranges from an average of 70 in Indonesia and Mexico to 128 in the USA and for pesticides a minimum of 66 in Thailand to a maximum of 758 in the Netherlands (Table A3).

For the empirical analysis, we encounter missing MRLs for some country–product–pesticide pairs. To deal with these cases, we follow established procedures in the literature. First, we replace them with default values where available, e.g. the EU sets a default value of 0.01 ppm. Second, many countries defer to Codex standards when no national MRLs are set for a given product–pesticide pair. See Table A4 for a list of country-specific deferral policies. If we still have cases of missing MRLs, we replace them with the least restrictive MRL value across all country–product–pesticide pairs in the sample (see also Drogué and DeMaria, 2012; Ferro, Otsuki and Wilson, 2015; Fernandes, Ferro and Wilson, 2019). To clarify the third step, let us revisit Table 1. In 2014, China had no limits established for Chlorpyrifos use in banana production. If it were the case that China has no established deferral policies, we would replace the missing MRL with the least restrictive MRL value across all countries in the sample for that particular product–pesticide pair—which in this case is 3 ppm. This last step is necessary because replacing missing MRLs with 0 implies that a particular chemical is banned in a country. Dropping missing country-specific chemicals will also make it impossible to compute a dissimilarity index for country pairs in which one regulates a chemical and the other does not. Limiting our data to only chemicals regulated in all countries would also imply erroneously that exporters can enter an importing country without complying with regulations on a chemical that is regulated in the importing country but not in the exporting country.[15]

Finally, to allow us to compare the stringency in standards across country and products over time, we need to compute a measure of bilateral

15 Our original dataset after cleaning (identifying HS6 digit products and manually detecting and correcting redundancies i.e. different names for the same products) was a sample of 23,232,790 observations on pesticides, products and countries. Out of these number 10,081,121 (i.e. 43 per cent) were missing values. We then replaced countries with default MRL values, deferral policies and the Codex standards. This step replaced 3,517,363 (15 per cent) of the missing values. The remaining 28 per cent (i.e. 6,563,758) were replaced by the least stringent MRL across all country–product–pesticide pairs. After these steps, the dataset is then collapsed to the HS6 digit product level.

asymmetry.[16] We adapt the non-linear exponential index of Li and Beghin (2014) at the product level as follows:

$$MRL_{ijkt} = \frac{1}{N_{pk}} \left(\sum_{p \varepsilon N_k} exp \left(\frac{MRL_{ikpt} - MRL_{jkpt}}{MRL_{ikpt}} \right) \right) \quad (2)$$

where i is the exporting country, j is the importing country, k is the product, t is time and p is the pesticide. MRL_{ikt} and MRL_{jkt} are the average product and time-varying MRL set by i and j, respectively. MRL_{ijkt} is the product and time-varying bilateral difference in MRL stringency between country pairs. The index is unit free, invariant to scale since we measure the MRLs for both countries in the same units, and the exponential function imposes increasing marginal difficulty of attaining stricter standards. For further details on the properties of the index, see Li and Beghin (2014). The original Li and Beghin (2014) index is calculated relative to the Codex. To fit our purpose, we adapt their specification following Hejazi, Grant and Peterson (2018) to measure standards relative to other countries that set their own MRLs. Where our index differs from Hejazi, Grant and Peterson (2018) is the time dimension of our index.

Equation (2) yields an index of the domain [0, $e \approx 2.718$]. It is normalised at 1 when the importing and exporting countries set the same standards. It approaches its upper limit when the importing country sets a much stricter standard than the exporting country, and vice versa. The index in equation (2) is an improvement on Li and Beghin (2014) in three ways (see also Hejazi, Grant and Peterson, 2018): (i) stricter importing country standards will not necessarily be restrictive if the exporter faces an MRL at home that is stricter than the level set by Codex or the importer, (ii) since Codex establishes a limited number of MRLs for pesticides, country comparisons to Codex may miss important regulatory differences that exist bilaterally and (iii) the index is fully bilateral allowing us to exploit its time variation to properly identify the trade effect.

Import tariffs are classical trade policy instruments that countries use to regulate trade. On average, applied tariff rates have been falling since the 1990s. This has also coincided with the proliferation of NTMs In our dataset, we observe similar patterns over our study period. Average applied tariffs fell from around 11 to 8 per cent, while MRLs became more stringent falling from an average of 3.89 to 2.39 ppm (see Figures 2 and A2 in the appendix). In our estimations, we control for effectively applied tariffs to account for any potential trade policy substitution between tariffs and standards. We retrieve tariff data from the United Nations Commission on Trade and Development (UNCTAD) via the World Integrated Trading System (WITS). Detailed summary statistics on all our dependent and control variables are shown in Table 2.

16 For a review of the different measures of bilateral asymmetry used in the literature, see Section 2.

Table 2. Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
MRL_{ijkt}^{HS2}	1.171	0.810	0	2.718	100,729
MRL_{ijkt}^{HS6}	1.123	0.813	0	2.718	631,227
Extensive margin (EM_{ijkt})	0.008	0.030	$8.82e-09$	0.559	100,729
Intensive margin (IM_{ijkt})	0.720	1.654	$1.55e-09$	70.320	100,729
Trade value (USD)	3.048	70.053	0	19,144.001	631,227
Tariffs (applied in %)	6.186	28.755	0	800.300	631,227
Unit values/Prices (log)	−5.744	1.125	−8.643	−2.487	399,526
Quality (log)	0.041	1.154	−3.135	2.934	399,526
Quality-adjusted price (log)	−5.785	1.436	−11.487	0.480	399,526

8. Results

8.1. The effect of standards on trade

Table 3 reports the estimated effects of the bilateral differences in MRLs on bilateral trade flows. At the extensive margin, column (1) suggests that the stricter the importing country standard relative to the exporting country standard, the lower the number of exported varieties. At the intensive margin, the pattern and sign remain consistent with the extensive margin. Stringent importing country standards have negative effects on trade at the intensive margin. The total trade effect in column (3) is also negative and shows that the standard's effect on trade is higher, though not by much, on the extensive margin compared with the intensive margin. This is consistent with the idea that the MRL-trade effect operates through affecting fixed costs more than variable costs. Conditional on exports, the effect on observed trade value is also negative (column 4). In column (5) we estimate the effect of MRLs on observed trade flows including zeroes using the PPML estimator. For our variable of interest, the coefficient estimates are consistent with those from the OLS model, but higher in magnitude because by including zero trade flows we also control for sample selection bias. In all cases, the estimated trade effects are statistically significant at the 5 per cent level or lower. Note that the coefficient estimates on $EM_{ijkt} \times IM_{ijkt}$ in column (3) are not equal to the coefficient estimate on X_{ijkt} in column (4). The former measures the relative performance of each exporter in an importer-product-year and unlike the latter do not represent absolute trade volumes.

Table 3. The effect of bilateral differences in MRLs on trade

	EM_{ijkt}^{HS2}	IM_{ijkt}^{HS2}	$EM_{ijkt}^{HS2} \times IM_{ijkt}^{HS2}$	X_{ijkt}^{HS6}	X_{ijkt}^{HS6}
	(1)	(2)	(3)	(4)	(5)
MRL_{ijkt}	−0.070***	−0.066**	−0.136***	−0.082***	−0.120***
	(0.022)	(0.033)	(0.036)	(0.023)	(0.028)
Log $(1 + \text{Tariff}_{ijkt})$	−0.021**	−0.075***	−0.095***	−0.259***	−0.111***
	(0.007)	(0.012)	(0.013)	(0.014)	(0.012)
Observations	100,143	100,143	100,143	615,483	2,682,478
R^2	0.775	0.579	0.729	0.687	

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. The trade margins in columns (1)—(3) are defined using the Feenstra and Kee (2004) measures. The dependent variables in columns (1)-(4) are log-specified and the models are estimated using OLS. The dependent variable is column (5) is observed trade volumes—including zeroes—and is estimated using PPML. EM_{ijkt} = the extensive margin, IM_{ijkt} = the intensive margin and X_{ijkt} = observed trade values.

