Quality and Gravity in International Trade*

Lisandra Flach[†]
LMU Munich, CESifo and CEPR

Florian Unger[‡]
University of Goettingen, CESifo

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Abstract

This paper introduces endogenous quality innovations in a multi-country model with heterogeneous firms. We show that quality investments lead to an additional margin of adjustment in the gravity equation. In industries with a high scope for quality differentiation, the elasticity of bilateral exports with respect to fixed costs is lower due to adjustments at the extensive margin, whereas the elasticity with respect to variable costs remains unaffected. We find robust and consistent evidence for the effect of quality differentiation on the gravity equation, using aggregate trade data and Brazilian firm-level data. We apply our model and evaluate the impact of trade policies that reduce fixed export costs. Our results highlight that trade and welfare effects are substantially lower and become much more dispersed across industries than predicted by heterogeneous firms models without quality differentiation.

JEL Classification: F12, F14, L11

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[†]Department of Economics, 80539 Munich, Germany; lisandra.flach@econ.lmu.de

[‡]Faculty of Business and Economics, 37073 Goettingen, Germany; florian.unger@wiwi.uni-goettingen.de

1 Introduction

Firm heterogeneity and product quality have been documented as important determinants to explain export success and patterns of international trade. A large literature following Melitz (2003) highlights that the presence of fixed costs can explain the selection of more productive firms into export markets. Chaney (2008) shows that the interaction of firm heterogeneity and fixed costs of exporting leads to adjustments on the extensive margin in the gravity equation as trade barriers prevent low productivity firms from exporting. Accounting for quality differentiation across industries is crucial to reconcile documented empirical patterns with trade models of firm heterogeneity. Empirical evidence documents that the most successful exporters offer high-quality products at higher prices, and are larger as well as more productive compared to exporters of low-quality varieties.[1] As high-quality firms generate larger sales, they can more easily overcome trade barriers and select into more distant markets (Baldwin and Harrigan, 2011; Crozet et al., 2012; Manova and Zhang, 2012). Related studies show that high quality industries are less sensitive to distance (Ferguson, 2012; Martin and Mayneris, 2015).[2] This evidence suggests that quality differences across industries do not only influence pricing patterns but also the effect of trade costs on export flows.

The purpose of this paper is to analyze how quality differentiation influences the effect of trade costs on export flows and on the extensive margin. We introduce endogenous quality choice in a multi-country model with heterogeneous firms. In our framework, the export decision is governed by variable and fixed trade costs. Besides this, firms also choose the optimal level of quality innovations, which are associated with additional fixed costs and increase product demand.[3] The main finding of this paper is that endogenous quality innovations reduce the impact of fixed costs of exporting on trade flows through adjustments on the extensive margin. We derive the gravity equation by assuming that the distribution of firm productivities is Pareto.[4] Our theoretical setup allows to divide the elasticity of trade flows with respect to fixed export costs into a direct negative effect as in Chaney (2008) and a new counteracting quality effect that depends on the scope for quality differentiation

[1]This evidence suggests that larger exporters offer varieties with lower quality-adjusted prices. See Baldwin and Harrigan (2011), Crozet et al. (2012), Manova and Zhang (2012), and Kugler and Verhoogen (2012), among others, for evidence on quality sorting in international trade.

[2]Martin and Mayneris (2015) find that distance has almost no effect on French exports of high-end varieties such as luxury products. Ferguson (2012) provides similar evidence using Swedish firm-level data.

[3]Similar formulations of fixed costs related to quality investments have been introduced by Sutton (2007), as well as Kugler and Verhoogen (2012).

[4]This assumption generates a reasonable approximation for the right tail of the observed firm size distribution (Axtell, 2001; Eaton et al., 2011). Arkolakis et al. (2012) provide an overview of models that feature Pareto distributed firm sizes.

in an industry. This measure captures the expenditures for quality innovations relative to firm sales, and is determined by exogenous technology parameters in the quality production function. In industries with a larger scope for quality differentiation, the returns from investments are higher. Hence, the most productive firms invest relatively more in innovation and reap larger market shares compared to low productivity firms.

The mechanism of our model has important implications for trade liberalizing policies and the gravity equation. We show that the combination of endogenous quality choice and fixed costs of exporting leads to an additional margin of adjustment in the gravity equation, which is not present in existing trade models with quality differentiation. As in models without quality choice, we show that a decrease in fixed trade costs induces low productivity firms to enter export markets. However, in an industry with high scope for quality differentiation, these entrants are relatively small as they face strong competition and can only reap a small market share compared to existing suppliers. Hence, the effect of fixed trade barriers on the extensive margin and on export flows is attenuated in industries with high quality differentiation. Note that this result is opposed to the impact of horizontal differentiation (Chaney, 2008). In our model a higher degree of horizontal differentiation leads to stronger effects of fixed costs on the extensive margin, as new entrants can reap larger market shares. We further highlight that the impact of variable trade costs on export flows does not depend on the scope for quality differentiation and is just determined by the Pareto shape parameter as in Chaney (2008).

We test the main predictions from our model using aggregate trade data and Brazilian firm-level data. Because we are interested in firm-level outcomes depending on the scope for quality differentiation of the industry, 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 measures with proxies for variable and fixed trade costs to estimate the effect on exports and on the extensive margin in the gravity equation.[5]

Our estimates confirm the main predictions of our model that the scope for quality differentiation reduces the elasticity of trade flows with respect to fixed costs, while horizontal differentiation has the opposite effect. Consistent with our model, we also find that the

[5]As proxies for variable costs, we use bilateral tariffs. Finding direct measures of fixed export costs is challenging as these are typically not observed. We follow the literature on trade costs by using common language, as well as administrative barriers from the World Bank as proxies for fixed costs. These measures capture the time and costs to comply with regulations in the origin and destination country and affect the extensive margin of exports. Related to our approach, Helpman et al. (2008) and Manova (2013) use regulation time and costs to start a business as a proxy for fixed costs between country pairs.

effect of variable trade costs on export flows and on the extensive margin does not vary with the industry's scope for quality differentiation. We further show that the effect of distance is reduced in more differentiated industries, which is consistent with evidence from highly disaggregated data.[6]

We use firm-level data to present two relations that provide further supportive evidence for the mechanism of our model. First, we show that quality differentiation strengthens the positive impact of productivity on firm-level sales, while horizontal differentiation attenuates this effect.[7] Second, we show a positive correlation between firm size and export prices, which is stronger in highly differentiated industries. These facts provide supportive evidence for our main mechanism that firms influence product quality by their investment decisions, which are related to the scope for quality differentiation in the industry.

Finally, we apply our model and evaluate the effects of a change in trade policy that reduces fixed costs of exporting. We simulate the effects on exports by industry and compare it to the results obtained by heterogeneous firms models without quality differentiation. Relative to this benchmark, our simulation shows that the positive effects of liberalizing policies on exports are substantially lower on average, and become much more dispersed across industries. We evaluate ex-ante welfare gains from trade and show that endogenous quality innovations also reduce the elasticity of welfare with respect to fixed costs of exporting.[8] Hence, we conclude that considering the interaction of fixed export costs and quality differentiation is important to evaluate the gains from policies aiming at reducing trade barriers.

Our paper builds on a large literature that explores micro-theoretical foundations for the gravity model and the gains from trade.[9] We contribute to this literature by showing that the interaction of endogenous quality choice and fixed trade costs leads to a new channel of adjustment in the gravity equation. This mechanism is not present in heterogeneous

[6]Evidence suggests that geographical distance correlates not only with variable but also with fixed costs of exporting (Helpman et al., 2008; Kropf and Saure, 2014). Related to our results, Johnson (2012) estimates a multi-country model with exogenous productivity and quality differences across firms, and shows that coefficients on trade costs are attenuated after controlling for selection into exporting, whereas this result is strongest for distance. In contrast, Chen and Juvenal (2018) show that negative income shocks during the global financial crisis 2008-2009 induced a stronger effect on high quality exports.

[7]Consistent with our model, investments in quality amplify the role of productivity differences and lead to stronger competition. In contrast, horizontal differentiation reduces competition among firms.

[8]Note that our framework belongs to a wide class of models for which ex-post welfare gains are determined by the trade elasticity and the domestic trade share as shown by Arkolakis et al. (2012). However, the effect of endogenous fixed costs plays an important role for ex-ante welfare evaluation. See Section 5 for a more detailed discussion.

[9]See Eaton and Kortum (2002), Anderson and van Wincoop (2003), Bernard et al. (2003), Chaney (2008), Allen et al. (2020), among others. Arkolakis (2010) shows that introducing market penetration costs leads to a "new consumers" margin besides common effects on the intensive and extensive margin. Whereas he focuses on the elasticity of trade with respect to variable costs, we show that fixed costs of quality investments change the trade elasticity with respect to fixed costs and hence the extensive margin of exports.

firms models with exogenous quality differences (Baldwin and Harrigan, 2011; Di Comite et al., 2014) and does also not occur in a framework with binary technology choice as in Bustos (2011).[10] The way how we model quality innovations is closely related to Kugler and Verhoogen (2012), who concentrate on the relationship between firm characteristics and prices while neglecting trade costs.

In contrast to exogenous quality differences, heterogeneous firms models with endogenous quality choice are in line with empirical evidence that exporters vary investments across destinations depending on trade costs and market size (Verhoogen, 2008; Bastos and Silva, 2010; Martin, 2012; Manova and Zhang, 2012; Bas and Strauss-Kahn, 2015; Flach, 2016). Within this literature, our framework is most closely related to three papers that allow for endogenous quality investments. First, Antoniades (2015) introduces market-specific quality choice in a two-country model with firm heterogeneity and endogenous markups. In line with this paper, our framework captures that prices increase with firm size if the scope for quality differentiation is large, and that trade costs reduce quality investments and hence firm-level prices. Antoniades (2015) shows that a larger market size increases the scope for quality differentiation while only considering variable trade costs. In contrast to our framework, this implies that there is no interaction of trade costs and quality differentiation in the gravity equation. A common feature is that the effect of variable trade costs only depends on the Pareto shape parameter. Second, Alcalá (2016) focuses on variable trade costs in a Ricardian model with Cournot competition and shows that the average quality of exports, measured by average export prices, increases in a country's revealed comparative advantage. Although the channel through which quality affects exports is quite different, a common feature with our framework is that quality differentiation increases the market shares of larger exporters.[11] Third, Fan et al. (2015) show that tariff reductions increase firm-level export prices and quantities. The authors rationalize this result by a quality upgrading mechanism. While our model predictions on firm-level outcomes are consistent with their finding, we focus on the implications for aggregate trade flows and the extensive margin.

Our model provides a supply-side explanation for the interaction of quality differentiation and trade costs. We further show that our results are robust when controlling for demand-side

[10] Di Comite et al. (2014) show that a model with consumer preferences that are asymmetric across varieties and heterogeneous across countries captures additional variation in export prices and exported quantities compared to single-attribute models of firm heterogeneity. While the paper focuses on variation at the firm-product level across countries using Belgian data, it does not consider endogenous quality choice and the implications for the gravity equation.

[11] Consistent with Alcalá (2016) we find evidence for positive effects of revealed comparative advantage on export flows, while the interaction of trade costs and quality differentiation remains robust. See Section 2.3, as well as Appendices A.5 and A.6 for a more detailed discussion of the model's predictions compared to related papers with firm heterogeneity and quality differentiation.

effects of product quality in international trade, which strongly suggests that these effects do not alter the positive predictions from our model. Fajgelbaum et al. (2011) develop a general equilibrium model with non-homothetic preferences that provides a demand-based explanation for trade in goods of different quality. In this framework, aggregate demand leads to trade specialization via home-market effects reminiscent of a Linder (1961) hypothesis.[12] 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.[13] While Fajgelbaum et al. (2011) build on a discrete choice of quality and variety, Eaton and Fieler (2019) introduce quality differentiation and an extensive margin of products in a general equilibrium model of international trade based on Eaton and Kortum (2002). The framework captures a positive relation between unit values and per capita income of trading partners by still delivering a standard gravity equation for trade flows. Feenstra and Romalis (2014) allow for non-homothetic preferences and quality choice on the supply side, which gives rise to Alchian and Allen (1964) effects.[14] Whereas they focus on the estimation of quality-adjusted prices, we exploit industry variation of quality differentiation to derive the implications for the gravity equation. Consistent with these studies, our results show that income effects, comparative advantage and product weight are important to explain trade patterns. Most importantly, our coefficient of interest remains stable and significant when controlling for demand side explanations. Hence, the main focus of this paper is on results for trade flows as we find no evidence that non-homotheticity would change those positive predictions.

Our paper also contributes to a growing literature that uses theoretically motivated demand equations to estimate the implications of price and quality effects (Redding and Weinstein, 2018; Jäkel, 2019). These papers typically exploit demand shocks over time while not taking into account the impact of endogenous fixed costs of quality choice.

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.

[12]Linder (1961) hypothesized that production in a country reflects the predominant tastes of local consumers. With monopolistic competition and increasing returns to scale, the demand patterns translate into patterns of specialization. Firms concentrate sales on products suited to local consumers and sell them to other countries where consumers have these tastes, giving rise to home market effects.

[13]Lugovskyy and Skiba (2015) consider the location of exporters and extend Alchian-Allen and Linder theories to a multilateral setting.

[14]Alchian and Allen (1964) show that, in the presence of per-unit costs, consumption shifts towards higher-quality products. 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.

