# Quality and Gravity in International Trade

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**Abstract**

This paper introduces endogenous quality innovations in a multi-country heterogeneous firm model and derives implications for the gravity equation. Using aggregate trade data and firm-level data, we confirm the theoretical predictions: fixed costs have a *lower* impact on exports and on the share of exporters in industries with a high degree of vertical product differentiation. Quality innovations change the trade elasticity with respect to fixed costs through the extensive margin, whereas the elasticity with respect to variable costs remains unaffected. We estimate the parameters of our model and simulate a reduction in fixed trade costs. Accounting for quality lowers gains from trade and leads to more heterogeneous effects across industries compared to a model without vertical differentiation.

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# 1 Introduction

Product quality is an important determinant of international trade. Firm-level studies document that vertical product differentiation is crucial to explain export participation and success in foreign markets. The most successful exporters offer high-quality products with higher prices, are larger as well as more productive, and earn greater sales compared to non-exporters (Kugler and Verhoogen, 2012; Manova and Zhang, 2012). Across destinations, high-quality firms can more easily overcome trade barriers and additional export costs, which explains the positive correlation between export prices and distance across destinations (Baldwin and Harrigan, 2011; Manova and Zhang, 2012). Hence, quality differentiation shapes the geography of international trade. In fact, Martin and Mayneris (2015) and Ferguson (2012) provide empirical evidence that high quality industries are less sensitive to distance.[1] This evidence suggests that the effect of trade costs on exports depends on the degree of vertical product differentiation in an industry. However, the implications of quality differentiation for aggregate trade flows and the gravity equation have received less attention.
In this paper, we develop a multi-country heterogeneous firm model with endogenous quality innovations and estimate the implied gravity equation using aggregate bilateral trade data and Brazilian firm-level data. We allow for industry variation in vertical product differentiation and show that quality innovations change the elasticity of bilateral trade flows with respect to fixed costs through adjustments on the extensive margin. Our empirical results confirm the theoretical predictions: fixed costs have a smaller impact on aggregate exports and on the share of exporters in industries with a high degree of vertical product differentiation.

Accounting for vertical differentiation is important for the evaluation of trade policy. We estimate the parameters of our model from the data and simulate the effects of policy measures that reduce the time for documentary compliance at the border and thus non-tariff barriers to trade.[2] Compared to a heterogeneous firm model without vertical differentiation, we show that the positive effects of liberalization policies on exports are lower and become much more heterogeneous across industries.

While the literature has mainly focused on demand-side explanations, we provide a supply-side mechanism to show how vertical product differentiation changes the elasticity of trade flows with respect to trade costs. This mechanism is based on the interaction of firm heterogeneity à la Melitz (2003) and endogenous sunk costs (Sutton, 2007; Kugler and Verhoogen,

[1] Martin and Mayneris (2015) show that distance has almost no effect on French exports of high-end varieties such as luxury products. For Swedish firm-level data, Ferguson (2012) finds that the share of exporting firms is less sensitive to distance in R&D intensive industries.

[2] As shown by Hummels and Schaur (2013), the time to deliver goods is an important barrier to trade.

2012). Firms are heterogeneous in productivity and decide on the level of product quality by destination, as well as on which markets to serve.[3] Quality innovations increase demand for a particular variety, but are associated with endogenous sunk costs. To understand the role of vertical differentiation in our model, consider industries that differ in their degree of vertical product differentiation. This measure captures the expenditures for quality innovations relative to firm size and is determined by technological parameters in the quality production function. In industries with a larger degree of vertical product differentiation, the returns from investments are higher. Hence, the most productive firms innovate relatively more and reap larger market shares compared to low productivity firms.

Now suppose that fixed trade costs decrease which induces low productivity firms to enter export markets. In an industry with high vertical product differentiation, these entrants are relatively small as they face strong competition and can only reap a tiny market share compared to entrants in other industries. Hence, the effect on the extensive margin and on export flows is attenuated in industries with high degree of vertical differentiation. We show that this result is opposed to the impact of horizontal differentiation as discussed in Chaney (2008). A high degree of horizontal differentiation leads to stronger effects of trade liberalization on the extensive margin as new entrants can reap larger market shares, whereas stronger quality differentiation reduces the impact of fixed costs on trade.

The predictions from the model are tested with aggregate trade data and firm-level data. As we are interested in the differential effects across industries, we combine trade data with two measures for quality differentiation that are closely related to our theoretical model: (i) the "quality ladder"suggested by Khandelwal (2010), and (ii) the R&D intensity of the industry along with a proxy for horizontal differentiation, as used by Kugler and Verhoogen (2012). We interact these proxies with measures of fixed trade costs to estimate the effect on exports and on the extensive margin in the gravity equation. As proxies for bilateral fixed costs, we use common language and measures of administrative barriers to trade from the World Bank. We also provide results using bilateral distance controlling for variable trade costs and for additive trade costs.[4]

Consistent with our theoretical model, vertical differentiation affects the fixed costs elasticity of trade, whereas the effect of variable costs does not depend on quality. The results remain robust to various empirical specifications and after controlling for demand-side explanations. Our results show that income effects and product weight are important to explain the empir-

[3] Consistent with the existing literature, our setup reflects quality sorting of firms (Crozet et al., 2012; Baldwin and Harrigan, 2011).

[4] Although bilateral distance might reflect both fixed and variable trade costs, it provides empirical insights that can be easily related to the previous literature, e.g. Chaney (2008), Martin and Mayneris (2015), Crozet and Koenig (2010), and Ferguson (2012). We discuss the details in section 4.

ical patterns, but that the coefficients for fixed costs remain stable and significant when we control for income factors associated with Alchian and Allen (1964) effects and home market effects.

The simulation of the model confirms the lower impact of fixed costs on trade in industries with a high degree of vertical differentiation, which reinforces the empirical results. In terms of welfare, our estimations predict that the gains from trade are lower in comparison to gravity models that build on Chaney (2008) and Melitz (2003), and more importantly, that the gains from trade are highly heterogeneous across industries.

**Related literature** This paper is related to a growing literature that analyzes product quality and trade costs in international trade. We build on a multi-country model with firm heterogeneity and derive gravity equations as in Chaney (2008) and Melitz and Redding (2014). Our theoretical setup allows to divide the trade costs elasticity in the gravity equation into a direct effect as in Chaney (2008) and a new counteracting quality effect that depends on the industrial degree of vertical differentiation. The empirical strategy is related to Crozet and Koenig (2010) who estimate the model of Chaney (2008) for French firm-level export data without considering product quality.

Our result that vertical differentiation reduces the effect of trade costs is consistent with empirical evidence showing that high quality industries are less sensitive to distance. Martin and Mayneris (2015) show that distance has almost no effect on exports of high-end varieties. Ferguson (2012) proposes a two-country model in which R&D intensive industries are less sensitive to iceberg trade costs, and provides empirical evidence using distance across destination markets. Also related to our paper, Johnson (2012) estimates a multi-country heterogeneous firm model and shows that coefficients on trade costs are attenuated after controlling for selection into exporting, whereas this result is strongest for distance. Our approach differs from these studies in three important respects. First, we provide a supply-side explanation for the interaction of industrial vertical differentiation and trade costs in the gravity equation. This new mechanism is related to endogenous sunk costs and would not appear in a model with binary technology choice as in Bustos (2011).[5] Second, we analyze the implications of this mechanism for trade using both firm-level data and aggregate world trade data, and provide a quantitative analysis of a reduction in fixed trade costs. Third, Martin and Mayneris (2015) and Ferguson (2012) provide empirical evidence at the product level, whereas we show in theory and empirics the implications of vertical differentiation for

[5] In Bustos (2011), firms face a binary choice between low and high technology, which does not change the fixed costs elasticity. In our model, the crucial mechanism is that endogenous sunk costs influence the selection of firms into exporting.

the elasticity of trade costs.[6]

The literature offers a rich set of demand-side explanations for the role of product quality in international trade. In our empirical analysis, we show that demand-side effects play an important role as well, whereas our supply-side mechanism related to sunk costs remains robust. Fajgelbaum et al. (2011) develop a general equilibrium model with non-homothetic preferences that offers a demand-based explanation for trade in goods of different quality. In their model, aggregate demand leads to trade specialization via home-market effects reminiscent of a Linder (1961) hypothesis. Feenstra and Romalis (2014) consider non-homothetic preferences as well and additionally introduce quality choice on the supply side, which gives rise to Alchian and Allen (1964) effects. They show that firm's quality choice leads to a positive relation between distance and quality.[7] Whereas they focus on the estimation of quality-adjusted prices, we exploit industry variation of vertical differentiation to derive the implications for the gravity equation.

We show that our supply-side mechanism remains robust when we control for product weights, income per capita, additive trade costs and Linder terms. Hallak (2010) finds evidence for the Linder (1961) hypothesis and shows in a sector by sector analysis that countries more similar in income trade more with each other. Lugovskyy and Skiba (2015) consider the geographic position of exporters and extend Alchian-Allen and Linder theories to a multilateral setting. Di Comite et al. (2014) use a model with asymmetries in consumer preferences to identify horizontal and vertical differentiation from Belgian firm-product level exports.

Consistent with empirical evidence on quality differentiation in international trade, our model captures that (i) firm size and prices are positively correlated (Kugler and Verhoogen, 2012), (ii) high quality firms select into more distant markets (Baldwin and Harrigan, 2011; Crozet et al., 2012; Manova and Zhang, 2012), and (iii) exporters vary product quality across destinations depending on distance and market characteristics (Verhoogen, 2008; Bastos and Silva, 2010; Martin, 2012; Manova and Zhang, 2012; Flach, 2016). These empirical regularities are captured in other heterogeneous firm models that allow for quality as well (Baldwin and Harrigan, 2011; Johnson, 2012; Antoniades, 2015). Related to this, Faber (2014) builds

[6] Moreover, whereas Ferguson (2012) proposes a two-country model in which firms choose the same level of quality for the domestic and foreign market and investigates the relation with iceberg transportation costs, we build a multi-country model that allows for quality differentiation across markets. In this way, in our model quality differentiation affects the elasticity with respect to fixed costs but not the elasticity with respect to variable trade costs.

[7] Feenstra and Romalis (2014) assume that quality production follows a Cobb-Douglas function. Fixed costs depend on productivity-adjusted wages, real expenditures in the destination market, and bilateral variables. In our model, firms pay additional sunk costs to increase product quality, whereas technology parameters at the industry level determine investment conditions and the degree of vertical differentiation.

on the model of Kugler and Verhoogen (2012) and shows that cheaper access to US imports leads to quality upgrading and reduces the relative price of higher quality products for Mexican store data. Breinlich et al. (2016) find that trade agreements implemented by the European Union have increased welfare primarily by raising the quality of imports.

The paper is structured as follows. Section 2 presents the theoretical model and derives predictions for the empirical analysis. Section 3 describes the data, and section 4 presents the empirical analysis. In section 5, we estimate the parameters of our model and simulate the effects of a reduction in trade barriers. Finally, section 6 concludes and more technical information is contained in a web appendix.

# 2 The model

This section introduces quality innovations associated with endogenous sunk costs as in Sutton (2007) in a heterogeneous firm model of international trade à la Melitz (2003). We derive the gravity equation and show that endogenous investments reduce the fixed costs elasticity of trade flows, especially in industries with a high degree of vertical differentiation.

## 2.1 Demand side

The world economy consists of $N$ countries indexed by $i \in N$. A representative consumer in one country derives utility from the consumption of a homogenous good $j = 0$, and a continuum of differentiated varieties in industries with $j \geq 1$. The upper-tier utility follows a Cobb-Douglas function with expenditure shares by industry $\beta_j$:

$$U = \sum_{j=0}^{J} \beta_j \log X_j, \;\; \sum_{j=0}^{J} \beta_j = 1, \;\; \beta_j \geq 0. \tag{1}$$

Preferences for differentiated goods in industry $j$ follow a CES utility function:

$$X_j = \left[ \int_{\omega \in \Omega_j} \left( q_j\left(\omega\right) x_j\left(\omega\right)\right)^{\frac{\sigma_j - 1}{\sigma_j}} d\omega \right]^{\frac{\sigma_j}{\sigma_j - 1}}, \, \sigma_j > 1, \, j \geq 1, \tag{2}$$

whereas individual varieties are indexed by $\omega \in \Omega_j$, and $\sigma_j$ denotes the constant elasticity of substitution by industry. Due to the upper-tier Cobb-Douglas utility function, consumers spend $Y_j = \beta_j Y$ on goods produced by industry $j$, whereas $Y$ is total income. Demand for one variety $x_j\left(\omega\right)$ depends negatively on the price $p_j\left(\omega\right)$ and positively on the quality level

$q_j(\omega)$:

$$x_j(\omega) = A_j q_j(\omega)^{\sigma_j - 1} p_j(\omega)^{-\sigma_j} \quad , \; A_j = Y_j P_j^{\sigma_j - 1}. \tag{3}$$

The quality-adjusted aggregate price index in one industry $j$ is defined as:

$$P_j = \left[ \int_{\omega \in \Omega_j} \left( \frac{p_j(\omega)}{q_j(\omega)} \right)^{1-\sigma_j} di \right]^{\frac{1}{1-\sigma_j}}. \tag{4}$$

## 2.2 Production and quality investment

Each country is endowed with inelastic labor $\overline{L}_i$ which is mobile across industries, but immobile across countries. As in Melitz (2003), a firm offers one differentiated variety $i$ in a monopolistically competitive industry. At the entry stage, each producer draws a productivity parameter $\varphi_i$ from a common probability distribution $g(\varphi)$. After successful entry, a firm sets the price for the good, and additionally chooses the optimal level of investment in quality $q_j(\omega)$. As equation (3) shows, these innovations increase the demand at any given price. We follow Kugler and Verhoogen (2012) as well as Sutton (2012) and assume that quality investments are associated with endogenous sunk costs:

$$f[q_j(\omega)] = \frac{q_j(\omega)^{\alpha_j}}{\alpha_j} \text{ with } \alpha_j > \sigma_j - 1. \tag{5}$$

The technology parameter $\alpha_j$ is industry-specific and determines the convexity of the investment cost function. We assume that investment costs are sufficiently convex ($\alpha_j > \sigma_j - 1$) to ensure a well-defined optimum.[8] Production is associated with fixed costs $f_j$ and variable costs such that the labor requirement of a single firm can be written as:

$$l_j(\omega) = f_j + \frac{q_j(\omega)^{\theta_j}}{\varphi} x_j(\omega) \text{ with } 0 < \theta_j < 1. \tag{6}$$

As in Melitz (2003), marginal production costs decrease in firm productivity $\varphi$. Additionally, a higher quality level leads to an increase in marginal production costs, whereas the parameter $\theta_j$ captures the elasticity of marginal costs with respect to quality. This assumption can be motivated by additional marketing or advertising expenditures and implies that higher quality is associated with higher prices.[9]

We assume that exporting from country $i$ to destination $n$ involves iceberg-transportation

[8] In particular, this convexity assumption is a sufficient condition to ensure that profits in equation (11) are well-defined and positive.

