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ARTICLE

Pesticide regulatory heterogeneity, foreign sourcing, and global agricultural value chains

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Abstract

Regulations on the production and consumption of goods are very heterogeneous across countries. Whereas the effects of regulations on exports are well known, the responses of importers to heterogeneous and frequently changing country-specific regulations are not well understood. We combine Swiss firm-level import customs transaction data with country-product-year-specific maximum residue limits to investigate the effect of pesticide regulatory heterogeneity on firm-level imports and assess the moderating role of firm size and global value chain participation. Relying on a global sourcing model, we find that regulatory heterogeneity reduces imports but less so in larger and diversified firms. Participating in global value chains also improves firms' flexibility toward heterogeneous regulation. Business diversification—although reducing the gains from trade and scale—could help firms cope with heterogeneous international regulations.

KEYWORDS
foreign sourcing, global agricultural value chains, heterogeneous firms, imports, pesticide regulations

JEL CLASSIFICATION
F14, Q17, Q18

1 | INTRODUCTION

Standards and technical regulations concerning the production and consumption of goods vary across countries. Whether these differences are regulations on the use of genetically modified organisms or hormone-treated beef, the level of chemical residues that are considered safe, or labeling requirements, there is no shortage of regulatory heterogeneity around the world. Both the regulations and their heterogeneity can be impediments to trade and global value chain (GVC) activity because they raise production costs for firms. Although the trade-reducing effect of standards and regulations is well documented for exports, it is unclear how importing firms, and those who import *and* export simultaneously, respond to heterogeneous and frequently changing country-specific regulations.

This paper investigates how regulatory heterogeneity affects foreign sourcing in agrifood firms. It also assesses how firm productivity and GVC activity relate to foreign sourcing when regulations are heterogeneous across source countries. Specifically, we estimate the effect of cross-country differences in pesticide regulations on firm-level imports and assess the moderating role of firm size and GVC participation as common proxies for firm productivity. The agrifood sector is a highly regulated sector, with pesticide regulations being one of the most prominent regulation around the world. To protect consumer health and reduce the impact of pesticides on the environment, biodiversity, and ecosystem services, many countries have set maximum residue limits (MRLs) on pesticides. Our data focus on Swiss agrifood importing firms, as they are highly integrated in GVCs. Both imports and exports play important roles in the Swiss agrifood sector, providing an ideal setting for studying firms' sourcing strategies under heterogeneous and dynamic international environmental and consumer protection regulations.

To guide our empirical analysis, we consider the theoretical model proposed in Antras and Helpman (2004) and test some of its predictions. Analogous to the heterogeneous firms literature that predicts that only productive firms can offset higher transaction costs and export (Melitz, 2003; Melitz & Redding, 2014), global sourcing models predict the decisions of firms concerning the organization and location of importing intermediate goods (Antras et al., 2017; Grossman & Helpman, 2004). In this class of models, firms maximize profits by trading off lower fixed costs but higher variable costs at home against higher fixed costs but lower variable costs abroad. Although some models predict that only more productive firms will sort into sourcing abroad (e.g., Antras et al., 2017; Antras & Helpman, 2004), others argue that low-productivity firms can offer comparatively higher powered incentives abroad than at home (Grossman & Helpman, 2004). In turn, these models predict that regulatory policy would result in fewer firms self-selecting into sourcing from abroad due to high or low productivity.

Our empirical approach relies on a combination of administrative data. To measure regulatory heterogeneity, we use data on country-product-year-specific MRLs maintained by the Global Crop Protection Database. As a vertical standard, MRLs are continuous measures of relative stringency and are thus comparable across country pairs. This vertical nature of MRLs allows us to create a country-pair-varying index of regulatory heterogeneity. We combine the bilateral MRL index with firm-product level import transaction data from Swiss customs from 2016 to 2018. We then exploit the exogeneity of country-specific pesticide regulations to identify the effect of MRL on firm-level import decisions using a reduced-form gravity model. We augment our model with firm size and firm-level GVC activity to assess how productivity differences across firms affect import behavior in the presence of pesticide regulations.

Our results—net of any potential firm-origin-product and origin-year confounding factors—are threefold. First, we find that firm-product level imports are reduced in response to tighter pesticide regulations in the importing country. A one standard deviation increase in the MRL index (i.e., standards in Switzerland are stricter than in the source country) reduces firm-product level imports by 18%. Second, pesticide regulatory heterogeneity hinders firm-level imports mainly through a decrease in the intensive margin (i.e., the average imports per product per firm), with no statistically significant effects on the extensive margin (i.e., the number of imported product varieties per firm). Third, more productive firms, including those engaged in GVC activity, and large employers cope better with pesticide regulatory heterogeneity: A one standard deviation increase in the MRL index reduces trade flows by 15% for GVC-active firms, 20% for non-GVC-active firms, 24% for small firms, 17% for medium-sized firms, and 12% for large firms.

In extending our main results, we decompose the observed import values into a price (unit value) and quantity component. We find that the trade reduction we observe is because firms import lower product volumes at higher prices. Furthermore, we show that when there is a substantial scope for product differentiation, the trade and price effects of regulatory heterogeneity are more pronounced. The negative effects are also lower for firms that sell multiple products or source from multiple origins, highlighting other potential sources of firm resilience. We also simulate changes in imports due to hypothetical country–product equivalence in pesticide regulations and show that there are potential benefits to harmonization. The trade effect in our baseline model is equivalent to an ad valorem tariff of 24%.

We contribute to four strands of the literature. First, we contribute to the empirical literature on foreign sourcing and firm productivity, specifically with results from the agricultural and food sector. A strand of this literature shows that higher productivity firms engage in foreign sourcing (e.g., Amiti & Wei, 2009; Bernard et al., 2018; Bøler et al., 2015; Chemo Dzukou & Vancauteren, 2024; Farinas & Martín-Marcos, 2010; Jafari et al., 2023; Tomiura, 2007). Another strand shows that reducing trade barriers enhances the productivity of firms that source from abroad and those that only source from home (e.g., Amiti & Konings, 2007; Defever et al., 2020). We contribute empirical evidence on the positive relationship between foreign input sourcing and firm productivity in the agrifood sector, where the decision to import against the alternative of sourcing domestically is largely exogenous, as agrifood inputs have geoclimatic constraints; for example, agricultural raw materials only grow in specific regions of the world.

Second, our paper is closely related to the recent literature on firm-based models of importing. The abundance of empirical evidence concerning the export behavior of firms in the general economy and for agriculture and food (Curzi et al., 2020; Eum et al., 2021; Fernandes et al., 2019; Ferro et al., 2015; Fiankor et al., 2021; Fontagné et al., 2015; Luckstead et al., 2024) contrasts with the sparsity of studies focusing on their importing activities (Fiankor et al., 2023; Movchan et al., 2020). However, even as export and import decisions are related, underlying firm-level considerations differ. Export decisions have to do with the demand characteristics of the foreign market, whereas the decision to import intermediate inputs and final products has to do with the production process at the firm level (Gibson & Graciano, 2011). Imports allow firms to benefit from factor endowments, technologies, and firm-specific relationships in foreign markets. Yet, the rise in international outsourcing makes the study of imports at the firm level all the more interesting in itself.

Third, we add microlevel evidence to the literature on the trade effects of agrifood policy (Abman et al., 2024; Arita et al., 2022; Berger et al., 2021; Brenton et al., 2022; Gouel, 2016; Larch et al., 2024; Luckstead, 2024; Sheldon et al., 2018). We focus on pesticide regulations where two mechanisms suggest why the trade effects may be ambiguous a priori. By addressing information asymmetries, regulations increase consumer trust, which, in turn, increases trade flows. By increasing production and compliance costs, however, technical regulations increase trade costs and decrease trade flows. Empirical evidence also supports this theoretical ambiguity. At the country-product level, recent works have found that cross-country variations in pesticide regulations reduce trade flows (Fiankor et al., 2021; Hejazi et al., 2022), increase trade (Shingal et al., 2021), or have both trade-promoting and -reducing effects (e.g., Curzi et al., 2018). The existing country-product approach suffers two major limitations. The aggregation of firm-level data at the country level masks several economic impacts of technical regulations due to firm heterogeneity (Antras & Helpman, 2004; Melitz, 2003). Furthermore, given that policymakers decide the levels of both import duties and technical regulations, the endogeneity of the standards–trade relationship is prevalent in country-level analyses (Shingal et al., 2021). Our contribution lies in pursuing this question using a firm-level dataset that also allows us to address the reverse causality problem. In this regard, our paper is closest to the work of Fernandes et al. (2019), who assessed how MRLs affect the export decisions of firms in developing countries. However, we differ from Fernandes et al. (2019) in two distinct ways: we assess firm-level import decisions and consider the trade effects for a developed country.