Because the dependent variable is in logs and the MRL_{ijkt} variable is in levels, the economic interpretation of our results is similar to semi-elasticity. Quantitatively a stricter importing country residue limit equivalent to an increase in MRL_{ijkt} by 0.1 units at the mean—which is an increase of about 9 per cent—reduces total trade by about 1.36 per cent (0.70 per cent at the extensive margin and 0.66 per cent at the intensive margin) and observed trade flows in USD by 0.82 per cent, on average.[17]

Regarding the other control variable, bilateral tariffs have their expected negative effect on trade. In column (4), a 10 per cent increase in bilateral tariffs will reduce observed trade flows by about 2.6 per cent *ceteris paribus*. Because the tariff variable is in logs and the MRL is in levels, the two coefficient estimates cannot be compared directly. However, consistent with Fernandes, Ferro and Wilson (2019), we find that both variables have qualitatively similar effects on trade, but unlike MRLs, the tariff effect is predominantly via the intensive margin.

If we estimate all the models in Table 3 using traditional country–pair gravity variables—bilateral distance, colony, common language and contiguity—instead of the country–pair fixed effects our coefficient estimates on the MRL_{ijkt} index are larger. This is consistent with the arguments by Egger and Nigai (2015) and Agnosteva, Anderson and Yotov (2019) that the bilateral fixed effects in our specification capture more systematic information about trade costs than the standard gravity variables. Hence, failure to control for the bilateral dimensions of the dataset leads to an upward bias in the standard-trade effect. See Table A5 of the appendix.

8.2. The effect of standards on prices, product quality and quality-adjusted prices

In this section, we estimate equation (1) by replacing the dependent variables with unit values and their components, quality and quality-adjusted prices.[18] The results are presented in Table 4. Conditional on exporting, bilateral differences in standards lead to higher prices (column 1). This may indicate that the increased costs to meet standards stricter than those existing domestically in the exporting country are passed on to consumers in the importing country as higher prices. Or, as we show in Table 3, by reducing trade and inducing non-compliant domestic producers and foreign exporters to exit the product-destination market maintaining the standard, standards reduce competition in the imposing country (Abel-Koch, 2013; Gaigné and Larue, 2016). Surviving exporters and domestic producers exploit this and charge higher prices. As a result, consumers in the importing country *j* are either willing to pay a premium

17 The mean MRL_{ijkt} at the extensive and intensive trade margin is 1.171, and for observed trade flows, the mean MRL_{ijkt} is 1.123. See Table 2.

18 The reduction in the number of observations is because the HS3 digit elasticities of substitutions (σ_{jk}) which we use in equation (8) are not available for all importer-product pairs. As a check of robustness, we replace missing σ_{jk} with the importer-specific mean across all products. The results are in line with our baseline findings.

Table 4. The effect of standards on prices, quality and quality-adjusted prices

	$Price_{ijkt}$	$Quality_{ijkt}$	Quality-adjusted $prices_{ijkt}$
	(1)	(2)	(3)
MRL_{ijkt}	0.027***	0.002	0.026**
	(0.008)	(0.013)	(0.012)
Log $(1 + Tariff_{ijkt})$	0.035***	−0.078***	0.113***
	(0.005)	(0.008)	(0.008)
Observations	399,526	399,526	399,526
R^2	0.774	0.436	0.687

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. Price, quality and quality-adjusted prices are in logs. All models are estimated using OLS.

for the improved quality or worse off because of the higher product prices. For tariffs, we do not observe any pricing-to-market effects. Faced with higher tariffs, exporters pass through the extra cost to consumers as higher prices.

In a second step, we decompose the price effect into a quality (column 2) and quality-adjusted price (column 3) component. Because the quality-adjusted price is the net-quality price, it sorts out quality embodied in price. The empirical findings show that stricter MRLs affect the quality and quality-adjusted prices of imports positively. Compared with quality-adjusted prices, the effects on quality are small in magnitude and are not statistically significant. This is consistent with the distributions plotted in Figure 1. With these results, we can assess how much of the variation in import prices is attributable to pure prices and quality upgrading. The MRL-induced price increase in column (1) is predominantly due to a pure price raising effect (i.e. 0.026/0.027 = 96 per cent) of the standard and less of a quality-upgrading effect. On average, a 0.1 unit increase in the MRL index at the mean is associated with a 0.02 per cent increase in product quality and a 0.26 per cent increase in quality-adjusted prices. Bilateral tariffs increase product prices, while a 10 per cent decrease in bilateral tariffs will increase estimated product quality by 0.8 per cent and decrease quality-adjusted prices by 1.13 per cent.[19]

Furthermore, we test whether differences in MRLs affect the pricing and quality strategy differently when the scope for product differentiation is high (i.e. vertical differentiation) or low (i.e. horizontal differentiation). When two products are vertically differentiated, consumers would prefer one to the other

19 Different mechanisms may be at play depending on the type of bilateral tariff applied by the importing country, e.g. specific tariffs are positively correlated with prices and quality while *ad valorem* tariffs are negatively correlated with prices and quality. See Curzi and Pacca (2015) for an empirical test of these two mechanisms in the food sector. Our findings here are a mix of the two mechanisms, i.e. tariffs affect prices positively and quality negatively. This result is driven in part by the fact that our analysis is done at the country level and considers multiple products. Different bilateral tariff regimes apply to these different products across countries over time. Hence, our tariff measure, i.e. applied bilateral tariffs, which is a combination of *ad valorem* and specific tariffs may be driving our findings.

if they were sold at the same price. With horizontal differentiation, goods are different but at the same price, some consumers will buy one or the other, depending on their preferences. Following Khandelwal (2010) we measure product differentiation using the so-called product 'quality ladder'. We compute the quality ladder as the difference between the maximum and minimum values of estimated quality in a product category. Products with values below the median are characterised by lower product differentiation (i.e. short-quality ladder). In our sample, these are mainly fruits, vegetables, nuts, spices and oilseeds. In contrast, products with values above the median (i.e. the long-quality ladder) are vertically differentiated. In our sample, these are mainly coffee, tea, certain fruits (citrus, apples, pineapples, guava, mangoes, banana, apricots and cherries), certain nuts (cashew, almonds, walnuts, pistachios and dates) and some vegetables (e.g. onions, salad beetroots, gherkins, sweet corn and sweet potatoes). The results presented in Table 5 confirm our main findings in both product classes. The price raising effect of bilateral differences in MRLs and the null effect on quality is confirmed in the two sub-samples. The homogeneous effects we observe across the two groups show that the products we consider are mostly horizontally differentiated. Thus, compliant producers take advantage of the limited scope for product differentiation to charge higher (quality-adjusted) prices.

8.3. Heterogeneity across country different trade routes

Here we assess the heterogeneity of the standards–trade, standards–price and standards–quality effect across different trade routes: South–South (i.e. trade between developing countries), North–North (i.e. trade between developed countries), South–North (i.e. exports from developing to developed countries) and North–South (i.e. exports from developed to developing countries). The results are presented in Table 6. We define the North as high-income countries. Because the MRL index is asymmetric, the direction of trade is important.[20] North–South and South–South trade flows are rarely studied in the applied trade literature yet offer important insights into the heterogeneity of the standards–trade effect. In a recent meta-analysis of the NTM and agricultural trade literature by Santeramo and Lamonaca (2019), only three papers considered South–South or South–North trade and 40 papers considered North–North and North–South trade.