[9] Baldwin and Harrigan (2011) and Kugler and Verhoogen (2012) show that this assumption is crucial to explain the positive correlation of prices with distance and firm size.

costs $\tau_{ni} \geq 1$, whereas $\tau_{ii} = 1$, and fixed trade costs $f_{ni} > 0$. Firms maximize total profits to choose the optimal price $p_{nij}$, as well as the optimal level of product quality $q_{nij}$:

$$\pi_{ij} = \sum_{n=1}^{N} \pi_{nij} = \sum_{n=1}^{N} 1_{\{x_{nij}>0\}} \left[ s_{nij} - \tau_{ni} \frac{{q_{nij}}^{\theta_j}}{\varphi} x_{nij} - \frac{1}{\alpha_j} q_{nij}^{\alpha_j} - f_{ni} \right], \tag{7}$$

whereas the indicator $1_{\{x_{nij}>0\}}$ takes a value of one if a firm in industry $j$ sells its product from country $i$ to destination $n$, and sales are defined as: $s_{nij} = p_{nij} x_{nij}$. Equation (7) implies that firms separately choose prices and product quality for each destination. Hence, we abstract from investment or price interdependencies across markets. This assumption is consistent with empirical evidence that points to quality-based market segmentation of exporters (Bastos and Silva, 2010; Manova and Zhang, 2012; Flach, 2016). Solving the maximization problem yields the optimal price of a firm in industry $j$ that sells from country $i$ to destination $n$:[10]

$$p_{nij}(\varphi) = \frac{\sigma_j}{\sigma_j - 1} \frac{\tau_{ni} q_{nij}^{\theta_j}}{\varphi}. \tag{8}$$

The price is set as a constant markup over marginal production costs that decrease in firm productivity $\varphi$, but increase in the level of quality innovation which is given by:

$$q_{nij} = \left[ (1-\theta_j) A_{nj} \left( \frac{\sigma_j}{\sigma_j - 1} \right)^{-\sigma_j} \left( \frac{\tau_{ni}}{\varphi} \right)^{1-\sigma_j} \right]^{\frac{1}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}}. \tag{9}$$

The quality level depends positively on the market size $A_{nj} = Y_{nj} P_{nj}^{\sigma_j - 1}$ and negatively on iceberg transportation costs $\tau_{ni}$. Firms with higher productivity have a larger incentive to invest in quality as they realize larger sales and thus face a higher return from innovations. Using equations (8) and (9), firm sales and profits from selling to a particular destination can be written as:

$$s_{nij}(\varphi) = A_{nj}^{\frac{\alpha_j}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}} \left[ (1-\theta_j)^{1-\theta_j} \left( \frac{\sigma_j}{\sigma_j - 1} \right)^{\theta_j - 1 - \alpha_j} \left( \frac{\tau_{ni}}{\varphi} \right)^{-\alpha_j} \right]^{\frac{\sigma_j - 1}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}}, \tag{10}$$

$$\pi_{nij} = s_{nij}(\varphi) \frac{\alpha_j - (1-\theta_j)(\sigma_j - 1)}{\alpha_j \sigma_j} - f_{ni}. \tag{11}$$

Selection of firms into exporting is determined by a zero-profit condition: $\pi_{nij}(\varphi_{nij}^*) = 0$. All producers from country $i$ and industry $j$ with $\varphi > \varphi_{nij}^*$ serve the foreign market $n$. By using

[10] See Appendix A.1 for a derivation of firm's maximization problem.

equation (11), the zero-profit condition can be written as:

$$s_{nij}(\varphi^*_{nij}) = \frac{\alpha_j \sigma_j f_{ni}}{\alpha_j - (1-\theta_j)(\sigma_j - 1)}, \tag{12}$$

which leads to the following cutoff productivity for serving market $n$:

$$\varphi^*_{nij} = \Delta \tau_{ni} \left( \frac{\alpha_j \sigma_j f_{ni}}{\alpha_j - (1-\theta_j)(\sigma_j - 1)} \right)^{\frac{\alpha_j - (\sigma_j - 1)(1-\theta_j)}{\alpha_j (\sigma_j - 1)}} A_{nj}^{\frac{-1}{\sigma_j - 1}}, \tag{13}$$

whereas $\Delta = (1-\theta_j)^{-\frac{(1-\theta_j)}{\alpha_j}} \left( \frac{\sigma_j}{\sigma_j - 1} \right)^{\frac{\alpha_j + 1 - \theta_j}{\alpha_j}}$. At the entry stage, firms pay fixed entry costs $f_{Ei}$ and draw their productivity parameter $\varphi$. Free entry ensures that expected profits equal the fixed entry costs $f_{Ei}$:

$$\sum_{n=1}^{N} \int_{\varphi^*_{nij}}^{\infty} \pi_{nij}(\varphi) g_i(\varphi) = f_{Ei}. \tag{14}$$

The combination of the zero-profit conditions (13) and the free-entry condition (14) uniquely pins down the entry cutoff productivity for serving the domestic market:[11]

$$\left(\varphi^*_{iij}\right)^{\xi_j} = \frac{\alpha_j (\sigma_j - 1) \sum_n \frac{f_{ni}}{f_{Ei}} \tau_{ni}^{-\xi_j} \left( \frac{f_{ni}}{f_{ii}} \right)^{-\frac{\xi_j [\alpha_j - (\sigma_j - 1)(1-\theta_j)]}{\alpha_j (\sigma_j - 1)}}}{\xi_j [\alpha_j - (\sigma_j - 1)(1-\theta_j)] - \alpha_j (\sigma_j - 1)}. \tag{15}$$

We use this model with quality differentiation to derive gravity equations of international trade and show that firms' investment behavior influences the elasticity of exports with respect to fixed costs. Before we do so, the next section discusses how vertical differentiation affects the competition of heterogeneous producers, which will be crucial for the subsequent gravity analysis.

## 2.3 The role of vertical differentiation

The competitiveness of a firm depends on its quality-price ratio, which follows immediately from combining equations (8) and (9), and reflects how attractive a variety is for consumers:

$$\frac{q_{nij}}{p_{nij}} = \left[ (1-\theta_j)^{1-\theta_j} A_{nj}^{1-\theta_j} \left( \frac{\sigma_j - 1}{\sigma_j} \right)^{\alpha_j + 1 - \theta_j} \left( \frac{\varphi}{\tau_{ni}} \right)^{\alpha_j} \right]^{\frac{1}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}}. \tag{16}$$

[11] See Appendix A.2 for a detailed derivation of the entry cutoff productivity.

The price-adjusted quality increases in firm productivity $\varphi$ and the market size $A_{nj}$ due to higher returns from investments. To compare the competitiveness of different producers, we consider the sales of a firm with productivity $\varphi$ relative to the least productive firm that sells from the same industry $j$ and country $i$ to destination $n$:

$$\frac{s_{nij}(\varphi)}{s_{nij}(\varphi^*_{nij})} = \left(\frac{\varphi}{\varphi^*_{nij}}\right)^{\frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}}. \tag{17}$$

Relative sales in equation (17) depend on the productivity difference, as well as on the technology parameters $\alpha_j$ and $\theta_j$. Following Kugler and Verhoogen (2012), these technology parameters determine the R&D intensity in an industry $j$, defined as the ratio of expenditures for quality innovations relative to firm sales:

$$\frac{\frac{1}{\alpha_j} q_{nij}^{\alpha_j}(\varphi)}{s_{nij}(\varphi)} = \frac{1-\theta_j}{\alpha_j}\frac{\sigma_j - 1}{\sigma_j}. \tag{18}$$

R&D intensity as shown in equation (18) is independent of firm size which is consistent with empirical evidence (Klette and Kortum, 2004). In our empirical analysis, we consider industries with different degree of vertical differentiation, which is determined by the technology parameters $\alpha_j$ and $\theta_j$ in the theoretical model. If investment costs are less convex (low $\alpha_j$) or the elasticity of marginal production costs with respect to quality is low (low $\theta_j$), returns from quality innovations become larger. In such an industry, firms have high incentives to invest in quality relative to sales, which leads to a large degree of vertical differentiation (18). The high incentive to innovate holds especially for high productivity firms as they earn larger sales. Equations (16) and (17) show that high productivity firms invest more in (price-adjusted) quality and earn relatively larger market shares compared to low productivity firms, whenever the degree of vertical differentiation is high. Thus, low productivity firms face stronger competition in industries with higher degree of vertical differentiation as it becomes more difficult for them to reap positive market shares. This impact of vertical differentiation on the competition among firms will be decisive to explain the effect of trade costs in the gravity equation, which is derived in the following subsection.

## 2.4 Gravity equation and comparative statics

We aggregate sales $s_{nij}(\varphi)$ of all firms that serve a particular destination to obtain an expression for export flows from country $i$ and industry $j$ to country $n$:

$$S_{nij} = \frac{1 - G_{ij}\left(\varphi_{nij}^{*}\right)}{1 - G_{ij}\left(\varphi_{iij}^{*}\right)} M_{ij} \int_{\varphi_{nij}^{*}}^{\infty} s_{nij}(\varphi) \frac{g_{ij}(\varphi)}{1 - G_{ij}\left(\varphi_{nij}^{*}\right)} d\varphi. \tag{19}$$

We assume that productivity $\varphi$ is Pareto distributed with density function $g_{ij}(\varphi) = \xi_j \varphi^{-\xi_j - 1}$, whereas $\xi_j$ is the Pareto shape parameter and $G_{ij}(\varphi)$ is the cumulative distribution function. This assumption implies that the share of exporters can be expressed as follows:

$$\gamma_{nij} = \frac{1 - G_{ij}\left(\varphi_{nij}^{*}\right)}{1 - G_{ij}\left(\varphi_{iij}^{*}\right)} = \tau_{ni}^{-\xi_j} \left(\frac{f_{ni}}{f_{nn}}\right)^{-\xi_j \frac{\alpha_j - \left(\sigma_j - 1\right)\left(1 - \theta_j\right)}{\alpha_j \left(\sigma_j - 1\right)}}, \tag{20}$$

and the gravity equation (19) can be written as:[12]

$$S_{nij} = \underbrace{\tau_{ni}^{-\xi_j} \left(\frac{f_{ni}}{f_{ii}}\right)^{-\xi_j \frac{\alpha_j - \left(\sigma_j - 1\right)\left(1 - \theta_j\right)}{\alpha_j \left(\sigma_j - 1\right)}} M_{ij}}_{\text{Extensive margin}} \underbrace{\frac{\xi_j \alpha_j \sigma_j f_{ni}}{\xi_j \left[\alpha_j - \left(\sigma_j - 1\right)\left(1 - \theta_j\right)\right] - \alpha_j \left(\sigma_j - 1\right)}}_{\text{Intensive margin}}. \tag{21}$$

Following Melitz and Redding (2014), total export sales can be divided into an extensive margin as well as an intensive margin component. To disentangle exporter and importer fixed effects, which will be important in the subsequent empirical analysis, we rewrite equation (21) and obtain:

$$S_{nij} = \frac{S_{ij}}{\Xi_{ij}} \left(\frac{Y_n}{P_n^{1-\sigma_j}}\right)^{\frac{\xi_j}{\sigma_j - 1}} \tau_{ni}^{-\xi_j} \left(f_{ni}\right)^{\frac{\alpha_j\left(\sigma_j - 1\right) - \xi_j\left[\alpha_j - \left(\sigma_j - 1\right)\left(1 - \theta_j\right)\right]}{\alpha_j\left(\sigma_j - 1\right)}}, \tag{22}$$

whereas $S_{ij} = \sum_n S_{nij}$ denotes total sales of industry $j$ in country $i$. Exporter-industry fixed effects are captured by $\frac{S_{ij}}{\Xi_{ij}}$, with $\Xi_{ij} = \sum_n \left(\frac{Y_{nj}}{P_{nj}^{1-\sigma_j}}\right)^{\frac{\xi_j}{\sigma_j - 1}} \tau_{ni}^{-\xi_j} f_{ni}^{\frac{\alpha_j\left(\sigma_j - 1\right) - \xi_j\left[\alpha_j - \left(\sigma_j - 1\right)\left(1 - \theta_j\right)\right]}{\alpha_j\left(\sigma_j - 1\right)}}$, and the second term $\left(\frac{Y_n}{P_n^{1-\sigma_j}}\right)^{\frac{\xi_j}{\sigma_j - 1}}$ reflects importer-industry fixed effects. We analyze the impact of fixed and variable trade costs on bilateral trade flows and on the extensive margin of international trade. The effect of fixed trade costs on exports from country $i$ and industry $j$

[12] See Appendix A.3 for a derivation of the gravity equation (21).

to destination $n$ follows immediately from equation (22):

$$\frac{d\ln S_{nij}}{d\ln f_{ni}} = \underbrace{1-\frac{\xi_j}{\sigma_j-1}}_{\text{Chaney (2008)}} + \underbrace{\frac{\xi_j\left(1-\theta_j\right)}{\alpha_j}}_{\text{Quality effect}}. \tag{23}$$

The total impact can be decomposed into two effects. The first part in equation (23) is the same elasticity as in Chaney (2008). The last term, however, is a new quality effect that would not be present in a model without vertical differentiation. For industries with lower technology parameters $\alpha_j$ and $\theta_j$ and thus a higher degree of vertical differentiation (18), the trade elasticity of export flows becomes lower.

**Prediction 1** The elasticity of trade flows with respect to fixed trade costs is lower in industries with higher degree of vertical differentiation.

This prediction is driven by adjustments at the extensive margin. To see this, the elasticity of the share of exporters with respect to fixed trade costs can be divided into a direct effect and a new quality effect as well, following from equation (20):

$$\frac{d\ln \gamma_{nij}}{d\ln f_{ni}} = \underbrace{-\frac{\xi_j}{\sigma_j-1}}_{\text{Chaney (2008)}} + \underbrace{\frac{\xi_j\left(1-\theta_j\right)}{\alpha_j}}_{\text{Quality effect}}. \tag{24}$$

**Prediction 2** The elasticity of the share of exporters with respect to fixed trade costs is lower in industries with higher degree of vertical differentiation.

As for export flows, the direct negative effect of fixed trade costs is reduced in industries with high degree of vertical differentiation. The intuition for this counteracting quality effect follows the discussion in subsection 2.3. A decrease in fixed trade barriers induces lower productivity firms to enter export markets. However, in industries with high degree of vertical differentiation, it becomes more difficult for new entrants with low productivity and thus low price-adjusted quality to reap positive market shares as they face strong competition from existing high quality firms. Hence, the effect of lower trade costs on the extensive margin and on export flows is relatively weak in those industries. Conversely, new entrants after trade liberalization are relatively large in industries with low degree of quality differentiation which leads to stronger effects at the extensive margin and on aggregate export flows.

The effect of quality differentiation on the elasticities (23) and (24) is opposed to the impact of horizontal differentiation, as discussed in Chaney (2008). If the degree of horizontal differentiation is high (lower $\sigma_j$), consumers react less sensitive to price differences, such that

new entrants with low productivity find it easier to reap market shares. Thus, horizontal differentiation increases the impact of fixed trade costs on the extensive margin, whereas vertical differentiation reduces the effect on trade. This implication will be important to distinguish between horizontal and vertical differentiation in the empirical analysis. As in Chaney (2008), the effect of variable trade costs on bilateral export sales and the share of exporters only depends on the Pareto shape parameter:

$$\frac{d \ln S_{nij}}{d \ln \tau_{ni}} = \frac{d \ln \gamma_{nij}}{d \ln \tau_{ni}} = -\xi_j. \tag{25}$$

Intuitively, the impact of vertical differentiation works through endogenous sunk costs and adjustments at the extensive margin. This channel is not present for changes in variable trade costs.

**Prediction 3** Variable trade costs reduce export sales and the share of exporters. The degree of vertical product differentiation has no effect on the elasticity of trade flows with respect to variable trade costs.