Fourth, our work adds to the literature on business diversification, GVC activity, and regulatory policy. Large strands of literature explore the effects of agrifood GVC participation on economic outcomes (Dalheimer et al., 2023; Lim & Kim, 2022; Montalbano & Nenci, 2022; Ndubuisi & Owusu, 2022; Van den Broeck et al., 2017). In the more recent past, GVCs have experienced reallocation and transformation that was largely driven by trade policy (e.g., Alfaro & Chor, 2023; Antràs & Chor, 2022; Freund et al., 2023). A number of papers study how policy shapes GVC participation at the macro level (e.g., Antràs et al., 2022; Antràs & Staiger, 2012; Freund et al., 2023) and also in the agri-food sector (Balié et al., 2019; Eissa & Zaki, 2023; Raimondi et al., 2023; Stolzenburg et al., 2019). Although GVC trade in the agrifood sector is relatively low compared with other sectors (World Bank, 2019a), it still offers scope to analyze GVC mechanisms because of its relatively short value chains. Yet, there is little work on the interaction between firm-level agrifood GVC activity and trade policy (Bellemare et al., 2022). By contrast, our work at the microlevel accounts for firm heterogeneity and assesses how diversified product portfolios of firms and their GVC participation relate to country-specific regulatory heterogeneity. If access to imported inputs enables domestic firms to upgrade their exports, then firms will have to ensure that they meet both the import standards at home and the export standards of their target destination. As traditional trade barriers are increasingly replaced by technical regulations, firms that participate in GVCs are more familiar with regulation-induced trade costs on both the import and export sides. GVC trade and standards and technical regulations have both been increasing in precisely the same countries—high-income countries, particularly in Europe—providing some first correlational intuition that GVC participation and regulation are not necessarily negatively connected. In addition, Grossman et al. (2023) and Dalheimer et al. (2023) highlight the importance of diversified sourcing in firm resilience and supply stability. We offer empirical insights into firm-level mechanisms with regard to GVC activity, source diversity, and product diversity.

The remainder of this paper is organized as follows. Section 2 introduces the theoretical background that guides our empirical application. We present our empirical strategy and data in Sections 3 and 4. In Section 5, we detail and discuss our results. Section 6 extends and checks the robustness of the main findings. Finally, we conclude the paper in Section 7.

2 | REGULATORY HETEROGENEITY, FOREIGN SOURCING, AND HETEROGENEOUS FIRMS

How does increasing the stringency of domestic pesticide regulations influence firm-level import decisions? In this section, we review the global sourcing model presented in Antras and Helpman (2004) and its predictions and contextualize it with country-specific pesticide regulations.

Whereas Melitz (2003) introduces the canonical model of heterogeneous firms self-selecting into exporting versus marketing domestically, Antras and Helpman (2004) provide a useful framework that models heterogeneous firms' decisions to outsource or insource and operate with either of these organizational structures at home or abroad. In Antras and Helpman (2004), heterogeneous firms trade off higher fixed costs and lower variable costs of sourcing abroad against lower fixed costs and higher variable costs of sourcing at home. One of the main results of this model is that less productive firms source domestically, whereas their more productive counterparts source inputs from abroad. However, the contrary is also conceivable. The model proposed in Grossman and Helpman (2004), for instance, predicts that less productive firms will instead source from abroad. Yet, in light of empirical evidence that supports the hypothesis that high productivity firms self-select into foreign sourcing (e.g., Amiti & Wei, 2009; Bernard et al., 2018; Bøler et al., 2015; Farinas & Martín-Marcos, 2010; Tomiura, 2007), we chose Antras and Helpman (2004) as a theoretical motivation for our analysis. Our setup is similar to recent works that, for instance, assess the effect of cultural distance (Gorodnichenko et al., 2024) and robotization (Baur et al., 2023) on firm-level foreign sourcing.

We focus our analysis on home firms operating in a monopolistically competitive agrifood industry. As presented in Melitz (2003), Antras and Helpman (2004), and other related works, we assume identical preferences of consumers that maximize utility from consuming the ith variety of good x at price p and substitute varieties with constant elasticity α. Following Antras and Helpman (2004), home firms face an inverse demand function of the form

$$p(i) = X^{\mu-\alpha} x(i)^{\alpha-1}, \tag{1}$$

where μ is a parameter and X is an indicator of aggregate demand. The production of final good x at home requires two product-specific inputs: headquarter services, $h(i)$—which are immobile across countries, and refer to services that can only be performed at the firms' headquarters or home location—and manufacturing components or materials $m(i)$—which are mobile across countries and refer to intermediate inputs that home firms can either import or source at home.[1] Labor is the only factor of production, so that one unit of labor is needed to produce one unit of $m(i)$. Labor supply is perfectly elastic in all countries but immobile across countries. Productivity differences across countries arise from different wage levels, w. Home firms that differ in productivity then use $h(i)$ and $m(i)$ to produce a final good output level x according to the following Cobb–Douglas production function:

$$x_i = \theta \left[\frac{h(i)}{\eta}\right]^{\eta} \left[\frac{m(i)}{1-\eta}\right]^{1-\eta}, \tag{2}$$

where θ is the firm-specific productivity, and η is a sector-specific parameter that captures the relative importance of $h(i)$ in the production process. If $\theta > \eta$, home firms produce more intensive in headquarter services. If $\theta < \eta$, home firms produce more intensive in materials that may be imported from other countries, depending on relative w^l, where l indexes the location of the supplier (i.e., home or foreign).[2] Both the decision to offshore and to which country depend on differentials in cost structures faced by home firms at home (H) and abroad (F). The final good firm can either produce the intermediate input $m(i)$ at home with wage rate w^H, or source it from abroad at wage rate w^F. Whereas Antras and Helpman (2004) distinguish between vertical integration and outsourcing as further organizational decisions of firms, we simplify the model and disregard the within-firm integration decision. This allows us to focus on the arm's-length trade case of the model where home firms outsource the production of $m(i)$ abroad.[3] We assume a foreign wage advantage such that $w^H > w^F$. However, if a home firm decides to source $m(i)$ from abroad, it also incurs trade costs $\tau > 1$. That notwithstanding, the marginal costs when sourcing from abroad are lower compared to production at home (i.e., $w^H > \tau w^F$). Each production decision is also associated with additional fixed costs, which are borne in w of home, regardless of the foreign country F that hosts the supplier. When offshoring, fixed organizational costs f at home are greater than abroad (i.e., $w^H f^H < w^H f^F$). However, the lower fixed costs at home must be pondered against lower variable costs abroad and are key to deciding where to source the inputs from. This is because costs incurred for searching, monitoring, and communicating are assumed to be higher when contracting suppliers from abroad.

[1]In our setting, headquarter services $h(i)$ refers, for example, to the final processing of agrifood products, whereas $m(i)$ refers to the production of the raw agricultural product.

[2]Again, food-producing firms may be constrained because when some inputs can only be grown in other countries (which is reflected in respective ws), the degree of headquarter services versus outsourced inputs is exogenous to some degree. However, the decision as to *which* country they outsource to is still endogenous.

[3]This is also possible in our case given that domestic sourcing is not observable in the firm-level dataset used in the empirical part of the paper. Another particularity of our case at hand is that the production of agri-food products often relies on inputs that can only be grown in certain regions. For example, chocolate requires cocoa that can only be grown in tropical regions, whereas dairy products, such as milk powders, can be sourced from countries with temperate climates. In these cases, the decision to source inputs from abroad is exogenous.