To allow direct comparisons of the magnitudes of the estimated coefficients across the different samples, the reported estimates are standardised beta coefficients. Generally, the findings remain consistent with our baseline. The bigger the bilateral difference in standards the bigger the trade effect. Hence, in all but at the intensive margin, the negative effects of standards on trade flows are larger for South–North trade and do not matter for North–South and South–South trade. At the extensive margin, the standard-trade effect is only

20 Take the case of Carbaryl use in citrus production (Table 1). For Vietnamese exports to the EU, the index will be $\exp[(7-0.01)/7] = 2.714$. Vietnamese imports from the EU will, however, not be affected as the index approaches its lower bound, i.e. $\exp[(0.01-7)/0.01] \approx 0$.

Table 5. The effect of standards on prices, quality and quality-adjusted prices: quality ladder

	Short quality ladder			Long quality ladder		
	$Price_{ijkt}$	$Quality_{ijkt}$	QA $price_{ijkt}$	$Price_{ijkt}$	$Quality_{ijkt}$	QA $price_{ijkt}$
	(1)	(2)	(3)	(4)	(5)	(6)
MRL_{ijkt}	0.027**	−0.008	0.036**	0.025**	0.001	0.025
	(0.011)	(0.019)	(0.018)	(0.011)	(0.017)	(0.016)
Log $(1 + Tariff_{ijkt})$	0.029***	−0.083***	0.112***	0.040***	−0.077***	0.117***
	(0.006)	(0.012)	(0.012)	(0.007)	(0.012)	(0.012)
Observations	203,554	203,554	203,554	195,837	195,837	195,837
R^2	0.785	0.473	0.694	0.759	0.423	0.682

Notes: The sample is divided according to the level of product differentiation, as indicated by the quality ladder. We compute the quality ladder as the difference between the maximum and the minimum value of estimated quality in a given product category. Products with quality ladder values below the median fall in the category short-quality ladder. Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. Price, quality and quality-adjusted (QA) prices are in logs. All models are estimated using OLS.

Table 6. Heterogeneities across different trade routes

	North-to-North		North-to-South		South-to-South		South-to-North	
	MRL_{ijkt}	$Tariff_{ijkt}$	MRL_{ijkt}	$Tariff_{ijkt}$	MRL_{ijkt}	$Tariff_{ijkt}$	MRL_{ijkt}	$Tariff_{ijkt}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EM_{ijkt}	0.002	0.001	−0.006	−0.016	−0.023	−0.023	−0.064***	0.009
	(0.011)	(0.006)	(0.024)	(0.015)	(0.028)	(0.016)	(0.013)	(0.007)
IM_{ijkt}	−0.030**	−0.036***	−0.018	−0.023	−0.004	−0.007	−0.023	−0.031***
	(0.015)	(0.008)	(0.025)	(0.018)	(0.036)	(0.023)	(0.020)	(0.010)
$EM_{ijkt} \times IM_{ijkt}$	−0.021*	−0.027***	−0.018	−0.027*	−0.018	−0.020	−0.058***	−0.018**
	(0.012)	(0.006)	(0.021)	(0.014)	(0.030)	(0.019)	(0.016)	(0.007)
$\ln(X_{ijkt})$	−0.024**	−0.117***	−0.019	−0.057***	−0.011	0.009	−0.033***	−0.041***
	(0.009)	(0.009)	(0.021)	(0.016)	(0.027)	(0.024)	(0.010)	(0.012)
$Price_{ijkt}$	0.025**	0.032***	0.028	0.004	0.032	−0.062	0.008	0.016
	(0.010)	(0.009)	(0.031)	(0.019)	(0.039)	(0.039)	(0.011)	(0.011)
$Quality_{ijkt}$	0.002	−0.112***	0.002	−0.022	0.058	−0.036	−0.027	−0.005
	(0.016)	(0.015)	(0.044)	(0.037)	(0.057)	(0.056)	(0.017)	(0.019)
QA $Price_{ijkt}$	0.018	0.115***	0.020	0.021	−0.022	−0.020	0.028**	0.016
	(0.011)	(0.012)	(0.032)	(0.028)	(0.036)	(0.041)	(0.013)	(0.014)

Notes: Robust country–pair–product clustered standard errors in parentheses. Point estimates are beta coefficients calculated by standardising the estimates from the regression analysis to have zero mean and unit standard deviation. They refer to how many standard deviations the explained variable will change per standard deviation increase in the corresponding explanatory variable. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. MRL_{ijkt} is measured in levels and tariffs are defined in logs, i.e. Log $(1 + Tariff_{ijkt})$. EM_{ijkt} = extensive margin, IM_{ijkt} = intensive margin, X_{ijkt} = observed trade values, QA $price_{ijkt}$ = quality-adjusted prices. All models are estimated using OLS.

statistically significant for South–North trade flows, indicating that there are a lot of less qualified exporters from the South due to the high fixed cost component of the standard. The general trend remains the same for observed trade values. The magnitude of the trade effects is larger for South–North trade compared with North–North trade. This is due to compliance-related costs (e.g. annual certification renewals, upgrading existing infrastructure or establishing new ones) and other supply-side constraints such as lower quality of domestic institutions, trade-related infrastructural deficiencies and limited capacities to produce. We control adequately for these other constraints using the country fixed effects in our models. Given these challenges in many developing countries, segregating crops for different markets based on the different residue limits is a challenge that can lead to increased border rejections and reduced trade volumes. The effect of standards on North–North trade is predominantly via the intensive margin. So, while standards do not affect the number of different crops exported by developed countries, on trading it reduces the volume. In terms of prices, differences in MRLs lead to increased product prices, but the effects are only statistically significant for trade between developed countries. The effects on quality are also not statistically significant across the different sub-samples. If we adjust prices for quality, successful exporters from the South to the North charge higher prices.

8.4. Sensitivity Analyses

Globally, the EU is reputed for setting very strict food safety standards (Curzi *et al.*, 2018). This is also evident from Table 1 and Figure 2. As a result, this section checks the robustness of our findings using different sensitivity analyses that focus on the EU. First, we re-estimate our baseline models but exclude EU trade (Table A6). In all cases, the MRL_{ijkt} variable has the expected sign but the effects are not statistically significant. This implies that our main findings are driven in most part by EU standards. In September 2008 the EU harmonised national MRL legislation among its Member States. To see how this harmonisation affects our findings, we re-estimate our models using the years post-harmonisation (i.e. 2009–2014) and treat the EU as a single importing country (Table A7). Our main findings remain unchanged. However, the point estimates increase in magnitude relative to our benchmark estimations. This is consistent with Figure 2 where we observe that MRL stringency increased over time across all regions, but especially in the EU. In a third step, we drop intra-EU trade from the baseline sample (Table A8). Here again, our main findings remain qualitatively the same. Finally, we consider only intra-EU trade over the period from 2005 to 2008 when the Member States had national MRLs (Table A9). Here, the standards–trade effect is not statistically significant but we observe statistically significant positive effects on quality and a decrease in quality-adjusted prices. This confirms that pre-harmonisation, MRLs induced product quality upgrading among EU Member States. These robustness checks confirm our main findings, but also highlight the important role of EU standards.

9. Discussion

Our empirical findings can be broadly categorised into three sets. First, we show that an increase in the stringency of standards in an importing country relative to standards in an exporting country limits trade by reducing the varieties of goods traded, the value of goods traded and observed trade flows. These findings are consistent with existing works on MRLs (e.g. Winchester *et al.*, 2012; Hejazi, Grant and Peterson, 2018; Curzi *et al.*, 2018). In the spirit of the Melitz (2003) and Chaney (2008) type models, stringent importing country standards by raising fixed and variable trade costs induce a selection effect that discriminates against non-compliant exporting countries.

