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Paulo Bastos

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Learning, Prices, and Firm Dynamics*

Paulo Bastos[†] Daniel A. Dias[‡] Olga A. Timoshenko[§]

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Abstract

We document new facts about the evolution of firm performance and prices in international markets, and propose a theory of firm dynamics emphasizing the interaction between learning about demand and quality choice to explain the observed patterns. Using data from the Portuguese manufacturing sector, we find that: (1) firms with longer spells of activity in export destinations tend to ship larger quantities at lower prices; (2) older exporters tend to use more expensive inputs; (3) revenue growth within destinations (conditional on initial size) tends to decline with market experience; and (4) input prices and quantities tend to increase with revenue growth within firms. We develop a model of endogenous input and output quality choices in a learning environment that is able to account for these patterns. Counterfactual simulations reveal that minimum quality standards on traded goods reduce welfare by lowering entry in export markets and reallocating resources from old and large towards young and small firms.

Keywords: Learning about demand, prices, product quality, firm dynamics, quality standards.

JEL: F12; F14; L11; O14.

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[†]Development Research Group, The World Bank, 1818 18th Street NW, Washington DC, United States. E-mail: pbastos@worldbank.org

[‡]Board of Governors of the Federal Reserve System, International Finance Division, Washington DC, United States and CEMAPRE, Portugal. E-mail: daniel.dias@frb.gov

[§]The George Washington University, Department of Economics and The Elliott School of International Affairs, 2115 G St., NW, Washington DC, 20052, United States. E-mail: timoshenko@gwu.edu

1 Introduction

A small proportion of firms generate the bulk of export revenue in each nation (Bernard et al., 2007; Mayer and Ottaviano, 2007). Richer countries tend to have more and larger exporters, with greater concentration in the top 5% (Fernandes, Freund, and Pierola, 2015). These large exporters help define specialization patterns and play a key role in shaping the impact of trade liberalization on macroeconomic volatility (Freund and Pierola, 2015; di Giovanni and Levchenko, 2012). To understand how and why (some) firms eventually become successful exporters, the heterogeneous-firm trade literature is paying growing attention to dynamics. While the increased availability of customs records has made it possible to study firms' export behavior over time, we still have a limited understanding of the mechanisms underlying the evolution of export performance over the firm life cycle.

In this paper, we use rich micro data to document new facts about the joint evolution of firm performance and prices over the life cycle, and develop a theory of firm dynamics emphasizing the interaction between learning about demand and quality choice to explain the observed patterns. Drawing on detailed trade and production data from the Portuguese manufacturing sector, we document that: (1) firms with longer spells of activity in export destinations tend to ship larger quantities at lower prices; (2) more experienced exporters tend to use more expensive inputs; and (3) input prices and quantities tend to increase with revenue growth within firms. In line with prior research, we also find that the positive relationship between export revenue and market experience reflects growth, not just market selection based on initial size; and that revenue growth within destinations (conditional on initial size) tends to decline with the length of activity there (Eaton et al., 2008; Berthou and Vicard, 2013; Ruhl and Willis, 2014).

To account for the joint observation of these patterns in the data, we introduce quality choice of outputs and inputs (Verhoogen, 2008; Kugler and Verhoogen, 2012) and learning about demand (Jovanovic, 1982; Arkolakis, Papageorgiou, and Timoshenko, 2015) into a Melitz (2003) model of monopolistic competition and firm heterogeneity. In the model, firms supply products of varying quality based on their beliefs about idiosyncratic expected demand. Through the life-cycle, an average surviving firm updates its demand expectations upwards, grows, and, as a result, finds it optimal to upgrade the quality of outputs, which requires using higher quality inputs. Since inputs of higher quality are more expensive, average input prices rise with export experience. The evolution of output prices is less clear-cut. On the one hand, quality upgrading leads to a higher price. On the other hand, an increase in demand expectations increases profitability and causes a price reduction. The model is thus able to rationalize the varying behavior of input and output prices over the firm life cycle observed in the data.

We explore the quantitative implications of our theory by calibrating it to match cross-sectional and dynamic moments of the distributions of sales, exports and prices observed in the Portuguese data. Calibrated to match the observed age-dependence of exports

growth and input prices, the model accounts for about a third of the (conditional) size-dependence of growth rates that emerges from the data, and correctly predicts that export prices decline with export-market age within firms.