Consider now the introduction of a nondiscriminatory, government-imposed quality regulation, which we assume to be exogenous and moderates market access to home. The regulation will affect both the fixed and variable costs of production and also alter the levels of τ. In our setup, we consider regulatory heterogeneity, defined as differences in country-level pesticide regulations between home and foreign. The wider the difference in pesticide regulations, the more difficult market access is. This is because inputs imported from countries where existing regulations are relatively weaker compared to requirements at Home will increase transaction costs for foreign suppliers and Home importers alike. To comply with the regulations, foreign suppliers of intermediate goods bear costs related to enforcement, process adaptation, and sourcing (Ing et al., 2016). Enforcement costs encompass efforts that firms must expend to show compliance. They are largely fixed and involve costs of acquiring expertise devoted to processing paperwork, R&D, search, and monitoring to meet the required standards at home. Product adaptation costs are also fixed and relate to changes in capital equipment required to meet standards at home. Sourcing costs arise when foreign firms are compelled to transition from low-quality inputs to high-quality ones to comply with the standards at home. Sourcing costs are variable, given that they affect every unit produced. Other costs, which are borne by home firms, include those of identifying and selecting suitable firms in different countries that are producing according to standards at home, developing trade relationships with foreign suppliers, maintaining an international sourcing network, and complying with custom and regulatory guidelines (Antràs & Staiger, 2012; Nucci et al., 2021). Thus, the fixed costs abroad are increased by τ, which represents the trade costs associated with the regulatory policy:

$$w^H f^H > \tau w^H f^F. \tag{3}$$

In equilibrium, the revenue from selling a quantity x of a representative variety of the final good may be written as

$$R(i) = X^{\mu-\alpha}\theta^{\alpha}\left[\frac{h(i)}{\eta}\right]^{\alpha}\eta\left[\frac{m(i)}{1-\eta}\right]^{\alpha(1-\eta)}, \tag{4}$$

and the profits of the importing firm are:

$$\pi^H = R(i) - w^H h(i) - \tau w^l m(i) - \tau w^H f^l. \tag{5}$$

Firm profits depend on firm productivity θ, exogenous demand (X), and an industry-specific parameter η. The terms $w^H h(i)$ and $w^F m(i)$ are the variable costs at home and abroad, respectively. Maximizing $\pi(\theta,X,\eta)$ implies that the firm chooses l, either H or F, and thereby trades off lower variable costs but higher fixed costs abroad against higher variable costs but lower fixed costs at home. At the threshold, $\pi(\theta,X,\eta) = 0$, firms will not import inputs but source them at home, facing higher variable but lower fixed costs, or, if sourcing domestically is not possible due to natural constraints, exiting the market.

Consequently, when the fixed cost component of importing inputs increases, profits will decrease, and firms with lower productivity will no longer maximize profits abroad but at home or by exiting the market. From the global sourcing model, introducing new or tightening existing MRLs will lead firms to source fewer inputs from abroad and accelerate the productivity-based self-selection of heterogeneous firms into importing.

Moreover, the decision to source from abroad is increasing in productivity. First, profits are linearly increasing with productivity and are determined by variable costs. Profits rise faster with productivity when sourcing abroad than from home because of the lower w. Thus, the market entry productivity thresholds also differ by input-sourcing location, being lower for sourcing at home than from abroad. The more productive firms will self-select into sourcing from abroad, whereas the less productive firms will source at home. Again, if inputs are not available at home, low-productivity firms will exit the market.

Furthermore, if home firms import intermediate inputs, suppliers must produce relationship-specific inputs. As such, importing firms often engage in relationships with suppliers that have a high degree of input specificity. This creates a lock-in between importers and their suppliers (Antràs & Staiger, 2012).[4] These relation-specific risks increase the associated costs of imports and GVC participation and emphasize the self-selection behavior of heterogeneous firms. As such, GVC-active firms may either be affected more severely by such policy uncertainty, because trade costs from both the export and import sides add up. It is also possible that they instead cope better with such regulatory policy uncertainty, because spillovers from know-how in complying with international policy generated on the export side reduce trade costs on the import side. Which one of these effects prevails can be determined empirically.

3 | EMPIRICAL SPECIFICATION

Here, we present the empirical framework we use to test the theoretical predictions laid out in Section 2.

3.1 | Baseline model: Firm-product-origin-time estimates

In line with recent works examining the effects of nontariff measures on agricultural and food imports (e.g., Movchan et al., 2020), we estimate the effects of pesticide regulatory heterogeneity on imports within a gravity framework. We assume that firm-level imports are a function of pesticide regulatory heterogeneity (a nontariff measure), tariffs, and firm-, product-, and origin-specific characteristics, and estimate the following model using ordinary least squares (OLS):

$$\ln X_{\text{fopt}} = \beta_0 + \beta_1 \text{MRL}_{\text{opt}} + \beta_2 \ln\left(1 + \text{Tariff}_{\text{opt}}\right) + \lambda_{\text{fpo}} + \lambda_{\text{ot}} + \varepsilon_{\text{fopt}} \quad (6)$$

where the indices f, o, p, and t represent firm, origin (source) country, HS8-digit product, and year. We suppress the destination index d for simplicity and because there is no variation along that dimension of the dataset. The dependent variable in Equation (6) is firm-origin-product-year specific import values of Swiss agrifood importing firms. MRL_{opt} captures the product- and country-varying differences in pesticide regulations between Switzerland and the product origin country o over time. $\text{Tariff}_{\text{opt}}$ are tariffs imposed by Switzerland on imports from a source country in a given year. λ_{fpo} are firm-origin-product fixed effects capturing all characteristics that are specific to the firm (including unobserved characteristics affecting their selection into import markets), product, and destination country (e.g., traditional variables in a gravity equation, such as bilateral distance, contiguity, linguistic similarity, but also firm-specific effects that are time invariant). The inclusion of λ_{fpo} implies that most of the variance for the estimation of the import elasticity with respect to pesticide regulations will come from the cross section of countries and products rather than from the time variation in MRL_{opt}. λ_{ot} are origin-year fixed effects that control for all time-varying characteristics of the exporter, including typical gravity model controls, such as GDP or agricultural production capacity. λ_{fpo} and λ_{ot} also control for the theoretical multilateral resistance terms that are core to the

[4]This logic can be applied directly to the agrifood value chains, particularly when product quality is taken into account (Raimondi et al., 2023; Scoppola, 2021). Farmers producing to destination country-specific pesticide standards may not be able to redirect their exports to other destinations with stricter pesticide regulations if the original importer defaults.

proper specification of gravity models (Anderson & Van Wincoop, 2003; Luckstead, 2024). $\varepsilon_{\text{fopt}}$ is the error term that we cluster at the firm-product-year level.

Consistent with our theoretical framework, we expect firm productivity to influence how imports respond to regulations. In follow-up analyses, we assess whether the trade effects of pesticide regulatory heterogeneity are heterogeneous across GVC participation and firm size as proxies of firm-level productivity. We capture this heterogeneity by introducing an interaction among the MRL_{opt} variable, firm size, and GVC participation in Equation (6).

3.2 | Margins of import adjustment

The effects of pesticide regulatory heterogeneity on observed import values may only be a part of the story. How it affects market structure may be just as important. Changes in aggregate imports can be driven by proportionate changes in the import values of all firms, some firms exiting the import market leaving surviving firms with increased market shares, or firms varying the range of products they import. Either of these cases will imply different things for policy. Thus, we also perform a firm-level decomposition of the total imports x_{fot} of firm f from origin country o in year t into an extensive and intensive margin (see also Berthou & Fontagné, 2016). The extensive margin is defined as the number of HS8-digit products within an HS6-digit product group that is imported by each firm from country o (N_{fopt}), and the intensive margin is defined as the average value of imports of firm f of product p from origin o $\left(\overline{x}_{\text{fopt}} \equiv x_{\text{fopt}}/N_{\text{fopt}}\right)$. This decomposition can be expressed in log form as:

$$\ln x_{\text{fot}} = \ln N_{\text{fopt}} + \ln \overline{x}_{\text{fopt}} \tag{7}$$

To assess how pesticide regulatory heterogeneity affects the different margins of import adjustment, we estimate a version of Equation (6) but introduce each of the constituent elements of Equation (7) as outcome variables. In Equation (7), the two import margins are a linear combination of total firm-level imports. Thus, the elasticity of each margin with respect to MRL_{opt} adds up to and reflects the elasticity of aggregate imports with respect to MRL_{opt} (i.e., $\delta \ln x_{\text{fot}}/\delta \text{MRL}_{\text{opt}} = \delta \ln N_{\text{fopt}}/\delta \text{MRL}_{\text{opt}} + \delta \ln \overline{x}_{\text{fopt}}/\delta \text{MRL}_{\text{opt}}$). This allows us to assess the contribution of each margin to the overall trade effect. A scatter plot of the two margins against total imports, net of origin-year and firm-year effects, shows a positive association (Figure A2).