Second, MRL-induced price increases are driven in most part by quality-adjusted prices. Estimated product qualities in Table 4 barely respond to differences in MRLs. This suggests that conditional on trading, country–product export volumes after controlling for product prices—which form the basis of our definition of quality—remain unchanged. MRLs are public mandatory standards and unlike private quality standards, e.g. Fairtrade, UTZ or Organic, are not directly communicated to consumers. This may explain the null quality effect. Because lower-quality firms exit the market, surviving firms take advantage of the reduced competition to exert some form of market power; they charge higher prices without necessarily increasing their market shares. The latter effect is also confirmed by the negative effect we see at the intensive trade margin. Even for compliant exporters, the number of exported varieties and export volumes decrease. This is consistent with the findings in Asprilla *et al.* (2019) that stricter NTMs in a given market reduce the number of surviving firms and increases their market power, but if anything, only has a small positive effect on import shares. Comparing the MRL and tariff coefficients also offers interesting insights. For one, we see that an increase in both MRL stringency and tariffs have positive effects on prices. But, these two trade policy instruments affect quality in ways that are not isomorphic to each other. For MRLs there is a null effect on quality whiles tariffs affect quality negatively. While stricter MRLs induce a price increase, there are no associated changes in product quality-upgrading. This is because MRL trade policy changes affect both home and foreign producing firms Thus, instead of displacing foreign firms in favour of domestic ones—like the tariff case—NTMs displace small firms in favour of larger ones, increasing the market power of compliant firms in the process (Asprilla *et al.*, 2019). For tariffs, price increases induce reductions in country–product market shares and thus lower quality. This is because tariffs increase the price of imports relative to domestic production. This decreases the demand faced by foreign exporting firms and hence their market shares.

Finally, MRLs hinder export flows from the South more than it does for the North. This confirms existing works by Xiong and Beghin (2014) and Curzi *et al.* (2018). In fact, for North–South trade, tariffs, but not differences in standards, are significant barriers to trade. It is also insightful to see that the tariff effects are larger for North–North trade compared with South–North trade.

Many developing countries are beneficiaries of preferential trading regimes provided by developed countries.

Overall, differences across national MRLs do not lead to a statistically significant effect on estimated product quality. As a consequence, we observe disruptions to trade and welfare losses to consumers—limited varieties and lower quantities at higher prices. The exception is for intra-EU trade where MRLs induce significant increases in quality-upgrading and lower quality-adjusted prices. The general importance of EU food standards is highlighted in our various sensitivity analyses. While food safety risks are borderless and the consequences are easily transmitted across countries, approaches to tackling them are still national in scope. But as Yeung *et al.* (2018) notes, there is no discernible gain in food safety from using national MRLs. Taken together, for the combined effects of heterogeneity in MRL standards, to be welfare improving, it should translate into relevant and currently unmeasured health and environmental effects. Future analyses should consider more seriously the possibility of measuring these kinds of (hidden) benefits.

For policy-making, because regulatory heterogeneity of standards hinders trade and lead to higher food prices, a move towards regulatory harmonisation or mutual recognition agreements is a necessary step to dampening these effects. The idea that harmonising standards will increase trade flows, in the end, is not far-fetched and has been shown empirically in contributions by Chen and Mattoo (2008) and Disdier, Fontagné and Cadot (2015), amongst others. A well-known downside is that the stricter developed country standards will then become the *de facto* mandatory standard. Nevertheless, because this allows producing according to a common benchmark, it can be seen as a cost-saving mechanism in the long run. A second approach is the need to ensure that NTMs are appropriate, transparent, science-based and do not overly restrict trade. For MRLs, this means that there should be a significant incentive for all countries to strengthen the Codex and ensure that it has the scientific capacity and resources to develop standards acceptable for most, if not all, countries.

Our study is not without limitations. At the most fundamental level, international trade takes place between firms Due to the lack of firm-level transaction and customs data this paper applies insights from heterogeneous firm models at the country level. As a result, our estimations ignore productivity and quality differences across firms within a country. For example, different firms in country *i* might be offering products of different quality levels. Lack of finer trade data implies that we cannot estimate quality for individual firms in country *i*, and our quality estimates reflect the average quality of product from country *i*. To test the exact mechanisms underlying our findings, extensions of our results with firm-level transactions and customs data are recommended. Our analysis is comprehensive for the sample covered—i.e. countries that established MRLs at least half the length of our panel—and not necessarily for all countries. There is room here for further work. It is also interesting to see how country-specific GAP moderate the effects we report here. Extensions of our analysis can also consider differences in the type of chemical applied in the production process. Our analyses consider all chemicals as homogeneous. Yet, recently Hejazi, Grant and Peterson (2018) show that the effects of MRLs are heterogeneous across chemical classes such as herbicides, pesticides and fungicides. In future research, it might be interesting to test empirically whether producers in country i already exporting to country j_1 with very strict MRLs find it easier to export to country j_2 with relatively laxer standards for product k. As a result, the welfare implications of MRLs may differ across importing countries depending on the stringency of their established residue limits.

10. Conclusion

How standards affect trade in agri-food products has been a subject of intense scrutiny. The rapid increase in the number of published studies assessing the standards–trade nexus—from about 14 in the year 2000 to about 140 studies in 2017 (Santeramo and Lamonaca, 2019)—is a good case in point. A limitation of this strand of literature is its predominant focus on the direct trade effects of standards, whiles ignoring other welfare effects. In this paper, we provide the first set of empirical evidence on the quality and quality-adjusted price effects of regulatory heterogeneity in agricultural markets. Specifically, we study the effects of bilateral differences in MRLs on trade, product prices, quality and quality-adjusted prices. Our empirical analysis exploits bilateral differences in MRLs of 59 countries across 145 products over the period from 2005 to 2014 within a structural gravity framework.

We find that regulatory heterogeneity in product standards decreases trade flows. Conditional on trading, stricter importer MRLs decrease the number of varieties traded and the volume of observed trade flows. Yet successful exporters charge higher prices (unit values). This holds even if we adjust prices for quality. However, we observe only a small but statistically insignificant effect on estimated product quality. This implies that MRL dissimilarity leads to higher product prices, but do not induce product quality upgrading. This may be driven by the reduced competition induced by stricter standards in the importing country, which surviving firms exploit to exert some form of market power. Even so, the increased compliance costs will reduce their trade volumes. This is supported by the negative effects at the intensive margin. Exploring the heterogeneity of these findings across different trade routes, we observe that the trade reducing and price raising effects are strongest for South–North trade, followed by North–North trade, but do not matter for South–South and North–South trade. For tariffs, we see that further liberalisation will induce quality-upgrading, increase trade volumes and available product varieties and also lower (quality-adjusted) prices.

The previous section already discusses several potential extensions of our analyses. However, given our results about the negative and asymmetric trade effects of MRL heterogeneity, and their failure to trigger a real process of quality upgrading, future analyses should devote more effort to investigating whether and to what extent, stricter MRLs really translate into health and environmental benefits. The last point is crucial, especially because the region currently imposing more stringent MRLs, i.e. the EU, already plans to further enhance provisions to reduce the use of chemical pesticides for health and environmental reasons.[21] How this process will be implemented through true cooperation and the promotion of international standards, vis-à-vis unilateral initiatives, could matter a lot from a trade and welfare perspective.

Table A1. List of products

2-digit HS group	6-digit HS products
HS 07	70190, 70200, 70310, 70320, 70390, 70410, 70420, 70511, 70521, 70610, 70690,
	70700, 70810, 70820, 70910, 70920, 70930, 70940, 70951, 70959, 70970,70990,
	71040, 71120, 71130, 71220, 71233, 71333, 71340, 71350, 71410, 71420, 71490
HS 08	80119, 80121, 80122, 80131, 80132, 80211, 80212, 80221, 80222, 80231, 80232
	80240, 80250, 80290, 80300, 80410, 80420, 80430, 80440, 80450, 80510, 80520,
	80540, 80550, 80590, 80610, 80620, 80711, 80720, 80810, 80820, 80910, 80920, 80930, 80940, 81010, 81020, 81030, 81040, 81050, 81060, 81090, 81190, 81310, 81320, 81330
HS 09	90111, 90112, 90121, 90122, 90210, 90220, 90230, 90240, 90411, 90412, 90500,
	90610, 90620, 90700, 90810, 90820, 90830, 90910, 90920, 90930, 90940, 90950,
	91010, 91020, 91030, 91040, 91050, 91099
HS 10	100110, 100190, 100200, 100300, 100400, 100510, 100590, 100610 100630,
	100700, 100810, 100820, 100890
HS 12	120100, 120210, 120220, 120400, 120510, 120600, 120710, 120720, 120740,
	120750, 120760, 120791, 120799, 120921, 121110, 121120, 121190, 121291,
	121299, 121300, 121490
HS 14	140110
HS 17	170310, 170380
HS 18	180100

Notes: Following Li and Beghin (2014), we detect and address exact redundancies in the dataset. These are cases where the same commodities have different names e.g. ‘pistachios’, ‘pistachios, nuts’, ‘pistachios: dry’, ‘nuts – pistachios’.