Armed with the calibrated model, we assess the implications of regulations imposing minimum product quality standards on traded goods. We find that this policy reduces welfare through two distinct channels. First, it reduces firm entry in export markets, and hence lowers the number of export varieties available to consumers. Second, it distorts an intensive margin of adjustment. To participate in the export market, marginal exporters are forced to comply with the standard by choosing higher quality inputs. This choice leads to a reallocation of productive resources from large and old towards small and young firms, which causes a further decline in welfare.

We contribute to several strands of existing research. A recent body of literature on firm dynamics offers variants of Melitz (2003) in which firms experience idiosyncratic shocks to their productivity, including Luttmer (2007), Impullitti, Irarrazabal, and Opro-molla (2013) and Arkolakis (2015). If modified to allow for quality choice (as in Kugler and Verhoogen (2012)), this class of models would generate a positive relationship between input prices and export experience: as entrepreneurs become more capable (for exogenous reasons), firms grow and find it optimal to upgrade the quality of outputs and inputs. However, as emphasized by Arkolakis, Papageorgiou, and Timoshenko (2015) this class of models is unable to explain the age-dependence of growth rates (conditional on size) observed in the data.

A related class of models links firm dynamics in export markets to learning about un-observed demand (Albornoz et al., 2012; Chaney, 2014; Eaton et al., 2014; Ruhl and Willis, 2014; Timoshenko, 2015a,b; Arkolakis, Papageorgiou, and Timoshenko, 2015). While the microfoundations of the learning process vary across models, this body of work makes it possible to rationalize the age-dependence of export growth (conditional on size) observed in the data. Existing learning models are not well-suited, however, to explain the observed increase in wages and material input prices with export experience.¹

Our findings also contribute, therefore, to the literature on product quality and trade at the firm-level. We borrow from Verhoogen (2008) and Kugler and Verhoogen (2012) the theoretical ideas that in order to produce higher quality outputs firms need to use higher quality inputs; and that all else equal more capable entrepreneurs will choose to produce higher quality products. These hypotheses have found considerable support in the data. Using detailed firm-product records from the Colombian manufacturing sector,

¹We also build on Cabral and Mata (2003) who show that the firm size distribution is significantly right-skewed and evolves over time toward a lognormal distribution largely because of firm growth (as opposed to selection based on initial size). A related body of evidence reveals that firm growth (in terms of employment, sales or export revenue) declines with age, conditional on initial size (Evans, 1987; Sutton, 1997; Haltiwanger, Jarmin, and Miranda, 2013; Arkolakis, 2015; Timoshenko, 2015a,b). While confirming that these patterns also hold in our data, we depart from previous work by examining the joint evolution of export performance and prices over the firm life cycle; and by providing theory and evidence that the interaction between learning about demand and quality choice is an important driver of firm dynamics.

Kugler and Verhoogen (2012) find that larger plants tend to charge more for outputs and pay higher prices for material inputs. In Portuguese data, Bastos, Silva, and Verhoogen (2014) find that firms experiencing an exogenous increase in the share of sales to richer export destinations (where consumers have higher willingness to pay for quality) tend to pay more for material inputs.² Our paper contributes to this literature by shedding light on the dynamic interaction between learning about demand and quality choice in shaping the evolution of firm performance and prices over the life cycle.³

Finally, our paper contributes to the theoretical literature on minimum quality standards and trade, including Das and Donnenfeld (1989), Fischer and Serra (2000) and Baltzer (2011). A common approach in this literature has been to examine the welfare impacts of quality standards in partial equilibrium models of oligopoly featuring a small (exogenously given) number of producers in each country. By revisiting this question in the context of a quantitative general equilibrium model of firm dynamics, we are able to identify several important new channels by which quality standards influence social welfare. In particular, we find that quality standards reduce welfare by lowering entry in export markets and reallocating resources from large and old towards young and small firms.⁴

The paper proceeds as follows. Section 2 describes the data employed. Section 3 presents stylized facts about the evolution of firm performance and prices. Section 4 develops a theory of firm dynamics featuring learning about demand, firm heterogeneity and quality choice of inputs and outputs. Section 5 explores the quantitative implications of the model by calibrating it to the Portuguese data and develops counterfactual simulations on the effects of imposing minimum quality standards in export markets. The last section concludes the paper.