3.3 | Identification strategy

Our identification strategy exploits the exogeneity of country-level MRL regulation to firm-level import decisions. The β_1 coefficient captures how cross-country and product variation in pesticide regulations affect within-firm import decisions. MRLs in both the importing and exporting countries are set by national health authorities, which are all external to the firm.[5] Swiss firms source their products from origin countries where Swiss pesticide regulations do not necessarily apply. However, the firms must ensure that their imports from third countries meet the pesticide standards set at home in Switzerland. The fact that importing firms have no control over the regulations in both the origin and destination countries mitigates the potential simultaneity between firm-level imports and

[5]Consider the more general case of a firm that wants to sell a pesticide (or import a cereal product) containing the active substance Tebuconazole for use in cereal production. The firm applies at the Federal Office of Agriculture (FOAG) with data including, among others, the proposed use in agricultural practice and results from experimental sites. The FOAG then sends these data to two other bodies for evaluation. Agroscope evaluates the proposed use of the pesticide for agricultural practice and concludes on a maximum concentration level, say 0.05 mg/kg. Agroscope now applies to the Federal Food Safety and Veterinary Office (FSVO) to set this as the MRL value. Firm-level imports of cereals will now have to meet this externally set value. See Swiss Federal Food Safety and Veterinary Office (2023) for more details.

pesticide regulations. In our application, we achieve this by regressing firm-level import data on country-level regulations within a gravity framework.

Regarding endogeneity stemming from omitted variable biases, we include a host of two- and three-way fixed effect combinations of firms, origin, product, and time in our regressions to capture additional potential confounding effects. The inclusion of λ_{fpo} further controls for the potential endogeneity of bilateral trade policy that arises from countries endogenously selecting into bilateral trade relationships (Baier & Bergstrand, 2007; Ridley & Devadoss, 2023).

4 | DATA

Our analyses combine two administrative databases on pesticide regulations and firm-level import data for Switzerland. In this section, we first present the MRL dataset obtained from the company Homologa. Second, we showcase Swiss firm-level customs data. But, first we justify our case study.

Focusing on Swiss data is relevant in our context, as it allows us to assess the effect of pesticide regulatory heterogeneity on an economic outcome in a politically relevant context. Switzerland is a destination with increasingly strict regulations amid heightened consumer interest in the application of synthetic pesticides (Huber & Finger, 2019). In June 2021, Swiss citizens voted on two initiatives that sought to ban the use of synthetic weed killers, insecticides, and fungicides in agriculture.[6] Second, Switzerland, as a net agrifood importing country, is heavily reliant on imports to meet domestic demand. Thus, even if the large-scale establishment of pesticide-free production in Switzerland is possible (Wang et al., 2023), Swiss importers need to source from countries where Switzerland has no direct influence on pesticide policies yet must ensure that their imports meet the pesticide standards set at home. The Swiss agrifood sector is also heavily focused on exporting value added, which is appropriate given our theoretical framework. Because Swiss agrifood exports in terms of value are mainly roasted coffee and extracts thereof, nonalcoholic beverages, cheese, chocolates, and edible preparations (Fiankor, 2023), a significant part of Swiss imports are intermediate inputs along the agricultural value chain.

4.1 | Pesticide regulations data

Our first dataset contains information on country-product-year-specific MRLs for pesticides. The source of the data is the Global Crop Protection Database, which is maintained by Homologa, using information from pertinent national ministries and legal publications.[7] An advantage of measuring product standards using pesticide residue limits in agricultural products is that as a vertical standard, it can be ordered by stringency and compared easily across countries (Fiankor et al., 2021).

We identify 522 products at the HS8-digit level (that fall within the HS2 product groups 07–12, 14, 15, 18, and 22) and 511 active ingredients for 65 countries.[8] The most frequently regulated active substances include cypermethrin, deltamethrin, permethrin, paraquat, DDT, fenvalerate, dieldrin, aldrin, lambda-cyhalothrin, malathion, carbendazim, and chlordane. See Table A2 for a list of the

[6]The first popular initiative, named "For a Switzerland without synthetic pesticides," called for a domestic ban within 10 years and the outlawing of imported foodstuffs produced using such pesticides. Under a second initiative called "For clean drinking water and healthy food: no subsidies for the use of pesticides and prophylactic antibiotics," only farms not using pesticides would be eligible for government subsidies.

[7]There are several commercial parties on the market responsible for providing information on plant protection products. Our source, the Agrobase-Logigram database, obtains its information directly from each country's pertinent ministry and standardizes it in terms of language, unit, and format. See https://homologa.com/ for more details. It is a standard source of data on pesticide regulations in the literature (see. e.g., Fiankor et al., 2021; Fernandes et al., 2019; Ferro et al., 2015; Shingal et al., 2021).

[8]The dataset contains generic product names, for example, bananas, apples, and avocados. We match these names to unique HS8-digit products from trade data. We detect and address redundancies in the dataset, that is, different names for the same commodity, for example, pistachios, nuts—pistachios, nuts—pistachios: dry. Moreover, given that not all 522 products are imported into Switzerland, our final dataset reflect a lower number of products.

TABLE 1 A comparison of maximum residue limits applied to selected products in 2018.

Active substances	Product	Switzerland	EU	Japan	USA	Canada	China	Codex
Carbaryl	Mandarins	0.01	0.01	7	10	10	–	15
Captan	Apples	3	10	5	25	5	15	15
Fenbutatin-oxide	Apple	2	2	5	15	3	5	5
Acetamiprid	Apples	0.8	0.8	2	1	1	0.8	0.8
Azoxystrobin	Tomatoes	3	3	3	0.2	0.2	3	3
Folpet	Avocado	0.02	0.03	30	25	25	–	–

100 most regulated active elements in our dataset. The number of products regulated and the number of active ingredients also vary across countries (Figure A1).

A sample of the MRL data structure is presented in Table 1. In certain cases, some countries have no regulations in place for product-pesticide pairs. For the empirical analysis, we replace these non-existing country-product-pesticide pairs following a standard approach in the literature (Fernandes et al., 2019; Li & Beghin, 2014).[9] First, we replace them with default values where available; for example, the EU sets a default value of 0.01 ppm.[10] Second, many countries defer to Codex standards when no MRLs are set for given product-pesticide pairs.[11] However, relative to many developed countries, Codex regulates comparatively fewer pesticides. Last, where no MRLs are available, we assign the least restrictive MRL value across product-pesticide pairs. Bringing the country pair, product, and time dimensions together, we measure the bilateral asymmetry in MRLs by adapting the nonlinear exponential index of Li and Beghin (2014)—see also Fiankor et al. (2021) and Hejazi et al. (2022)—as follows:

$$\mathrm{MRL}_{odpt} = \frac{1}{N_{cp}}\left[\sum_{c \epsilon N_p} \exp\left(\frac{\mathrm{MRL}_{opt} - \mathrm{MRL}_{dpt}}{\mathrm{MRL}_{opt}}\right)\right] \tag{8}$$

where o is the origin/exporting country, d is the destination/importing country (i.e., Switzerland), p is the HS8-digit product, t is time, and c is the chemical or active element. MRL_{opt} and MRL_{dpt} are the average product- and time-varying MRL set by o and d, respectively. MRL_{odpt} is the product- and time-varying bilateral difference in MRL stringency between Switzerland and the exporting country. However, because Switzerland is the only destination in our dataset, index d is redundant and MRL_{odpt} becomes MRL_{opt}. Equation (8) yields an index of the domain $[0, e \approx 2.718]$. It is normalized at 1 when Switzerland and the exporting country set the same standards. It approaches its upper limit when Switzerland sets a much stricter standard than the exporting country, and vice versa. A spatial distribution of the index is presented in Figure 1. We observe that Switzerland shares similar standards with the European Union but has, on average, stricter standards relative to countries in the Americas, Australasia, Africa, and the Middle East. We offer further descriptive evidence that depicts the average variations in MRL_{opt} over time (Figure A5) and across countries (Figure A6) in the Appendix.

[9]For instance, notice from Table 1 that in 2018, China had no established limits for Carbaryl use in the production of mandarins and Folpet use in the production of avocados. If China bans the active element, it would have had a value of 0. Because this is not the case, it is likely that China does not regulate the use of these active elements in the production of these particular crops. To ensure that we work with a balanced set of product-pesticide combinations across all countries, we replace these missing values following standard approaches in this literature.
[10]See Article 18 of Regulation (EC) No 396/2005. http://data.europa.eu/eli/reg/2005/396/oj.
[11]The Codex Alimentarius Commission is the body responsible for all matters regarding the implementation of the Joint FAO/WHO Food Standards Program. They also establish standards that are seen by many as the social optimum.