21 The EU Commission plans to reduce the overall use and risk of chemical pesticides and more hazardous pesticides by 50 per cent by 2030.

Table A2. List of importing and exporting countries

Argentina, Australia, Austria, Belgium, Bulgaria, Brazil, Bahrain, Cambodia, Canada, Chile, China, Croatia, Colombia, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Laos, Latvia, Lithuania, Luxembourg, Malaysia, Mexico, Malta, Myanmar, the Netherlands, Norway, New Zealand, Philippines, Poland, Portugal, Russia, Singapore, South Africa, South Korea, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, Ukraine, UK, USA, Vietnam.

Table A3. Average number of regulated pesticides per country

Country/region	Pesticides	Country/region	Pesticides
Thailand	66	Croatia	559
ASEAN	80	Finland	559
Singapore	109	Latvia	559
Indonesia	112	Slovenia	559
Vietnam	163	Bulgaria	559
Egypt	175	Cyprus	559
Colombia	175	Switzerland	563
Malaysia	177	Ireland	567
Chile	227	Denmark	570
India	247	Greece	570
Mexico	266	Estonia	574
Canada	312	Sweden	574
Brazil	316	Malta	578
New Zealand	326	UK	579
Argentina	340	Portugal	583
Israel	342	Czech Republic	584
Codex	343	Slovak Republic	589
South Africa	351	Hungary	625
Hong Kong	353	Poland	627
Ukraine	369	Luxembourg	650
China	403	France	664
Taiwan	406	Germany	665
Australia	435	Belgium	668
USA	448	Italy	671
Russia	486	Austria	706
Korea	490	Japan	707
Turkey	496	Spain	724
Norway	512	The Netherlands	758
Lithuania	559		

Table A4. MRL deferral policies by country

	Deferral policy	
Country	1	2
Argentina	Codex	0.01
Australia	0.01	
Bahrain	ASEAN	Codex
Brazil	Codex	
Cambodia	ASEAN	Codex
Canada	0.1	
China	Codex	
Colombia	Codex	
Egypt	Codex	EU
EU	0.01	
India	Codex	
Indonesia	Codex	
Israel	Codex	
Japan	0.01	
Laos	ASEAN	Codex
Malaysia	Codex	0.01
Myanmar	ASEAN	Codex
New Zealand	Codex	
Norway	0.01	
Philippines	ASEAN	Codex
Russia	Codex	
Singapore	Codex	
South Africa	Codex	EU
South Korea	Codex	
Switzerland	0.01	
Taiwan	0.01	
Thailand	Codex	
Turkey	0.01	EU
USA	0.01	
Vietnam	ASEAN	Codex

Table A5. The effect of bilateral differences in MRLs on trade: no bilateral fixed effects

	EM_{ijkt}^{HS2}	IM_{ijkt}^{HS2}	$EM_{ijkt}^{HS2} \times IM_{ijkt}^{HS2}$	X_{ijkt}^{HS6}
	(1)	(2)	(3)	(4)
MRL_{ijkt}	−0.127***	−0.047	−0.174***	−0.195***
	(0.024)	(0.037)	(0.041)	(0.024)
$\text{Log}\ (1 + \text{Tariff}_{ijkt})$	−0.073***	−0.108***	−0.181***	−0.404***
	(0.009)	(0.014)	(0.016)	(0.014)
Colony_{ij}	0.275***	0.193***	0.467***	0.216***
	(0.044)	(0.073)	(0.089)	(0.031)
Language_{ij}	0.165***	0.238***	0.403***	0.363***
	(0.039)	(0.063)	(0.076)	(0.028)
Contiguity_{ij}	0.053	0.598***	0.652***	0.999***
	(0.046)	(0.067)	(0.086)	(0.027)
$\text{Log Distance}_{ijkt}$	−0.704***	−0.925***	−1.628***	−1.037***
	(0.015)	(0.023)	(0.028)	(0.012)
Observations	100,279	100,279	100,279	615,616
R^2	0.706	0.472	0.626	0.637

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time and exporter-product-time fixed effects included in all regressions. Intercepts included but not reported.

Table A6. The effect of bilateral differences in MRLs on trade, prices and quality upgrading: without EU trade

	EM_{ijkt}	IM_{ijkt}	$EM_{ijkt} \times IM_{ijkt}$	X_{ijkt}	X_{ijkt}	Price$_{ijkt}$	Quality$_{ijkt}$	QA price$_{ijkt}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MRL$_{ijkt}$	−0.008	−0.023	−0.030	−0.038	−0.082	0.020	0.010	0.009
	(0.037)	(0.057)	(0.061)	(0.036)	(0.057)	(0.014)	(0.025)	(0.024)
Log (1 + Tariff$_{ijkt}$)	−0.018	−0.052***	−0.070***	−0.177***	−0.062*	0.007	−0.050**	0.056***
	(0.013)	(0.018)	(0.021)	(0.030)	(0.035)	(0.010)	(0.021)	(0.020)
Observations	30,297	30,297	30,297	146,480	638,503	82,503	82,503	82,503
Estimator	OLS	OLS	OLS	OLS	PPML	OLS	OLS	OLS

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. EM_{ijkt} = extensive margin, IM_{ijkt} = intensive margin, X_{ijkt} = observed trade values, QA price$_{ijkt}$ = quality-adjusted prices.

Table A7. The effect of bilateral differences in MRLs on trade, prices and quality upgrading: post-2009 with EU as a single importer

	EM_{ijkt}	IM_{ijkt}	$EM_{ijkt} \times IM_{ijkt}$	X_{ijkt}	X_{ijkt}	Price_{ijkt}	Quality_{ijkt}	QA price_{ijkt}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MRL_{ijkt}	−0.003	−0.145***	−0.148***	−0.092***	−0.050	0.050***	0.002	0.048**
	(0.034)	(0.053)	(0.057)	(0.034)	(0.058)	(0.014)	(0.024)	(0.023)
$\text{Log}\ (1 + \text{Tariff}_{ijkt})$	−0.003	−0.051***	−0.054***	−0.208	−0.112***	0.028***	−0.001	0.029*
	(0.011)	(0.018)	(0.019)	(0.022)	(0.029)	(0.010)	(0.017)	(0.016)
Observations	31,884	31,884	31,884	160,261	870,374	80,570	80,570	80,570
Estimator	OLS	OLS	OLS	OLS	PPML	OLS	OLS	OLS

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. EM_{ijkt} = extensive margin, IM_{ijkt} = intensive margin, X_{ijkt} = observed trade values, QA price_{ijkt} = quality-adjusted prices.