²Other recent papers provide several additional pieces of evidence on the relationship between output prices, input prices and firm characteristics. In cross-sectional data, Bastos and Silva (2010) find that more productive Portuguese firms ship larger volumes at higher prices to a given destination, and that exporters tend to charge higher prices in richer destinations. Manova and Zhang (2012) show that Chinese firms that export more, serve more markets and charge higher prices for exports tend to pay more for their imported inputs. Examining data for manufacturing plants in India, the US, Chile, and Colombia, Hallak and Sivadasan (2013) document that, conditional on size, exporting firms charge higher prices, pay higher wages, use capital more intensively, and purchase more expensive material inputs. Lederman, Brambilla, and Porto (2012) show that Argentine firms exporting to high-income countries hire more skilled workers than other exporters and domestic firms.

³Our paper is also related to the literature on product quality and trade at the product-country level, including influential contributions by Schott (2004), Hummels and Klenow (2005), Hallak (2006), Khandelwal (2010), Hallak and Schott (2011), Brambilla and Porto (2016), and Flach (2016).

⁴Our model is also able to account for recent empirical evidence on the effects of product standards on exporting behavior. Using detailed firm-product-destination data for France, Fontagné et al. (2015) find that standards reduce entry in export markets and lead to an increase in export prices, especially among small exporters.

2 Data description

We examine detailed data from the *Foreign Trade Statistics* (FTS), the *Enterprise Integrated Accounts System* (EIAS), and the *Annual Survey of Industrial Production* (IAPI) of Portugal for the period 2005-2009.

The FTS are the country's official information source on international trade statistics, gathering export and import transactions (values and physical quantities) of firms located in Portugal by product category (CN classification, 8-digit) and destination or source market. These data are collected in two different ways. Data on trade with countries outside the EU (external trade) are collected via the customs clearance system, which covers the universe of external trade transactions. Information on the transactions with other EU member States (internal trade) are obtained via the Intrastat system, where the information providers are companies engaged in internal trade and registered in the VAT system whose value of annual shipments exceeds a legally binding threshold. Trade transactions in these data are *free on board*, hence excluding any duties or shipping charges. Despite the above-mentioned constraint, the export and import transactions included in the FTS data aggregate to nearly the total value of merchandise exports and imports reported in the official national accounts.

The EIAS is a census of firms operating in Portugal run by the National Statistics Institute (INE) since 2005. Among other variables, it contains information on total employment, sales, wage bill, capital stock, value added, date of constitution, industry code and location. Also run by INE, the IAPI is a survey that gathers information on values and physical quantities of outputs, material inputs, and energy sources of firms by product category (based on the PRODCOM classification, 12-digit).⁵

We have further used FTS data spanning a longer period (1990-2009) to compute export-age and export-destination-age. In each year, these variables are defined, respectively, as the number of consecutive years the firm has been an exporter in any market or an exporter in a particular export destination.⁶ As is customary in the empirical trade literature, we restrict the analysis to firms whose main activity is in the manufacturing sector excluding the Petroleum industry. We impose these restrictions using the firm's self-reported industry code in the EIAS data set, where sectors are defined by the Revision 2.1 of the National Classification of Economic Activities (CAE).⁷ All nominal variables

⁵In the period 2005-2009, the IAPI sampling scheme covered selected industrial sectors. It ranked firms in descending order of sales and included them until 90% of total sales in the corresponding sector were covered, with some minor qualifications (see Appendix B for details). This sampling scheme makes it difficult to undertake meaningful cross-sectional comparisons between cohorts of firms or exporters in a given year. Our main focus when using these data is, therefore, on within-firm changes over time, conditional on firms being sampled.

⁶Since our measures of export experience are computed from trade-transactions data spanning the period 1990-2009, they are truncated at the difference between the reference year and 1990 (and hence are bounded by the upper limit of 20 years).

⁷Firms reporting their main activity to be in the manufacturing sector account for about 82% of total exports in the FTS data set for 2005-2009.

are expressed in 2005 euros, using the GDP deflator of Portugal.