2 The model

We introduce quality innovations with endogenous fixed costs as in Sutton (2007) in a multi-country heterogeneous-firm model based on Melitz (2003) and Chaney (2008). To serve a foreign destination, firms have to pay fixed export costs and iceberg-transportation costs. Firms additionally choose the optimal level of quality innovations in each market. These investments increase demand for a variety, and are associated with endogenous fixed costs. We show that endogenous quality choice leads to an additional channel of adjustment in the gravity equation as it reduces the elasticity of bilateral exports with respect to fixed trade costs, especially in industries with a high scope for quality 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 β_j:

$$U_i = \sum_{j=0}^{J} \beta_j \log X_{ij}, \;\; \sum_{j=0}^{J} \beta_j = 1, \;\; \beta_j \geq 0. \tag{1}$$

Preferences for differentiated goods in industry j are given by a CES utility function:

$$X_{ij} = \left[\int_{\omega \in \Omega_{ij}} \left(q_{ij}\left(\omega\right) x_{ij}\left(\omega\right) \right)^{\frac{\sigma_j - 1}{\sigma_j}} d\omega \right]^{\frac{\sigma_j}{\sigma_j - 1}}, \; j \geq 1, \tag{2}$$

where individual varieties are indexed by $\omega \in \Omega_{ij}$, and $\sigma_j > 1$ denotes the constant elasticity of substitution by industry. Due to the upper-tier Cobb-Douglas utility function, consumers spend $Y_{ij} = \beta_{ij} Y_i$ on goods produced by industry j, where Y_i is total income of country i. Demand for one variety $x_{ij}\left(\omega\right)$ depends negatively on the price $p_{ij}\left(\omega\right)$ and positively on the quality level $q_{ij}\left(\omega\right)$:

$$x_{ij}\left(\omega\right) = A_{ij} q_{ij}(\omega)^{\sigma_j - 1} p_{ij}\left(\omega\right)^{-\sigma_j} \;\; , \tag{3}$$

where $A_{ij} = Y_{ij} P_{ij}^{\sigma_j - 1}$ captures aggregate variables in industry j. The quality-adjusted aggregate price index in one industry j is defined as:

$$P_{ij} = \left[\int_{\omega \in \Omega_{ij}} \left(\frac{p_{ij}\left(\omega\right)}{q_{ij}\left(\omega\right)} \right)^{1 - \sigma_j} d\omega \right]^{\frac{1}{1 - \sigma_j}}. \tag{4}$$

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. We choose the homogenous good in sector $j = 0$ as the numeraire, which is produced in all countries with a unit labor requirement. Following Melitz and Redding (2014), this assumption requires that the consumption share of the homogenous good and the labor endowments are large enough, implying that wages equalize to one in all countries. Within the industries $j \geq 1$, there is monopolistic competition and each firm offers one differentiated variety ω. At the entry stage, producers pay sunk entry costs f_{Ei} and draw a productivity parameter φ from a common probability distribution $g(\varphi)$. After successful entry, we consider the decision of a firm to export from country i to destination n. The costs of producing a variety ω and selling it to country n consist of three components:

$$l_{nij}(\omega) = f_{ni} + \tau_{ni} \frac{q_{nij}(\omega)^{\theta_j}}{\varphi} x_{nij}(\omega) + \frac{q_{nij}(\omega)^{\alpha_j}}{\alpha_j}. \tag{5}$$

First, if a firm exports from country i to country n, it has to pay fixed costs $f_{ni} > 0$. The second element on the right-hand side of Eq. (5) shows variable production costs. As in Melitz (2003), marginal production costs decrease in firm productivity φ, and increase in iceberg-transportation costs, such that $\tau_{ni} \geq 1$ units of a good have to be shipped to destination n for one unit to arrive, where $\tau_{ii} = 1$. Additionally, we allow for a positive relation of the quality level with marginal production costs, where $0 < \theta_j < 1$ 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.[15]

Firms choose the optimal quality level of a variety in each export market $q_{nij}(\omega)$, which increases demand for this product at any given price. Following Kugler and Verhoogen (2012) and Sutton (2012), the third term in Eq. (5) is the most important cost component in our model as it shows that quality innovations lead to additional endogenous fixed costs $\frac{q_{nij}(\omega)^{\alpha_j}}{\alpha_j}$. The technology parameter α_j is industry-specific and determines the convexity of the investment cost function. We assume that investment costs are sufficiently convex to ensure a well-defined optimum, i.e. $\alpha_j > (1 - \theta_j)(\sigma_j - 1)$.[16]

Firms maximize total profits to choose the optimal price p_{nij}, as well as the optimal level of product quality q_{nij} for a variety exported to country n.[17] We assume that firms separately

[15] 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.

[16] In particular, this convexity assumption is a necessary condition to ensure that profits in Eq. (13) are well-defined and positive.

[17] To simplify notation, we drop the index ω in what follows.

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). Total export profits of a firm with productivity φ are:

$$\pi_{ij} = \sum_{n=1}^{N} \pi_{nij} = \sum_{n=1}^{N} 1_{\{x_{nij}>0\}} \left[s_{nij} - \tau_{ni} \frac{q_{nij}^{\theta_j}}{\varphi} x_{nij} - \frac{1}{\alpha_j} q_{nij}^{\alpha_j} - f_{ni} \right], \tag{6}$$

where 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 $s_{nij} = p_{nij} x_{nij}$. We show the detailed solution of profit maximization in Appendix A.1. The optimal price of a firm in industry j that sells from country i to destination n is given by:

$$p_{nij}(\varphi) = \frac{\sigma_j}{\sigma_j - 1} \frac{\tau_{ni} q_{nij}(\varphi)^{\theta_j}}{\varphi}. \tag{7}$$

Firms set prices as a constant markup over marginal production costs which decrease in firm productivity φ. In contrast to Melitz (2003), marginal production costs and hence prices depend positively on the level of quality innovations, which is endogenously chosen by the firm:

$$q_{nij}(\varphi) = \left[(1-\theta_j) A_{nj} \left(\frac{\sigma_j}{\sigma_j - 1} \right)^{-\sigma_j} \left(\frac{\tau_{ni}}{\varphi} \right)^{1-\sigma_j} \right]^{\frac{\zeta_j}{(\sigma_j-1)(1-\theta_j)}}, \tag{8}$$

where $\zeta_j \equiv \frac{(\sigma_j-1)(1-\theta_j)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$. The optimal quality level depends on aggregate market characteristics, captured by $A_{nj} = Y_{nj} P_{nj}^{\sigma_j - 1}$. In particular, a higher income in the destination market Y_{nj} increases demand and hence the incentive to invest in quality innovations. Conversely, the returns from quality investments decrease in iceberg transportation costs τ_{ni}.

The competitiveness of a firm is determined by its quality-price ratio, which follows immediately from combining Eqs. (7) and (8):

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

where firm sales from exporting to country n can be written as function of the quality-price ratio (9):[18]

$$s_{nij}(\varphi) = A_{nj}\left(\frac{q_{nij}}{p_{nij}}(\varphi)\right)^{\sigma_j - 1}. \quad (10)$$

Note that the assumption $0 < \theta < 1$ implies that higher quality leads to a less than proportional increase in prices. If $\theta > 1$, firms have no incentive to invest as the price increase would be larger than the quality upgrade, resulting in higher quality-adjusted prices (9) and hence lower sales (10). If $\theta = 0$, marginal productions costs only depend on firm productivity as in Melitz (2003). The comparison with Melitz (2003) further shows that endogenous quality choice in our framework affects competition among heterogeneous producers. From Eqs. (8) and (9) follows that high productivity firms invest more in (price-adjusted) quality as they realize larger sales and thus face higher returns from innovations. We compare the revenues of two firms that sell from the same industry j and country i to destination n, where $\varphi_1 > \varphi_2$:

$$\frac{s_{nij}(\varphi_1)}{s_{nij}(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1 - \theta_j)}}. \quad (11)$$

Relative sales in Eq. (11) depend on the productivity difference, as well as on the technology parameters α_j and θ_j. One key feature of our framework is to allow industries to differ in their scope for quality differentiation, which is captured by these technology parameters and is defined as the ratio of expenditures for quality innovations relative to firm sales:[19]

$$\frac{\frac{1}{\alpha_j} q_{nij}^{\alpha_j}(\varphi)}{s_{nij}(\varphi)} = \frac{1 - \theta_j}{\alpha_j}\frac{\sigma_j - 1}{\sigma_j}. \quad (12)$$

This ratio is derived by combining Eqs. (8) and (10), which allows to write the expenditures for quality investments as a fraction of sales: $\frac{1}{\alpha_j} q_{nij}(\varphi)^{\alpha_j} = \frac{1-\theta_j}{\alpha_j}\frac{\sigma_j - 1}{\sigma_j} s_{nij}(\varphi)$, where $\frac{1-\theta_j}{\alpha_j}\frac{\sigma_j - 1}{\sigma_j} < 1$. The scope for quality differentiation (12) is independent of firm size, which is consistent with empirical evidence (Klette and Kortum, 2004). The fraction of sales that firms spend on quality innovations increases with lower horizontal differentiation. A larger σ_j implies that consumers are more sensitive to price changes. Hence, firms have a higher incentive to invest in quality, which reduces the quality-adjusted price and induces consumers to increase demand for high-price varieties. If investment costs are less convex (low α_j) or the elasticity of marginal production costs with respect to quality is low (low θ_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 scope for vertical differentiation (12).

[18] By inserting the quality-price ratio (9) into Eq. (10), sales can be written as follows: $s_{nij}(\varphi) = A_{nj}^{1+\zeta_j}(1-\theta_j)^{\zeta_j}\left(\frac{\sigma_j}{\sigma_j - 1}\right)^{-\frac{\alpha_j + 1 - \theta_j}{1-\theta_j}\zeta_j}\left(\frac{\tau_{ni}}{\varphi}\right)^{-\frac{\alpha_j}{1-\theta_j}\zeta_j}$.

[19] This expression is closely linked to the scope for quality differentiation in Kugler and Verhoogen (2012).

One key implication of endogenous quality choice is that the positive relationship between productivity and sales is amplified in industries with high scope for quality differentiation. This follows directly from Eq. (11): $\frac{d\ln s_{nij}(\varphi)}{d\ln\varphi} = \frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)} > 0$, where $\frac{d\ln s_{nij}(\varphi)}{d\ln\varphi d\alpha_j} < 0$. We provide empirical support for this relationship in Section 4.3. Hence, in industries with higher scope for vertical product differentiation (lower α_j), high productivity firms reap larger market shares, whereas low productivity firms face stronger competition. These two effects of quality differentiation are reflected in firm profits. From Eq. (6) it follows that profits from exporting to destination n are given by:

$$\pi_{nij}(\varphi) = \frac{s_{nij}(\varphi)}{\sigma_j} - \frac{q_{nij}(\varphi)^{\alpha_j}}{\alpha_j} - f_{ni} = \frac{1}{1+\zeta_j}\frac{s_{nij}(\varphi)}{\sigma_j} - f_{ni}, \tag{13}$$

where $1+\zeta_j = \frac{\alpha_j}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$. Quality innovations increase competition and hence reduce firm profits, captured by $\zeta_j > 0$. Note, however, that sales increase as well, and especially so for highly productive firms. 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 Eq. (13), the zero-profit condition can be written as:

$$s_{nij}(\varphi^*_{nij}) = (1+\zeta_j)\,\sigma_j f_{ni}, \tag{14}$$

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

$$\varphi^*_{nij} = \kappa_j \tau_{ni}\left[(1+\zeta_j)\,\sigma_j f_{ni}\right]^{\frac{1-\theta_j}{\alpha_j\zeta_j}} A_{nj}^{\frac{-1}{\sigma_j-1}}, \tag{15}$$

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

$$\sum_{n=1}^{N}\int_{\varphi^*_{nij}}^{\infty} \pi_{nij}(\varphi) g_{ij}(\varphi) d\varphi = f_{Ei}. \tag{16}$$

The combination of the zero-profit conditions (15) and the free-entry condition (16) uniquely pins down the entry cutoff productivity for serving the domestic market (see Appendix A.2 for a detailed derivation). Note that imposing free entry is not crucial for the subsequent analysis, as the gravity equation of trade could equivalently be derived by assuming that the total mass of potential entrants is proportional to labor income as in Chaney (2008). We assume that productivity φ is Pareto distributed with density function $g_{ij}(\varphi) = \xi_j \varphi^{-\xi_j-1}$, where ξ_j denotes the Pareto shape parameter. Empirical studies have shown that this assumption generates a reasonable approximation for the right tail of the observed firm size distribution (Axtell, 2001; Eaton et al., 2011).[20] We further assume that $\xi_j > \alpha_j (\sigma_j - 1) / [\alpha_j - (\sigma_j - 1)(1 - \theta_j)]$ to ensure a well-defined equilibrium. Note that the corresponding condition in a Melitz (2003)-type model without quality differentiation is $\xi_j > \sigma - 1$. In Section 5, we show that the condition in our model requires a slightly larger Pareto shape parameter than the assumption in Melitz (2003), but is always satisfied when using parameter estimates by industry to simulate our model.

2.3 Discussion

Our framework nests a model without endogenous quality choice as a special case if $\alpha \to \infty$. In this case, the increase in investment costs with respect to quality becomes prohibitively large and the scope for quality differentiation (12) approaches zero, such that all firms choose a quality level $q = 1$. As in standard Melitz (2003)-type models, the price (7) decreases in productivity, while the relation of firm sales and productivity only depends on the elasticity of substitution: $\frac{d \ln s_{nij}(\varphi)}{d \ln \varphi} = (\sigma_j - 1)$. The equilibrium conditions in Eqs. (13)-(15) simplify as $\zeta_j = 0$.