Table A8. The effect of bilateral differences in MRLs on trade, prices and quality upgrading: excluding intra-EU trade

	EM_{ijkt}	IM_{ijkt}	$EM_{ijkt} \times IM_{ijkt}$	X_{ijkt}	X_{ijkt}	$Price_{ijkt}$	$Quality_{ijkt}$	QA $price_{ijkt}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MRL_{ijkt}	−0.075***	−0.045	−0.119***	−0.065***	−0.056	0.019**	−0.005	0.024*
	(0.023)	(0.034)	(0.037)	(0.024)	(0.043)	(0.009)	(0.015)	(0.014)
Log $(1 + Tariff_{ijkt})$	−0.034***	−0.022*	−0.056***	−0.142***	−0.059**	0.010*	−0.023**	0.033***
	(0.008)	(0.011)	(0.013)	(0.017)	(0.025)	(0.006)	(0.011)	(0.010)
Observations	73,730	73,730	73,730	362,235	1,840,257	227,653	227,653	227,653
Estimator	OLS	OLS	OLS	OLS	PPML	OLS	OLS	OLS

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. EM_{ijkt} = extensive margin, IM_{ijkt} = intensive margin, X_{ijkt} = observed trade values, QA $price_{ijkt}$ = quality-adjusted prices.

Table A9. The effect of bilateral differences in MRLs on trade, prices and quality upgrading: intra-EU trade (2005–2008)

	EM_{ijkt}	IM_{ijkt}	$EM_{ijkt} \times IM_{ijkt}$	X_{ijkt}	X_{ijkt}	$Price_{ijkt}$	$Quality_{ijkt}$	QA $price_{ijkt}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MRL_{ijkt}	−0.081	−0.121	−0.202	0.302	−0.241	0.144	0.319***	−0.176*
	(0.168)	(0.252)	(0.272)	(0.215)	(0.307)	(0.088)	(0.122)	(0.099)
Observations	9934	9934	9934	86,956	270,547	58,614	58,614	58,614
Estimator	OLS	OLS	OLS	OLS	PPML	OLS	OLS	OLS

Notes: Robust country–pair–product clustered standard errors in parentheses. ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent, respectively. Importer-product-time, exporter-product-time and importer-exporter fixed effects included in all regressions. Intercepts included but not reported. EM_{ijkt} = extensive margin, IM_{ijkt} = intensive margin, X_{ijkt} = observed trade values, QA $price_{ijkt}$ = quality-adjusted prices. Tariffs are excluded from this regression because the EU is a customs union.

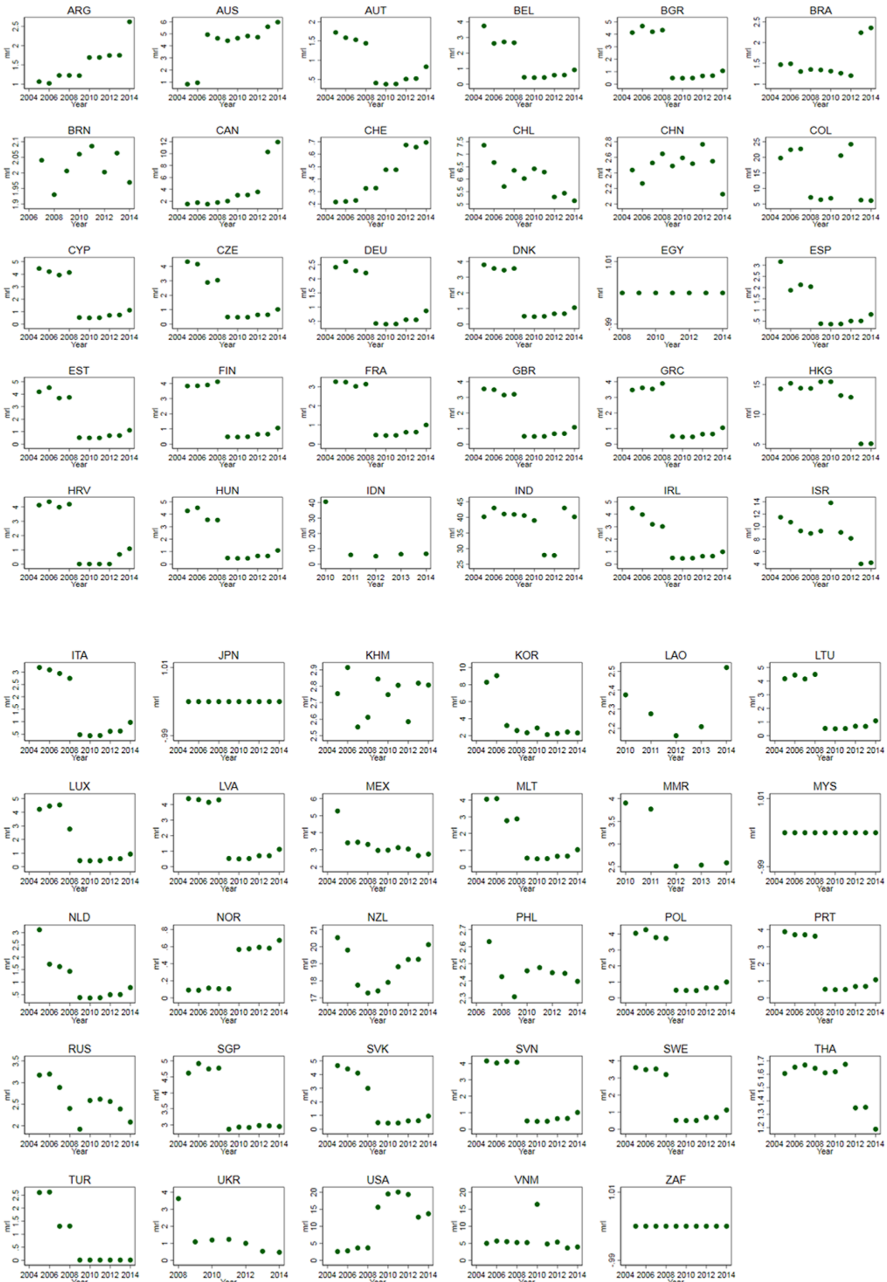

Figure A1. Variation in MRLs across countries and over time.

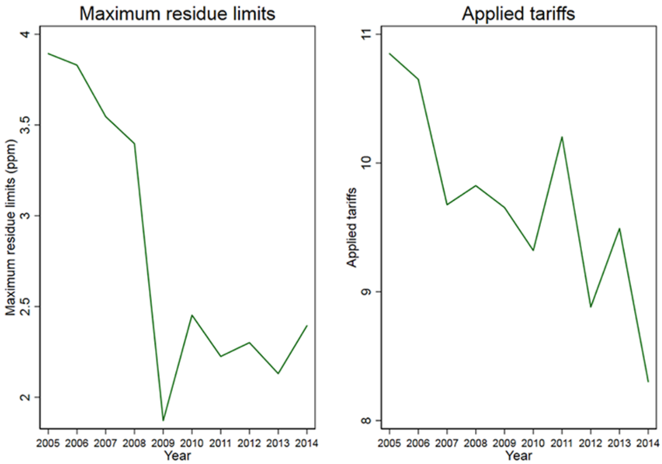

Figure A2. Evolution of tariffs and MRLs over time (2005–2014).
Source: Homologa database and UNCTAD.