Table A1 in the Appendix reports summary statistics on the FTS and EIAS data sets. In line with evidence for several other countries (Bernard et al., 2007), we observe that exporters tend to be larger, older, more productive, more capital intensive and pay higher wages than non-exporters. The average exporter in the period 2005-2009 obtained 3.45 million euros of export proceeds, served 5.4 destinations and exported in 8.3 different product categories. Exporting firms sourced on average 2.23 million euros from other nations, distributed by a mean of 14.2 product categories and 3.5 different countries. The average exporter in the sample has 8.3 years of experience in external markets (4.9 years of experienced by individual destination). Table A2 in the Appendix reports summary statistics on manufacturing firms surveyed in IAPI. As noted above, the sampling procedure of IAPI implies that the survey tends to cover larger firms. This is confirmed by the relatively larger volumes of sales and exports by firms in this sample. More than half of manufacturing firms surveyed by IAPI are exporters. Firms with export activity tend to have larger volumes of sales and input purchases, and source a wider variety of manufactured inputs than non-exporting firms.

3 Stylized facts

This section provides a comprehensive analysis of the evolution of firm performance over the life cycle. While the key novel stylized facts we document refer to the joint evolution of performance and prices in international markets, we place these patterns in the context of broader evidence on the dynamics of firm size. This makes it possible to compare key patterns in our data with those reported in the existing empirical literature, and thereby provide an integrated analysis of firm dynamics in both the domestic and external markets.

3.1 Firm performance across cohorts

We begin by examining the relationship between firm performance and age in the cross-section. When examining measures of firm size, we consider the age of the firm. When analyzing export revenue, we consider export-age, defined as the number of consecutive years the firm has been an exporter.

Figure 1 depicts the firm size and export revenue distributions of various cohorts of firms and exporters, based on data for 2005.⁸ As in Cabral and Mata (2003) and Angelini and Generale (2008), we use nonparametric estimation methods, notably a kernel density smoother. These methods offer a convenient way of estimating the density of the distribution without imposing much structure on the data.⁹ The patterns displayed in

⁸A cohort is defined as the group of firms for which the corresponding age measure in 2005 lied between 1-5 years, 6-10 years, and so on. Results for each of the other years in the sample are similar, and are available upon request.

⁹As in Angelini and Generale (2008) we use a bandwidth of 0.7. Estimation with alternative bandwidths leads to qualitatively similar results.

the top and middle panels of Figure 1 are well in line with those reported by Cabral and Mata (2003): as firms get older, the size distribution shifts progressively to the right. The diagram reported in the lower panel of this figure focuses solely on exporting firms, and shows that the distribution of export revenue by export-age. As we look at more experienced exporters, the distribution of export revenue shifts systematically to the right.

Inspection of Figure 1 points to a clear relationship between firm performance and age, and between export revenue and export-age. We examine this issue further by estimating an equation of the form:

$$\log y_{it} = \beta \log age_{it} + \lambda_{kt} + \eta_r + \varepsilon_{ikrt}, \quad (1)$$

where y_{it} is a measure of size or export performance of firm i in year t , age_{it} is either the number of years passed since birth of the firm or the number of consecutive years the firm has been an exporter in year t , λ_{kt} is an industry-year fixed-effect, η_r is a region fixed-effect, and ε_{ikrt} a random term. Industry-year and region dummies are included to account for possible systematic relationships between firm age and industry affiliation or region.

Table 1 reports the corresponding results. The point estimates clearly corroborate the visual evidence. The estimates in columns (1)-(2) reveal that, among all manufacturing firms, a 10% increase in firm age is associated with a rise of 4.3% in total employment and 5.3% in total sales. Columns (3)-(4) show that these relationships remain fairly similar when restricting the focus to exporters. Finally, the estimates in columns (5)-(7) reveal that export revenue increases systematically with the length of activity in export markets: the estimates in column (5) indicate that when export-age increases by 10%, export revenue increases by 15.9%, on average; those in column (7) reveal that if export-destination-age increases by 10%, export revenue in that market rises by 11.3% on average in that same destination.