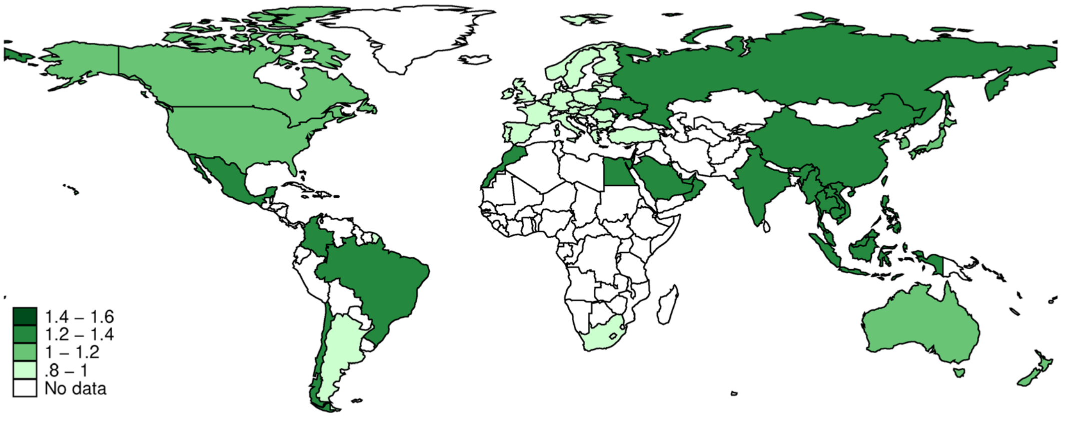

FIGURE 1 Pesticide regulatory differences across countries. Indices are based on Equation (8). Darker shades refer to wider differences in regulations between Switzerland and the country of origin. Lighter shades of green mean regulations are similar across country pairs. White-shaded regions refer to missing data.

4.2 | Firm-level customs data

Our second data source is a unique dataset from Swiss customs that contains shipments in values (Swiss Francs, CHF) and in volumes (kg) by firm-product-origin from 2016 to 2018 covering the universe of importing firms.[12] We restrict our sample to products for which a pesticide limit is applied. We match the names of the products in the Homologa dataset to HS8-digit product codes from Swiss customs.

We provide detailed summary statistics of the importing firms in Table 2. Over the study period, we observe 10,271 unique importing firms, 255 HS8-digit products, and 65 origin countries. The number of importing firms steadily increases over the study period. The number of unique HS8-digit products imported averages 235 over the 3 years. Firm characteristics are systematically related to participation in international trade, whether importing or exporting (Bernard et al., 2007).

Our firm-level dataset allows us to define two measures of productivity. Our first measure is firm-level GVC participation. We define firms that conduct both imports and exports (i.e., two-way trading) as being engaged in GVCs. Firms that only import are the comparison group. This definition is consistent with recent approaches in the literature to capture firm-level indicators of GVC participation (Rigo, 2021; World Bank, 2019b). Two-way traders or GVC-active firms necessarily face higher trade costs, and for this reason, only the most productive firms can operate as such. Importing lowers firm costs (raising revenue), making it easier for firms to cover the fixed costs of exporting, and export entry raises firm revenue, which makes it easier for firms to cover fixed import costs (Johnson, 2018). To offer some insights into the two firm groups, we provide descriptive statistics in Figure 2. Over the study period, GVC-active firms imported more in value terms than firms that were only importers. For firms that are only importers, their imports decreased over the study period. The reverse is the case for GVC-active firms, whose imports increased over time. GVC-active firms constitute 15% of all firms in our sample, yet they import more products and import from more countries. This is consistent with empirical evidence that firms that simultaneously export and import are typically better performers, larger, and more productive than firms that only import (Andersson et al., 2008; Castellani et al., 2010; Kasahara & Lapham, 2013; Melitz & Redding, 2014; Muûls & Pisu, 2009).

[12]Firm-level customs datasets are difficult to come by. In Europe, the more common ones used in the literature are those for France (e.g., Curzi et al., 2021; Jafari et al., 2023). So, although a lack of such proprietary data means we are unable to arbitrarily choose what country to analyze, we also believe that the Swiss case is an ideal case study of a small open economy that is strongly integrated in global agrifood value chains.

TABLE 2 Firm-level characteristics across years, GVC activity, and firm sizes.

	N	Firms	Products	Origin	Import value per firm (CHF)	Import volume per firm (kg)	Origins per firm
Years							
2016	26,857	5908	232	63	47,492	38,601	1.84
2017	27,054	5920	239	63	46,694	37,488	1.86
2018	26,447	6053	234	63	47,948	34,468	1.83
GVC activity							
No GVC	48,692	9237	240	62	12,927	10,768	1.61
GVC	31,666	1656	241	65	100,000	76,997	3.60
Firm sizes							
Large	18,863	1505	219	62	134,634	110,942	2.70
Medium	19,786	1814	207	61	33,722	24,677	2.25
Small	34,149	5804	250	64	15,729	94,27	1.61

Note: The number of firms based on size does not add up to the 10,271 unique firms we observe because some firms do not have their employment data reported. Large firms are importing firms with >50 employees. Medium-sized firms are firms with 10–49 employees. The reference group is small firms with <10 employees.

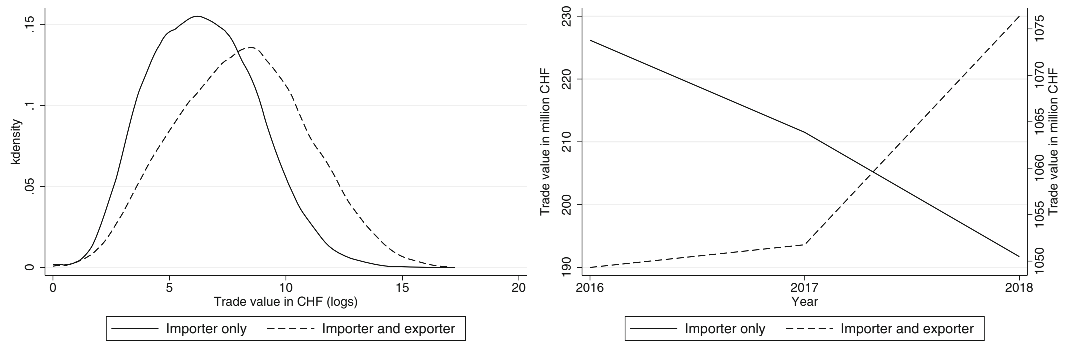

FIGURE 2 Imports by GVC participation. "Importer only" refers to firms that we observe in the dataset only as importers of agricultural and food products. "Importer and exporter" are firms that imported but also exported some agricultural and food products over the sample period.

Our second productivity measure is firm size.[13] Given both internal (e.g., scale, productivity, experience, technology) and external (e.g., border and behind-the-border measures) barriers to international trade of firms, there are likely to be scale effects. Small importers often lack specialized teams and international operations departments, import infrequently or in small batches, and cannot take advantage of productivity-related returns to scale (Fontagné et al., 2020). Our dataset includes a categorical variable that captures the number of people employed within a firm, which will allow us to test how some of these firm characteristics are linked to trade. Based on this employment information, we define three sets of sized-based firm structures: (i) small firms with < 10 employees, (ii) medium-sized firms with > 10 but < 249 employees, and (iii) large firms with > 249 employees.[14] Another salient feature of our dataset is the large number of small-sized firms, as 64% of the firms we observe are small, 20% are medium sized, and 16% are large. However, import

[13]The degree of participation in GVCs is generally not independent of export size: Large firms are more likely to be more engaged in GVCs (Antràs, 2020).

[14]This follows the official definition adopted by the Swiss Federal Statistical Office for small and medium-sized enterprises (Swiss Federal Statistical Office, 2023).

TABLE 3 Summary statistics.

Variable	Mean	*SD*	Min	Max	*N*
Import value (000 CHF)	69,965	520,647	1	31,340,624	50,488
Import volumes (tonnes)	53,780	1,033,227	0	159,124,704	50,488
Extensive margin	529	776	1	2503	50,488
Intensive margin	1050	48,206	0.001	7,445,081	50,488
MRL_{opt}	1.044	0.267	0.795	2.371	50,488
$Tariff_{opt}$ (CHF/kg)	40	86	0	1756	50,488
GVC	0.443	0.497	0	1	50,488

volumes and values increase with firm size. Because, in the presence of sunk costs to import, small firms should be less likely to trade, a higher share of importers should be found in a sample consisting of larger firms. The same is true for the number of product origins per firm, which ranges from a low of two countries for small firms to three countries for large firms.