# 3 Data

To investigate the predictions from the theory, we first need trade data at the aggregate level and at the firm level. We use world bilateral trade flows from Baci-Comtrade and Brazilian firm-level data from SECEX (Foreign Trade Secretariat). The Baci-Comtrade data provide information on total exports $S_{nij}$ from country $i$ to country $n$ in industry $j$. The main advantage of this dataset is that transportation costs are always removed, such that the results can be consistently interpreted in terms of fob export values (Gaulier and Zignago, 2010). This reduces concerns with freight and transportation costs as confounding factors.[13] Nonetheless, it is still important to control for $\tau_{ni}$, in particular as it affects trade through the quality function shown in equation (9). The firm-level data from SECEX provide information on total exports $s_{njf}$ from firm $f$ to country $n$ in industry $j$. With this information, we construct the share of exporters by destination and industry, $\gamma_{nj}$.[14]

To investigate the predictions across industries, we need information on the degree of vertical product differentiation by industry. The first measure we use is the "quality ladder" suggested

[13] In an earlier version of this paper (Flach and Unger, 2016), we have used NBER-UN and Comtrade data constructed by Feenstra, Lipsey, Deng, Ma, and Mo (2005). As we want to evaluate the role of fixed costs, the Baci data reduce concerns with freight and transportation costs as confounding factors.

[14] The firm-level customs data are available at the 8-digit NCM classification (*Nomenclatura Comum do Mercosur*). The customs data are combined with the 4-digit SITC classification of goods and the CNAE industry classification (*Classificação Nacional de Atividades Econômicas*). For the aggregate and the firm-level data, we use data for the year 2000. More details are provided in the data appendix.

by Khandelwal (2010), which is closely related to the degree of vertical differentiation (18) in our theoretical model. Intuitively, a higher degree of differentiation leads to more favorable investment conditions, such that firms invest more in quality and generate larger sales conditional on firm size and prices. This follows the idea of Khandelwal (2010) that quality can be inferred from the estimation of market shares after controlling for prices and country characteristics.[15] Because this measure is available for a larger number of industries (see summary statistics in Table B1), we use it as the main measure of vertical differentiation.

The second measure of differentiation is the R&D intensity of the industry used by Kugler and Verhoogen (2012), which resembles exactly our theoretical model. As shown in equation (18) in the theory, we express the R&D intensity in an industry $j$ as the ratio of expenditures for quality innovations relative to firm sales. Another advantage is that we use this measure combined with a proxy for *horizontal* differentiation based on the Gollop and Monahan (1991) index, as made available by Kugler and Verhoogen (2012).[16] When we use the measure of horizontal differentiation along with vertical differentiation, we can directly relate the empirical results to equation (23) in the theory, where we decompose the trade elasticity into a component that only depends on horizontal differentiation as in Chaney (2008) and a new component that depends on vertical differentiation. All industry-level measures are aggregated to the 4-digit SITC classification (Standard International Trade Classification) revision 2. Besides the close relation to our theory, another advantage of the industry-level measures for quality differentiation (both R&D intensity and the "quality ladder") is that they are taken from the analysis of US data, and hence, they are less subject to endogeneity concerns in our empirical analysis.

Finally, we need information on variable and fixed trade costs. Tariff data ($\tau_{ni}$) come from TRAINS-WTI[17] and additive trade costs are estimated based on Irarrazabal et al. (2015), as described in the data appendix B.1. As proxies for fixed costs, we use common language ($Language_{ni}$) from CEPII and measures of administrative trade barriers from the *Doing Business - Trading Across Borders* (World Bank, 2016). We also investigate the effect of bilateral distance ($Dist_{ni}$) on trade, controlling for variable trade costs. Although distance might reflect both fixed and variable trade costs, it has the advantage of being a truly exogenous measure and of providing empirical insights that can be easily related to the

[15]See Appendix A.4 for a more formal comparison of our model to Khandelwal (2010).

[16]We take the values computed by Kugler and Verhoogen (2012) based on the Gollop and Monahan (1991) index. The measure exploits the dissimilarity of input mixes across plants within an industry and was originally created to measure diversification across establishments of multi-establishment firms. However, as described by Kugler and Verhoogen (2012), it also captures well horizontal differentiation across firms.

[17]The tariff data have the advantage of being a time-varying measure of variable costs, such that we can identify the coefficient including importer-exporter-industry fixed effects. We use the AHS tariffs (effective applied tariffs) and conduct robustness checks using MFN (Most Favored Nation) tariffs.

previous literature (Chaney, 2008; Crozet and Koenig, 2010; Ferguson, 2012; Martin and Mayneris, 2015).

The measures of administrative trade barriers from the World Bank refer to the time for documentary compliance $t\_doc_{ni}$ and border compliance $t\_border_{ni}$. The first measure includes the time in hours to comply with the documentary requirements of the government agencies in the origin and destination country, including transit economies. The second measure captures the time in hours to comply with the regulations relating to customs clearance and mandatory inspections to cross the border. As a shipment moves from one destination to the other, documents have to be prepared and submitted to customs agencies and border authorities both in the origin and destination countries. To capture this, we compute bilateral measures of documentary and border compliance for each country-pair, which refers to the sum of time-to-ship goods measured in hours.[18] The variables are described in more detail in the Appendix B.1. The main variables of interest are summarized in Table B1.[19]

# 4 Empirical analysis

The objective of this section is to provide theory-consistent estimations of the trade elasticity with respect to fixed costs and variable costs depending on the industrial degree of vertical differentiation. We provide results for aggregate trade flows and for the extensive margin of exports in sections 4.1 and 4.2, respectively, and robustness checks in section 4.3.

## 4.1 The elasticity of trade flows with respect to fixed costs: Results for aggregate trade flows

To test prediction 1, we write a log-linearized version of the gravity equation shown in equation (22) and obtain:

$$\ln S_{nij} = \ln\left(\frac{S_{ij}}{\Xi_{ij}}\right) + \ln\left(\frac{Y_n}{P_n^{1-\sigma_j}}\right)^{\frac{\xi_j}{\sigma_j-1}} - \xi_j \ln \tau_{ni} + \frac{\alpha_j(\sigma_j-1)-\xi_j[\alpha_j-(\sigma_j-1)(1-\theta_j)]}{\alpha_j(\sigma_j-1)} \ln f_{ni}.$$

Because we are interested in the elasticity with respect to fixed costs, we hold constant origin-specific and destination-specific terms (income and price indices). Empirically, this

[18] This approach is motivated by the methodology of the Trading Across Borders dataset (see http://www.doingbusiness.org/methodology/trading-across-borders), and closely related to Manova (2013) who computes bilateral measures of fixed costs using data on regulation costs from Djankov et al. (2002).

[19] For the firm-level data, there are more missing observations for the variables $t\_border_{ni}$ and $t\_doc_{ni}$. The main reason is the large number of observations between Brazil and countries with value *zero* for the compliance measures, such as Austria, Belgium, Germany, Italy, Netherlands, and Sweden. We conduct robustness checks using the log of the variable + 1 for all specifications and the results remain robust.

means that we include importer-industry and exporter-industry fixed effects in the gravity regressions, which absorb the terms $\left(\frac{S_{ij}}{\Xi_{ij}}\right)$ and $\left(\frac{Y_n}{P_n^{1-\sigma_j}}\right)^{\frac{\xi_j}{\sigma_j-1}}$, respectively. The effect of variable trade costs ($\tau_{ni}$) on sales depends only on the Pareto shape parameter, as shown in prediction 3 from the model. In the empirical analysis, we provide evidence for prediction 3 using proxies for variable trade costs such as tariffs.[20]

The main interest of prediction 1 refers to the differential effects across industries depending on the ratio $\frac{1-\theta_j}{\alpha_j}$ (the sensitivity with respect to quality). We use $ladder_j$ or the R&D intensity of the industry as proxies for the degree of vertical differentiation. Hence, to investigate the effect of quality on the trade elasticity at the aggregate level, we add an interaction term between fixed costs and the degree of vertical differentiation of the industry, as follows:

$$\ln S_{nij} = \beta_1 fixedcosts_{ni} + \beta_2 fixedcosts_{ni} * ladder_j + \beta_3 \ln \tau_{ni} + \beta_4 \ln \tau_{ni} * ladder_j + \rho_{ij} + \mu_{nj} + \varepsilon_{nij}, \tag{26}$$

where $n$ is the importer, $i$ is the exporter, $j$ is the SITC 4-digit industry, $S_{nij}$ are the export flows from country $i$ to $n$ in industry $j$, $ladder_j$ is the degree of differentiation of industry $j$, $\mu_{nj}$ and $\rho_{ij}$ are importer-industry and exporter-industry fixed effects, and $\varepsilon_{nij}$ is the error term. The terms $\mu_{nj}$ and $\rho_{ij}$ control for the multilateral resistance term of Anderson and van Wincoop (2003) and allow for a theory-consistent estimator. Moreover, they absorb any other characteristic specific to an importer-industry and exporter-industry pair.[21]

In addition, we conduct the analysis including bilateral importer-exporter fixed effects $\upsilon_{ni}$, which help mitigate endogeneity concerns related to trade policy and other characteristics specific to a country pair.[22]

We use different measures of fixed costs. First, we conduct the analysis using language, time for border compliance and time for documentary compliance. Second, we run regressions using distance (controlling for variable trade costs), as distance provides important insights related to the quality sorting literature (Crozet et al., 2012; Martin and Mayneris, 2015).

Higher fixed costs imply that $\beta_1 < 0$ (see the discussion in section 2.4). The new element in the estimation and main coefficient of interest is $\beta_2$. Prediction 1 shows that the elasticity

[20] Note that in all tables in the empirical analysis we include estimations with interacted importer-exporter $ni$ fixed effects, which reduce endogeneity concerns related to trade policy and account for every possible common characteristic within a country pair $ni$. We also use trade data based on fob values, which reduces concerns with freight costs.

[21] The fixed effects we include control for the sectoral quality variable as well as for country-specific effects. This is why these terms do not appear explicitly in the empirical specification.

[22] Because we include $\upsilon_{ni}$ in the tables shown in the empirical analysis, we account for every possible common characteristic within a country pair $ni$, which explains why we do not include standard time-invariant gravity covariates in the empirical analysis.

of trade flows with respect to fixed trade costs is *lower* in industries with higher degree of vertical differentiation. Hence, in industries with a high $ladder_j$, we expect a dampening effect, such that $\beta_2 > 0$.[23]

Another new element in the estimation is $\beta_4$. As standard in the literature, we expect that $\beta_3 < 0$, i.e. that higher variable trade costs have a negative impact on trade flows. However, prediction 3 from our model also shows that the elasticity of trade flows with respect to variable trade costs depends only on the Pareto shape parameter and is not affected by product quality. Hence, our model predicts that $\beta_4$ is not significant.

The baseline results for equation (26) are reported in Table 1 for $t\_border_{ni}$, $t\_doc_{ni}$, and $Language_{ni}$ and in Table 3 for distance. We report the coefficients for $ladder_j$ in Table 1 and discuss the results using R&D intensity and horizontal differentiation in section 4.3.

Table 1 shows that the level effect $\beta_1$ is always negative for $t\_border_{ni}$ and $t\_doc_{ni}$, whereas the interaction term $\beta_2$ is positive and significant. Higher fixed costs associated with time and costs for border and documentary compliance imply lower trade flows, but this effect is less pronounced in high quality ($ladder_j$) industries. As expected, for $Language_{ni}$ the mechanism works in the opposite direction. A common language implies lower fixed costs and hence more trade. However, this effect is smaller in high quality industries, which confirms prediction 1.

The magnitudes of our estimates seem to be plausible. For instance, for $t\_border_{ni}$, a 10% decrease in the time for border compliance increases trade by 3.7% in industries with the lowest degree of quality differentiation whereas it increases trade by only 1.9% in industries with the highest degree of quality differentiation. This example illustrates that the impact of fixed costs on trade differs for industries in the same country pair but with varying degrees of quality differentiation.[24]

Another striking feature of Table 1 is that the interaction term for $\ln \tau_{ni} * ladder_j$ is not significant, which provides empirical evidence for prediction 3 from our model. This result remains robust when we include importer-exporter fixed effects, $\upsilon_{ni}$, which control for gravity covariates and help mitigate endogeneity concerns related to omitted characteristics specific to a country pair.

To provide a better visualization of the industry-specific effects, we aggregate the data to the 2-digit industry and estimate industry-specific coefficients for the interaction term (see

[23] Besides being closely related to our theoretical framework, another advantage of the empirical measure $ladder_j$ is that it is taken from the analysis of US data and hence, it is less subject to endogeneity concerns in our empirical analysis. The same argument applies for the R&D intensity data from Kugler and Verhoogen (2012), which is taken from the U.S. Federal Trade Commission (FTC) 1975 Line of Business Survey.

[24] The overall effect (negative for $t\_border_{ni}$ and $t\_doc_{ni}$ and positive for $Language_{ni}$) of fixed costs on trade remains with the same sign for the whole distribution of industries.

the estimation details in equation (45) in the appendix). The estimated coefficients are reported in the appendix Figure B1. As shown in the left panel for border compliance and in the right panel for documentary compliance, there is a strong positive correlation between vertical differentiation and the estimated interaction term. Hence, more positive coefficients are associated with industries with a higher $ladder_j$.

A further result that reinforces our industry-specific quality mechanism is the relation between industry-specific vertical differentiation and horizontal differentiation. As we discuss in detail in the robustness checks for R&D intensity (section 4.3), a high degree of vertical differentiation has a dampening effect on the trade elasticity, whereas a high degree of horizontal differentiation leads to stronger effects on trade, as predicted by our model.[25]

In Table 1 we lose many observations because of missing data on tariffs. To overcome concerns with sample selection, in the robustness checks shown in the appendix Table B4, we replicate the results from Table 1 using the complete sample without tariff data. The results remain stable and significant.

**Distance and trade** The distance effect on trade and its relation to quality production has attracted a lot of attention in the literature (Crozet and Koenig, 2010; Ferguson, 2012; Martin and Mayneris, 2015). Hence, despite the fact that it reflects fixed and variable trade costs, it provides relevant insights that can be easily related to the previous literature. In Table 3 columns 1 and 2, we show that the interaction term $\beta_2$ is positive and significant. This result is consistent with the empirical literature showing that high quality industries are less sensitive to distance (Ferguson, 2012; Martin and Mayneris, 2015).

Columns 1 and 2 also provide evidence for prediction 3 from our model. As expected, tariffs $\ln \tau_{ni}$ have a negative and significant effect on trade flows. However, the interaction term $\ln \tau_{ni} * ladder_j$ shows that quality has no effect on the trade elasticity with respect to variable costs, whereas our coefficient of interest $\ln Dist_{ni} * ladder_j$ is positive and significant. The results remain robust when we include importer-exporter fixed effects, $\upsilon_{ni}$, as shown in column 2.

Note that all results include interacted $ij$ and $nj$ fixed effects, which control for any omitted characteristic specific to an importer-industry and exporter-industry pair. In addition, in the even columns we add $ni$ fixed effects, which avoid concerns with endogeneity coming from the importer-exporter pair. Finally, we use trade data based on fob values, which reduces concerns with variable costs as confounding factors.