Compared to this special case, our model with endogenous quality choice captures several empirical facts that have been documented in the literature. Appendix A.6 summarizes the predictions compared to related models with firm heterogeneity. First, the relation of firm size and prices is positive in industries with large scope for quality differentiation (Kugler and Verhoogen, 2012). From Eq. (7) it follows that $\frac{d \ln p_{nij}}{d \ln \varphi} > 0$ if and only if $\alpha < \sigma_j - 1$. This feature is rationalized in models that allow for quality differentiation, whether modeled as an exogenous draw linked to productivity (Baldwin and Harrigan, 2011) or as endogenous quality choice at the firm level (Kugler and Verhoogen, 2012; Antoniades, 2015; Alcalá, 2016). Second, our framework captures that trade costs have a negative impact on firm-level FOB prices in highly differentiated sectors. This result is obtained in models with endogenous quality choice (Antoniades, 2015; Fan et al., 2015). Models with exogenous quality like Baldwin and Harrigan (2011) predict no effect on firm-level FOB prices, but rather a positive effect of trade costs on the average export price as high quality products select into more distant markets. Consistent with this result, our framework predicts that an increase in fixed costs of exporting raises the average export price if and only if the scope for quality differentiation is large (see Appendix A.3 for a formal proof). Third, endogenous innovations provide a rationale for the fact that quality differentiation increases the market

[20] See Arkolakis et al. (2012) for an overview of models that feature Pareto distributed firm sizes. Head et al. (2014) show that relaxing the assumption of Pareto distributed firm sizes can lead to better approximations of the complete firm size distribution. While we stress an additional margin of adjustment related to the extensive margin, Fernandes et al. (2019) show that a generalized Melitz model with a joint lognormal distribution of firm productivity is able to match the important role of the intensive margin in trade dynamics.

shares of high productivity firms, which is a feature that our framework shares with Kugler and Verhoogen (2012) and Alcalá (2016). Among the papers that allow for endogenous quality choice, Kugler and Verhoogen (2012) neglect trade costs, while Antoniades (2015) and Alcalá (2016) only consider variable trade costs.[21]

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:

$$S_{nij} = \frac{1 - G_{ij}\left(\varphi^*_{nij}\right)}{1 - G_{ij}\left(\varphi^*_{iij}\right)} M_{ij} \int_{\varphi^*_{nij}}^{\infty} s_{nij}(\varphi) \frac{g_{ij}(\varphi)}{1 - G_{ij}\left(\varphi^*_{nij}\right)} d\varphi, \tag{17}$$

where M_{ij} is the number of active producers in country i and industry j, and $G_{ij}(\varphi)$ is the cumulative distribution function. Note that with Pareto distributed productivity, we use the density function $g_{ij}(\varphi) = \xi_j \varphi^{-\xi_j - 1}$, in order to express the share of exporters by industry as follows:

$$\gamma_{nij} = \frac{1 - G_{ij}\left(\varphi^*_{nij}\right)}{1 - G_{ij}\left(\varphi^*_{iij}\right)} = \tau_{ni}^{-\xi_j} \left(\frac{f_{ni}}{f_{ii}}\right)^{-\xi_j \frac{\alpha_j - (\sigma_j - 1)(1 - \theta_j)}{\alpha_j (\sigma_j - 1)}}. \tag{18}$$

We show in Appendix A.3 that exports sales in Eq. (17) can be decomposed into two different margins:[22]

$$S_{nij} = \underbrace{\tau_{ni}^{-\xi_j} \left(\frac{f_{ni}}{f_{ii}}\right)^{-\xi_j \frac{\alpha_j - (\sigma_j - 1)(1 - \theta_j)}{\alpha_j (\sigma_j - 1)}} M_{ij}}_{\text{Extensive margin}} \underbrace{\frac{\xi_j \alpha_j \sigma_j f_{ni}}{(\sigma_j - 1)\left(\xi_j \frac{1 - \theta_j}{\zeta_j} - \alpha_j\right)}}_{\text{Intensive margin}}. \tag{19}$$

The extensive margin captures the number of exporters, whereas the intensive margin is defined as the average export sales of firms. To account for multilateral resistance terms as in Anderson and van Wincoop (2003), we disentangle inward and outward multilateral resistances, which refer to exporter's and importer's ease of market access. This is important

[21] Note that Alcalá (2016) allows for endogenous quality choice at the firm level. While neglecting fixed costs, the assumptions on the structure of marginal production costs imply that quality depends only on firm productivity, such that trade costs do not directly affect firm-level FOB prices as in Baldwin and Harrigan (2011). Bas and Strauss-Kahn (2015) and Fan et al. (2015) provide evidence that trade liberalization induces firms to upgrade product quality and increase their prices. Compared to these papers, we show in the following analysis that the interaction between fixed trade costs and endogenous quality choice leads to an additional effect in the gravity equation of trade.

[22] Melitz and Redding (2014) show this decomposition for a heterogenous firms model without vertical differentiation.

for the subsequent empirical analysis, as it allows for a theory-consistent estimation of the gravity equation. We rewrite Eq. (19) and obtain:

$$S_{nij} = \frac{S_{ij}}{\Xi_{ij}} \left(\frac{Y_n}{P_n^{1-\sigma_j}} \right)^{\frac{\xi_j}{\sigma_j - 1}} \tau_{ni}^{-\xi_j} f_{ni}^{\frac{\alpha_j(\sigma_j-1)-\xi_j[\alpha_j-(\sigma_j-1)(1-\theta_j)]}{\alpha_j(\sigma_j-1)}}, \tag{20}$$

where $S_{ij} = \sum_n S_{nij}$ denotes total sales of industry j in country i. Outward multilateral resistances, which will be controlled for empirically using exporter-industry fixed effects, are captured by $\frac{S_{ij}}{\Xi_{ij}}$, with $\Xi_{ij} = \sum_n \left(\frac{Y_{nj}}{P_{nj}^{1-\sigma_j}} \right)^{\frac{\xi_j}{\sigma_j - 1}} \tau_{ni}^{-\xi_j} f_{ni}^{\frac{\alpha_j(\sigma_j-1)-\xi_j[\alpha_j-(\sigma_j-1)(1-\theta_j)]}{\alpha_j(\sigma_j-1)}}$. The second term $\left(\frac{Y_n}{P_n^{1-\sigma_j}} \right)^{\frac{\xi_j}{\sigma_j - 1}}$ in Eq. (20) reflects inward multilateral resistances that will be controlled for empirically using importer-industry fixed effects. We analyze the impact of fixed costs and variable trade costs on bilateral export flows. The effect of fixed trade costs on exports from country i and industry j to destination n follows immediately from Eq. (20):

$$\frac{d \ln S_{nij}}{d \ln f_{ni}} = \underbrace{1 - \frac{\xi_j}{\sigma_j - 1}}_{\text{Chaney (2008)}} + \underbrace{\frac{\xi_j (1 - \theta_j)}{\alpha_j}}_{\text{Quality effect}}. \tag{21}$$

The total impact of fixed costs on exports can be decomposed into two effects. The first part in Eq. (21) is the same elasticity as in Chaney (2008). Higher fixed costs lead to exit of least productive firms. The last term, however, is a new quality effect that would not be present in a model without vertical differentiation. The elasticity of exports with respect to fixed cost is smaller in industries with lower technology parameters α_j and θ_j, and thus a higher scope for quality differentiation (12),

Prediction 1 The elasticity of trade flows with respect to fixed trade costs is lower in industries with larger scope for quality differentiation.

This prediction is driven by adjustments at the extensive margin. To see this, we also decompose the elasticity of the share of exporters with respect to fixed trade costs into a direct effect and a new quality effect, following from Eq. (18):

$$\frac{d \ln \gamma_{nij}}{d \ln f_{ni}} = \underbrace{-\frac{\xi_j}{\sigma_j - 1}}_{\text{Chaney (2008)}} + \underbrace{\frac{\xi_j (1 - \theta_j)}{\alpha_j}}_{\text{Quality effect}}. \tag{22}$$

Prediction 2 The elasticity of the share of exporters with respect to fixed trade costs is lower in industries with larger scope for quality differentiation.

Table 1: Main predictions of model with endogenous quality choice

Type of differentiation	Quality diff. (low α_j)	Horizontal diff. (low σ_j)
Firm-level effects		
Degree of competition	high	low
Market share of small firms	smaller	larger
Relation between productivity and firm-level exports	larger	smaller
Effects of trade costs		
Effect of fixed trade costs on aggregate exports	smaller	larger
Effect of variable trade costs on aggregate exports	unaffected	unaffected

As for export flows, the direct negative effect of fixed trade costs is reduced in industries with large scope for quality differentiation. Note that the overall effect on the extensive margin is still negative, as we assume that investment costs are sufficiently convex, i.e. $\alpha_j > (1-\theta_j)(\sigma_j - 1)$. The intuition for this counteracting quality effect in Eqs. (21) and (22) is closely linked to the impact of product differentiation on competition among heterogeneous producers discussed in Section 2.2. A decrease in fixed trade barriers induces lower productivity firms to enter export markets, which is captured by the first part of the elasticity in Eq. (22). However, the scope for quality differentiation amplifies the positive relation between productivity and exports. Hence, new entrants with lower productivity and thus low price-adjusted quality reap smaller market shares as they face strong competition from existing high quality firms. As as consequence, the impact of lower trade costs on the extensive margin and on export flows becomes smaller in those industries.

Table 1 summarizes the main predictions of our framework with endogenous quality choice. One key implication of our framework is that the effect of quality differentiation on the elasticities (21) and (22) is opposed to the impact of horizontal differentiation, as discussed in Chaney (2008). If the degree of horizontal differentiation is high (lower σ_j), consumers react less sensitively to price differences, such that new entrants with low productivity find it easier to reap market shares. In contrast to the role of quality differentiation, horizontal differentiation increases the impact of fixed trade costs on the extensive margin, whereas the relation of productivity and firm-level exports becomes smaller (see Table 1). 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 on the share of exporters only depends on the Pareto shape parameter:

$$\frac{d\ln S_{nij}}{d\ln \tau_{ni}} = \frac{d\ln \gamma_{nij}}{d\ln \tau_{ni}} = -\xi_j. \tag{23}$$

Intuitively, the impact of vertical differentiation works through endogenous fixed 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 scope for quality differentiation has no effect on the elasticity of trade flows with respect to variable trade costs.

These predictions highlight the important role of the interaction of fixed trade costs and endogenous quality choice in our framework. Existing models with endogenous quality choice do not allow for this interaction and hence cannot generate Predictions 1-2 (see also the overview in Appendix A.6). Kugler and Verhoogen (2012) show the positive relation of firm size and prices in industries with high quality differentiation while neglecting trade costs. Antoniades (2015) and Alcalá (2016) only consider variable trade costs. In Appendix A.5, we show that a model with endogenous quality choice and endogenous markups based on Antoniades (2015) predicts that the impact of trade costs only depends on the Pareto shape parameter and does not vary with the scope for quality differentiation, which is exactly the result of Prediction 3. Note that in the special case of $\alpha \rightarrow \infty$, the quality effect disappears. The effect of trade costs on trade flows and on the extensive margin in Eqs. (21)-(23) will be also reduced if the productivity distribution is more dispersed captured by a lower Pareto shape parameter ξ_j. Intuitively, there is a lower mass of small firms, which reduces the effect of trade barriers. We take into account differences in the Pareto shape parameter across industries when we estimate the model in Section 5 (see Table 6 for details).

3 Data

To test the predictions, 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).[23] Nonetheless, it is important to control for variable trade costs τ_{ni}, in particular as it affects trade through the quality function shown in Eq. (8). Firm-level data from SECEX

[23] An earlier version of this paper (Flach and Unger, 2016) provides results using the NBER-UN Comtrade data constructed by Feenstra, Lipsey, Deng, Ma, and Mo (2005) instead of the Baci-Comtrade data. We show that the magnitudes of the effects are similar. However, as we want to evaluate the role of fixed costs, the Baci data reduce concerns with freight and transportation costs as confounding factors.

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, γ_{nj}.[24]

To investigate the predictions across industries, we need information on the scope for quality differentiation by industry. The first measure we use is the "quality ladder"suggested by Khandelwal (2010), which is closely related to the scope for quality differentiation (12) in our theoretical model. Intuitively, higher vertical 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. We provide a more technical comparison of our model with Khandelwal (2010) in Appendix A.4. Because this measure is available for a larger number of industries (see summary statistics in Table B2), we use it as the main proxy for vertical differentiation. The second measure of differentiation is the R&D intensity of the industry used by Kugler and Verhoogen (2012), which exactly corresponds to our theoretical model. As shown in Eq. (12), 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).[25] By using both measures, we can directly relate the empirical results to Eq. (21), where we decompose the trade elasticity into a component that only depends on horizontal differentiation as in Chaney (2008) and a new component that also 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 thus are less subject to endogeneity concerns in our empirical analysis.

Finally, we need information on variable and fixed trade costs. Tariff data (τ_{ni}) come from TRAINS-WTI[26], and additive trade costs are estimated based on Irarrazabal et al. (2015),

[24]The firm-level customs data are available at the 8-digit NCM classification (*Nomenclatura Comum do Mercosur*), which we combine with the 4-digit SITC classification and the CNAE industry classification (*Classificação Nacional de Atividades Econômicas*). We use a cross-section for the year 2000 (the last year for which we have firm-level data). The details are provided in the data appendix.

[25]We take the values computed by Kugler and Verhoogen (2012) based on the Gollop and Monahan (1991) index. The index 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.

[26]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.

as described in the data appendix B.1. Finding direct measures of fixed export costs is challenging as these are typically not observed. We follow the recent literature on trade barriers and use proxies for fixed costs, which have been shown to affect the extensive margin of exports. Consistent with empirical evidence of Helpman et al. (2008) and Kropf and Saure (2014), we use common language ($Language_{ni}$) from CEPII as a first proxy for fixed costs. Language similarities tend to facilitate information flows and hence the settlement of trade procedures.[27]

As a second proxy for fixed costs, we use measures of administrative trade barriers from the *Doing Business - Trading Across Borders* data base (World Bank, 2016). These measures refer to the time for documentary compliance t_doc_{ni} and border compliance t_border_{ni}. The choice of these measures is motivated by the fact that, by construction, they reflect administrative costs that should not depend on a firms volume of exports to a particular country. Hence, they affect firm-level fixed costs rather than variable costs of trade. Hummels and Schaur (2013) show that the time to deliver goods is an important barrier to trade. The first measure (t_doc_{ni}) 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.[28] The variables are described in more detail in the Appendix B.1 and summarized in Table B2.[29]

We also investigate the effect of bilateral distance ($Dist_{ni}$) on trade, controlling for tariffs as a proxy for variable trade costs. Helpman et al. (2008) show that distance negatively affects both the intensive and extensive margin of exporting, which indicates that it captures both fixed and variable export costs. Further evidence suggests that geographical proximity facilitates information and hence reduces fixed costs.[30] Hence, although distance might reflect

[27] Helpman et al. (2008) show that common language affects the extensive margin of exports and predominantly reduce the fixed costs of trade. Kropf and Saure (2014) find that a common language is associated with a 57% reduction in fixed costs per shipment.

[28] This approach is motivated by the methodology of the Doing Business Trading Across Borders dataset (see http://www.doingbusiness.org/methodology/trading-across-borders), and it is related to Helpman et al. (2008) and Manova (2013), who compute bilateral measures of fixed costs using data on regulation costs from Djankov et al. (2002), e.g. the number of days and procedures to start a business by country pair.