A list of exporting countries included in the study, which is restricted to countries that have established MRLs for different agrifood products, is provided in Table A1. We provide further descriptive information on the source countries in Figure A4. Here, we observe a gravity-type relationship, whereby the count of products imported and the count of firms importing from a particular origin increases with the market size of the origin but decreases with bilateral distance. Summary statistics of the variables included in our baseline regressions are presented in Table 3.

5 | RESULTS

We present and discuss the results of our empirical analysis in this section. We begin with our baseline findings in Section 5.1 and decompose the effects into different margins of import adjustment in Section 5.2.

5.1 | Baseline model: Regulatory heterogeneity and firm-product level imports

We present the regression results for the effect of pesticide regulatory heterogeneity on firm-product level imports in Table 4. We find a negative and statistically significant effect of the differences in pesticide regulations across countries relative to Swiss standards on firm-product level imports. From the estimates in Column 1, where we also control for tariffs and include a host of fixed effects, a 1 standard deviation increase in the MRL_{opt} index—that is, Swiss standards are stricter than standards in the origin country—reduces firm-product level import values by 18% (i.e., 0.267×0.672). As expected, the coefficient of tariffs is negative and statistically significant. The elasticity of firm-product level imports with respect to tariffs is about -0.83.

To assess how participation in GVCs moderates the effect of this regulatory heterogeneity, we interact the variable capturing the GVC status of a firm with the MRL variable in Equation (6). The results are presented in Column 2 of Table 4. The coefficient of the interaction term is positive and statistically significant. This means that the average trade-reducing effect of pesticide regulatory heterogeneity is smaller for firms engaged in GVCs. A one standard deviation increase in the MRL index reduces trade flows by 15% for GVC-active firms and 20% for non-GVC-active firms that only import. Therefore, despite the vulnerabilities associated with increased interconnections, firms engaged in GVCs are more productive and are likely to be more successful in minimizing the costs of technical regulations. Another mechanism that could reduce the associated trade costs for GVC-

TABLE 4 OLS results for the effect of pesticide regulatory heterogeneity on firm-level import values.

	Baseline	GVC activity	Firm size
	(1)	(2)	(3)
MRL_{opt}	−0.672***	−0.758***	−0.890***
	(0.249)	(0.250)	(0.264)
GVC_{ft}		−0.133	
		(0.090)	
$MRL_{opt} \times GVC_{ft}$		0.181**	
		(0.083)	
MRL_{opt} × Medium-size firm			0.242***
			(0.078)
MRL_{opt} × Large-size firm			0.425***
			(0.085)
Log $(1 + Tariff_{opt})$	−0.829***	−0.832***	−0.858***
	(0.206)	(0.206)	(0.212)
Firm-origin-product FE	Yes	Yes	Yes
Origin-year FE	Yes	Yes	Yes
Observations	50,488	50,488	46,237
adj. R^2	0.868	0.868	0.871
Estimator	OLS	OLS	OLS

Note: The dependent variable is the import values of firm f of HS8-digit product p from origin country o in year t. p values are in parentheses. *** denotes significance at 1%. Intercepts included but not reported. Standard errors are clustered at the firm-product-year level. GVC_{ft} is a dummy variable that takes the value 1 if firm f imports and exports in year t. Large firms are importing firms with $>$ 50 employees. Medium-sized firms are firms with 10–49 employees. The reference group is small firms with $<$ 10 employees. The number of observations is lower in Column (3) because some firms in the trade dataset do not specify the number of employees.

active firms is positive spillover from information networks. GVC-active firms are relatively more experienced in gathering intelligence on a variety of indicators, including production processes and standards compliance of potential international partners. These information networks are likely to help identify suppliers that meet regulations.

We now examine whether the effect varies by firm size. We begin with a focus on employment and define firm size based on the number of persons engaged as employees. The interaction between MRL_{opt} and the firm size dummy yields a positive and statistically significant coefficient (Column 3 of Table 4). This implies that the larger the importing firm, the smaller the negative effect of pesticide regulatory heterogeneity. As an alternative measure of firm size, we construct three size bins based on percentiles of the import value distribution. The thrust of the results is the same as in Table 4 (see Table A3).

5.2 | Decomposing effects into different margins of import adjustment

In Table 5, we decompose total HS6-digit firm-level import values (Column 1) into an extensive margin (i.e., the number of HS8-digit product varieties imported) and an intensive margin (i.e., average import values per firm).[15] We find a small positive but statistically insignificant effect

[15] Note also that the number of observations in Table 5 is different from that in Table 4 because to calculate the margins, HS8-digit firm-level imports are collapsed to the HS6-digit level. This allows us to define the extensive margin as the number of HS6-digit products imported within an HS8-digit product class.

TABLE 5 OLS results for the effect of pesticide regulatory heterogeneity on margins of import adjustment.

	Baseline			Firm-level GVC activity			Firm size		
	x_{fot}	N_{fopt}	$\bar{x}_{fopt}$	x_{fot}	N_{fopt}	$\bar{x}_{fopt}$	x_{fot}	N_{fopt}	$\bar{x}_{fopt}$
Dependent variable (ln)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
MRL_{opt}	−0.656***	0.012	−0.668***	−0.742***	0.018	−0.760***	−0.864***	0.006	−0.870***
	(0.247)	(0.046)	(0.252)	(0.250)	(0.047)	(0.255)	(0.263)	(0.047)	(0.265)
GVC_{ft}				−0.121	0.021**	−0.142			
				(0.092)	(0.008)	(0.091)			
$MRL_{opt} \times GVC_{ft}$				0.174**	−0.011**	0.184**			
				(0.084)	(0.005)	(0.084)			
MRL_{opt} × Medium-size firm							0.243***	0.031**	0.212***
							(0.078)	(0.013)	(0.077)
MRL_{opt} × Large-size firm							0.473***	0.052***	0.422***
							(0.084)	(0.016)	(0.083)
Log (1 + $Tariff_{opt}$)	−0.046	0.010	−0.056*	−0.045	0.010	−0.056*	−0.046	0.012	−0.058*
	(0.033)	(0.007)	(0.032)	(0.033)	(0.007)	(0.032)	(0.034)	(0.008)	(0.033)
Firm-origin-product FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Origin-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	47,033	47,033	47,033	47,033	47,033	47,033	42,941	42,941	42,941
adj. R^2	0.864	0.658	0.866	0.864	0.658	0.866	0.870	0.679	0.871

Note: x_{fot} is total imports of firm f from origin country o in year t. N_{fopt} is the extensive margin, defined as the number of HS8-digit products within an HS6-digit product group that is imported by each firm from country o in year t. $\bar{x}_{fopt}$ is the intensive margin, defined as the average value of imports of firm f of product p from origin o in year t. p values are in parentheses. ***, **, and * denote significance at 1%, 5%, and 10%. Intercepts included but not reported. Standard errors are clustered at the firm-product-year level. All models are estimated using OLS. GVC_{ft} is a dummy variable that takes the value 1 if firm f imports and exports in year t. Large firms are importing firms with > 50 employees. Medium-sized firms are firms with 10–49 employees. The reference group is small firms with < 10 employees. The number of observations is lower in Columns (7)–(9) because some firms in the trade dataset do not specify the number of employees.

for the extensive margin and a large negative but statistically significant effect for the intensive margin. As a result, the trade reduction induced by pesticide regulatory heterogeneity is driven by adjustments along the intensive margin. The larger intensive margin effect we find relative to the extensive margin points to the fact that the effects of pesticide regulations increase more the variable costs of importing for firms and less their fixed costs. As a result, we observe that market structure remained unaltered, but aggregate imports dropped drastically as all firms reduced their imports in response to regulatory heterogeneity. This is contrary to the evidence on the export side where the trade-reducing effects of technical regulations are driven more by the extensive margin and less by the intensive margin (see, e.g., Curzi et al., 2020; Fiankor et al., 2021; Fontagné et al., 2015). Consistent with our baseline findings, the negative effects on imports are less pronounced for two-way traders involved in GVC activity and larger firms. Here, the negative tariff effect is fully captured by adjustments along the intensive margin.

6 | EXTENSIONS

This section extends our main findings in four ways. First, we assess the effect of pesticide regulatory heterogeneity on import volumes in kg and import prices (measured as unit values) before assessing whether product quality moderates the effects of regulatory heterogeneity on firm-level import values. Third, we examine whether product and source country diversification can help firms cope with regulatory heterogeneity. Based on our baseline findings, we also simulate changes to imports due to hypothetical scenarios of country-product equivalence in pesticide regulations. Finally, we calculate ad valorem tariff equivalents of the regulatory heterogeneity.