To illustrate the effects across industries, we estimate industry-specific coefficients and plot

[25] We report the baseline results without horizontal differentiation and discuss them in detail in the robustness checks, as data on horizontal differentiation are only available for a restricted sample of industries (see Kugler and Verhoogen (2012)).

the interaction term $\ln Dist_{ni} * ladder_j$ controlling for the level effect, as shown in Appendix B.3.1. As expected, there is a strong positive correlation between vertical differentiation and the estimated interaction term (see Figure B2). For industries with high quality ladders, distance has a much lower impact on exports.

The results reported in Table 3 allow for a comparison of coefficients across columns. Table B13 in Appendix B.3.2 provides robustness checks using the complete sample without tariff data, for which we lose many observations.

Table 1: Fixed costs and aggregate trade flows

| Dependent variable $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $\ln t\_border_{ni}$ | -0.374*** | | | | | |
| | (0.0634) | | | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0375*** | 0.0113* | | | | |
| | (0.0133) | (0.00635) | | | | |
| $\ln t\_doc_{ni}$ | | | -0.612*** | | | |
| | | | (0.0588) | | | |
| $\ln t\_doc_{ni} * ladder_j$ | | | 0.0530*** | 0.0406*** | | |
| | | | (0.0135) | (0.0118) | | |
| $language_{ni}$ | | | | | 1.418*** | |
| | | | | | (0.0965) | |
| $language_{ni} * ladder_j$ | | | | | -0.108*** | -0.103*** |
| | | | | | (0.0198) | (0.0179) |
| $\ln \tau_{ni}$ | -1.365** | | -1.697*** | | -1.667*** | |
| | (0.625) | | (0.620) | | (0.614) | |
| $\ln \tau_{ni} * ladder_j$ | 0.443 | 0.470 | 0.218 | 0.218 | 0.270 | 0.260 |
| | (0.575) | (0.577) | (0.572) | (0.574) | (0.561) | (0.562) |
| Constant | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes |
| Observations | 226,332 | 226,332 | 240,477 | 240,477 | 249,338 | 249,338 |
| R-squared | 0.565 | 0.707 | 0.557 | 0.705 | 0.563 | 0.703 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair and by industry.

## 4.2 The elasticity of trade flows with respect to fixed costs: Results for the share of exporters

To investigate prediction 2 regarding the effect of fixed costs on the share of exporters ($\gamma_{nij}$), we use Brazilian firm-level data. Hence, the dimension $i$ is fixed in the estimations, such that $\gamma_{nij}$ in equation (20) is estimated only by $n$ and $j$. We estimate equation (20) as follows:

$$\gamma_{nj} = \beta_1 fixedcosts_n + \beta_2 fixedcosts_n * ladder_j + \beta_3 \ln \tau_n + \beta_4 \ln \tau_n * ladder_j + \nu_j + \varepsilon_{nj}, \quad (27)$$

where $\gamma_{nj}$ is the share of Brazilian exporters in industry $j$ and destination country $n$, defined as the number of exporters in industry $j$ exporting to destination country $n$ divided by the total number of exporters in industry $j$. The measure $fixedcosts_n$ refers to the time for documentary and border compliance to export from Brazil to destination country $n$. We provide additional results using distance to country $n$. Because we only use data for Brazilian firms, common language $Language_{ni}$ does not provide enough variation to identify the effect. In all tables, we also include results with importer fixed effects $\upsilon_n$ in addition to industry fixed effects $\nu_j$.

Prediction 2 suggests that the share of exporters reacts stronger in industries with lower degree of vertical differentiation. Hence, we expect that in industries with high $ladder_j$ the effect of fixed costs on trade is reduced, i.e. that $\beta_2 > 0$.

The first empirical evidence for equation (27) is reported in Table 2 using $t\_border_{ni}$ and $t\_doc_{ni}$ as proxies for fixed costs. Whereas the share of exporters decreases in fixed costs, this effect is dampened in high quality industries, as suggested by our model.

**Distance and the share of exporters** We report results for the distance effect in Table 3 in columns 3 and 4. As for aggregate trade flows, we find that the share of exporters decreases in distance, but this effect is smaller in high quality industries. The effect remains robust when we control for tariffs, destination country $n$ and industry $j$ fixed effects.[26] Moreover, we estimate industry-specific coefficients and show a strong positive correlation between vertical differentiation and the estimated interaction term (see Figure B2).

[26] See Table B14 in Appendix B.3.2 for robustness checks using the complete sample without tariff data.

Table 2: Fixed costs and the share of exporters

| Dependent variable $\gamma_{nj}$ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $\ln t\_border_n$ | -0.0385*** | | | |
| | (0.00685) | | | |
| $\ln t\_border_n * ladder_j$ | 0.00813** | 0.00715* | | |
| | (0.00373) | (0.00371) | | |
| $\ln t\_doc_n$ | | | -0.0304*** | |
| | | | (0.00391) | |
| $\ln t\_doc_n * ladder_j$ | | | 0.0126** | 0.0110* |
| | | | (0.00630) | (0.00624) |
| $\ln \tau_n$ | -0.0970 | | -0.0962 | |
| | (0.0654) | | (0.0644) | |
| $\ln \tau_n * ladder_j$ | -0.0566 | -0.0431 | -0.0557 | -0.0298 |
| | (0.0694) | (0.0497) | (0.0684) | (0.0489) |
| Constant | yes | yes | yes | yes |
| $n$ fixed effects | no | yes | no | yes |
| $j$ fixed effects | yes | yes | yes | yes |
| Observations | 32,884 | 32,884 | 32,881 | 32,881 |
| R-squared | 0.540 | 0.575 | 0.540 | 0.575 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer $n$ and by industry $j$.

Table 3: Distance and trade

| Dependent variable: | Aggregate trade flows ($\ln S_{nij}$) | | Share of exporters ($\gamma_{nj}$) | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $\ln Dist_{ni}$ | -1.377*** | | | |
| | (0.0317) | | | |
| $\ln Dist_{ni} * ladder_j$ | 0.0883*** | 0.0994*** | | |
| | (0.00760) | (0.00749) | | |
| $\ln \tau_{ni}$ | -1.667*** | | | |
| | (0.614) | | | |
| $\ln \tau_{ni} * ladder_j$ | 0.270 | 0.260 | | |
| | (0.561) | (0.562) | | |
| $\ln Dist_n$ | | | -0.0832* | |
| | | | (0.0474) | |
| $\ln Dist_n * ladder_j$ | | | 0.00784** | 0.00687* |
| | | | (0.00373) | (0.00370) |
| $\ln \tau_n$ | | | -0.0974 | |
| | | | (0.0658) | |
| $\ln \tau_n * ladder_j$ | | | -0.0576 | -0.0433 |
| | | | (0.0702) | (0.0504) |
| Constant | yes | yes | yes | yes |
| Fixed effects | $nj$, $ij$ | $nj$, $ij$, $ni$ | $j$ | $j$, $n$ |
| Observations | 249,338 | 249,338 | 32,884 | 32,884 |
| R-squared | 0.641 | 0.704 | 0.540 | 0.575 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
In columns 1 and 2, errors are clustered by $ni$ and $j$.
In columns 3 and 4, errors are clustered by $n$ and $j$.

## 4.3 Robustness checks

This section shows that our results are robust to alternative specifications and estimation strategies. Section 4.3.1 reports results for R&D intensity controlling for horizontal differentiation. In section 4.3.2, we consider product weights and income per capita to account for Alchian-Allen effects and home market effects. Section 4.3.3 uses panel data to exploit time variation in tariffs. Furthermore, we account for zeros in trade using PPML estimation (4.3.4) and for additive trade costs (4.3.5). Finally, section 4.3.6 shows that the effect of vertical differentiation is not driven by export values per unit, as the estimation for export quantities leads to similar results.

### 4.3.1 R&D intensity and horizontal differentiation

Because the measure $ladder_j$ is available for a larger number of industries, we use it as the preferred proxy of vertical differentiation. However, as shown in equation (18) in the theoretical model, quality differentiation reflects the ratio of firm investment to firm sales, which is exactly the R&D intensity from Kugler and Verhoogen (2012). In order to get closer to the theoretical model, we replicate the analysis for total exports and the share of firms (predictions 1 and 2) using R&D intensity. Another advantage is that we can also control for horizontal differentiation using the Gollop and Monahan (1991) index from Kugler and Verhoogen (2012). Hence, we can directly relate the empirical results to equation (23) in the theory, where we decompose the trade elasticity into a component that only depends on horizontal differentiation as in Chaney (2008), and a new counteracting quality effect that is also influenced by vertical differentiation.

Table 4 shows the results for administrative barriers to trade and common language.[27] The same results are reported for distance in Table B5 and for the share of firms in Table B6. In all tables, the coefficients for the interaction term with R&D confirm the baseline results: the negative effect of fixed costs on trade is smaller in industries with higher R&D intensity. However, R&D intensity does not necessarily mean vertical differentiation. To account for horizontal differentiation, we follow Kugler and Verhoogen (2012) and use the Gollop and Monahan (1991) index (GM index) as a proxy for horizontal differentiation. Equation (23) suggests that the effect of vertical differentiation on the trade elasticity works in the opposite direction compared to the impact of horizontal differentiation.[28] The results in Table 4 confirm the expected direction by showing a negative effect of the interaction term for horizontal

[27]Note that all columns in Table 4 already include importer-exporter fixed effects, which implies that the level effect of fixed costs is no longer identified.

[28]As in Chaney (2008), the impact of trade costs on the extensive margin is larger for products with higher degree of horizontal differentiation (lower elasticity of substitution $\sigma_j$).

differentiation on trade, whereas the effect for vertical differentiation remains positive and significant. The same holds for the distance effect and for the share of firms, as reported in Tables B5 and B6. Note that we report the results for R&D intensity for the larger sample without tariff data, as the R&D data and the GM index are only available for a restricted sample of industries (see Kugler and Verhoogen (2012)).

Table 4: Robustness checks using R&D intensity and horizontal differentiation

| Dependent variable $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $\ln t\_border_{ni}$ * $\ln R\&D$ | 0.0656*** | 0.0649*** | | | | |
| | (0.0161) | (0.0160) | | | | |
| $\ln t\_border_{ni}$ * GM index | | -0.0649 | | | | |
| | | (0.0654) | | | | |
| $\ln t\_doc_{ni}$ * $\ln R\&D$ | | | 0.0576* | 0.0570* | | |
| | | | (0.0343) | (0.0343) | | |
| $\ln t\_doc_{ni}$ * GM index | | | | -0.412** | | |
| | | | | (0.177) | | |
| $language_{ni}$ * $\ln R\&D$ | | | | | -0.0538** | -0.0535** |
| | | | | | (0.0229) | (0.0229) |
| $language_{ni}$ * GM index | | | | | | -0.0593 |
| | | | | | | (0.120) |
| Constant | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | yes | yes | yes | yes | yes | yes |
| Observations | 115,938 | 115,938 | 143,151 | 143,151 | 159,706 | 159,706 |
| R-squared | 0.704 | 0.704 | 0.697 | 0.697 | 0.687 | 0.687 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

### 4.3.2 Additive trade costs

In previous results, we have shown that the effect of fixed costs remains robust controlling for ad valorem tariffs as a proxy for variable trade costs. However, Irarrazabal et al. (2015) find that an important part of trade costs is additive rather than ad valorem, meaning that they are defined as a constant monetary cost per unit traded, rather than as a constant percentage of the producer price. Additive trade costs might affect our variable of interest, as they influence relative consumption patterns both within and across markets (Alchian and Allen, 1964). A high quality product becomes cheaper relative to a low quality product in the presence of additive tariffs. To estimate additive trade costs ($ATC_{nj}$), we use firm-

level data and follow Irarrazabal et al. (2015).[29] The estimation procedure is described in Appendix B.1.

Table B7 reports results for the distance effect controlling for additive trade costs $ATC_{nj}$ as well as for the interaction term $ATC_{nj} * ladder_j$ in columns 3 and 4. Because the sample is much smaller in comparison to the baseline results, we also report the results without $ATC_{nj}$ in columns 1 and 2 of Table B7, such that the coefficients can be compared.[30] The results reveal that the effect of $ATC_{nj}$ on the share of firms is negative, meaning that higher additive trade costs are associated with less firm entry. Perhaps surprisingly, the interaction effect $ATC_{nj} * ladder_j$ is also negative and significant. On the other hand, our coefficient of interest remains stable and is even slightly higher in magnitudes once we control for additive trade costs.

#### 4.3.3 Results controlling for product weights and income per capita

The effect of fixed costs on trade could be driven by alternative mechanisms, such as demand and income effects associated with Alchian and Allen (1964) or home market effects related to the Linder (1961) hypothesis.

First, one important concern is that the results could capture a correlation between the degree of differentiation and the relative product weight: goods that are heavier with respect to their value are likely to travel shorter distances. Moreover, as shown by Alchian and Allen (1964), consumption shifts towards higher-quality products when products face per-unit costs. Hence, we can expect that products with higher value-per-weight are shipped to longer distances. We exploit information on the unit codes of products and compute the log average export value per weight by industry ($\ln uv_{nij}$) and interact this variable with the fixed costs measures. If our results for the fixed costs elasticity are affected by relatively lighter products (in terms of value per weight) being able to reach longer destinations, the interaction term should be positive and should affect our distance coefficient. In the results for total sales ($\ln S_{nij}$) shown in Table B9, we control for the interaction term between $\ln uv_{nij}$ and our measures of fixed costs. The positive and significant coefficients for the interaction term mean that fixed costs are less important for products with higher value per weight, which is consistent with the Alchian and Allen hypothesis. However, our coefficient of interest remains significant and with similar magnitudes when adding the interaction term

[29] Irarrazabal et al. (2015) allow for additive trade costs besides the standard iceberg transportation costs ($\tau_{nij}$) and propose a framework to structurally estimate the magnitude of additive trade costs using firm-level data. The underlying mechanism relates higher additive trade costs with a less negative demand elasticity, and more so among low price firms.

[30] Note that the sample gets too restrictive if we control for tariffs besides $ATC_{nj}$, given the large amount of missing values for tariff data.

as a control variable.[31] Note that the level effect $\ln uv_{nij}$ shown in Table B9 is negative once we add $i$, $n$, $j$, $ij$ and $nj$ fixed effects. Within an industry and for every $ij$ and $nj$, products with higher unit values are associated with lower trade volumes. The level effect is no longer negative if we do not account for these fixed effects, which are crucial to control for multilateral resistance terms.

Second, our results could reflect systematic variation between the type of product traded and the similarity of income per capita in the origin and destination countries. For instance, it could capture the fact that high-income countries trade more products of high quality because of home market effects, which implies that quality is an important determinant of the direction of trade (Linder, 1961). On the demand side, high-income countries spend a larger fraction of their income on high quality goods. On the supply side, countries develop a comparative advantage according to local demand and tastes of consumers, and sell these products to other countries that share these tastes.

To account for income similarity, we investigate the sensitivity of the results when adding a "Linder term". We follow Hallak (2010) and construct a measure of *dissimilarity* of income between pairs of countries as follows: $Linder_{ni} = (\ln CGDP_i - \ln CGDP_n)^2$, where $CGDP$ is the income per capita of a country. We expect that a larger Linder term $Linder_{ni}$ (i.e., more dissimilar incomes) leads to smaller trade flows. The Linder (1961) hypothesis is confirmed in Table B8. There is a negative relation between income dissimilarity ($Linder_{ni}$) and trade flows. This negative relation is even stronger for high-quality goods, as reported by the interaction term $Linder_{ni} * ladder_j$. However, also in this case, our coefficients of interest remain significant and with similar magnitudes, which lends support to our mechanism.