[29] 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.

[30] Kropf and Saure (2014) show that doubling bilateral distance is associated with an increase in the fixed

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 previous findings on the effects of trade costs (Crozet and Koenig, 2010; Baldwin and Harrigan, 2011; Ferguson, 2012; Martin and Mayneris, 2015).

4 Empirical analysis

The objective of this section is to provide theory-consistent estimations of the trade elasticity with respect to fixed costs and with respect to variable costs depending on the industrial scope for quality differentiation. We show 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 use a log-linearized version of the gravity equation (20) and obtain:

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

Because we are interested in the elasticity of exports with respect to fixed costs, we hold constant origin-specific and destination-specific terms (income and price indices). Hence, we include importer-industry and exporter-industry fixed effects in the gravity regressions, which absorb the first and second terms on the right-hand side $\left(\frac{S_{ij}}{\Xi_{ij}}\right)$ and $\left(\frac{Y_n}{P_n^{1-\sigma_j}}\right)$, respectively. The third term on the right-hand side refers to the effect of variable trade costs (τ_{ni}) on sales, which depends only on the Pareto shape parameter, as shown in prediction 3. In the empirical analysis, we provide evidence for prediction 3 using proxies for variable trade costs such as tariffs.

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

costs per shipment by 24% . Portes et al. (2001) and Portes and Rey (2005) show that geographical proximity is a good proxy for information. Breinlich and Tucci (2011) use a firm's distance to Milan as a measure of fixed costs for Italian exporters. The underlying idea is that proximity to Italy's business capital should lower fixed costs of learning about export markets.

as follows:

$$\ln S_{nij} = \beta_1 fixedcosts_{ni} + \beta_2 fixedcosts_{ni} * ladder_j + \beta_3 \ln \tau_{ni} + \beta_4 \ln \tau_{ni} * ladder_j + \rho_{ij} + \mu_{nj} + \varepsilon_{nij}, \quad (24)$$

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 scope for differentiation in industry j, μ_{nj} and ρ_{ij} are importer-industry and exporter-industry fixed effects, and ε_{nij} is the error term. The terms μ_{nj} and ρ_{ij} control for the multilateral resistance terms 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.[31]

In addition, we conduct the analysis including bilateral importer-exporter fixed effects υ_{ni}, which help mitigate endogeneity concerns related to trade policy and other characteristics specific to a country pair.[32]

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 β_2. Prediction 1 shows that the elasticity of trade flows with respect to fixed trade costs is *lower* in industries with higher scope for quality differentiation. Hence, in industries with a high $ladder_j$, we expect a dampening effect, such that $\beta_2 > 0$.[33]

As is standard in the literature, we expect that $\beta_3 < 0$, i.e. that higher variable trade costs have a negative impact on trade flows.[34] 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 β_4 is not significantly different from zero.

The baseline results for Eq. (24) are reported in Table 2, for the proxies t_border_{ni}, t_doc_{ni}, and $Language_{ni}$. Table 2 shows that the level effect β_1 is always negative for t_border_{ni} and t_doc_{ni}, whereas the interaction term β_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

[31] The fixed effects 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.

[32] Because we include υ_{ni}, 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.

[33] 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.

[34] Consistent with the literature, we find that β_3 is close to -1. As we are mainly interested in the interaction term across industries, Table 4 shows the effect of distance including the positive interaction term.

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, considering the coefficient of t_border_{ni}, a 10% decrease in the time for border compliance increases trade by 3.7% in industries with the lowest scope for quality differentiation, whereas it increases trade by only 1.9% in industries with the highest scope for quality differentiation. This example illustrates that the impact of fixed costs on trade differs across industries in the same country pair but with varying quality differentiation. The overall effect of the fixed costs covariates on trade is not overturned and remains negative for t_border_{ni} and t_doc_{ni}, and positive for $Language_{ni}$ for the whole distribution of industries, which is consistent with the predictions discussed in Section 2.4. For t_border_{ni}, if we evaluate the effect at the sample mean, we find that a 10% decrease in the time for border compliance increases trade by 2.9%.

Another striking feature of Table 2 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 is also the case when we include importer-exporter fixed effects, υ_{ni}, which control for gravity covariates and help mitigate endogeneity concerns related to omitted characteristics specific to a country pair. The magnitudes of the coefficients for $\ln \tau_{ni}$ are plausibe, given the Pareto interpretation of gravity coefficients (Crozet and Koenig, 2010), see the results in Section 5.

To provide a better visualization of the industry-specific effects, we aggregate the data to the 2-digit industry level and estimate industry-specific coefficients for the interaction term (see the estimation details in Eq. (30) 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, larger positive coefficients are associated with industries with a higher $ladder_j$.

A further result that supports our industry-specific quality mechanism is that horizontal differentiation affects the trade elasticity in the opposite direction in comparison to quality differentiation. As we discuss in detail in the robustness checks for R&D intensity (Section 4.3), a high scope for quality 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 and consistent with Chaney (2008).[35]

In Table 2 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 B5,

[35] 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).

we replicate the results from Table 2 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 et al., 2012; Ferguson, 2012; Martin and Mayneris, 2015). Typically, distance is taken as a proxy for variable trade costs. However, several empirical studies have shown that distance also correlates with fixed costs of exporting (see the discussion in the data section above). Hence, despite the fact that distance might reflect both fixed and variable trade costs, it provides relevant insights that can be easily related to the previous literature. Moreover, the literature finds that distance has heterogeneous impact across country pairs, which is inconsistent with a constant elasticity specification. For instance, Novy (2013) relies on a homothetic translog demand system and demonstrates that the distance elasticities are not constant, implying that a reduction of trade barriers has heterogeneous impact across country pairs. In Table 4, columns 1 and 2, we investigate the distance effect on trade controlling for tariffs as a proxy for variable trade costs. As shown in column 1, distance has a negative effect on export flows, whereas its interaction term with $ladder_j$ is positive and significant. This result is consistent with previous empirical evidence showing that high quality industries are less sensitive to distance (Ferguson, 2012; Martin and Mayneris, 2015).

Columns 1 and 2 show supportive evidence for prediction 3, as tariffs $\ln \tau_{ni}$ have a negative and significant effect on trade flows. Importantly, the interaction of quality differentiation with variable costs ($\ln \tau_{ni} * ladder_j$) is not significant.

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 column 2 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 better illustrate the distance effect across industries, we estimate industry-specific coefficients and plot 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 4 allow for a comparison of coefficients across columns. Table B14 in Appendix B.3.2 provides robustness checks using the complete sample without tariff data, for which we lose many observations.

Table 2: Aggregate trade flows and fixed-cost covariates across industries

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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on fixed costs covariates interacted with industry's j scope for quality differentiation. As proxies for fixed costs, we use time for border compliance, time for documentary compliance and language. We include tariffs as a proxy for variable costs. Besides controlling for multilateral resistance terms, columns 2, 4 and 6 include interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. 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 (γ_{nij}), we use Brazilian firm-level data. Hence, the dimension i is fixed, such that γ_{nij} in Eq. (18) is estimated as follows:

$$\gamma_{nj} = \beta_1 fixedcosts_n + \beta_2 fixedcosts_n * ladder_j + \beta_3 \ln \tau_n + \beta_4 \ln \tau_n * ladder_j + \nu_j + \varepsilon_{nj}, \quad (25)$$

where γ_{nj} is the share of Brazilian exporters, defined as the number of exporters in industry j exporting to destination country n divided by the total number of exporters in this industry. 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 υ_n in addition to industry fixed effects ν_j.

Prediction 2 suggests that the share of exporters reacts less sensitively to fixed trade costs in industries with higher scope for quality differentiation. Hence, we expect that in industries with high $ladder_j$, the effect of fixed costs on trade is reduced, i.e. that $\beta_2 > 0$.

Empirical evidence for Eq. (25) is reported in Table 3 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 predicted by our theoretical model. Surprisingly, for variable trade costs the results are not statistically significant.[36]

Distance and the share of exporters We report results for the distance effect in Table 4, 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 dampening effect in high quality industries remains robust when controlling for tariffs and n and j fixed effects, as reported in column 4.[37] Moreover, we estimate industry-specific coefficients and show a strong positive correlation between vertical differentiation and the estimated interaction term (see Figure B2).

[36] As for aggregate trade flows in Table 2, we would have expected a negative effect of variable trade costs on the extensive margin (see prediction 3). However, Table 3 shows no statistically significant effect of variable trade costs on the share of exporters. The same holds when using MFN tariffs instead of applied tariffs, as reported in Table B15. This might be driven by the fact that the results for the extensive margin are restricted to Brazilian firms, implying lower variation in comparison to the results regarding trade flows. For reasons of comparability with other covariates, we aggregate tariff data at the country pair level, which also results in lower variation.

[37] See Table B15 in Appendix B.3.2 for robustness checks using the complete sample without tariff data.

Table 3: Share of exporters and fixed-cost covariates across industries

Dependent variable γ_{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: Results regressing the share of exporters by destination country and industry (γ_{nj}) on fixed costs covariates interacted with industry's j scope for quality differentiation. As proxies for fixed costs, we use time for border compliance and documentary compliance. We include tariffs as a proxy for variable costs. Results in columns 2 and 4 include destination country fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer n and by industry j.

Table 4: Distance and trade

Dependent variable:	Aggregate trade flows ($\ln S_{nij}$)		Share of exporters (γ_{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: Results regressing aggregate trade flows (columns 1 and 2) or the share of exporters (columns 3 and 4) on bilateral distance interacted with industry's j scope for quality differentiation. As additional controls, we include tariffs. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. 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 using R&D intensity as a proxy for vertical differentiation 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 (4.3.4) and control 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 for vertical differentiation. However, as shown in Eq. (12) in the theoretical model, quality differentiation reflects the ratio of investment to sales, which corresponds to 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 Eq. (21) 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 5 shows the results for administrative barriers to trade and common language.[38] The same results are reported for distance in Table B6 and for the share of firms in Table B7. 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 imply vertical differentiation. We follow Kugler and Verhoogen (2012) and use the Gollop and Monahan (1991) index (GM index) as a proxy for horizontal differentiation. Eq. (21) suggests that the effect of vertical differentiation on the trade elasticity works in the opposite direction compared to the impact of horizontal differentiation.[39] The results in Table 5 confirm the expected direction by showing a negative effect of the interaction term for horizontal differentiation on trade, whereas the effect for

[38]Note that all columns in Table 5 already include importer-exporter fixed effects, which implies that the level effect of fixed costs is no longer identified.

[39]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 σ_j).

vertical differentiation remains positive and significant. The same holds for the distance effect and for the share of firms, as reported in Tables B6 and B7, respectively. Note that we report the results with 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 (Kugler and Verhoogen, 2012).

Table 5: 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on time for border compliance, time for documentary compliance and language. We interact the proxies for fixed costs with the industry's R&D intensity. We also use industry's GM index to account for horizontal differentiation. Besides controlling for multilateral resistance terms, results in all columns include interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. 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).[40] The estimation procedure is described in Appendix B.1.

Table B8 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 B8, such that the coefficients can be compared.[41] The results document 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.[42] Most importantly, our coefficient of interest remains stable and is even slightly larger 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 quality differentiation and the relative product weight: goods that are heavier compared to their value are likely to travel shorter distances. Moreover, as shown by Alchian and Allen (1964), consumption shifts towards higher-quality products when per-unit costs are present. 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 will affect our fixed costs 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

[40]Irarrazabal et al. (2015) allow for additive trade costs besides the standard iceberg transportation costs (τ_{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 to a smaller demand elasticity, and more so among low price firms.

[41]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.

[42]The negative coefficient for the interaction term $ATC_{nj} * ladder_j$ means that the effect is augmented in high quality industries. Even though the coefficient is quite low in terms of magnitudes and only significant at the 10% level, we would expect a positive interaction term. The negative coefficient is no longer significant (though still negative) when we estimate $ATC_{nj} * ladder_j$ without $Dist_n * ladder_j$, which indicates a correlation between distance and additive trade costs.

costs. The positive and significant coefficients for the interaction term indicate 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 as a control variable.[43] Note that the level effect $\ln uv_{nij}$ shown in Table B9 is negative once we include ij and nj fixed effects.[44]

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.[45] Hallak (2006) provides empirical evidence that rich countries tend to import relatively more from countries that produce high-quality goods. The hypothesis goes back to Linder (1961), who first accounted for the importance of quality for the direction of trade, and suggested that income similarity leads to more trade.

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 lower trade flows. The Linder (1961) hypothesis is confirmed in Table B10. There is a negative relation between income dissimilarity ($Linder_{ni}$) and trade flows, which is even stronger for high-quality goods, as reported by the interaction term $Linder_{ni} * ladder_j$.[46] However, also in this case, our coefficients of interest remain significant and with similar magnitudes, which lends support to our mechanism and suggests that non-homotheticity likely does not change the positive predictions from our model. Our results are closely related to Fajgelbaum and Khandelwal (2016) who show that accounting for non-homothetic preferences does hardly change the estimated gravity coefficients compared to

[43]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.

[44]This means that, 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 in our framework to account for multilateral resistance terms.

[45]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.

[46]This result can be reconciled with Fieler (2011). In a Ricardian model of trade with non-homothetic preferences, she shows that trade volumes depend on the degree of differentiation of the goods. In Fieler (2011), the large volume of trade between high income countries is explained by the fact that rich countries demand relatively more goods with high-income elasticity (more differentiated goods), which are generally produced by rich countries.

homothetic preferences.[47]

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

The results from Tables 2 and 4 show that quality does not affect the elasticity with respect to variable costs (proxied by tariffs). We investigate the robustness of prediction 3 using panel data, which has the advantage that we can account for importer-exporter-industry fixed effects (υ_{nij}). We estimate a time-varying gravity equation as follows:

$$\ln S_{nijt} = \beta_1 \ln \tau_{nijt} + \beta_2 \ln \tau_{nijt} * \ln ladder_j + \upsilon_{nij} + \mu_t + \varepsilon_{nijt}, \tag{26}$$

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 τ_{nijt} on S_{nijt} should be solely captured by β_1. The results are reported in Table B11. Using panel data, we show that $\beta_1 < 0$ in all columns, which is consistent with the literature and our baseline findings. The results in columns 3 and 4 reinforce that β_2 is not significant, in accordance with prediction 3 from the model.