6.1 | Assessing quantity and price effects

To gain further insights into the negative trade effect, we assess how regulatory heterogeneity affects import prices and import volumes. With no direct measure of firm-level import prices, we use unit values defined as the ratio of import values in CHF to import volumes in kg.[16] The results presented in Table 6 show that the observed trade reduction is a result of firms importing fewer quantities at higher prices. By reducing trade and the number of firms that are active traders, regulations reduce competition in the importing country (Gaigné & Larue, 2016), which surviving firms can exploit to exert their market power, for example, by charging higher prices. Producers in the origin country may also be passing on the extra cost of producing "higher quality products" to consumers in the importing country. Therefore, the price increase that we observe may reflect quality upgrading, mark-ups, or some combination of the two mechanisms.

6.2 | Heterogeneous effects for product differentiation

Regulations may be more pronounced in sectors in which there is substantial scope for vertical product differentiation and less so for homogeneous goods. In this section, we assess whether product differentiation moderates the effects of regulatory heterogeneity on imports and import prices. For this purpose, we adopt the concept of "quality ladder" by Khandelwal (2010) as a proxy for the level of

[16]Given that we consider imports, the unit values we calculate are not free-on-board prices but include cost, insurance, and freight costs. We note that unit values are an imprecise proxy for prices because there may be more than one distinct product within an HS8-digit code despite the high degree of disaggregation. Some price changes may be due to compositional changes within a product code or due to errors in measuring quantities. This is the typical drawback of customs data, in which despite the richness of firm-level variables we do not observe prices of individual products.

TABLE 6 OLS results for the effect of pesticide regulatory heterogeneity on firm-level import volumes and prices.

	Import quantity	Import prices
Dependent variable (log)	**(1)**	**(2)**
MRL_{opt}	−0.471*	0.122***
	(0.246)	(0.027)
Log (1 + $Tariff_{opt}$)	−1.043***	0.312***
	(0.212)	(0.068)
Firm-origin-product FE	Yes	Yes
Origin-year FE	Yes	Yes
Observations	50,305	50,305
adj. R^2	0.893	0.854

Note: The dependent variable in Column (1) is import volumes in kg of firm f of HS8-digit product p from origin country o in year t. The dependent variable in Column (2) is import prices, measured as unit values, paid by firm f for product p imported from origin country o in year t, UV_{fopt}. All models are estimated using ordinary least squares. p values are in parentheses. *** denotes significance at 1%.

product differentiation (Curzi et al., 2020).[17] To begin, we need to measure product quality. Lacking direct proxies, we estimate product quality directly from our trade data, following Khandelwal et al. (2013) as the residual from a demand equation. The intuition behind the approach is that conditional on prices, products with higher market shares in the destination country are assigned higher quality.[18] Using our estimates of product quality, we compute the quality ladder as the difference between the maximum and minimum values of the estimated quality in a given product-origin category. Products with values less than or equal to median quality ladder are characterized by lower product differentiation (i.e., short-quality ladder), and products with values above the median (i.e., long-quality ladder) are vertically differentiated.

We assess the effects of regulatory heterogeneity on import values and prices within two subsamples of products based on where they fall on the quality ladder. The findings presented in Table 7 show that most of the effects are driven by products that fall within the long-quality ladder. Thus, when there is a large scope for product differentiation, the trade and price effects of regulatory heterogeneity are more pronounced.

6.3 | Heterogeneous effects for product and import diversification

Another source of resilience toward regulatory heterogeneity could be experiences drawn from other business activities. Our data allow us to differentiate between firms that source from multiple origins and firms that sell multiple products. Such firms might share some of the fixed costs of foreign sourcing with other input market origins or have drawn experiences from the operational process of the different products they are importing. We identify a group of firms that import products in only one HS4-digit industry over the study period, which we call mono-industry firms (De Sousa et al., 2020).[19] In our data, 7047 firms—representing 69% of the sample of firms—are mono-industry firms. The empirical literature also documents that many firms trade with only a few countries (Arkolakis & Muendler, 2013; Fiankor, 2023). This is also reflected in our data, with the number of source countries averaging around two per firm. In our sample, three-quarters of the firms we

[17]We compute quality ladder as the difference between the maximum and minimum values of the estimated quality in a given product-origin pair. In particular, products with a quality ladder value below the median (short-quality ladder) are characterized by lower product differentiation, hence, horizontal differentiation prevails. In contrast, products displaying quality ladder values above the median (long-quality ladder) are more vertically differentiated.

[18]We present further details on the procedure for estimating product quality in Appendix 9. When we regress import values and import prices on our quality estimate, we find a positive and statistically significant relationship in both cases (Table A4). This means that higher quality products are imported in higher volumes and at higher prices.

[19]Our findings remain the same in direction and statistical significance if we define the industry at the HS2 digit level.

TABLE 7 OLS results for the effect of pesticide regulatory heterogeneity on firm-level import values and prices across different levels of product differentiation.

	Long quality ladder		Short quality ladder	
	Import values	Import prices	Import values	Import prices
Dependent variable (log)	**(1)**	**(2)**	**(3)**	**(4)**
MRL_{opt}	−1.986***	0.239***	−0.202	−0.005
	(0.675)	(0.033)	(0.303)	(0.025)
Log $(1 + Tariff_{opt})$	−1.747***	−0.047	−2.016***	0.491
	(0.401)	(0.467)	(0.385)	(0.318)
Firm-origin-product FE	Yes	Yes	Yes	Yes
Origin-year FE	Yes	Yes	Yes	Yes
Observations	24,429	18,474	23,988	17,868
adj. R^2	0.875	0.740	0.869	0.772

Note: The dependent variable in Columns (1) and (3) is import values of firm f of HS8-digit product p from origin country o in year t. The dependent variable in Columns (2) and (4) is import prices, measured as unit values, paid by firm f for product p imported from origin country o in year t. p values are in parentheses. *** denotes significance at 1%. Intercepts included but not reported. Standard errors are clustered at the firm-product-year level. The lower number of observations is because the elasticity of substitution used to estimate product quality is not available for all product-origin country pairs. We compute the quality ladder as the difference between the maximum and the minimum value of the estimated quality in a given product category. Products with quality ladder values below or equal to the median fall into the short-quality ladder category.

observe show imports from only one country over the period (i.e., 7635 firms or 74%), that is, mono-origin firms. How heterogeneous pesticide regulations affect these two sets of firms is an empirical question. By importing from multiple countries and across multiple industries, multi-origin, and multi-industry firms may be exposed to increased costs of coping with multiple country-specific regulations for different products. Mono-origin and mono-industry firms may perform better if they have to accommodate the regulations of only one source country or one sector. However, multi-origin and multi-industry firms are often large and more productive. We test this hypothesis and show the results in Table 8. We find that multi-industry and multi-origin firms are less affected by pesticide regulatory heterogeneity. It appears that the mono-origin and mono-industry firms are less resilient to trade risks, given their limited basket of traded goods, the over-reliance on few source markets, and the concentration of all fixed components on one single market. However, similar to GVC participation and firm size being indicators of productivity, one could argue that multi-origin and multiproduct firms are also more productive—although the empirical evidence here is somewhat scarce. Thus, these results warrant some caution, as this endogeneity could bias these estimates, even if the mechanism and direction of the effect remain plausible.

6.4 | Simulating changes in imports due to hypothetical country-product equivalence in pesticide regulations

Here we conduct policy-relevant evaluations in the form of simple counterfactual analyses that simulate how different hypothetical regulatory heterogeneity regimes affect imports. Using the estimates from our baseline model (column 1 of Table 4), we predict import flows as follows:

$$\ln \widehat{X}_{fopt} = \widehat{\beta}_1 MRL_{opt} + \widehat{\beta}_2 \ln\left(1 + Tariff_{opt}\right) + \widehat{\lambda}_{fpo} + \widehat{\lambda}_{ot} \quad (9)$$

A graph of the observed import values against the predicted import values for all firm-product-origin-time combinations shows that our model predicts import values very well (Figure A3).

TABLE 8 OLS results for the effect of pesticide regulatory heterogeneity on firm-level import values by multi-industry and multi-origin status of firms.