#### 4.3.4 The elasticity of trade flows with respect to variable costs: results using panel data

The results from Tables 1 and 3 show that quality does not affect the elasticity with respect to variable costs (proxied by tariffs). We can investigate the robustness of prediction 3 using panel data, which has the advantage that we can account for importer-exporter-industry fixed effects ($\upsilon_{nij}$). We estimate a time-varying gravity equation as follows:

$$\ln S_{nijt} = \beta_1 \ln \tau_{nijt} + \beta_2 \ln \tau_{nijt} * \ln ladder_j + \upsilon_{nij} + \mu_t + \varepsilon_{nijt}, \tag{28}$$

[31] The magnitudes of the interaction term should be interpreted with caution, as $\ln uv_{nij}$ represents the value of sales per weight and sales also appear on the left-hand side of the regression. Hence, measurement error may appear on both sides of the regression, generating a mechanical positive bias in the OLS estimate. Despite this caveat, the results suggest that our coefficient of interest remains stable.

where $S_{nijt}$ are bilateral trade flows in industry $j$ and year $t$. As the elasticity of exports with respect to variable trade costs depends only on the Pareto shape parameter (see prediction 3), the effect of $\tau_{nijt}$ on $S_{nijt}$ should be solely captured by $\beta_1$. The results are reported in Table B10. Using panel data, we show that $\beta_1 < 0$ in all columns, in accordance with the literature and with our baseline results. The results in columns 3 and 4 reinforce that $\beta_2$ is not significant, in accordance with prediction 3 from the model.

### 4.3.5 Zeros and trade: Results using poisson pseudo maximum likelihood

A standard concern regarding the estimation of gravity equations using OLS is the presence of zero trade. To tackle this issue, we investigate the robustness of the main results using a poisson pseudo maximum likelihood (PPML) estimation. Estimation of bilateral trade flows (with importer-exporter $ni$ data) using PPML is standard in the literature.[32] However, because our data have the industry dimension in addition to country pairs $ni$, the estimation with $nij$ dimensions where $j$ is a 4-digit industry implies too many zero values. Hence, for the PPML we use a more aggregated industry classification at the 3 digit instead of 4 digit level.

The results are reported in Table B11. Except for the level effect of language which is less precisely estimated, all other coefficients remain significant and with the expected sign. Moreover, by accounting for zeros in trade, the coefficient of interest is even larger in magnitudes in all specifications.[33]

### 4.3.6 Trade quantities

Products of higher quality are traded at higher values. In previous robustness checks, we have shown that the results remain robust when we control for the value per weight of the product. As an alternative to account for a potential bias in trade flows, we investigate traded quantities instead of values. Table B12 shows that the effect of fixed costs on trade *quantities* is lower in industries with higher degree of vertical differentiation. Hence, the results are not driven by the value per unit of the product.

[32] Santos-Silva and Tenreyro (2006) highlight the potential pitfalls of log-linear estimations due to sample selection in the presence of zero trade flows and heteroskedasticity with the log transformation. They suggest the estimation of the gravity equation in their multiplicative form using PPML estimators. Head and Mayer (2014) provide a detailed review of the gravity literature.

[33] The coefficients are not directly comparable as the estimations are conducted at a different level of aggregation. However, a replication of the baseline results using the data at 3-digit level reveals that the OLS results are in fact smaller in magnitudes in comparison to the PPML estimations.

# 5 Estimation of model

The preceding analysis has shown that vertical differentiation reduces the effect of fixed costs on trade flows and on the share of exporters. In this section we analyze the quantitative effects of lower trade barriers and compare it to a benchmark model without vertical differentiation. To do so, we need industry estimates for the following parameters of our model: the Pareto shape parameter $\xi_j$, the elasticity of substitution $\sigma_j$, and the technology ratio $\frac{1-\theta_j}{\alpha_j}$. We follow a three-step procedure to obtain the parameter values for each industry. First, we use the estimates for the Pareto shape parameter from Crozet and Koenig (2010).[34] This step exploits that the elasticity of trade flows with respect to variable trade costs is only determined by the Pareto shape parameter $\xi_j$ (eq. (25)). Second, we estimate the elasticity of exports with respect to fixed costs (eq. (23)), measured by the time required for border compliance.[35] Third, we use data on R&D intensity from Kugler and Verhoogen (2012), which corresponds to the degree of vertical differentiation (eq. (18)) in our theoretical model.[36]

Table 5: Parameter estimates by industry

| Industry | $\xi_j$ | $\sigma_j$ | $\frac{1-\theta_j}{\alpha_j}$ |
|---|---|---|---|
| Builder's carpentry and joinery | 1.65 | 2.31 | 0.009 |
| Newsprint | 3.71 | 3.46 | 0.011 |
| Printing paper and writing paper | 3.71 | 3.99 | 0.011 |
| Paper and paperboard | 3.71 | 3.91 | 0.011 |
| Packing containers, box files of paper | 3.71 | 3.93 | 0.007 |
| Paper pulp, paper, paperboard | 3.71 | 3.34 | 0.056 |
| Textile yarn, synthetic fibres, not for retail | 1.84 | 2.45 | 0.076 |
| Machinery, equipment for heating and cooling | 3.21 | 3.49 | 0.041 |
| Filtering, purifying machinery, for liquids, gases | 3.21 | 3.21 | 0.042 |
| Parts of purifying and filtering machinery | 3.21 | 3.18 | 0.042 |
| Valves for pipes boiler shells | 3.21 | 3.10 | 0.025 |
| Shaft, crank, bearing housing, pulley | 3.21 | 3.00 | 0.049 |
| Precious jewellery | 1.92 | 2.49 | 0.082 |
| Sound recording tape, discs | 1.92 | 2.55 | 0.059 |
| Orthophaedic appliances, hearing aids | 1.92 | 2.53 | 0.084 |

Table 5 reports estimates for 4-digit industries which are among the 15 largest in terms of sales within their 2-digit classification. The coefficients for all other industries for which

[34] Crozet and Koenig (2010) estimate the model of Chaney (2008) using French firm-level data. Note that in our model the elasticity of trade flows with respect to variable trade costs does not depend on the degree of vertical differentiation and is the same as in Chaney (2008).

[35] In the Web Appendix we conduct the analysis using bilateral distance instead of time for border compliance and find similar results.

[36] Note that this does not allow to determine the technology parameters separately, but only the ratio $\frac{1-\theta_j}{\alpha_j}$. However, it is sufficient to quantify the effects of changes in trade costs in equations (23) and (24).

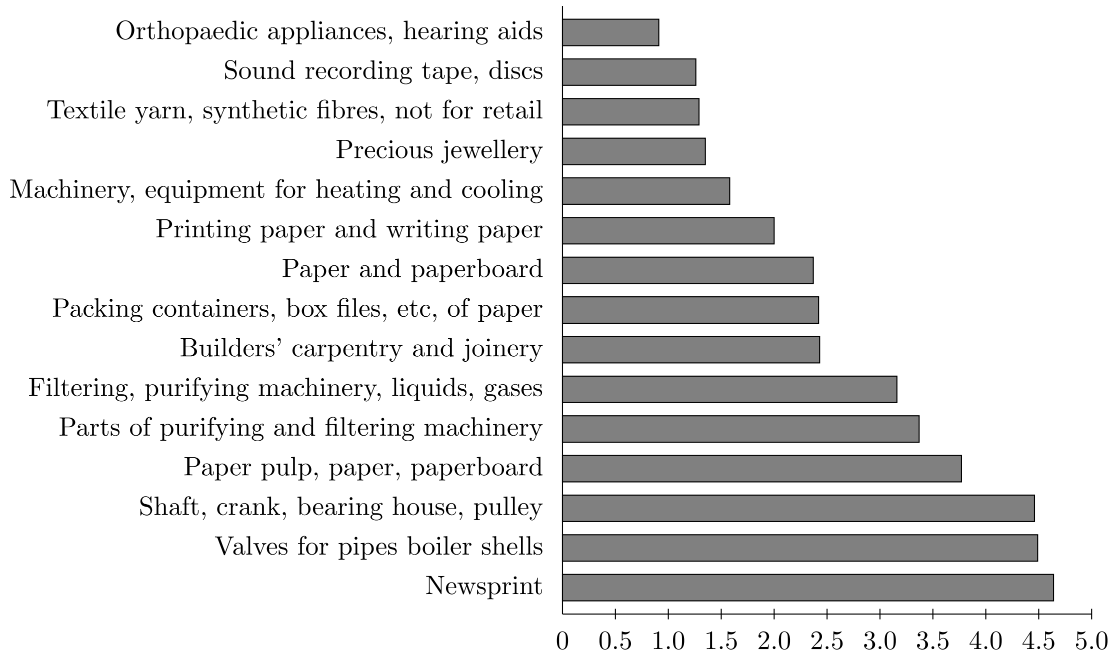


Figure 1: Effects of trade liberalization on exports by industry (in %)

we have both R&D data and information on the Pareto shape paremeter are reported in appendix Table B15.

We use these estimates to simulate a 10% decrease in fixed trade costs, which could stem from policy measures that lower administrative barriers to trade trade and thus the time for documentary compliance at the border. Figure 1 shows the effects on export flows by industry. The strongest reaction can be observed for newsprint (exports increase by 4.6%), whereas the smallest positive effect occurs for orthopaedic appliances (about 0.9%). The estimation coefficients for the other industries are shown in the appendix Figure B3.

In a next step, we compare the trade effects to a benchmark model without vertical differentiation. As discussed in subsection 2.4, the impact of lower trade barriers can be divided into a direct Chaney (2008)-effect and a new quality effect. For our benchmark case, we shut down the latter channel and compute the elasticity of trade flows and the extensive margin without quality differentiation. Intuitively, the quality channel would disappear, whenever technology parameters $\theta_j$ and $\alpha_j$ are sufficiently high. In this case, returns from quality investments are rather low and vertical differentiation has a negligible effect on the margins of international trade.

Figure 2 depicts the relative effects of lower trade barriers compared to a benchmark model without vertical differentiation. The gray bars show the effect for total trade flows and the black bars the reaction at the extensive margin. Our model suggests a positive, but sub-

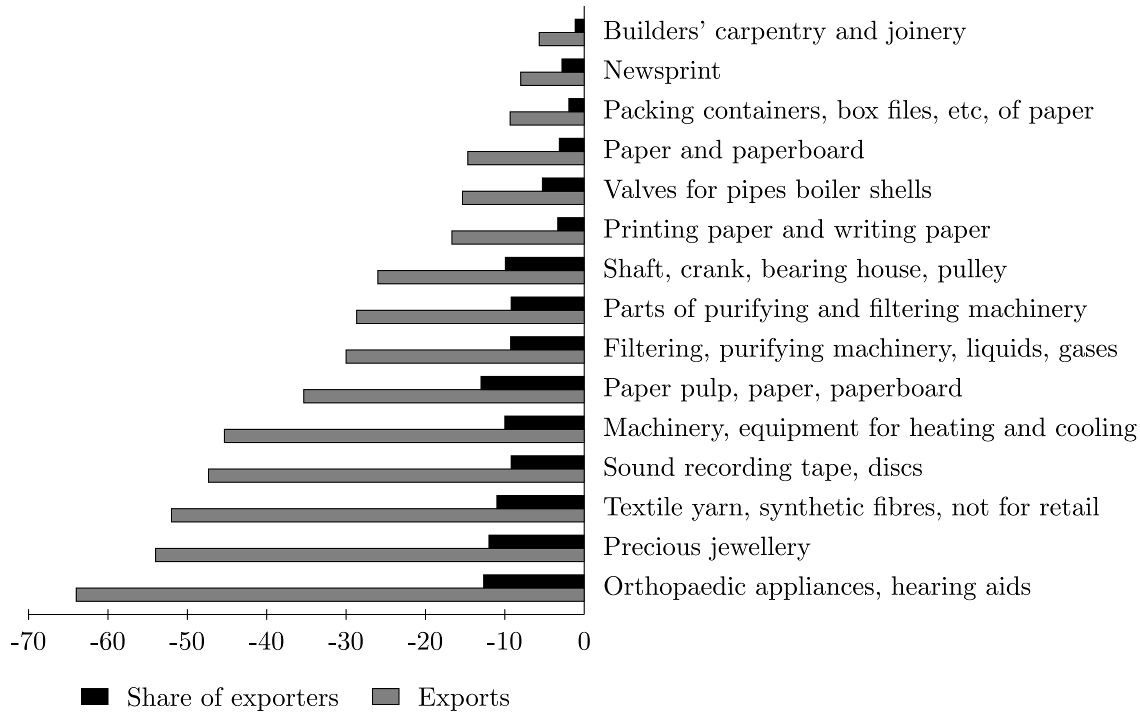


Figure 2: Effects of trade liberalization on exports relative to benchmark model (in %)

stantially smaller effect of a reduction in fixed trade barriers across all industries. Compared to a model without vertical differentiation, the effect on export flows is on average by 30% lower in the 15 largest industries, whereas the reaction on the extensive margin is attenuated by 7.6%. Figure 2 further shows that the relative effects are very heterogeneous across industries. Whereas industries with a low degree of vertical differentiation show only a small deviation from the benchmark model, the trade effects become substantially smaller in industries with high quality products. In particular, for orthopaedic appliances and precious jewellery the positive effects on exports are reduced by 64% and 53% respectively compared to a model without vertical differentiation.[37] Across all industries, we find that the correlation between the effect of lower trade barriers and the R&D intensity of the industry is negative and significant, and of at least -0.85 (for both total exports and the share of exporters).

**Welfare effects** The relative trade effects as shown in Figure 2 are very similar to the welfare implications compared with the benchmark case without vertical differentiation. To analyze the welfare effects of lower fixed trade costs, we use the inverse of the industry price

[37]Consistent with this result, Martin and Mayneris (2015) show that distance has almost no effect on French exports of luxury products.

index (4) as welfare measure:[38]

$$W_j = P_j^{-1} = \Omega_{iij} \left(\beta_j L_i\right)^{\frac{1}{\sigma_j - 1}} \varphi_{iij}^{*} \ , \tag{29}$$

whereas $\Omega_{iij} = (1-\theta_j)^{\frac{1-\theta_j}{\alpha_j}} \left(\frac{\sigma_j - 1}{\sigma_j}\right)^{\frac{1+\alpha_j-\theta_j}{\alpha_j}} \left(\frac{\alpha_j - (1-\theta_j)(\sigma_j - 1)}{\alpha_j \sigma_j f_{ii}}\right)^{\frac{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}{\alpha_j\left(\sigma_j - 1\right)}}$ and the entry cutoff productivity $\varphi_{iij}^{*}$ is defined in equation (15). The effect of fixed trade costs on welfare is thus given by:

$$\frac{d \ln W_j}{d \ln f_{ni}} = \left(\frac{1}{\xi_j} - \frac{1}{\sigma_j - 1} + \frac{1-\theta_j}{\alpha_j}\right) \lambda_{nij}, \tag{30}$$

whereas $\lambda_{nij}$ is the trade share of goods from industry $j$ and country $i$ to destination $n$:

$$\lambda_{nij} = \frac{S_{nij}}{S_{ij}} = \frac{\left(\frac{f_{ni}}{f_{ii}}\right)^{-\xi_j \frac{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}{\alpha_j\left(\sigma_j - 1\right)}} f_{ni} \tau_{ni}^{-\xi_j}}{\sum_n \left(\frac{f_{ni}}{f_{ii}}\right)^{-\xi_j \frac{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}{\alpha_j\left(\sigma_j - 1\right)}} f_{ni} \tau_{ni}^{-\xi_j}}. \tag{31}$$

The elasticity shown in equation (30) reveals that welfare effects are lower in industries with a high degree of vertical differentiation. A comparison with the elasticity shown in equation (23) makes clear that vertical differentiation influences relative welfare responses in a very similar way as trade flows. In industries with high quality differentiation, a reduction in fixed costs or trade barriers has only a limited impact on firm entry and thus welfare gains are low. Hence, the analysis shows that our model predicts lower gains from trade compared to gravity models that build on Chaney (2008) and Melitz (2003), and more importantly the gains are more heterogeneous. This is especially true in industries with a high degree of vertical differentiation and large firm heterogeneity.