4.3.5 Zeros and trade

A standard concern regarding the estimation of gravity equations using OLS is the presence of zero trade flows. The literature suggests two estimation approaches to tackle this issue: the estimation of bilateral trade flows using a Poisson pseudo-maximum-likelihood (PPML) estimator[48], and accounting for Heckman (1979) sample selection correction as in Helpman et al. (2008).

However, different from standard gravity equations at the importer-exporter level, we exploit the industry dimension in addition to country pairs ni, which implies a large number of fixed effects to account for multilateral resistance terms at the country and sector level. As shown by French (2017) using country and *sector-level* data, biases due to heteroskedasticity and sample selection may be less severe than previously thought. By accounting for comparative

[47] We acknowledge that this result does not hold in general as non-homotheticity of preferences might change the structure of the gravity equation. For example, the framework of **?** with heterogeneous incomes and tastes for differentiated products does not allow to derive a gravity equation in closed form.

[48] 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. Fally (2015) shows that the estimation of PPML with fixed effects is consistent with the introduction of multilateral resistance terms as in Anderson and van Wincoop (2003). Head and Mayer (2014) provide a detailed review of the gravity literature.

advantage in the regressions, he finds that the results using a sector-level model are more robust to distributional assumptions. Nonetheless, we estimate a gravity model accounting for zero trade flows as a robustness exercise. Given the large amount of zero values at the 4-digit industry level, we instead estimate a PPML using a more aggregated industry classification at the 3-digit level. The estimation using Heckman selection as in Helpman et al. (2008) in the context of our data would force us to impose several assumptions, as both the selection equation and the equation of interest (trade flows) contain a large number of individual fixed effects, which are correlated with the explanatory variable. Hence, in our framework with a large number of nj and ij fixed effects in addition to ni fixed effects, usual Heckman selection can not identify the parameters of interest. Accordingly, we estimate a PPML, which has been standard practice in the trade literature.

The results are reported in Table B12. 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.[49]

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 B13 shows that the effect of fixed costs on trade *quantities* is lower in industries with higher scope for quality differentiation. Hence, the results are not driven by the value per unit of the product.

4.3.7 Taste parameter, firm choices and the scope for quality differentiation

We present three additional empirical facts that provide supportive evidence for the mechanism of our model with endogenous quality. First, we investigate the relation between productivity and firm sales depending on the industry's scope for quality differentiation. In Appendix A.4, we show that the scope for quality differentiation in our model (12) is closely linked to the "quality ladder" by Khandelwal (2010) used in our empirical analysis. In Eq. (A17), we demonstrate that, conditional on industry and destination country fixed effects, the positive relationship between firm sales s_{nij} and productivity φ *increases* in the scope

[49] Because of the different level of aggregation, the coefficients are not directly comparable. However, a replication of our baseline results using data at 3-digit level reveals that the OLS results are in fact smaller in magnitudes in comparison to the PPML estimations, which suggests that the reduced-form results with OLS provide a lower bound for the estimations.

for quality differentiation.[50]

To provide further evidence on the interpretation of the taste parameter and firm investment choices, we estimate Eq. (A17) using Brazilian firm-level data. We regress firm sales by destination on productivity, its interaction with quality differentiation and control variables. As shown in Table B16 columns 2 and 3, we find a positive effect of the interaction term $\varphi_i^k * ladder_j$ on firm sales, where φ_i^k is the productivity of a firm k in origin country i (Brazil). This means that the positive relation between firm sales by destination and productivity (φ_i^k) is increasing in the scope for quality differentiation ($ladder_j$), controlling for destination-industry nj fixed effects. This is what we expect from our model, as the slope of the sales curve $\frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$ decreases in α_j (see Appendix A.4). In all columns, we control for interacted industry-country fixed effects, as suggested by Eq. (A17). In the absence of data on total factor productivity at the firm level, we use firm size as a proxy for productivity. In the results shown in the table, we use quantity as a proxy for size. As an alternative, we could use firm global sales as a proxy for firm size. However, in this case measurement error issues become more severe due to non-classical measurement error. If measurement error in global sales is positively correlated with the error in sales by destination, this mechanical positive relationship generates a positive bias.

In column 3, we include the GM index as a proxy for horizontal differentiation. From the model, we expect that the effect of vertical differentiation on firm sales works in the opposite direction in comparison to the impact of horizontal differentiation. As shown in column 3 by the negative coefficient $\varphi_i^k *$ GM index, the results are in accordance with our theoretical framework, as the slope of the sales curve $\frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$ increases in σ_j.

Second, to strengthen this feature of our model regarding the relation between the slope of the sales curve and quality differentiation, we also provide empirical evidence on the skewness of firm sales depending on the scope for differentiation of the industry. Our model implies that a higher scope for quality differentiation is associated with higher skewness of firm sales. Intuitively, in more differentiated industries, firms have more incentives to invest in quality because the returns on quality investments are higher. As a consequence, they obtain a larger portion of the market share compared to lower productivity firms, and thus the distribution of firm sales is more skewed.

We use firm-level data to calculate the skewness of firm sales across industries ($skewness_j$). Following Bernard et al. (2011), we use entropy of firm sales as a proxy for skewness. We regress skewness on $ladder_j$ and find a positive and statistically significant correlation between the industry's scope for differentiation ($ladder_j$) and the skewness of firm sales across

[50] In Eq. (A17), A_{nj} represents destination-industry fixed effects and κ_j captures industry characteristics. See also the discussion in Section 2.2.

industries.[51] This result strengthens the mechanism from our theoretical model, as firm sales are more skewed towards more productive firms in industries with a higher scope for quality differentiation.

Finally, an additional prediction from our model refers to the relation between firm productivity and output prices. As shown in Table B16, columns 4 to 6, there is a positive relation between firm productivity and output prices. In accordance with our theoretical model, we find that this relation is magnified in industries with high scope for vertical differentiation (see positive interaction term $\varphi_i^k * ladder_j$). For horizontal differentiation the effect goes in the opposite direction, though the effect is not statistically significant (see interaction term $\varphi_i^k *$ GM index).[52]

4.3.8 Comparative Advantages

Empirical research has shown that accounting for specialization is important to understand the patterns of trade. In a Ricardian model with comparative advantage, Alcalá (2016) shows that the average quality of a country's exports in an industry increases with the country's revealed comparative advantage (RCA) in that industry. To investigate whether comparative advantage alters the positive predictions from our model, we account for industry and country-specific comparative advantages in the empirical analysis. Following Alcalá (2016), we use a measure of the Balassa-RCA ($BRCA_{ij}$) to account for comparative advantage. In addition, we also use a dummy for comparative advantage (CA_dum_{ij}) suggested by Mayda and Rodrik (2005).[53]

The results controlling for comparative advantage are reported in Table B17, columns 3 to 6. For comparability of the coefficients across different empirical specifications, we also report the results without controlling for comparative advantage in columns 1 and 2.[54]

[51] We regress skewness of firm sales on $ladder_j$ and find a positive coefficient of 0.164 with a standard error of 0.0622, implying statistically significant coefficient at the 1% level across 468 industries. Entropy is measured as $\sum_k s_{kj} \ln(s_{kj})$, where s_{kj} is the share of sales of firm k in industry j. An increase in entropy means an increase in firm sales towards more productive firms.

[52] We estimate the following equation $\ln p_{gnij}^k = \beta_1 \varphi_i^k + \beta_2 \varphi_i^k * ladder_j + \beta_3 \varphi_i^k * GM + \rho_{nj} + \mu_{gn} + \varepsilon_{gnkj}$, where φ_i^k is the productivity of a firm k in origin country i (Brazil), g is the good from firm k in industry j sold to destination country n. μ_{gn} are product-destination fixed effects and ρ_{nj} are industry-destination fixed effects.

[53] In the measure suggested by Mayda and Rodrik (2005), a country has a comparative advantage if its exports in an industry exceed its imports in this industry by one minus an adjustment factor that controls for the long-run world-wide average trade deficit. In Mayda and Rodrik (2005), comparative advantage is calculated as a dummy CA_dum_{ij} which is one if country i has a comparative advantage in sector j, and zero otherwise.

[54] The measure of comparative advantage is not bilateral, implying that we cannot account for importer-exporter and country-industry fixed effects as in previous regressions. Hence, we show the results without RCA to compare the sensitivity of the coefficients. In columns 1, 3 and 5, we control for importer, exporter and industry fixed effects, and in columns 2, 4 and 6, we also include importer-industry fixed effects.

In accordance with previous literature, exports are higher in sectors in which the country has a comparative advantage, as shown in columns 2 to 6 by the positive coefficients of $BRCA_{ij}$ and CA_dum_{ij}. However, a comparison between the coefficients reported in columns 2, 4 and 6 (or columns 1, 3 and 5) reveals that our coefficient of interest $\ln t\_border_{ni} * ladder_j$ remains stable and significant when controlling for comparative advantage, which strongly suggests that it does not alter the positive predictions from our model.

4.3.9 Quality choice across destination countries

One additional feature of our model that we investigate in the data is the more dominant presence of high-productivity firms in high-income countries, in which the quality choice is stronger.[55] We investigate this feature of the model in the following way. We calculate the skewness of firm sales across destination countries and investigate the relation between income per capita and the skewness of firm sales. In Table B18, we show that higher income per capita is associated with higher skewness of firm sales in an industry. This effect holds controlling for GDP and for industry fixed effects, which suggests that, conditioning on country size, firm sales are relatively more concentrated towards more productive firms in high-income countries.

5 Estimation of the model and welfare gains from trade

In this section, we analyze the quantitative effects of a policy change that lowers fixed trade costs and compare the results to a benchmark model without vertical differentiation. To do so, we need industry estimates for the Pareto shape parameter ξ_j, the elasticity of substitution σ_j, and the technology ratio $\frac{1-\theta_j}{\alpha_j}$. We proceed in three steps to obtain the parameter values for each industry. Estimating the Pareto shape parameter from firm-level data is challenging and beyond the scope of this paper. Instead, the main focus of this simulation exercise is to compare the welfare gains obtained in our framework to a benchmark case without quality differentiation. For this purpose, we exploit that in both frameworks, the effect of variable trade costs on trade flows in Eq. (23) is solely determined by the Pareto shape parameter ξ_j. Hence, in a first step we use the industry-specific estimates for the Pareto shape parameter obtained by Crozet and Koenig (2010) from French firm-level data.[56]

[55] Bastos et al. (2018) find evidence for income-based quality choice: selling to richer destinations lead firms to raise the average quality of goods they produce and to purchase higher quality-inputs.

[56] Crozet and Koenig (2010) use firm-level data to estimate the structural parameters of the Chaney (2008) model.

We are left with two unknown parameters. In a second step, we estimate the elasticity of exports with respect to fixed costs by industry, where fixed costs are measured by the time required for border compliance.[57] We use the inverse of this elasticity in Eq. (21) and denote it by $\epsilon_j = \frac{\xi_j}{\sigma_j - 1} - 1 - \frac{\xi_j(1-\theta_j)}{\alpha_j}$. As a last step, let $\psi_j = \frac{1-\theta_j}{\alpha_j}\frac{\sigma_j - 1}{\sigma_j}$ be the scope for quality differentiation as shown in Eq. (12). This measure corresponds to the proportion of firm R&D investments in total sales, and hence we use data on R&D intensity from Kugler and Verhoogen (2012) to obtain this ratio. By combining Eqs. (12) and (21), we can express the elasticity of substitution by industry as $\sigma_j = \frac{1+\xi_j+\epsilon_j}{1+\epsilon_j+\xi_j\psi_j}$. Hence, with estimates for the Pareto shape parameters and the two relationships, we are able to obtain industry-specific values for the elasticity of substitution, and, by inserting back into Eq. (12), we obtain the ratio $\frac{1-\theta_j}{\alpha_j}$. Note that this procedure does not allow to determine the technology parameters α_j and θ_j separately. However, the ratio is sufficient to quantify the effects of changes in trade costs in Eqs. (21) and (22).

Table 6: Parameter estimates by industry

Industry	ξ_j	σ_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

Notes: Parameter estimates for 4-digit industries that are among the 15 largest in terms of sales within every 2-digit classification. The values for the Pareto shape parameter ξ_j are from Crozet and Koenig (2010).

Table 6 reports estimates for 4-digit industries which are among the 15 largest (in terms of sales) within every 2-digit classification. The coefficients for all other industries for which we have both R&D data and information on the Pareto shape parameter are reported in

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

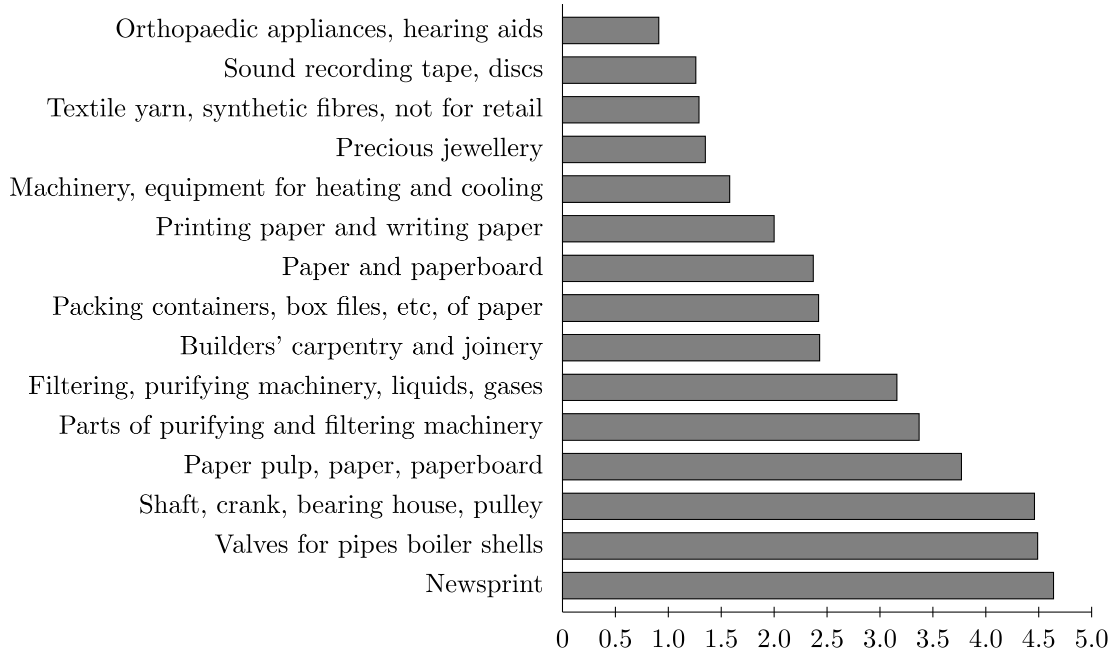

Figure 1: Effects of trade liberalization on exports by industry (in %)

Appendix, Table B19. The estimates for the Pareto shape parameter from Crozet and Koenig (2010) lie between 1.65 and 3.71, which is in line with estimates for other countries.[58] The estimates in Table 6 satisfy the assumption on the Pareto shape parameter, as described in Section 2.2, $\xi_j > \frac{\alpha_j}{1-\theta_j}(\sigma_j - 1) / \left(\frac{\alpha_j}{1-\theta_j} - \sigma_j + 1\right)$. For example, the required minimum value for builder's carpentry and joinery is $\xi = 1.33$, where the estimate is 1.65. The required estimates are slightly higher than the ones imposed in a Melitz (2003) model.[59] 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 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 Appendix, Figure B3.