Appendix A: Measures of the extensive and intensive margins

We define the extensive trade margin as the worldwide average export overall years to country j in those HS2 digit categories R where country i exports to j, relative to the worldwide average export to j overall years t in all categories. Formally, let $h2$ and $h6$ be the two-digit and six-digit level of the HS classification, respectively. R^{h2}_{ijt} is the exporting country i's categories set exported to j, in year t, and R^{h2}_{jW} accounts for the set of world categories exported to the country j over all the considered years. Defining $\bar{V}^{h2}_{jW,h6}$ as the average value of the world's exports to country j of the category h6 over time, then the bilateral extensive margin for industry $h2$ in year t is given as:

$$EM_{ijh2,t} = \frac{\sum_{h6\varepsilon R^{h2}_{ijt}} \bar{V}^{h2}_{jW,h6}}{\sum_{h6\varepsilon R^{h2}_{jW}} \bar{V}^{h2}_{jW,h6}} \tag{3}$$

Similarly, let $\bar{V}^{h2}_{ijh6t}$ be the value of exports of country i to j of the category $h6$ at time t, then the bilateral intensive margin in industry $h2$ compares the export trade values of country i to country j of products in a certain set of goods in year t with the average export value of the world to country j for the same set of products.

$$IM_{ijh2,t} = \frac{\sum_{h6\varepsilon R^{h2}_{ijt}} V^{h2}_{ijh6t}}{\sum_{h6\varepsilon R^{h2}_{ijt}} \bar{V}^{h2}_{jW,h6}} \tag{4}$$

Hence, it measures country i's overall market share within the set of categories it exports to j. A nice property of the decomposition is that the product of the margins equals the ratio of exports from i to j relative to country j's total imports. Taking the natural logs and using some algebra, Hummels and Klenow (2005) show that the log of the value of the trade flow from i to j, ln X_{ijkt}, can be decomposed linearly into:

$$lnX_{ijkt} = lnEM_{ijkt} + lnIM_{ijkt} + lnX_{jkt} \quad (5)$$

where the value of j's imports from the world, X_{jkt}, is accounted for by the λ_{jkt} term in equation (1).

Appendix B: Estimating quality following Khandelwal, Schott and Wei (2013)

Consider the following CES utility function, which expresses the preferences of consumers for a variety n in country j, assuming that consumers' preferences incorporate quality:

$$U = \left[\int_{\nu \varepsilon V} [\lambda(\nu) q(\nu)]^{\frac{\sigma-1}{\sigma}} d\nu \right]^{\frac{\sigma}{(\sigma-1)}} \quad (6)$$

where q(ν)is the consumed quantity of $\nu$and $\lambda(\nu)$is its quality, while $\sigma > 1$ is the elasticity of substitution parameter which is assumed to be constant. Maximising (6) under the usual budget constraint gives the demand of consumers in country j for product k coming from country i as depending on the price and quality of the product, prices of substitute products and on the income of the consumer, yielding:

$$q_{ijkt} = \lambda_{ijkt}^{\sigma-1} p_{ijkt}^{-\sigma} P_{jt}^{\sigma-1} Y_{jt} \quad (7)$$

where p_{ijkt} and λ_{ijkt} are the price and the relative quality attributed by country j, to product k, exported by country i, respectively. The terms P_{jt} and Y_{jt} account, respectively, for the importing countries' price index and income level. Log linearising equation (7) and moving the endogenous price to the left-hand side of the equation, we can estimate the quality for each country–product–year as the residual from the following OLS regression:

$$lnq_{ijkt} + \sigma_{jk} lnp_{ijkt} = \alpha_k + \alpha_{jt} + e_{ijkt} \quad (8)$$

where q_{ijkt} and $p_{ijk\text{t}}$ are, respectively, the quantity and the price (unit value) of product k, exported by country i to country j at time t. α_k are product fixed effects that capture differences in prices and quantities across product categories due to the inherent characteristics of products. α_{jt} are importer-year fixed effects that account for both the destination price index P_{jt} and income Y_{jt}. Estimating (8) separately for each country and HS4 digit industry, the estimated quality is given as $ln\hat{q}_{ijkt} \equiv \hat{e}_{ijkt} / (\sigma_{jk} - 1)$. We allow the elasticity of substitution to differ across HS3 digit product classes using data from Broda, Greenfield and Weinstein (2017).

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References

Abel-Koch, J. (2013). Endogenous Trade Policy with Heterogeneous Firms. *Tech. Rep., Gutenberg School of Management and Economics*. Mainz: Johannes Gutenberg-Universität,

Agnosteva, D. E., Anderson, J. E. and Yotov, Y. V. (2019). Intra-national trade costs: assaying regional frictions. *European Economic Review* 112: 32–50.

Anderson, J. E. and van Wincoop, E. (2003). Gravity with gravitas: a solution to the border puzzle. *American Economic Review* 93: 170–192.

Arita, S., Beckman, J. and Mitchell, L. (2017). Reducing transatlantic barriers on US-EU agrifood trade: what are the possible gains? *Food Policy* 68: 233–247.

Asfaw, S., Mithöfer, D. and Waibel, H. (2010). Agrifood supply chain, private-sector standards, and farmers' health: evidence from Kenya. *Agricultural Economics* 41: 251–263.

Asprilla, A., Berman, N., Cadot, O. and Jaud, M. (2019). Trade policy and market power: firm-level evidence. *International Economic Review* 60: 1647–1673.

Baier, S. L. and Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? *Journal of International Economics* 71: 72–95.

Beghin, J. C., Maertens, M. and Swinnen, J. (2015). Nontariff measures and standards in trade and global value chains. *Annual Review of Resource Economics* 7: 425–450.

Bojnec, S. and Fertő, I. (2017). Quality upgrades of EU agri-food exports. *Journal of Agricultural Economics* 68: 269–279.

Breinlich, H., Dhingra, S. and Ottaviano, G. I. (2016). How have EU's trade agreements impacted consumers? CEP Discussion Paper 1417, Centre for Economic Performance, London School of Economics and Political Science.

Broda, C., Greenfield, J. and Weinstein, D. E. (2017). From groundnuts to globalization: a structural estimate of trade and growth. *Research in Economics* 71: 759–783.

Cadot, O., Carrere, C. and Strauss-Kahn, V. (2011). Export diversification: what's behind the' hump? *Review of Economics and Statistics* 93: 590–605.

Chaney, T. (2008). Distorted gravity: the intensive and extensive margins of international trade. *American Economic Review* 98: 1707–1721.

Chen, M. X. and Mattoo, A. (2008). Regionalism in standards: good or bad for trade? *Canadian Journal of Economics* 41: 838–863.

Correia, S. (2016). REGHDFE: Stata module to perform linear or instrumental-variable regression absorbing any number of high-dimensional fixed effects. Statistical Software Components, Boston College Department of Economics.

Crozet, M., Head, K. and Mayer, T. (2012). Quality sorting and trade: firm-level evidence for French wine. *The Review of Economic Studies* 79: 609–644.

Curzi, D., Luarasi, M., Raimondi, V. and Olper, A. (2018). The (lack of) international harmonization of EU standards: import and export effects in developed versus developing countries. *Applied Economics Letters* 25: 1552–1556.

Curzi, D. and Olper, A. (2012). Export behavior of Italian food firms: does product quality matter? *Food Policy* 37: 493–503.

Curzi, D. and Pacca, L. (2015). Price, quality and trade costs in the food sector. *Food Policy* 55: 147–158.

Curzi, D., Schuster, M., Maertens, M. and Olper, A. (2020). Standards, trade margins and product quality: firm-level evidence from Peru. *Food Policy* 91: 101834.

Disdier, A.-C., Fontagné, L. and Cadot, O. (2015). North-South standards harmonization and international trade. *The World Bank Economic Review* 29: 327–352.

Disdier, A.-C., Fontagné, L. and Mimouni, M. (2008). The impact of regulations on agricultural trade: evidence from the SPS and TBT agreements. *American Journal of Agricultural Economics* 90: 713–726.

Disdier, A.-C. and Marette, S. (2010). The combination of gravity and welfare approaches for evaluating nontariff measures. *American Journal of Agricultural Economics* 92: 713–726.

Drogué, S. and DeMaria, F. (2012). Pesticide residues and trade, the apple of discord? *Food Policy* 37: 641–649.

Egger, P. H. and Nigai, S. (2015). Structural gravity with dummies only: constrained ANOVA-type estimation of gravity models. *Journal of International Economics* 97: 86–99.

Commission, E. U. (2020). A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/farm-fork_en

Feenstra, R. C. and Kee, H. L. (2004). On the measurement of product variety in trade. *American Economic Review* 94: 145–149.

Feenstra, R. C. and Kee, H. L. (2008). Export variety and country productivity: estimating the monopolistic competition model with endogenous productivity. *Journal of International Economics* 74: 500–518.