# 6 Conclusion

This paper shows in theory and empirics that the elasticity of trade with respect to fixed costs is lower in industries with a higher degree of vertical product differentiation. We introduce quality innovations with endogenous sunk costs in a multi-country heterogeneous firm model of international trade and derive the gravity equation. Our model predicts that export flows and the share of exporters are less sensitive to fixed costs in more vertically differentiated industries. In vertically differentiated industries, investment conditions are more favorable

[38] Note that overall welfare is given by the upper-tier utility function in equation (1) and is a weighted sum of the industry consumption levels. As we are interested in the gains from trade by industry, we focus on the inverse price index.

and thus incentives to innovate are high. This holds in particular for high productivity firms with large sales, which increases competition. Hence, small and low productivity firms can only reap tiny market shares, which reduces the impact of trade liberalization on the extensive margin and thus on aggregate export flows.

We test the predictions from our model using aggregate bilateral trade data and Brazilian firm-level data. We account for industrial variation in vertical differentiation using the "quality ladder" suggested by Khandelwal (2010) and industry-level R&D intensity.

Consistent with our theory, we find strong support for our hypothesis that vertical differentiation interacts with fixed costs in the gravity equation and affects bilateral trade through the extensive margin. Instead, the interaction of quality and variable trade costs is not significant, as suggested by our theory.

This paper aims to contribute to the literature on quality and gravity in international trade. The analysis suggests that accounting for vertical differentiation is important for understanding the geography of international trade, as well as for the evaluation of trade liberalizing policies. We estimate the model and simulate the effect of lower fixed trade barriers. The results show that gains from liberalization policies are lower and become much more heterogeneous across industries compared to a benchmark model without vertical differentiation.

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# A Mathematical Appendix

## A.1 Firm maximization problem

A firm in industry $j$ and country $i$ maximizes profits (7) and takes into account consumer's demand (3), whereas sales in destination $n$ are defined as: $s_{nij} = p_{nij}x_{nij}$. The first-order conditions with respect to the optimal price $p_{nij}$ and quality choice $q_{nij}$ are given by:

$$\frac{\partial \pi_{nij}}{\partial p_{nij}} = A_{nj} q_{nij}^{\sigma_j - 1} \left[ (1-\sigma_j)\, p_{nij}^{-\sigma_j} + \tau_{ni}\sigma_j p_{nij}^{-\sigma_j - 1} \frac{q_{nij}^{\theta_j}}{\varphi} \right] = 0, \tag{32}$$

$$\frac{\partial \pi_{nij}}{\partial q_{nij}} = A_{nj} p_{nij}^{-\sigma_j} q_{nij}^{\sigma_j - 2} \left[ (\sigma_j - 1)\, p_{nij} - \tau_{ni} \frac{\theta_j + \sigma_j - 1}{\varphi} q_{nij}^{\theta_j} \right] - q_{nij}^{\alpha_j - 1} = 0. \tag{33}$$

The optimal price (8) follows immediately from condition (32). Inserting equation (8) into the second condition (32) and simplifying yields to the optimal quality level (9).

## A.2 Derivation of entry cutoff productivity

To derive the entry cutoff productivity (15), we combine the zero-profit condition (12) with the free-entry condition (14). Sales (10) of a firm in industry $j$ in country $i$ from serving market $n$ can be expressed relative to the cutoff productivity $\varphi^*_{nij}$:

$$s_{nij}(\varphi) = \frac{\alpha_j \sigma_j f_{ni}}{\alpha_j - (1-\theta_j)(\sigma_j - 1)} \left( \frac{\varphi}{\varphi^*_{nij}} \right)^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}}. \tag{34}$$

Inserting expression (34) into the free-entry condition (14) leads to:

$$\sum_n \left[ \left(1 - G_{ij}\left(\varphi^*_{nij}\right)\right) \right] f_{ni} \left[ \left( \frac{\widetilde{\varphi}_{nij}}{\varphi^*_{nij}} \right)^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}} - 1 \right] = f_{Ei}, \tag{35}$$

whereas the following definition of average productivity is used:

$$\widetilde{\varphi}_{nij} = \left[ \frac{1}{1 - G_{ij}\left(\varphi^*_{nij}\right)} \int_{\varphi^*_{nij}}^{\infty} \varphi^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}} g_i(\varphi) d\varphi \right]^{\frac{\alpha_j - (\sigma_j - 1)(1-\theta_j)}{\alpha_j(\sigma_j - 1)}}. \tag{36}$$

As described in section 2.4, we assume that productivity is Pareto distributed with density function $g_{ij}(\varphi) = \xi_j \varphi^{-\xi_j - 1}$, whereas $\xi$ is the Pareto shape parameter. This implies that the

probability of serving market $n$, can be written as: $1 - G_{ij}\left(\varphi^*_{nij}\right) = \left(\varphi^*_{nij}\right)^{-\xi_j}$, which allows to rewrite the free-entry condition (35):

$$\sum_n f_{ni}\left(\varphi^*_{nij}\right)^{-\xi_j} = \frac{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right] - \alpha_j(\sigma_j - 1)}{\alpha_j(\sigma_j - 1)} f_{Ei}. \tag{37}$$

In a last step, we exploit that the cutoff productivity of serving a particular destination $n$ relative to the entry cutoff productivity in the domestic market is a function of fixed and variable trade costs:

$$\frac{\varphi^*_{nij}}{\varphi^*_{iij}} = \tau_{ni}\left(\frac{f_{ni}}{f_{nn}}\right)^{\frac{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}{\alpha_j\left(\sigma_j - 1\right)}}. \tag{38}$$

Combining equations (37) and (38) leads to the expression for the entry cutoff productivity (15) in the main text.

## A.3 Gravity equation

This part derives the gravity equation as presented in section 2.4. We insert the expression for sales (10) into equation (19) and use the definition of average productivity (36), which leads to:

$$S_{nij} = \frac{1 - G_{ij}\left(\varphi^*_{nij}\right)}{1 - G_{ij}\left(\varphi^*_{iij}\right)} M_{ij}\left(\frac{Y_{nj}\widetilde{\varphi}^{\sigma-1}_{nij}}{P^{1-\sigma_j}_{nj}}\right)^{\frac{\alpha_j}{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}} \Theta^{\frac{\sigma_j - 1}{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}}, \tag{39}$$

whereas $\Theta = (1-\theta_j)^{1-\theta_j}\left(\frac{\sigma_j}{\sigma_j - 1}\right)^{\theta_j - 1 - \alpha_j}\tau_{ni}^{-\alpha_j}$. The assumption that productivity is Pareto distributed (compare Appendix A.2), implies that: $\frac{1-G_{ij}\left(\varphi^*_{nij}\right)}{1-G_{ij}\left(\varphi^*_{iij}\right)} = \left(\frac{\varphi^*_{nij}}{\varphi^*_{iij}}\right)^{-\xi_j}$. Furthermore, average productivity can be expressed relative to the cutoff productivity $\varphi^*_{nij}$:

$$\left(\frac{\widetilde{\varphi}_{nij}}{\varphi^*_{nij}}\right)^{\frac{\alpha_j\left(\sigma_j - 1\right)}{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}} = \frac{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right]}{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right] - \alpha_j(\sigma_j - 1)}. \tag{40}$$

We insert these two relationships together with expression (13) into equation (39), which yields:

$$S_{nij} = \underbrace{\left(\frac{\varphi^*_{iij}}{\varphi^*_{nij}}\right)^{\xi_j} M_{ij}}_{\text{Extensive margin}} \underbrace{\frac{\xi_j\alpha_j\sigma_j f_{ni}}{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right] - \alpha_j(\sigma_j - 1)}}_{\text{Intensive margin}}. \tag{41}$$

In a last step, we exploit the relationship in equation (38) to arrive at equation (21).

## A.4 Vertical differentiation and the "quality ladder"

This part shows that the degree of vertical differentiation in equation (18) is closely linked to the 'quality ladder" by Khandelwal (2010), which we use in the empirical analysis. To see this, we consider a log-linearized version of firm sales (10) as a function of the quality-price ratio (16):

$$\ln s_{nij}(\varphi) = \ln A_{nj} + (\sigma_j - 1)\frac{\ln q_{nij}}{\ln p_{nij}}, \tag{42}$$

whereas the log-linearized quality-price ratio is given by:

$$\frac{\ln q_{nij}}{\ln p_{nij}} = \frac{(1-\theta_j)\left[\ln(1-\theta_j) + \ln A_{nj}\right] + (\theta_j - 1 - \alpha_j)\ln\left(\frac{\sigma_j}{\sigma_j - 1}\right) + \alpha_j\left(\ln\varphi - \ln\tau_{nij}\right)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}. \tag{43}$$

Combining equations (42) and (43) leads to the following expression for firm sales:

$$\ln s_{nij}(\varphi) = \frac{\alpha_j lnA_{nj} + (\sigma_j - 1)(\Delta_j + \alpha_j ln\varphi - \alpha_j ln\tau_{nj})}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}, \tag{44}$$

whereas $A_{nj}$ represents destination-industry fixed effects, and $\Delta_j = (1-\theta_j)\ln(1-\theta_j) - (\alpha_j + 1 - \theta_j)\ln\left(\frac{\sigma_j}{\sigma_j-1}\right)$ captures industry characteristics. Conditional on these effects, the positive relationship between firm sales and productivity $\varphi$ increases in the degree of vertical differentiation, as the slope of the sales curve $\frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$ decreases in $\alpha_j$. Intuitively, a higher degree of vertical differentiation leads to a larger market share after controlling for exporter productivity, as well as industry- and destination characteristics. Hence, the degree of vertical differentiation and the "quality ladder" by Khandelwal (2010) are closely related, as both measures capture the quality component in the demand function. Note that this argument holds also for the estimation of market shares as in Khandelwal (2010).

# B Empirical Appendix

## B.1 Data and descriptive statistics

**Firm-level data from SECEX (Foreign Trade Secretariat)**

We use firm-level data for Brazilian manufacturing exporters collected by the Foreign Trade Secretariat to compute the share of exporters by industry and destination. The data contain export values and export quantities by firm, 8-digit product, and destination country. Firms in the SECEX data are identified by the unique CNPJ tax number and products are coded according to the 8-digit NCM Mercosur classification of goods (NCM-SH *Nomenclatura Comum do Mercosul, Sistema Harmonizado*). The first 6 digits coincide with the 6-digit HS classification, which allows a direct mapping between product-level data and the 4-digit SITC classification (Standard International Trade Classification).

Since we are only interested in manufacturing exporters, we exclude observations related to agriculture and the mining sector, as well as commercial intermediates. Hence, we consider only the sample of products which refer to machinery, metals, stone/glass, plastics/rubbers, footwear, textiles, wood products, and leather products. If the observation contains zero exporting value, it was removed from the sample. As described in Arkolakis et al. (2016), these observations correspond to reporting errors or shipments of commercial samples. As in Arkolakis et al. (2016), 484 observations are removed.

The main reason for using the year 2000 is data availability, as 2000 is the last year for which there is information on world trade flows from NBER-UN coded by Feenstra et al. (2005).

**Doing Business - Trading Across Borders** (World Bank, 2016).

We use data from Doing Business by the World Bank to create bilateral measures of fixed costs associated with the administrative costs to ship goods, which is constructed as the sum of importer trade time/cost and exporter trade time/cost for a bilateral pair.

The first measure refers to the time for importer and exporter documentary compliance ($t\_doc_{ni}$), which includes the time in hours to comply with the documentary requirements of the government agencies in the origin and destination country, including transit economies. The measure includes the time and cost for obtaining documents, preparing documents (such as time spent to prepare customs declaration or certificate of origin), processing documents (for instance, time spent waiting for a phytosanitary certificate to be issued), presenting documents, and submitting documents (such as the time spent submitting customs declaration, in person or electronically).

An alternative measure is the time for border compliance ($t\_bord_{ni}$), which includes the

time in hours to comply with the regulations relating to customs clearance and mandatory inspections to cross the border. The measure includes the time and cost for obtaining, preparing and submitting documents during port or border handling, customs clearance and inspection procedures. The time for border compliance also includes inspections by agencies other than customs (if applied to more than 10% of shipments). For instance, inspections related to health, safety and phytonsanitary standards. The data are obtained for the most widely used port or border of the country.

Note that the measures from the *Doing Business - Trading across borders* are not bilateral. However, since they are divided into the cost to import and to export of every country, we create for the importer-exporter pair a bilateral measure, which refers to the sum of time-to-ship goods measured in hours.

Summary statistics for the main variables used in the baseline estimations are shown in Table B1.

Table B1: Summary statistics

| Variable | Obs | Mean | Std. Dev. |
|---|---|---|---|
| Sample using bilateral world trade data, year 2000 | | | |
| $\ln S_{nij}$ | 890,042 | 3.951 | 2.449 |
| $ladder_j$ | 890,042 | 1.913 | 0.715 |
| R&D intensity | 161,662 | 0.03 | 0.02 |
| Gollop Monahan (GM) index | 161,662 | 0.503 | 0.137 |
| $\ln Dist_{ni}$ | 876,355 | 8.234 | 1.079 |
| $\ln t\_border_{ni}$ | 763,801 | 4.171 | 1.16 |
| $\ln t\_doc_{ni}$ | 815,461 | 3.357 | 1.69 |
| $Language_{ni}$ | 876,806 | 0.162 | 0.368 |
| $\tau_{nij}$ | 256,031 | 1.084 | 0.107 |
| Sample using firm-level data, year 2000 | | | |
| Share of firms $\gamma_{nj}$ | 60,029 | 0.126 | 0.113 |
| $\ln Dist_n$ | 60,029 | 8.603 | 0.751 |
| $ladder_j$ | 60,029 | 1.756 | 0.625 |
| $\ln t\_border_n$ | 43,802 | 3.835 | 1.368 |
| $\ln t\_doc_n$ | 42,647 | 3.047 | 1.841 |
| R&D intensity | 14,333 | 0.028 | 0.016 |
| GollopMonahan index | 14,333 | 0.51 | 0.103 |

The data indicate a statistically significant correlation at the 1% level between distance and the measures of compliance from the World Bank, as reported in Table B2.[39]

[39] The correlations between distance and $\ln t\_border_{ni}$ and $\ln t\_doc_{ni}$ are slightly higher (0.2366 and 0.3816, respectively) using the NBER-Comtrade data.

Table B2: Correlation between distance and compliance measures

| Correlation | $\ln t\_border_{ni}$ | $\ln t\_doc_{ni}$ |
|---|---|---|
| $\ln Dist_{ni}$ | 0.178*** | 0.241*** |

Notes: *** significant at 1%. Correlations based on Baci data.