In a next step, we compare the trade effects to a benchmark model without vertical differentiation. As discussed in Section 2.4, the impact of lower trade barriers can be divided into a common effect as in Chaney (2008) and a new quality effect. For our benchmark case,

[58] By using data for all French firms, Eaton et al. (2011) estimate a Pareto shape parameter of 4.87. Bernard et al. (2003) find a value of 3.6 for U.S. firms, while Corcos et al. (2012) estimate 1.79 for European firms.

[59] Note that in Melitz (2003), the restriction on the Pareto shape parameter is $\xi > \sigma - 1$. For the example of builder's carpentry and joinery, this would require a minimum value of $\xi = 1.31$.

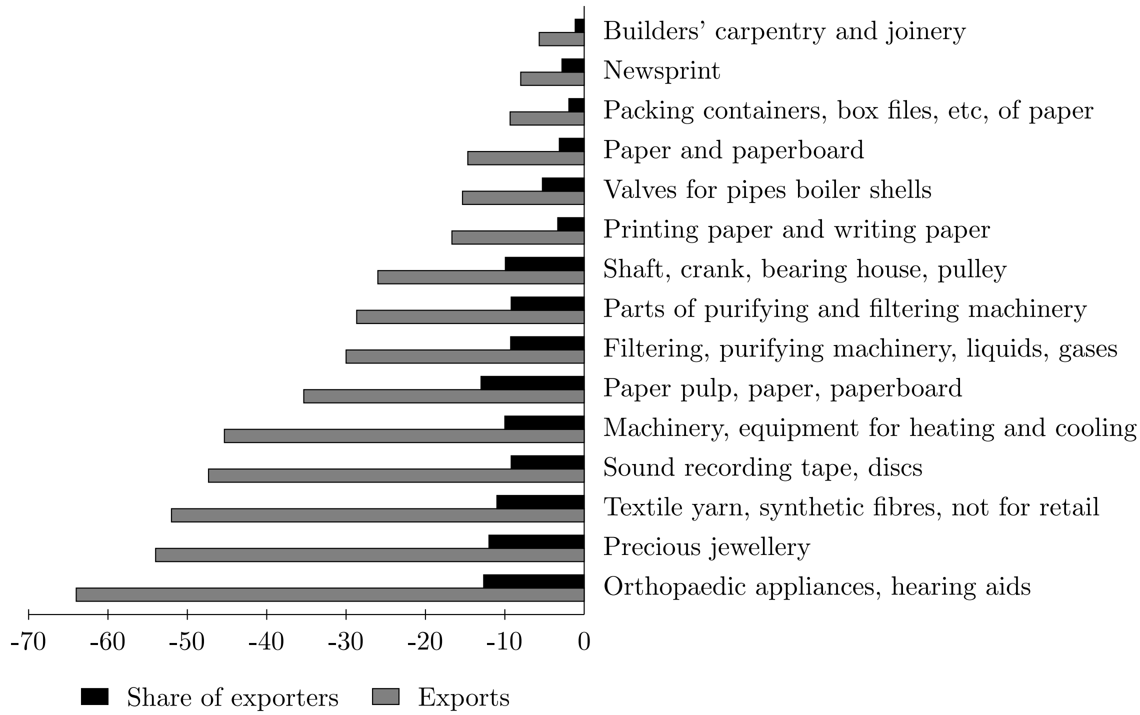

Figure 2: Effects of trade liberalization on exports relative to benchmark model (in %)

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 are sufficiently high ($\theta_j \to 1$, $\alpha_j \to \infty$). In this case, returns from quality investments are rather low and vertical differentiation has a negligible effect on the margins of international trade. In this exercise, we do not allow the elasticity of substitution and the Pareto shape parameter to differ across the models. Note again that this is reasonable as the elasticity of trade flows with respect to variable costs is the same in both cases, as discussed above. Hence, this procedure allows us to quantify the additional impact of vertical differentiation in the gravity equation related to fixed costs.

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 substantially 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 highly dispersed across industries. Whereas industries with a low scope for quality 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.[60] 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 Similar to the comparison of trade flows, we quantify the gains from trade and relate it to a benchmark model without quality differentiation. To analyze the welfare effects of a reduction in fixed trade costs, we use the inverse of the industry price index (4). Note that overall welfare is given by the upper-tier utility function in Eq. (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, which can be written as follows:

$$W_j = P_j^{-1} = \Omega_{iij} \left(\beta_j L_i\right)^{\frac{1}{\sigma_j - 1}} \varphi_{iij}^* \ , \tag{27}$$

where $\Omega_{iij} = (1-\theta_j)^{\frac{1-\theta_j}{\alpha_j}} \left(\frac{\sigma_j - 1}{\sigma_j}\right)^{\frac{\alpha_j + 1 - \theta_j}{\alpha_j}} \left(\frac{1}{(1+\zeta_j)\sigma_j f_{ii}}\right)^{\frac{1}{(1+\zeta_j)(\sigma_j - 1)}}$ and the entry cutoff productivity φ_{iij}^* is defined in Eq. (A8). We express welfare in the open economy relative to autarky as follows:

$$\frac{W_j}{W_j^A} = \Lambda_j^{-\frac{1}{\xi_j}} , \tag{28}$$

where $\Lambda_j = \frac{S_{iij}}{S_{ij}} = f_{ii}\tau_{ii}^{-\xi_j} / \left(\sum_n f_{ni}\tau_{ni}^{-\xi_j} \left(\frac{f_{ni}}{f_{ii}}\right)^{-\frac{\xi_j}{\sigma_j - 1} + \frac{\xi_j(1-\theta_j)}{\alpha_j}} \right)$ is the domestic trade share in industry j, defined as proportion of domestic sales in total sales. Note that this can be interpreted as an industry-version of the welfare formula shown in Arkolakis et al. (2012). One important implication of their work is that a wide class of models predicts the same welfare gains from an ex-post perspective, conditional on identical observed trade flows. However, when considering ex-ante welfare gains, our model with quality differentiation differs from a framework without vertical differentiation in two important aspects. First, from (28) follows that the level of gains when moving from autarky to trade is larger in industries with higher scope for quality differentiation. Intuitively, endogenous quality innovations enhance the benefits exporters can reap when selling to additional markets. We take this first welfare result with caution as our framework is based on homothetic preferences. Bertoletti et al. (2018) develop a general equilibrium model of trade that features non-homotheticity based on "indirect additive preferences" and show that gains from trade are substantially

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

lower compared to Arkolakis et al. (2012). The opposite results are based on different modeling approaches. While Bertoletti et al. (2018) focus on a demand-side explanation of quality differentiation and abstract from selection effects, our mechanism builds on the interaction of endogenous quality choice and extensive margin effects.[61] The comparison shows that the source of quality differentiation is crucial for welfare implications.

Besides the move from autarky to trade, we consider a change of fixed costs of exporting as a second effect. Hence, we take the derivative of Eq. (28), which delivers the effect of fixed trade costs on welfare gains from trade:

$$\frac{d\ln\left(\frac{W_j}{W_j^A}\right)}{d\ln f_{ni}} = -\frac{1}{\xi_j}\frac{d\ln\Lambda_j}{d\ln f_{ni}} = \frac{1}{\xi_j} - \frac{1}{\sigma_j - 1} + \frac{1-\theta_j}{\alpha_j}. \tag{29}$$

A comparison of Eq. (29) with the elasticity in Eq. (21) reveals that vertical differentiation influences relative welfare responses in a similar way as trade flows. Hence, the relative welfare effects are comparable to the relative trade effects shown in Figure 2. In industries with high quality differentiation, welfare gains from reductions in fixed trade costs are relatively low. As discussed previously for trade flows, our model does not imply any difference in the elasticity of welfare with respect to variable trade costs.

As an illustrative example, we consider the industry of precious jewellery, which belongs to one of the most vertically differentiated industries in our sample. Given the parameter estimates in Table 6, the welfare elasticity with respect to fixed costs in Eq. (29) is 0.07. In contrast, the benchmark model without quality differentiation yields much larger welfare gains of 0.15. Hence, for this particular industry our model implies welfare gains that are 45% of the gains based on a heterogeneous firms model without vertical differentiation. As in the case of trade flows, the difference is driven by the counteracting effect of the scope for vertical differentiation, captured by the last term in Eq. (29). In contrast, for industries with low quality differentiation, the difference in welfare effects is much smaller. As an example, welfare gains in the paper industry are 85% of the gains in the benchmark model.

Industries with higher scope for quality differentiation show larger gains from trade relative to autarky, but they are less sensitive to changes in the fixed costs of exporting. While the former result is likely to be affected by the assumption of non-homothecity, there is good reason to expect that the latter effect is also relevant in settings with non-homothetic preferences. Fajgelbaum and Khandelwal (2016) and Bertoletti et al. (2018) show that models with non-homothetic preferences also yield a log-linear gravity equation where the effect of variable trade costs is governed by the Pareto shape parameter as in Arkolakis et al.

[61] The lower ex-post gains from trade in Bertoletti et al. (2018) stem from imperfect pass-through of prices as the impact of the trade share is reduced in the welfare formula compared to Eq. (28).

(2012).[62] Fernandes et al. (2019) estimate a generalized Melitz model with a joint lognormal distribution of firm productivity and compare trade and welfare effects to a Melitz-Pareto model. While the generalized version is able to match the important role of the intensive margin in trade dynamics, the effects on welfare are quite similar in both frameworks. Our results highlight an additional channel of adjustment related to the extensive margin of trade. Hence, we conclude that accounting for endogenous quality choice considerably reduces welfare gains from any policy experiment that decreases fixed costs of exporting. Another important result is that gains from trade become much more dispersed across industries compared to gravity models that build on Chaney (2008) and Melitz (2003). Therefore, when neglecting vertical differentiation, one might not only overestimate overall welfare gains, but also draw different conclusions on which industries benefit most from liberalizing policies.

6 Conclusion

This paper shows both theoretically and empirically that the elasticity of trade flows with respect to fixed costs is lower in industries with a higher scope for quality differentiation. We introduce quality innovations with endogenous fixed costs in a multi-country heterogeneous firms model of international trade and derive the gravity equation. Our model predicts that endogenous quality choice leads to an additional channel of adjustment in the gravity equation as export flows and the share of exporters are less sensitive to fixed costs in more vertically differentiated industries. In those industries, investment conditions are more favorable 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 a reduction in fixed costs 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. Consistent with our theory, we find strong support for our hypothesis that quality 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.

Our results suggest that accounting differences in quality differentiation across industries is

[62] Fajgelbaum and Khandelwal (2016) show that accounting for non-homothetic preferences leads to an additional component in the gravity equation which captures the elasticity of trade flows with respect to importer's inequality-adjusted real income. Bertoletti and Etro (2017) show that "indirect additively preferences" lead to Linder effects in the gravity equations. Our empirical approach takes these effects into account as discussed in subsection 4.3.3.

important for understanding the geography of international trade and for the evaluation of trade liberalizing policies. We apply our model and simulate the effect of lower fixed trade barriers. The results show that gains from liberalization policies are lower, and become much more dispersed 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 (6) 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:

$$\frac{\partial \pi_{nij}}{\partial p_{nij}} = A_{nj} q_{nij}^{\sigma_j - 1} \left[(1-\sigma_j) p_{nij}^{-\sigma_j} + \tau_{ni}\sigma_j p_{nij}^{-\sigma_j - 1} \frac{q_{nij}^{\theta_j}}{\varphi} \right] = 0, \tag{A1}$$

$$\frac{\partial \pi_{nij}}{\partial q_{nij}} = A_{nj} p_{nij}^{-\sigma_j} q_{nij}^{\sigma_j - 2} \left[(\sigma_j - 1) p_{nij} - \tau_{ni} \frac{\theta_j + \sigma_j - 1}{\varphi} q_{nij}^{\theta_j} \right] - q_{nij}^{\alpha_j - 1} = 0. \tag{A2}$$

The optimal price (7) follows immediately from condition (A1). Inserting Eq. (7) into the second condition (A1) and simplifying leads to the optimal quality level (8).