Dependent variable (log)	Import values (1)	Import values (2)
MRL_{opt}	−0.788***	−0.774***
	(0.251)	(0.250)
MRL_{opt} × Multi-industry firms	0.120***	
	(0.034)	
MRL_{opt} × Multi-origin firms		0.104***
		(0.030)
Log (1 + $Tariff_{opt}$)	−0.832***	−0.827***
	(0.207)	(0.207)
Firm-origin-product FE	Yes	Yes
Origin-year FE	Yes	Yes
Observations	50,488	50,488
adj. R^2	0.868	0.868

Note: The dependent variable is the import values of firm f of HS8-digit product p from origin country o in year t. p values are in parentheses. *** denotes significance at 1%. Intercepts included but not reported. Standard errors are clustered at the firm-product-year level. Intercepts included but not reported. Multi-industry firms are firms that import products in more than one 4-digit industry over the study period. Multi-origin firms are firms that imported from more than one country over the study period.

TABLE 9 Simulated changes in total Swiss imports due to changes in MRL_{opt}.

Predicted imports (A)	Scenario	Simulated imports (B)	Difference ($B - A$)	Δ imports
3239	A standard deviation increase in MRL_{opt}	2709	−530	−16.4%
3239	A standard deviation decrease in MRL_{opt}	3873	+634	+19.57%
3239	EU and Swiss standards are harmonized	3174	−65	−2%

Note: The predicted and simulated import values are in million Swiss francs (CHF).

We simulate changes in predicted imports $\widehat{X}_{fopt}$ by introducing counterfactual values of MRL_{opt} in Equation (9) for different scenarios in Table 9. We begin by evaluating the one standard deviation increase in MRL_{opt} by which we interpret our baseline findings. In this case, Swiss standards become even more stringent relative to standards in the rest of the world. This reduces total imports by about 16% amounting to 530 million CHF. However, if Swiss standards become less stringent relative to those in the rest of the world, which we simulate by a standard deviation decrease in MRL_{opt}, Swiss imports will rise by about 20%. Third, we simulate a harmonization scenario, as we expect it to reduce the costs of market entry.[20] We simulate a scenario in which pesticide regulations are completely harmonized between Switzerland and the EU (while all other countries maintain their existing regulations). In this scenario, total Swiss imports decline by a mere 2%.[21] This result implies

[20]Indeed, Article 4 of the Sanitary and Phytosanitary (SPS) Agreement requires that WTO members recognize each other's technical measures as equivalent if the exporter objectively demonstrates to the importer that its measures achieve an appropriate level of SPS protection. Although this is rarely achieved in practice, harmonization or mutual recognition should allow countries to avoid the extra costs of meeting additional approval procedure requirements to import goods.

[21]Note that we still observe a drop in imports because standards are only harmonized between the EU and Switzerland, with all other countries maintaining different regulations. However, the 2% drop in imports we observe in this scenario is 14 percentage points lower than what we simulate in the scenario where all countries maintain their respective standards.

that in response to the harmonization, industry productivity increases, and the most productive nontraders begin to import, and existing importing firms expand their imports.

6.5 | Ad-valorem tariff equivalents of pesticide regulatory heterogeneity

To put the simulated changes in imports in Table 9 into context, we convert the econometric estimate of the MRL_{opt} effect into comparable economic magnitudes using ad-valorem equivalents (AVE). AVE is a concept that is often used to express the size of trade costs associated with a non-tariff policy measure. It is the tariff rate that would lead to a change in trade equivalent to the change in trade induced by the pesticide regulatory heterogeneity in question. Given that we estimate a gravity model, the β_1 coefficient in Equation (6) is a combination of the trade policy effect $\left(MRL_{opt}\right)$ and the elasticity of substitution (σ) between products from different origins. As a result, once we have an estimate for σ, we can compute the AVE of MRL_{opt} as:

$$AVE_{MRL} = \left[\exp\left(\frac{\alpha\beta_1}{\sigma}\right) - 1\right] \times 100 \tag{10}$$

where α measures a unit change in the policy variable. In our gravity regressions, the tariff coefficient acts as a direct price shifter and can be interpreted directly as the elasticity of substitution (Ridley & Devadoss, 2023). In essence, the term $\alpha\beta_1$ is the trade effect, and dividing it by the tariff coefficient gives the comparable tariff rate that would yield the same trade effect. If we take the β_1 and $\sigma = \beta_2$ coefficients from Column (1) of Table 4, we can compute the AVEs for different values of α. For a more general case of $\alpha = 1$, a one-unit increase in MRL_{opt} would generate a tariff rate of 124%. For the specific case of a 1 standard deviation increase in MRL_{opt}, we obtain a tariff rate of 24%. This AVE is consistent with recent evidence by Ning and Grant (2019), who estimate an AVE of 21.9% for aflatoxin regulations imposed by the EU and 26% for MRLs imposed by Japan.

6.6 | Robustness checks

We subject our baseline findings to a series of sensitivity analyses. First, we estimate the effect of pesticide regulatory heterogeneity on firm-level import values and volumes using the Poisson pseudo-maximum likelihood estimator (Table A5). Second, we drop the λ_{fpo} and use a more relaxed specification of the baseline equation that includes only firm-product-year $\left(\lambda_{fpt}\right)$ fixed effects (Table A6). Thus far, our estimations measure regulatory heterogeneity subject to those set by individual origin countries. However, the Codex Alimentarius Commission, which is part of the joint FAO/WHO Food Standards Programme, also establishes pesticide limits (see Table 1). In this robustness check (Table A7), we consider the Codex standards to be the social optimum (Curzi et al., 2018; Li & Beghin, 2014) and categorize pesticide limits that exceed those of the Codex as being overly stringent and potentially trade distorting. Because the EU is Switzerland's largest trading partner (see also Figure A4), we isolate an EU-specific effect in Table A8. All four robustness checks confirm our main findings but with occasional differences in magnitudes and levels of statistical significance.

7 | CONCLUSION

Standards and technical regulations around the world are heterogeneous and continue to change frequently. As governments are concerned with environmental, animal, and consumer protection, they implement a variety of mandates and standards to regulate trade. Trade theory suggests that such trade barriers reduce exports, and there is manifold empirical evidence available in support of this mechanism. However, at the firm level, it is not well understood how importing firms respond to heterogeneous regulations when importing inputs. In light of increases in both global pesticide regulation and GVC participation, firms respond to regulation through substitution and other coping mechanisms. In this paper, we use data on Swiss agrifood importing firms to investigate the effects of heterogeneous pesticide regulations on firms' import decisions.

Our empirical findings are as follows: First, firm-level imports decline in response to stricter pesticide regulation—a standard deviation increase in the MRL index (i.e., standards are stricter at home than in the exporting country) reduces imports by 18%, equivalent to a tariff rate of 24%. Second, decomposing the trade effect into an extensive and an intensive margin, we find that the reduction in imports over the reference period is entirely driven by a reduction in the intensive margin, defined as the average imports per product per firm. Third, the import-reducing effects of pesticide regulatory heterogeneity are decreasing in firm-level productivity, measured as GVC participation and firm size. As a result, stricter regulations reallocate imports from smaller and import-only firms to larger and GVC-active firms. Overall, the finding that NTMs reduce firm-level imports in the agricultural sector is consistent with the evidence found by Movchan et al. (2020) for Ukrainian agrifood firms. However, in the case of Ukrainian imports, the effect is more pronounced for more productive firms. We find the reverse for Swiss importing firms.

Although GVC-active firms are more exposed to regulations on both the import and export sides, we argue that returns to scale and spillovers from information networks help them establish partnerships that allow for more trade in accordance with standards in both the import and export destinations, thereby adding resilience to business operations. Size certainly helps to cope with heterogeneous international regulations; however, we argue that the diversification of businesses is a viable strategy to cope with uncertainty in global trade and value chains. Diversification along the import, export, and product levels comes at the cost of the gains from trade and returns to scale, but it increases resilience toward frequently changing regulations. This implies that businesses trade off direct operational profitability against long-term resilience more strongly when facing novel regulations. Moreover, more diversified business operations help address uncertainty stemming from other international policies and uncertainty in general.

Furthermore, our findings have implications for importing countries beyond Switzerland. Across Europe, citizens and policymakers alike are pushing for more ambitious pesticide regulations. The EU, for example, aims to halve the risk and use of chemical pesticides by 2030. Achieving this goal will require significant changes in agricultural practices, land use, and production systems, with implications beyond Europe, such as changes in trade patterns, standards, and product prices (Finger, 2024). If these approaches to low pesticide regulation emerging in Europe become the benchmark, our results show that they have implications for foreign sourcing.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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