**Estimation of additive trade costs**

An important part of trade costs is additive rather than ad valorem (Irarrazabal et al., 2015), meaning that part of the costs are defined as a constant monetary cost per unit traded, rather than as a constant percentage of the producer price (ad valorem). We follow Irarrazabal et al. (2015) and use firm-level data to estimate additive trade costs ($ATC_{ni}$) using a nonlinear least squares estimator. For that, we only need export unit values at the firm-product-destination level.

Irarrazabal et al. (2015) allow for the presence of additive trade costs besides the standard iceberg transportation costs ($\tau_{ni}$) and propose a framework to structurally estimate the magnitude of additive trade costs using firm-level data. The underlying mechanism relates higher additive trade costs with a less negative demand elasticity, and more so among low price firms. Although consumer prices are unobserved, information on free on board export prices can be used for the empirical analysis. Hence, from a standard framework with CES preferences, Irarrazabal et al. (2015) derive the following estimating equation:

$$\ln x_{nij} = \tilde{a}_{nj} - \sigma_j \ln(\tilde{p}_{nij} + \tilde{t}_{nj}) + \epsilon_{nij},$$

where $\tilde{t}_{nj} = \frac{t_{nj}}{\tau_{nj}}$ and $\tilde{a}_{nj} = a_{nj} + \sigma_j \ln \tau_{nj}$. $\tilde{p}_{nij}$ are the free on board prices for a firm $i$ exporting product $j$ to country $n$, $a_{nj}$ is a standard demand shifter, $\tau_{nj}$ represents the standard multiplicative trade costs, and $t_{nj}$ are the additive trade costs.[40]

$\tilde{t}_{nj}$ can be further decomposed into product- and destination-specific fixed effects, $\tilde{t}_{nj} = \tilde{t}_n \tilde{t}_j$. This decomposition allows to separately identify trade costs that are due to product and market characteristics. Hence, the quantitative analysis exploits the relationship between f.o.b. price and export quantity across firms within a product-destination pair.

Using this framework and firm-level data with information on prices by product and destination, we can minimize the sum of the squared residuals. To limit the number of fixed effects, we follow Irarrazabal et al. (2015) and restrict the sample to product-destinations that are exported by many firms. In the context of the Brazilian data, we keep products that are sold by at least 50 firms and 30 destination countries. We drop extreme unit values

[40]Note that the model allows firms to vary quality of a given product across destination markets, which is important in our framework. Quality differences across markets would be captured by the constant term $\tilde{a}_{nj}$.

below the 1st percentile or above the 99th percentile for every product-destination.[41] Finally, with the estimates of $\tilde{t}_n$ and $\tilde{t}_j$, we calculate trade costs relative to the median f.o.b. prices by $nj$, such that $ATC_{nj} = \frac{\tilde{t}_{nj}}{\tilde{p}_{nj}}$, which is the measure used in the empirical analysis. Table B3 provides summary statistics.

Table B3: Summary statistics - $ATC_{nj}$

| Variable | Obs | Mean | Std. Dev. |
|---|---|---|---|
| $ATC_{nj}$ | 8,050 | 0.021 | 0.016 |

[41] One concern with this procedure could be selection bias, as firms do not randomly enter into different product-destinations, which can create a correlation between prices and the error term. However, as Irarrazabal et al. (2015) argue, this selection effect would only affect the slope parameters, and not the estimates of trade costs.

## B.2 Robustness checks

To provide a better visualization of the results for the fixed costs coefficients, we aggregate the data to the *2-digit industry level* and run the following regression with industry-specific coefficients:

$$\ln S_{nij} = \beta_1 fixedcosts_{ni} + \sum_{j=1}^{J} \beta_j ladder_j * fixedcosts_{ni} + \tau_{ni} + \rho_{ij} + \mu_{nj} + \varepsilon_{nij}, \tag{45}$$

where $ladder_j$ is the industry-specific quality ladder and $\beta_j$ are the industry-specific coefficients. We expect that, controlling for the level effect ($fixedcosts_{ni}$) and for average tariffs ($\tau_{ni}$), higher quality ladders are associated with a more positive $\beta_j$.

The interaction terms by industry ($\sum_{j=1}^{J} \beta_j ladder_j * fixedcosts_{ni}$) are reported in Figure B1 for border compliance (left panel) and and documentary compliance (right panel). As expected, more positive coefficients are associated with a higher ladder. Note that, because we aggregate the data taking means by 2-digit industry level in Figure B1, the quality ladder varies less than in our empirical analysis. Whereas the 2-digit log ladder ranges from zero to one, the 4-digit log ladder used in the empirical analysis ranges from -2.32 to 1.56.

Figure B1: Correlation between vertical differentiation and the estimated industry-specific coefficient for border compliance (left) and documentary compliance (right)

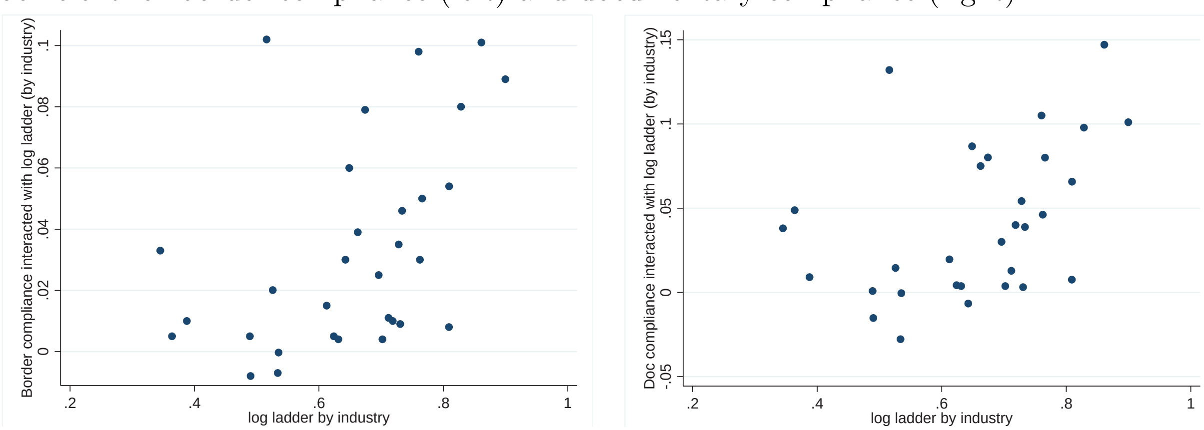


Table B4: Fixed costs and aggregate trade flows without tariff data

| Dependent variable $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $\ln t\_border_{ni}$ | -0.361*** | | | | | |
| | (0.0443) | | | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0420*** | 0.0248*** | | | | |
| | (0.00770) | (0.00700) | | | | |
| $\ln t\_doc_{ni}$ | | | -0.675*** | | | |
| | | | (0.0360) | | | |
| $\ln t\_doc_{ni} * ladder_j$ | | | 0.0191*** | 0.0238*** | | |
| | | | (0.00734) | (0.00619) | | |
| $language_{ni}$ | | | | | 1.497*** | |
| | | | | | (0.0657) | |
| $language_{ni} * ladder_j$ | | | | | -0.0887*** | -0.106*** |
| | | | | | (0.0119) | (0.0101) |
| Constant | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes |
| Observations | 756,669 | 756,669 | 808,536 | 808,536 | 866,688 | 866,688 |
| R-squared | 0.491 | 0.670 | 0.493 | 0.671 | 0.494 | 0.668 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

Table B5: Robustness checks using R&D intensity and horizontal differentiation: Results for distance

| Dependent variable: | Full sample without tariffs | | | | Sample with tariff data | | | |
|---|---|---|---|---|---|---|---|---|
| $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| $\ln Dist_{ni}$ | -0.925*** | | -0.797*** | | -0.420*** | | -0.425*** | |
| | (0.0345) | | (0.0383) | | (0.0757) | | (0.0752) | |
| $\ln Dist_{ni} * \ln R\&D$ | 0.0619*** | 0.0810*** | 0.0626*** | 0.0824*** | 0.105*** | 0.125*** | 0.102*** | 0.120*** |
| | (0.00762) | (0.00773) | (0.00759) | (0.00769) | (0.0144) | (0.0150) | (0.0153) | (0.0154) |
| $\ln Dist_{ni} *$ GM index | | | -0.255*** | -0.352*** | -0.852*** | -1.037*** | -0.844*** | -1.026*** |
| | | | (0.0404) | (0.0386) | (0.101) | (0.0990) | (0.0990) | (0.0982) |
| $\ln \tau_{nij}$ | | | | | -1.642** | -2.329*** | -0.677 | -0.563 |
| | | | | | (0.683) | (0.413) | (1.802) | (1.172) |
| $\ln \tau_{nij} * \ln R\&D$ | | | | | | | 0.0328 | 0.0573 |
| | | | | | | | (0.0533) | (0.0360) |
| Constant | yes | yes | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes | no | yes |
| Observations | 188,244 | 188,244 | 188,244 | 188,244 | 59,967 | 59,341 | 59,967 | 59,341 |
| R-squared | 0.576 | 0.686 | 0.576 | 0.686 | 0.639 | 0.718 | 0.639 | 0.718 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors clustered by importer-exporter pair.

Table B6: Robustness checks using R&D intensity and horizontal differentiation: Results for the share of firms - all measures of fixed costs

| Dependent variable: $\gamma_{nj}$ | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $\ln t\_doc_{ni} * \ln R\&D$ | 0.00850* | 0.00774* | | | | |
| | (0.00482) | (0.00468) | | | | |
| $\ln t\_doc_{ni} *$ GM index | | -0.0454** | | | | |
| | | (0.0219) | | | | |
| $\ln t\_border_{ni} * \ln R\&D$ | | | 0.0291*** | 0.0281*** | | |
| | | | (0.00797) | (0.00725) | | |
| $\ln t\_border_{ni} *$ GM index | | | | -0.123*** | | |
| | | | | (0.0406) | | |
| $\ln Dist_{ni} * \ln R\&D$ | | | | | 0.0131*** | 0.0122*** |
| | | | | | (0.00325) | (0.00309) |
| $\ln Dist_{ni} *$ GM index | | | | | | -0.0724*** |
| | | | | | | (0.0134) |
| Constant | yes | yes | yes | yes | yes | yes |
| $j$ fixed effects | yes | yes | yes | yes | yes | yes |
| $n$ fixed effects | yes | yes | yes | yes | yes | yes |
| Observations | 10,232 | 10,232 | 13,239 | 13,239 | 13,990 | 13,990 |
| R-squared | 0.436 | 0.436 | 0.426 | 0.426 | 0.510 | 0.510 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors clustered by importer-exporter pair.

Table B7: Results controlling for additive trade costs $ATC_{nj}$

| Dependent variable $\gamma_{nj}$ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $\ln Dist_n * ladder_j$ | 0.0138* | 0.0145* | 0.0142* | 0.0147** |
| | (0.00746) | (0.00742) | (0.00739) | (0.00739) |
| $\ln Dist_n$ | -0.109*** | | -0.121*** | |
| | (0.0148) | | (0.0149) | |
| $ATC_{nj}$ | | | -0.0226*** | -0.0224** |
| | | | (0.00821) | (0.00975) |
| $ATC_{nj} * ladder_j$ | | | | -0.00170* |
| | | | | (0.000953) |
| Constant | yes | yes | yes | yes |
| $j$ fixed effects | yes | yes | yes | yes |
| $n$ fixed effects | no | yes | no | yes |
| Observations | 8,050 | 8,050 | 8,050 | 8,050 |
| R-squared | 0.404 | 0.450 | 0.413 | 0.451 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer $n$.

Table B8: The Linder term and aggregate trade flows

| Dep. variable $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $Linder_{ni}$ | -0.0933*** | | -0.0594*** | | -0.107*** | | -0.0511*** | |
| | (0.00750) | | (0.00780) | | (0.00683) | | (0.00538) | |
| $Linder_{ni} * ladder_j$ | -0.00184 | -0.00293** | -0.00216 | -0.00541*** | -0.00176 | -0.00166 | -0.00451*** | -0.00528*** |
| | (0.00157) | (0.00130) | (0.00171) | (0.00148) | (0.00150) | (0.00125) | (0.00140) | (0.00126) |
| $\ln t\_border_{ni}$ | -0.279*** | | | | | | | |
| | (0.0447) | | | | | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0370*** | 0.0266*** | | | | | | |
| | (0.00766) | (0.00706) | | | | | | |
| $\ln t\_doc_{ni}$ | | | -0.551*** | | | | | |
| | | | (0.0390) | | | | | |
| $\ln t\_doc_{ni} * ladder_j$ | | | 0.0257*** | 0.0352*** | | | | |
| | | | (0.00826) | (0.00706) | | | | |
| $Language_{ni}$ | | | | | 1.501*** | | | |
| | | | | | (0.0662) | | | |
| $Language_{ni} * ladder_j$ | | | | | -0.0898*** | -0.107*** | | |
| | | | | | (0.0119) | (0.0102) | | |
| $\ln Dist_{ni}$ | | | | | | | -1.208*** | |
| | | | | | | | (0.0221) | |
| $\ln Dist_{ni} * ladder_j$ | | | | | | | 0.0572*** | 0.0780*** |
| | | | | | | | (0.00431) | (0.00428) |
| Constant | yes | yes | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes | no | yes |
| Observations | 752,605 | 752,605 | 804,361 | 804,361 | 838,191 | 838,185 | 841,255 | 838,569 |
| R-squared | 0.499 | 0.670 | 0.496 | 0.672 | 0.504 | 0.669 | 0.582 | 0.669 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

Table B9: Value per weight and aggregate trade flows

| Dep. variable $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $\ln u\_value_{nij}$ | -0.165*** | -0.0592*** | -0.251*** | -0.0670*** | -0.147*** | -0.0229*** | -0.270*** | -0.222*** |
| | (0.0212) | (0.0109) | (0.0165) | (0.00719) | (0.00629) | (0.00314) | (0.0276) | (0.0218) |
| $\ln t\_border_{ni}$ | -0.358*** | | | | | | | |
| | (0.0447) | | | | | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0383*** | 0.0210*** | | | | | | |
| | (0.00781) | (0.00701) | | | | | | |
| $\ln t\_border_{ni} * \ln u\_value_{nij}$ | 0.00522 | 0.00962*** | | | | | | |
| | (0.00464) | (0.00243) | | | | | | |
| $\ln t\_doc_{ni}$ | | | -0.710*** | | | | | |
| | | | (0.0367) | | | | | |
| $\ln t\_doc_{ni} * ladder_j$ | | | 0.0123* | 0.0204*** | | | | |
| | | | (0.00728) | (0.00620) | | | | |
| $\ln t\_doc_{ni} * \ln u\_value_{nij}$ | | | 0.0277*** | 0.0129*** | | | | |
| | | | (0.00373) | (0.00173) | | | | |
| $Language_{ni}$ | | | | | 1.415*** | | | |
| | | | | | (0.0689) | | | |
| $Language_{ni} * ladder_j$ | | | | | -0.0921*** | -0.110*** | | |
| | | | | | (0.0121) | (0.00997) | | |
| $Language_{ni} * \ln u\_value_{nij}$ | | | | | 0.0262** | 0.0221*** | | |
| | | | | | (0.0104) | (0.00661) | | |
| $\ln Dist_{ni}$ | | | | | | | -1.245*** | |
| | | | | | | | (0.0225) | |
| $\ln Dist_{ni} * ladder_j$ | | | | | | | 0.0505*** | 0.0717*** |
| | | | | | | | (0.00425) | (0.00426) |
| $\ln Dist_{ni} * \ln u\_value_{nij}$ | | | | | | | 0.0247*** | 0.0244*** |
| | | | | | | | (0.00324) | (0.00258) |
| Constant | yes | yes | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes | no | yes |
| Observations | 758,012 | 756,983 | 809,943 | 808,916 | 868,459 | 867,074 | 866,688 | 866,688 |
| R-squared | 0.495 | 0.670 | 0.498 | 0.672 | 0.498 | 0.669 | 0.578 | 0.669 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

Table B10: Variable trade costs and aggregate trade flows

| Dependent variable: $\ln S_{nijt}$ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $\ln \tau_{nijt}$ | -0.627*** | -0.272*** | -0.359** | -0.399*** |
| | (0.0555) | (0.0537) | (0.170) | (0.0992) |
| $\ln \tau_{nijt} * ladder_j$ | | | 0.0454 | |
| | | | (0.0833) | |
| $\ln \tau_{nijt} * \ln ladder_j$ | | | | 0.216 |
| | | | | (0.139) |
| Constant | yes | yes | yes | yes |
| $nij$ fixed effects | yes | yes | yes | yes |
| year $t$ fixed effects | no | yes | yes | yes |
| Observations | 798,412 | 798,412 | 798,412 | 798,131 |
| R-squared | 0.919 | 0.920 | 0.920 | 0.920 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The errors are clustered by importer-exporter pair.