A.2 Derivation of entry cutoff productivity

To derive the entry cutoff productivity, we combine the zero-profit condition (14) with the free-entry condition (16). Sales (10) of a firm in industry j and country i from serving market n can be expressed relative to the cutoff productivity φ_{nij}^*:

$$s_{nij}(\varphi) = \frac{\alpha_j \sigma_j f_{ni}}{\alpha_j - (1-\theta_j)(\sigma_j - 1)} \left(\frac{\varphi}{\varphi_{nij}^*} \right)^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}}. \tag{A3}$$

Inserting Eq. (A3) into the free-entry condition (16) leads to:

$$\sum_n \left[1 - G_{ij}\left(\varphi_{nij}^*\right)\right] f_{ni} \left[\left(\frac{\widetilde{\varphi}_{nij}}{\varphi_{nij}^*} \right)^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}} - 1 \right] = f_{Ei}, \tag{A4}$$

where the following definition of average productivity is used:

$$\widetilde{\varphi}_{nij} = \left[\frac{1}{1 - G_{ij}\left(\varphi_{nij}^*\right)} \int_{\varphi_{nij}^*}^{\infty} \varphi^{\frac{\alpha_j(\sigma_j - 1)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}} g_i(\varphi) d\varphi \right]^{\frac{\alpha_j - (\sigma_j - 1)(1-\theta_j)}{\alpha_j(\sigma_j - 1)}}. \tag{A5}$$

As described in section 2.4, we assume that productivity is Pareto distributed with density function $g_{ij}(\varphi) = \xi_j \varphi^{-\xi_j - 1}$, where ξ 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 (A4):

$$\sum_n f_{ni}\left(\varphi^*_{nij}\right)^{-\xi_j} = \frac{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right] - \alpha_j(\sigma_j - 1)}{\alpha_j(\sigma_j - 1)} f_{Ei}. \tag{A6}$$

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:

$$\frac{\varphi^*_{nij}}{\varphi^*_{iij}} = \tau_{ni}\left(\frac{f_{ni}}{f_{nn}}\right)^{\frac{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}{\alpha_j\left(\sigma_j - 1\right)}}. \tag{A7}$$

Combining Eqs. (A6) and (A7) leads to the following entry cutoff productivity:

$$\left(\varphi^*_{iij}\right)^{\xi_j} = \frac{\alpha_j\zeta_j\sum_n \frac{f_{ni}}{f_{Ei}}\tau_{ni}^{-\xi_j}\left(\frac{f_{ni}}{f_{ii}}\right)^{-\frac{\xi_j\left(1-\theta_j\right)}{\alpha_j\zeta_j}}}{\xi_j(1-\theta_j) - \alpha_j\zeta_j}. \tag{A8}$$

A.3 Gravity equation and average export price

This part derives the gravity equation as presented in section 2.4. We insert the expression for sales (10) into Eq. (17) and use the definition of average productivity (A5), which leads to:

$$S_{nij} = \frac{1 - G_{ij}\left(\varphi^*_{nij}\right)}{1 - G_{ij}\left(\varphi^*_{iij}\right)} M_{ij}\left(\frac{Y_{nj}\widetilde{\varphi}_{nij}^{\sigma-1}}{P_{nj}^{1-\sigma_j}}\right)^{\frac{\alpha_j}{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}} \Theta^{\frac{\sigma_j - 1}{\alpha_j - \left(\sigma_j - 1\right)\left(1-\theta_j\right)}}, \tag{A9}$$

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

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

We insert these two relationships together with expression (15) into Eq. (A9), which yields:

$$S_{nij} = \underbrace{\left(\frac{\varphi^*_{iij}}{\varphi^*_{nij}}\right)^{\xi_j} M_{ij}}_{\text{Extensive margin}} \underbrace{\frac{\xi_j\alpha_j\sigma_j f_{ni}}{\xi_j\left[\alpha_j - (\sigma_j - 1)(1-\theta_j)\right] - \alpha_j(\sigma_j - 1)}}_{\text{Intensive margin}}. \tag{A10}$$

We assume that $\xi_j > \alpha_j (\sigma_j - 1) / [\alpha_j - (\sigma_j - 1)(1 - \theta_j)]$ to ensure a well-defined equilibrium. In a last step, we exploit the relationship in Eq. (A7) to obtain Eq. (19).
We additionally derive the average price of varieties that are exported from industry j and country i to destination n. We combine the optimal price (7) and quality choice (8) with the cutoff productivity of serving market n in Eq. (15), which after some modifications leads to:

$$p_{nij}(\varphi) = \frac{\sigma_j}{\sigma_j - 1} \frac{\tau_{ni}}{\varphi} (\alpha_j \zeta_j f_{ni})^{\frac{\theta_j}{\alpha_j}} \left(\frac{\varphi}{\varphi^*_{nij}} \right)^{\frac{\zeta_j \theta_j}{1-\theta_j}}. \tag{A11}$$

With Pareto distributed productivity, the average export price is given by:

$$\bar{p}_{nij} = \frac{\xi_j}{\left(\varphi^*_{nij}\right)^{-\xi_j}} \int\limits_{\varphi^*_{nij}}^{\infty} p_{nij}(\varphi)\, \varphi^{-\xi_j - 1} d\varphi. \tag{A12}$$

By inserting the firm-level price (A11) into Eq. (A12), we obtain:

$$\bar{p}_{nij} = \frac{\sigma_j}{\sigma_j - 1} \frac{\tau_{ni}}{\varphi^*_{nij}} \frac{\xi_j}{\xi_j + 1 - \frac{\zeta_j \theta_j}{1-\theta_j}} (\alpha_j \zeta_j f_{ni})^{\frac{\theta_j}{\alpha_j}}. \tag{A13}$$

Inserting Eq. (A7) into Eq. (A13) leads to:

$$\bar{p}_{nij} = \frac{\sigma_j}{\sigma_j - 1} \frac{\xi_j (\alpha_j \zeta_j)^{\frac{\theta_j}{\alpha_j}}}{\xi_j + 1 - \frac{\zeta_j \theta_j}{1-\theta_j}} \frac{1}{\varphi^*_{iij}} f_{ii}^{\frac{1}{(1+\zeta_j)(\sigma_j - 1)}} f_{ni}^{\frac{\sigma_j - 1 - \alpha_j}{\alpha_j (\sigma_j - 1)}}. \tag{A14}$$

From Eq. (A14) it follows that the effect of fixed trade costs on the average export price, after controlling for industry- and country-fixed effects, is given by: $\frac{d \ln \bar{p}_{nij}}{d \ln f_{ni}} = \frac{\sigma_j - 1 - \alpha_j}{\alpha_j (\sigma_j - 1)}$, which is positive if and only if the scope for quality differentiation is large ($\alpha_j < \sigma_j - 1$).

A.4 Scope for quality differentiation and the "quality ladder"

This part shows that the scope for quality differentiation in Eq. (12) 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 (9):

$$\ln s_{nij}(\varphi) = \ln A_{nj} + (\sigma_j - 1) \ln \left(\frac{q_{nij}}{p_{nij}} \right), \tag{A15}$$

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

$$\ln\left(\frac{q_{nij}}{p_{nij}}\right) = \frac{(1-\theta_j)\left[\ln(1-\theta_j) + \ln A_{nj}\right] + (\theta_j - 1 - \alpha_j)\ln\left(\frac{\sigma_j}{\sigma_j - 1}\right) + \alpha_j\left(\ln\varphi - \ln\tau_{ni}\right)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}. \tag{A16}$$

Combining Eqs. (A15) and (A16) leads to the following expression for firm sales:

$$\ln s_{nij}(\varphi) = \frac{\alpha_j \ln A_{nj} + \alpha_j(\sigma_j - 1)(\ln\varphi - \ln\tau_{ni} - \ln\kappa_j)}{\alpha_j - (\sigma_j - 1)(1-\theta_j)}, \tag{A17}$$

where A_{nj} represents destination-industry fixed effects, and $\ln\kappa_j = -\frac{1-\theta_j}{\alpha_j}\ln(1-\theta_j) + \frac{\alpha_j+1-\theta_j}{\alpha_j}\ln\left(\frac{\sigma_j}{\sigma_j-1}\right)$ captures industry characteristics. Conditional on these effects, the positive relationship between firm sales and productivity φ increases in the scope for quality differentiation, as the slope of the sales curve $\frac{\alpha_j(\sigma_j-1)}{\alpha_j-(\sigma_j-1)(1-\theta_j)}$ decreases in α_j. Intuitively, a higher scope for quality differentiation leads to a larger market share after controlling for exporter productivity, as well as industry- and destination characteristics. Hence, the scope for quality 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).

A.5 Quality differentiation with endogenous markups

This section derives the gravity equation in a framework with endogenous markups and quality differentiation. We follow Antoniades (2015) and assume that preferences of consumers are given by:

$$U = q_o^c + \alpha \int_{i\in\Omega} q_i^c di + \beta \int_{i\in\Omega} z_i q_i^c di - \frac{1}{2}\gamma \int_{i\in\Omega} (q_i^c)^2 di - \frac{1}{2}\eta\left\{\int_{i\in\Omega} q_i^c di\right\}^2,$$

where q_o^c denotes the consumption of the numeraire good and q_i^c is the consumed quantity of variety $i \in \Omega$. The parameters α, β, γ and η are assumed to be positive. From the consumer's maximization problem follows that the inverse demand for variety i is given by:

$$p_i = \alpha - \gamma q_i^C + \beta z_i - \eta Q^C,$$

where z_i is the quality of each product. On the supply side, we follow the same assumptions as Antoniades (2015). First, firms differ in their marginal cost c, that follow a Pareto distribution given by $G(c) = \left(\frac{c}{c_m}\right)^k$, with $c \in [0, c_M]$. Second, firms choose the optimal level of product quality and face the following cost function: $TC = qc + q\delta z + \theta(z)^2$, where $\delta > 0$ captures that variable production costs increase with the quality level and the parameter $\theta > 0$ reflects additional fixed cost of quality upgrades. Third, exporting from country i to destination n is associated with iceberg trade costs $\tau_{ni} > 1$. Additionally, the parameter β is a country-specific taste parameter for quality, while δ and θ capture industry- or country-specific differences in the production of quality. For notational simplicity, we drop the industry index j in the following analysis.

From profit maximization as in Antoniades (2015) follows that the optimal export price and quantity when selling from country i to country n are given by:

$$p_{ni}(c, z) = \frac{\tau_{ni}}{2}(c_{ni} + c) + \frac{1}{2}(\beta_n + \delta_i) z_{ni}, \tag{A18}$$

$$q_{ni}(c, z) = \frac{L_n}{2\gamma}\tau_{ni}(c_{ni} - c) + \frac{L_n}{2\gamma}(\beta_n - \delta_i) z_{ni}, \tag{A19}$$

where the optimal quality choice is $z_{ni} = \tau_{ni}\lambda_{ni}(c_{ni} - c)$, with $\lambda_{ni} = \frac{L_n(\beta_n - \delta_i)}{4\theta_i\gamma - L_n(\beta_n - \delta_i)^2}$. Combining Eqs. (A18) and (A19) together with the optimal quality choice allows to write a firm's export sales as follows:

$$s_{ni}(c) = \frac{L_n}{4\gamma}\tau_{ni}^2(c_{ni} - c)\left[(c_{ni} + c) + (\beta_n + \delta_i)\lambda_{ni}(c_{ni} - c)\right]\left[1 + (\beta_n - \delta_i)\lambda_{ni}\right]. \tag{A20}$$

Analogous to Eq. (17), the exports from country i to destination n can be expressed as:

$$S_{ni} = M_{ni}\frac{1}{G(c_{ni})}\int_0^{c_{ni}} s_{ni}(c)\, dG(c),$$

where M_{ni} is the mass of exporters. We insert Eq. (A20) and exploit that cost draws are Pareto distributed, which leads to:

$$S_{ni} = \frac{N_i L_n c_{nn}^{k+2}\tau_{ni}^{-k}}{2\gamma(k+2)c_M^k}\left[1 + (\beta_n - \delta_i)\lambda_{ni}\right]\left[1 + \frac{(\beta_n + \delta_i)\lambda_{ni}}{k+1}\right], \tag{A21}$$

where N_i represents the mass of potential entrants in country i, and c_{nn} denotes the domestic cost cutoff in the destination country. Note that these two components can be captured by country fixed effects when estimating the gravity equation. The last two expressions reflect the additional impact of quality differentiation, which varies across country pairs, and possibly by industry. In particular, a higher taste parameter for quality in the destination (β_n) leads to an additional increase in exports besides the common market size effect, captured by L_n. Without quality differentiation ($\beta_n = \delta_i = 0$), the gravity equation simplifies to the one which would be obtain in the model of Melitz and Ottaviano (2008):

$$S_{ni} = \frac{N_i L_n c_{nn}^{k+2} \tau_{ni}^{-k}}{2\gamma\,(k+2)\,c_M^k}. \tag{A22}$$

In both cases, the effect of trade costs in Eqs. (A21) and (A22) is governed by the Pareto shape parameter: $\frac{d\ln S_{ni}}{d\ln \tau_{ni}} = -k < 0$.

A.6 Main results of related papers with firm heterogeneity

Table B1: Predictions of trade models with firm heterogeneity and quality differentiation

	(1)	(2)	(3)	(4)	(5)
	Firm FOB price		Avg. FOB price	Firm exports	Aggregate exports
	Firm size	Trade costs	Trade costs	Firm size & Quality	Trade costs & Quality
Melitz (2003)	−	0	−	none	none
A. Exogenous quality					
Baldwin and Harrigan (2011)	+	0	+	+	none
Johnson (2012)	+/−	0	+/−	none	none
Di Comite et al. (2014)	+/−	none	none	none	none
B. Endogenous quality					
Kugler and Verhoogen (2012)	+/−	none	none	+	none
Antoniades (2015)	+/−	−	−	+	none
Fan et al. (2015)	+/−	+/−	none	+	none
Alcalá (2016)	+/−	0	+/−	+	none
Endogenous quality choice and fixed trade costs	+/−	+/−	+/−	+	+

Notes: The table compares the predictions of trade models with firm heterogeneity allowing for exogenous quality differences (Panel A), and with endogenous quality choice (Panel B). The last line shows the predictions of our framework with endogenous quality choice and fixed trade costs. Models with exogenous quality can explain a positive relationship between firm size and firm-level FOB prices (column 1), while models with endogenous quality choice additionally capture that trade costs reduce firm-level FOB prices due to a reduction in quality investments (column 2). Selection of high-quality products into more distant markets leads to a positive relationship between trade costs and average FOB prices (column 3). Models that explicitly account for quality differences across industries (Kugler and Verhoogen, 2012; Fan et al., 2015; Antoniades, 2015) predict that the correlation of firm-level prices with firm size is positive if and only if the scope for quality differentiation is large. Kugler and Verhoogen (2012) neglect trade costs, while Antoniades (2015) and Alcalá (2016) focus on variable trade costs. Fan et al. (2015) only consider firm-level effects. Models with endogenous quality choice predict an additional interaction of firm size and quality differentiation which positively affects export sales (column 4). In our framework, the interaction of endogenous quality choice and fixed costs generates an additional interaction in the gravity equation (column 5).