Feenstra, R. C. and Ma, H. (2014). Trade facilitation and the extensive margin of exports. *The Japanese Economic Review* 65: 158–177.

Fernandes, A. M., Ferro, E. and Wilson, J. S. (2019). Product standards and firms' export decisions. *The World Bank Economic Review* 33: 353–374.

Ferro, E., Otsuki, T. and Wilson, J. S. (2015). The effect of product standards on agricultural exports. *Food Policy* 50: 68–79.

Fiankor, -D.-D.-D., Martínez-Zarzoso, I. and Brümmer, B. (2019). Exports and governance: the role of private voluntary agrifood standards. *Agricultural Economics* 50: 341–352.

Fiankor, -D.-D.-D., Flachsbarth, I., Masood, A. and Brümmer, B. (2020). Does Global GAP certification promote agrifood exports? *European Review of Agricultural Economics* 47: 247–272.

Fischer, R. and Serra, P. (2000). Standards and protection. *Journal of International Economics* 52: 377–400.

Fontagne, L., Orefice, G., Piermartini, R. and Rocha, N. (2015). Product standards and margins of trade: firm-level evidence. *Journal of International Economics* 97: 29–44.

Gaigné, C. and Larue, B. (2016). Quality standards, industry structure, and welfare in a global economy. *American Journal of Agricultural Economics* 98: 1432–1449.

Hallak, J. C. (2006). Product quality and the direction of trade. *Journal of International Economics* 68: 238–265.

Handford, C. E., Elliott, C. T. and Campbell, K. (2015). A review of the global pesticide legislation and the scale of challenge in reaching the global harmonization of food safety standards. *Integrated Environmental Assessment and Management* 11: 525–536.

Hatanaka, M., Bain, C. and Busch, L. (2006). Differentiated standardization, standardized differentiation: the complexity of the global agrifood system. *Between the Local and the Global*. Bingley: Emerald Group Publishing Limited, 39–68.

Hejazi, M., Grant, J. H. and Peterson, E. (2018). Hidden trade costs? Maximum residue limits and US exports of fresh fruits and vegetables. Research report CAT-2018-06, Center for Agricultural Trade.

Helpman, E., Melitz, M. and Rubinstein, Y. (2008). Estimating trade flows: trading partners and trading volumes. *The Quarterly Journal of Economics* 123: 441–487.

Hummels, D. and Klenow, P. J. (2005). The variety and quality of a nation's exports. *American Economic Review* 95: 704–723.

Kareem, F. O., Martínez-Zarzoso, I. and Brümmer, B. (2018). Protecting health or protecting imports? Evidence from EU non-tariff measures. *International Review of Economics & Finance* 53: 185–202.

Khandelwal, A. (2010). The long and short (of) quality ladders. *The Review of Economic Studies* 77: 1450–1476.

Khandelwal, A. K., Schott, P. K. and Wei, S.-J. (2013). Trade liberalization and embedded institutional reform: evidence from Chinese exporters. *American Economic Review* 103: 2169–2195.

Korinek, J., Melatos, M. and Rau, M.-L. (2008). A review of methods for quantifying the trade effects of standards in the agri-food sector doi:

Krugman, P. (1980). Scale economies, product differentiation, and the pattern of trade. *The American Economic Review* 70: 950–959.

Kugler, M. and Verhoogen, E. (2011). Prices, plant size, and product quality. *The Review of Economic Studies* 79: 307–339.

Leland, H. E. (1979). Quacks, lemons, and licensing: A theory of minimum quality standards. *The Journal of Political Economy* 87: 1328–1346.

Li, Y. and Beghin, J. C. (2014). Protectionism indices for non-tariff measures: an application to maximum residue levels. *Food Policy* 45: 57–68.

Maertens, M. and Swinnen, J. F. (2009). Trade, standards, and poverty: evidence from Senegal. *World Development* 37: 161–178.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica* 71: 1695–1725.

Movchan, V., Shepotylo, O. and Vakhitov, V. (2020). Non-tariff measures, quality and exporting: evidence from microdata in food processing in Ukraine. *European Review of Agricultural Economics* 47: 719–751.

Murina, M. and Nicita, A. (2017). Trading with conditions: the effect of sanitary and phytosanitary measures on the agricultural exports from low-income countries. *The World Economy* 40: 168–181.

Olper, A. (2016). The political economy of trade-related regulatory policy: environment and global value chain. *Bio-based and Applied Economics* 5: 287–324.

Olper, A., Curzi, D. and Pacca, L. (2014). Do food standards affect the quality of EU imports? *Economics Letters* 122: 233–237.

Otsuki, T., Wilson, J. S. and Sewadeh, M. (2001). What price precaution? European harmonisation of aflatoxin regulations and African groundnut exports. *European Review of Agriculture Economics* 28: 263–284.

Persson, M. and Wilhelmsson, F. (2016). EU trade preferences and export diversification. *The World Economy* 39: 16–53.

Peterson, E., Grant, J., Roberts, D. and Karov, V. (2013). Evaluating the trade restrictiveness of phytosanitary measures on US fresh fruit and vegetable imports. *American Journal of Agricultural Economics* 95: 842–858.

Raimondi, V., Falco, C., Curzi, D. and Olper, A. (2019). Trade effects of geographical indication policy: the EU case. *Journal of Agricultural Economics* 71: 330–356.

Ronnen, U. (1991). Minimum quality standards, fixed costs, and competition. *The Rand Journal of Economics* 22: 490–504.

Santeramo, F. G. and Lamonaca, E. (2019). The effects of non-tariff measures on agri-food trade: a review and meta-analysis of empirical evidence. *Journal of Agricultural Economics* 70: 595–617.

Santos Silva, J. M. C. and Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics* 88: 641–658.

Schuster, M. and Maertens, M. (2015). The impact of private food standards on developing countries' export performance: an analysis of asparagus firms in Peru. *World Development* 66: 208–221.

Shapiro, C. (1983). Premiums for high quality products as returns to reputations. *The Quarterly Journal of Economics* 98: 659–679.

Shingal, A., Ehrich, M. and Foletti, L. (2020). Re-estimating the effect of heterogeneous standards on trade: endogeneity matters. *The World Economy*

Swinnen, J. (2016). Economics and politics of food standards, trade, and development. *Agricultural Economics* 47: 7–19.

Tran, N., Wilson, N. L. and Anders, S. (2012). Standard harmonization as chasing zero (tolerance limits): the impact of veterinary drug residue standards on crustacean imports in the EU, Japan, and North America. *American Journal of Agricultural Economics* 94: 496–502.

Vandemoortele, T. and Deconinck, K. (2014). When are private standards more stringent than public standards? *American Journal of Agricultural Economics* 96: 154–171.

Vigani, M., Raimondi, V. and Olper, A. (2012). International trade and endogenous standards: the case of GMO regulations. *World Trade Review* 11: 415–437.

Winchester, N., Rau, M.-L., Goetz, C., Larue, B., Otsuki, T., Shutes, K., Wieck, C., Burnquist, H. L., Souza, M. J., Pinto de, and Faria, R. N. D. (2012). The impact of regulatory heterogeneity on agri-food trade. *The World Economy* 35: 973–993.

Winter, C. K. and Jara, E. A. (2015). Pesticide food safety standards as companions to tolerances and maximum residue limits. *Journal of Integrative Agriculture* 14: 2358–2364.

Xiong, B. and Beghin, J. (2012). Does European aflatoxin regulation hurt groundnut exporters from Africa? *European Review of Agricultural Economics* 39: 589–609.

Xiong, B. and Beghin, J. (2014). Disentangling demand-enhancing and trade-cost effects of maximum residue regulations. *Economic Inquiry* 52: 1190–1203.

Yeung, M., Kerr, W. A., Coomber, B., Lantz, M. and McConnell, A. (2018). Declining harmonization in maximum residue levels for pesticides. *British Food Journal* 120: 901–913.