Table B11: Zeros and aggregate trade flows: Estimations using PPML

| Dependent variable $S_{nij}$ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $\ln t\_border_{ni}$ | -0.823*** | | | |
| | (0.0588) | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0571*** | | | |
| | (0.00555) | | | |
| $\ln t\_doc_{ni}$ | | -0.850*** | | |
| | | (0.0535) | | |
| $\ln t\_border_{ni} * ladder_j$ | | 0.0571*** | | |
| | | (0.00721) | | |
| $Language_{ni}$ | | | -0.449 | |
| | | | (0.334) | |
| $Language_{ni} * ladder_j$ | | | 0.226*** | |
| | | | (0.0594) | |
| $\ln Dist_{ni}$ | | | | -1.188*** |
| | | | | (0.0606) |
| $\ln Dist_{ni} * \ln ladder_j$ | | | | 0.0145** |
| | | | | (0.00643) |
| Constant | yes | yes | yes | yes |
| $j$ fixed effects | yes | yes | yes | yes |
| $n$ fixed effects | yes | yes | yes | yes |
| $i$ fixed effects | yes | yes | yes | yes |
| Observations | 1,194,388 | 1,216,636 | 1,418,523 | 1,429,163 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The estimations are conducted at the 3-digit level.

Table B12: Trade quantities and fixed costs

| Dep. variable $\ln Q_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $\ln t\_border_{ni}$ | -0.442*** | | | | | | | |
| | (0.0514) | | | | | | | |
| $\ln t\_border_{ni} * ladder_j$ | 0.0506*** | 0.0312*** | | | | | | |
| | (0.00939) | (0.00832) | | | | | | |
| $\ln t\_doc_{ni}$ | | | -0.797*** | | | | | |
| | | | (0.0416) | | | | | |
| $\ln t\_doc_{ni} * ladder_j$ | | | 0.0202** | 0.0260*** | | | | |
| | | | (0.00901) | (0.00743) | | | | |
| $Language_{ni}$ | | | | | 1.734*** | | | |
| | | | | | (0.0742) | | | |
| $Language_{ni} * ladder_j$ | | | | | -0.0984*** | -0.118*** | | |
| | | | | | (0.0146) | (0.0121) | | |
| $\ln Dist_{ni}$ | | | | | | | -1.421*** | |
| | | | | | | | (0.0246) | |
| $\ln Dist_{ni} * ladder_j$ | | | | | | | 0.0590*** | 0.0811*** |
| | | | | | | | (0.00506) | (0.00493) |
| Constant | yes | yes | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes | no | yes |
| Observations | 759,371 | 756,983 | 811,306 | 808,916 | 870,464 | 867,074 | 870,464 | 867,074 |
| R-squared | 0.542 | 0.690 | 0.544 | 0.692 | 0.548 | 0.692 | 0.617 | 0.692 |

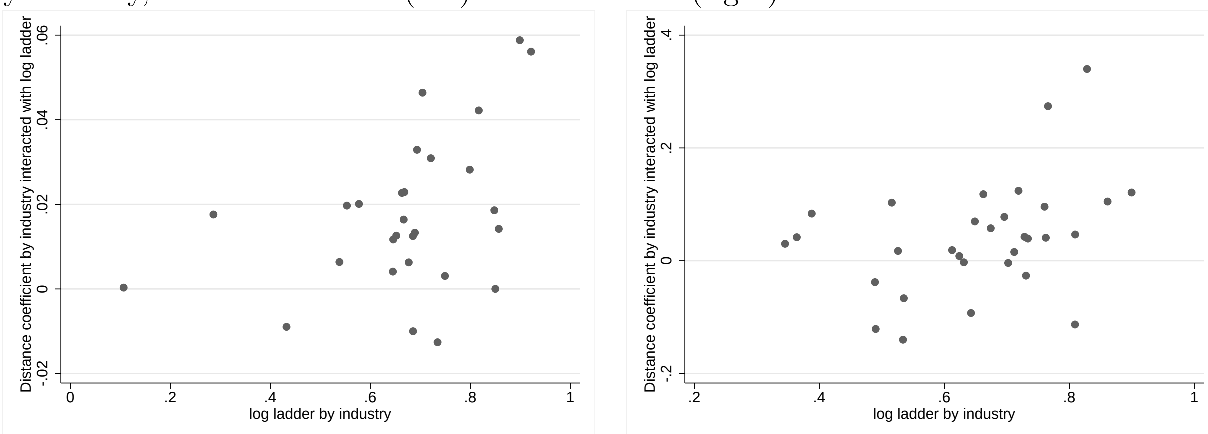
Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

## B.3 Robustness checks for the distance effect

### B.3.1 The distance coefficient by industry: Results for aggregate trade flows and the share of firms

In Figure B2, we run a regression as shown in eq. (45). The interaction terms by industry $(\sum_{j=1}^{J} \beta_j ladder_j * distance_{ni})$ are reported for total trade in the left panel. We conduct the same analysis for the share of firms, as shown in the right panel. As expected, more positive coefficients are associated with a higher ladder.

Figure B2: Correlation between vertical differentiation and the estimated distance coefficient by industry, for share of firms (left) and total sales (right)




### B.3.2 Robustness checks using MFN tariffs: Results for aggregate trade flows and the share of firms

Because there are many missing values in the tariff data, the results from Table 3 are reported for a restricted sample. Tables B13 and B14 report the results for the interaction term $\ln Dist_{ni} * ladder_j$ using the complete sample without tariff data. In columns (3) to (6) we conduct a robustness check using MFN tariffs instead of AHS tariffs as a control variable. The results for the distance coefficient remain stable and significant.

Table B13: Fixed costs and aggregate trade flows: Results using the full sample and $\ln \tau_{nij}$ MFN as alternative

| Dependent variable | Full sample without tariffs | | MFN tariffs | | | |
|---|---|---|---|---|---|---|
| $\ln S_{nij}$ | (1) | (2) | (3) | (4) | (5) | (6) |
| $\ln Dist_{ni}$ | -1.212*** | | -1.285*** | | -1.284*** | |
| | (0.0210) | | (0.0288) | | (0.0287) | |
| $\ln Dist_{ni} * ladder_j$ | 0.0561*** | 0.0779*** | 0.129*** | 0.146*** | 0.129*** | 0.146*** |
| | (0.00421) | (0.00418) | (0.0122) | (0.0120) | (0.0122) | (0.0120) |
| $\ln \tau_{nij}$ MFN | | | -1.046*** | -1.167*** | -0.918*** | -1.082*** |
| | | | (0.214) | (0.197) | (0.318) | (0.304) |
| $ladder_j * \ln \tau_{nij}$ MFN | | | | | -0.246 | -0.163 |
| | | | | | (0.442) | (0.430) |
| Constant | yes | yes | yes | yes | yes | yes |
| $nj$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ij$ fixed effects | yes | yes | yes | yes | yes | yes |
| $ni$ fixed effects | no | yes | no | yes | no | yes |
| Observations | 870,078 | 866,688 | 249,309 | 249,309 | 249,309 | 249,309 |
| R-squared | 0.577 | 0.669 | 0.641 | 0.703 | 0.641 | 0.703 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer-exporter pair.

Table B14: Fixed costs and the share of exporters: Results using the full sample and $\ln \tau_{nij}$ MFN as alternative

| Dependent variable | Full sample without tariffs | | MFN tariffs | | | |
|---|---|---|---|---|---|---|
| $\gamma_{nj}$ | (1) | (2) | (3) | (4) | (5) | (6) |
| $\ln Dist_n$ | -0.0676*** | | -0.0554*** | | -0.0527*** | |
| | (0.00398) | | (0.00381) | | (0.00381) | |
| $\ln Dist_n * ladder_j$ | 0.00988*** | 0.0105*** | 0.00490** | 0.00561*** | 0.00489** | 0.00560*** |
| | (0.00209) | (0.00215) | (0.00210) | (0.00208) | (0.00210) | (0.00208) |
| $\ln \tau_{nj}$ MFN | | | -0.0190 | -0.0130 | -0.0152 | -0.00660 |
| | | | (0.0187) | (0.0184) | (0.0297) | (0.0295) |
| $ladder_j * \ln \tau_{nj}$ MFN | | | | | 0.00310 | 0.00444 |
| | | | | | (0.00365) | (0.00363) |
| Constant | yes | yes | yes | yes | yes | yes |
| $j$ fixed effects | yes | yes | yes | yes | yes | yes |
| $n$ fixed effects | no | yes | no | yes | no | yes |
| Observations | 60,032 | 60,032 | 30,646 | 30,646 | 30,646 | 30,646 |
| R-squared | 0.472 | 0.490 | 0.557 | 0.569 | 0.558 | 0.569 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.
The errors are clustered by importer $n$.

## B.4 Estimation of the model: Results by industry

Table B15: Parameter estimates by industry - all industries

| Industry | $\xi_j$ | $\sigma_j$ | $\frac{1-\theta_j}{\alpha_j}$ |
|---|---|---|---|
| Orthopaedic appliances, hearing aids, artificial parts of the body | 1.92 | 2.5328084 | 0.08427226 |
| Manufactured goods, nes | 1.92 | 2.5037295 | 0.09157573 |
| Imitation jewellery | 1.92 | 2.495056 | 0.09178792 |
| Precious jewellery, goldsmiths' or silversmiths' wares | 1.92 | 2.485599 | 0.08198333 |
| Articles of ceramic materials, nes | 4.11 | 4.4223808 | 0.02584388 |
| Yarn 85% of synthetic fibres, not for retail; monofil, strip, etc | 1.84 | 2.4500743 | 0.07603289 |
| Small-wares and toilet articles, nes; sieves; tailors' dummies, etc | 1.92 | 2.4268638 | 0.09354608 |
| Correspondence stationary | 3.71 | 3.6792942 | 0.05355607 |
| Registers, exercise books, file and book covers, etc, of paper | 3.71 | 3.6216666 | 0.05663891 |
| Sound recording tape, discs | 1.92 | 2.548698 | 0.05924533 |
| Pins, needles, etc, of iron, steel; metal fittings for clothing | 2.82 | 2.8466496 | 0.08478367 |
| Machinery, plant, laboratory equipment for heating and cooling, nes | 3.21 | 3.4913555 | 0.04064025 |
| Starches, insulin and wheat gluten | 1.89 | 2.4111645 | 0.07688856 |
| Paper and paperboard cut to size or shape, nes | 3.71 | 3.4833425 | 0.05470464 |
| Sewing machines, furniture, needles etc, and parts thereof, nes | 3.92 | 3.9627907 | 0.03343799 |
| Pens, pencils and, fountain pens | 1.92 | 2.3123101 | 0.09691082 |
| Ash and residues, nes | 2.82 | 3.5330875 | 0.01534253 |
| Textile machinery, nes for cleaning, cutting, etc, and parts nes | 3.92 | 3.9064639 | 0.03360152 |
| Umbrellas, canes and similar articles and parts thereof | 1.92 | 2.2568579 | 0.09875992 |
| Articles of paper pulp, paper, paperboard or cellulose wadding, nes | 3.71 | 3.3429936 | 0.05564537 |
| Building and monumental stone, worked, and articles thereof | 4.11 | 3.9932018 | 0.03068408 |
| Converted paper and paperboard, nes | 3.71 | 3.294737 | 0.05599541 |
| Articles and manufacture of carving, moulding materials, nes | 1.92 | 2.2091164 | 0.10048776 |
| Other articles of precious metals or rolled precious metals, nes | 1.92 | 2.2395777 | 0.09214305 |
| Centrifuges | 3.21 | 3.2406243 | 0.04194282 |
| Anti-knock preparation, anti-corrosive; viscosity improvers; etc | 1.89 | 2.5972014 | 0.02926971 |
| Filtering and purifying machinery, apparatus for liquids and gases | 3.21 | 3.2120021 | 0.0421103 |
| Parts of footwear of any material except metal and asbestos | 2.53 | 3.0811458 | 0.02516858 |
| Parts, nes of the machines falling within headings 7435 and 7436 | 3.21 | 3.1795202 | 0.04230568 |
| Shaft, crank, bearing housing, pulley and pulley blocks, etc | 3.21 | 3.0001353 | 0.04949888 |
| Other hand tools | 2.82 | 3.1055048 | 0.03097386 |
| Power hand tools, pneumatic or non-electric, and parts thereof, nes | 3.21 | 3.1756062 | 0.03503141 |
| Hand tools, used in agriculture, horticulture or forestry | 2.82 | 3.0251904 | 0.0313694 |
| Non-military arms and ammunition therefor | 1.92 | 2.3555395 | 0.04344284 |
| Refractory goods, nes | 4.11 | 4.1359039 | 0.01450776 |
| Household appliances, decorative article, etc, of base metal, nes | 2.82 | 3.0428759 | 0.0253216 |
| Printing paper and writing paper, in rolls or sheets | 3.71 | 3.9929087 | 0.01067298 |
| Cocks, valves and similar appliances, for pipes boiler shells, etc | 3.21 | 3.0986253 | 0.02510054 |
| Paper and paperboard, in rolls or sheets, nes | 3.71 | 3.9054852 | 0.01075341 |
| Baby carriages and parts thereof, nes | 1.92 | 2.3976859 | 0.02744749 |
| Kraft paper and paperboard, in rolls or sheets | 3.71 | 3.8625474 | 0.01079471 |
| Hat shapes, hat-forms, hat bodies and hoods | 1.84 | 2.2813661 | 0.03204751 |
| Fibre building board of wood or other vegetable material | 3.71 | 3.8143888 | 0.01084254 |
| Packing containers, box files, etc, of paper, used in offices | 3.71 | 3.9284439 | 0.00670739 |
| Newsprint | 3.71 | 3.463928 | 0.01124685 |
| Builders' carpentry and joinery (including prefabricated) | 1.65 | 2.3120879 | 0.00881072 |
| Lime, quick, slaked and hydraulic (no calcium oxide or hydroxide) | 4.11 | 4.2393897 | 0.0026174 |

Figure B3: Effects of trade liberalization by industry, relative effects for all industries using $lt\_border_{ni}$