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 it 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. This approach is similar to Helpman et al. (2008) and Manova (2013), who compute bilateral measures of fixed costs using data on regulation costs from Djankov et al. (2002). As one of the proxies for fixed costs, Helpman et al. (2008) use the sum of the number of days and procedures (for both countries) to start a business, which leads to a measure of fixed costs of doing business by country pair. The precise methodology used to create the variables is available at the Doing Business Webpage (see http://www.doingbusiness.org/methodology/trading-across-borders).

Summary statistics for the main variables are shown in Table B2.

Table B2: 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
τ_{ni}	256,031	1.085	0.105
Sample using firm-level data, year 2000			
Share of firms γ_{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 B3.[63]

Table B3: Correlation between distance and fixed costs covariates

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 this purpose, 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 (τ_{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 to a lower 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, τ_{nj} represents the standard multiplicative trade costs, and t_{nj} are the additive trade costs.[64]

$\tilde{t}_{nj}$ 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 des-

[63]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.

[64]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 $\tilde{a}_{nj}$.

tination, 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 below the 1st percentile or above the 99th percentile for every product-destination.[65]
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 B4 provides summary statistics.

Table B4: Summary statistics - ATC_{nj}

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

[65] 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

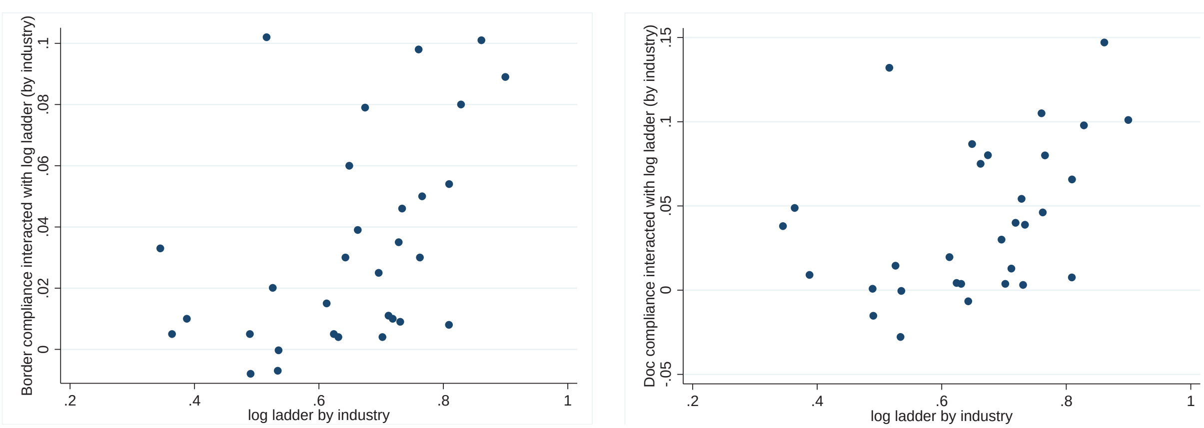
To provide a better visualization of the results for the fixed costs coefficients, we aggregate the data to the *2-digit industry level* and run the following regression with industry-specific coefficients:

$$\ln S_{nij} = \beta_1 fixedcosts_{ni} + \sum_{j=1}^{J} \beta_j ladder_j * fixedcosts_{ni} + \tau_{ni} + \rho_{ij} + \mu_{nj} + \varepsilon_{nij}, \qquad (30)$$

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



Notes: The figures show the scope for quality differentiation on the horizontal axis and the estimated industry-specific coefficients for the interaction terms $ladder_j * fixedcosts_{ni}$ on the vertical axis. The coefficients on the vertical axis are estimated regressing aggregate trade flows on $\sum_{j=1}^{J} \beta_j ladder_j * fixedcosts_{ni}$ and controls, where β_j are industry-specific coefficients. The figures show results for two proxies for fixed costs: time for border compliance (left) and time for documentary compliance (right). In accordance with our model, a larger positive coefficient for the interaction term is associated with higher scope for quality differentiation.

Table B5: Fixed costs covariates 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on fixed costs covariates interacted with industry's j scope for quality differentiation. As proxies for fixed costs, we use time for border compliance, time for documentary compliance and language. Besides controlling for multilateral resistance terms, columns 2, 4 and 6 also control for interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B6: 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on distance and on the interaction term between distance and the industry's j scope for differentiation. $\ln R\&D$ intensity of the industry proxies the industry's j scope for vertical differentiation and the GM index accounts for horizontal differentiation. Besides controlling for multilateral resistance terms, results in all columns include interacted importer-exporter fixed effects. We include tariffs as control variables. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B7: Robustness checks using R&D intensity and horizontal differentiation: Results for the share of firms using all fixed costs covariates

Dependent variable: γ_{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: Results regressing the share of exporters by destination country and industry (γ_{nj}) on fixed costs covariates interacted with industry's j scope for differentiation. $\ln R\&D$ intensity of the industry proxies the industry's j scope for vertical differentiation and the GM index accounts for horizontal differentiation. Results include industry and destination country fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer n.

Table B8: Results controlling for additive trade costs ATC_{nj}

Dependent variable γ_{nj}	(1)	(2)	(3)	(4)
$\ln Dist_n$	-0.109***		-0.121***	
	(0.0148)		(0.0149)	
$\ln Dist_n * ladder_j$	0.0138*	0.0145*	0.0142*	0.0147**
	(0.00746)	(0.00742)	(0.00739)	(0.00739)
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: Results regressing the share of exporters by destination country and industry (γ_{nj}) on distance, additive trade costs (ATC_{nj}), and interaction terms with industry's j scope for quality differentiation. Results in columns 2 and 4 include industry and destination country fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer n.

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

The coefficients shown in Figure B2 result from a regression as shown in Eq. (30). 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 quality ladder.

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

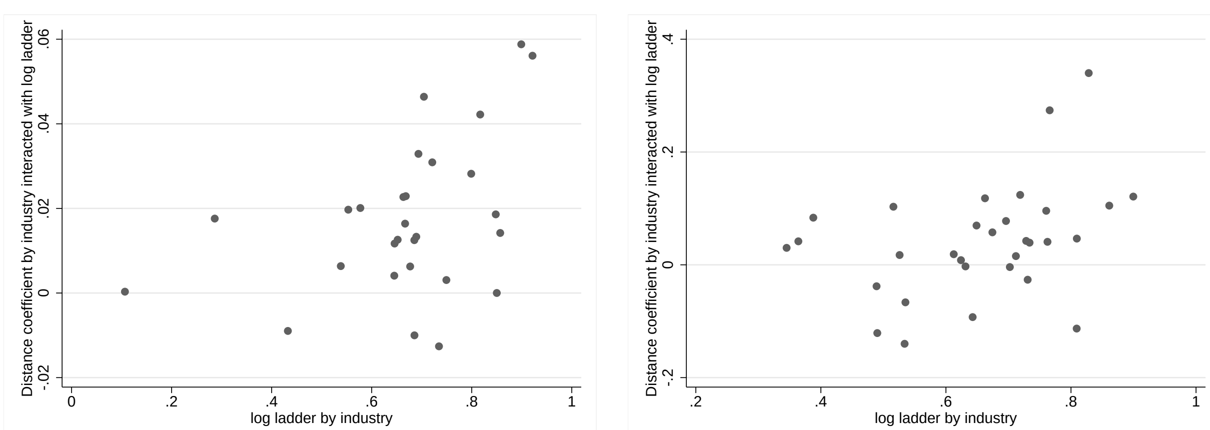


Table B9: Value per weight and aggregate trade flows

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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on fixed costs covariates interacted with industry's j scope for quality differentiation. Results include value per weight $\ln u\_value_{nij}$ and its interaction with fixed costs covariates as control variables. Besides controlling for multilateral resistance terms, columns 2, 4 and 6 include interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B10: 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on fixed costs covariates interacted with industry's j scope for quality differentiation. Results include the linder term $Linder_{ni}$ and its interaction with the scope for quality differentiation $ladder_j$ as control variables. Besides controlling for multilateral resistance terms, columns 2, 4, 6 and 8 include interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B11: 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nijt}$) on tariffs $\ln \tau_{nijt}$ and its interaction term with industry's j scope for quality differentiation using panel data. Besides controlling for importer-exporter-industry nij fixed effects, columns 2, 3 and 4 include year fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B12: 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: Results regressing aggregate bilateral trade flows by industry (S_{nij}) on fixed costs covariates, distance and interaction terms with industry's j scope for quality differentiation using PPML. All results include importer, exporter and industry fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. The estimations are conducted at the 3-digit level.

Table B13: 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: Results regressing aggregate bilateral trade quantities by industry ($\ln Q_{nij}$) on fixed costs covariates, distance and interaction terms with industry's j scope for quality differentiation. Besides controlling for multilateral resistance terms, columns 2, 4, 6 and 8 control for interacted importer-exporter fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. The estimations are conducted at the 3-digit level. The errors are clustered by importer-exporter pair.

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 4 are reported for a restricted sample. Tables B14 and B15 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 B14: 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: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on distance and its interaction term with industry's j scope for quality differentiation. Columns 1 and 2 report results for the full sample without tariff data and columns 3 to 6 report results for the smaller sample for which we have tariff data. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B15: 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			
γ_{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: Results regressing the share of exporters by industry and destination (γ_{nj}) on distance and its interaction term with industry's j scope for quality differentiation. Columns 1 and 2 report results for the full sample without tariff data and columns 3 to 6 report results for the smaller sample for which we have tariff data. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer.

Table B16: Scope for quality differentiation and productivity across destinations: Effect on sales and prices

Dependent variable		$\ln s^k_{nij}$			$\ln p^k_{gnij}$	
	(1)	(2)	(3)	(4)	(5)	(6)
φ^k_i	0.0453***	0.0230***	0.0564***	0.251***	0.166***	0.163***
	(0.00281)	(0.00370)	(0.00849)	(0.00181)	(0.00503)	(0.0197)
$\varphi^k_i * ladder_j$		0.0248***	0.0329***		0.0273***	0.0360***
		(0.000969)	(0.00200)		(0.00271)	(0.00582)
$\varphi^k_i *$ GM index			-0.153***			-0.0223
			(0.0109)			(0.0366)
Constant	2.591***	2.232***	2.452***	0.594***	0.950***	0.605***
	(0.0409)	(0.0479)	(0.0924)	(0.0183)	(0.0172)	(0.0356)
Observations	92,581	92,098	21,250	146,251	146,239	38,061
R-squared	0.491	0.491	0.348	0.129	0.459	0.321
nj fixed effects	yes	yes	yes	yes	yes	yes
gn fixed effects	no	no	no	no	yes	yes

Notes: Results regressing firm outcomes by destination on firm productivity φ^k_i and its interaction terms with industry-level measures: $ladder_j$ proxies for the scope for quality differentiation of the industry and the GM index proxies for horizontal differentiation. Columns 1 to 3 report results for firm sales by destination country n ($\ln s^k_{nij}$). Columns 4 to 6 report results for firm unit values $\ln p^k_{gnij}$ by destination n and good g. Results refer only to Brazilian firms, implying origin i=Brazil. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively.

Table B17: Robustness checks controlling for comparative advantage

Dependent variable: $\ln S_{nij}$	(1)	(2)	(3)	(4)	(5)	(6)
$\ln t\_border_{ni}$	-0.243***	-0.0954***	-0.253***	-0.109***	-0.259***	-0.126***
	(0.0367)	(0.0343)	(0.0371)	(0.0347)	(0.0368)	(0.0348)
$\ln t\_border_{ni}* \ ladder_j$	0.0128***	0.0309***	0.0121***	0.0329***	0.0171***	0.0464***
	(0.00311)	(0.00643)	(0.00307)	(0.00649)	(0.00309)	(0.00651)
$BRCA_{ij}$			0.0601***	0.0416***		
			(0.00244)	(0.00199)		
CA_dum_{ij}					0.351***	0.675***
					(0.0110)	(0.0347)
Constant	4.939***	4.185***	4.891***	4.156***	4.876***	4.103***
	(0.147)	(0.143)	(0.149)	(0.144)	(0.148)	(0.143)
i fixed effects	yes	yes	yes	yes	yes	yes
n fixed effects	yes	yes	yes	yes	yes	yes
j fixed effects	yes	yes	yes	yes	yes	yes
nj fixed effects	no	yes	no	yes	no	yes
Observations	719,995	719,995	719,995	719,995	719,995	719,995
R-squared	0.287	0.368	0.302	0.383	0.302	0.382

Notes: Results regressing aggregate bilateral trade flows by industry ($\ln S_{nij}$) on the fixed costs covariate $\ln t\_border_{ni}$ and its interaction term with the scope for quality differentiation $ladder_j$. Results include Balassa-RCA ($BRCA_{ij}$) and a dummy for comparative advantage (CA_dum_{ij}) suggested by Mayda and Rodrik (2005) as control variables to account for comparative advantage. Besides controlling for i, n and j fixed effects, columns 2, 4 and 6 include interacted importer-industry fixed effects. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively. Errors are clustered by importer-exporter pair.

Table B18: Robustness checks: Distribution of firm size across destinations

Dependent variable: $\ln skewness_{nj}$	(1)	(2)	(3)
$\log GDP_n$ per capita	0.0504***	0.0495***	0.0707***
	(0.00406)	(0.00234)	(0.00229)
$\log GDP_n$		0.00161	0.00699*
		(0.00428)	(0.00422)
Constant	0.0564	-0.425***	-1.299***
	(0.0366)	(0.0452)	(0.0657)
j fixed effects	no	no	yes
Observations	20,151	20,151	20,151
R-squared	0.006	0.025	0.207

Notes: Results regressing the skewnnes of firm sales by industry and destination $\ln skewness_{nj}$ on GDP per capita and GDP of destination country n. Following Bernard et al. (2011), we use entropy of firms sales to calculate skewness. ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively.

B.4 Estimation of the model: Results by industry

Table B19: Parameter estimates by industry - all industries

Industry	ξ_j	σ_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 lnt_border_{ni}