3.2 Growth versus selection on initial size

In the analysis above, we characterized the evolution of firm size and export performance over the life cycle using cross-sectional data. A potential explanation for the observed heterogeneity in performance across cohorts is selection on initial conditions. If firms that are initially larger or obtain more revenue when they start serving foreign markets are more likely to survive, older firms and more experienced exporters will naturally be larger and have stronger export performance even in the absence of systematic growth patterns over the life cycle.

Following Cabral and Mata (2003) we first evaluate the empirical relevance of this mechanism by identifying the universe of entrants in 2005 and tracking their performance until 2009. We then perform a similar exercise for the universe of new exporters in 2005 and following them in export markets until 2009.

From the 1,268 manufacturing firms that were born in 2005, 948 were still operating in 2009. The upper and middle panel of Figure 2 depicts the distributions of log employment and log sales of these two sets of firms in 2005, as well the 2009 distributions for survivors. Inspection of this figure reveals that the distribution of survivors in 2009 is clearly to the right of that of the universe of entrants in 2005. If selection based on initial size (exit of initially smaller firms) were to explain this evolution, the firm size distribution (FSD) of survivors in 2005 would be expected to be shifted to the right compared to the overall distribution of entrants in 2005. By contrast, if differential growth of initially similar firms were to explain this evolution, the initial FSD of survivors would be expected to resemble that of the universe of entrants in 2005. Inspection of Figure 2 shows that firm growth, as opposed to selection based on initial size, is the main driver of the evolution of performance over the life cycle.

The lower panel of Figure 2 depicts similar distributions, but now focusing on the export revenue of all new exporters in 2005. From the 1,173 manufacturing firms that started exporting in 2005, 233 were still exporting in 2009. The distribution of firms that continued exporting until 2009 is clearly to the right of the universe of new exporters in 2005. Hence, this evolution reflects both growth of export revenue among survivors and selection based on initial size: while firms that survived in export markets until 2009 were already larger exporters in 2005, their export revenue grew considerably (in real terms) between 2005 and 2009.

3.3 Growth, size and age

We further characterize the growth process described above by examining the relationship between firm growth and age. We first examine if and how firm growth is systematically related with age, even when controlling for size. Following the literature (Evans, 1987; Sutton, 1997; Haltiwanger, Jarmin, and Miranda, 2013) we estimate a regression of the form:

$$\log y_{it} - \log y_{it-1} = \alpha \log y_{it-1} + \beta \log age_{it-1} + \lambda_{kt} + \eta_r + \varepsilon_{ikrt}, \quad (2)$$

where y_{it} denotes employment or sales by firm i in year t , y_{it-1} represents the same variable in the previous year, and age denotes the age of the firm in $t - 1$. The results in Table 2 confirm the well-known result that firm growth declines with age, even when controlling for size. This finding holds irrespective of whether firm size is measured by employment or sales.

We then perform a similar analysis for growth of export revenue, both overall and within individual destinations. We estimate an equation of the form:

$$\log y_{ijt} - \log y_{ijt-1} = \alpha \log y_{ijt-1} + \beta \log age_{ijt-1} + \lambda_{jt} + \lambda_k + \eta_r + \varepsilon_{ijkrt}. \quad (3)$$

In this case we use two different measures of experience in export markets. Our preferred measure, log export-destination-age, is the log of the number of consecutive years the firm

has been serving market j in year t . We also report results using the number of consecutive years the firm has been an exporter (in any market) in year t , log export-age.

The results are reported in Table 3 and suggest once again that export growth declines with export experience. This relationship holds both for total exports and exports in individual destinations, and prevails when controlling for initial export size. As emphasized by Arkolakis, Papageorgiou, and Timoshenko (2015) this feature of the data cannot be explained by models of random productivity evolution, but can be matched by models of learning about unobserved demand.

3.4 Prices and firm dynamics

We proceed by examining the heterogeneity of prices and physical quantities of exported goods and inputs, across and within firms. To examine the behavior of export prices and quantities at the firm-destination level, we first run regressions of the form:

$$\log v_{ipjt} = \psi_{pjt} + \lambda_{ijt} + \varepsilon_{ipjt}, \quad (4)$$

where i indexes firm, p product, j destination and t year; v_{ipjt} is the unit value (or physical quantity) of exports by firm i in product category p to destination j and year t ; ψ_{pjt} is a product-destination-year fixed effect; λ_{ijt} is a firm-destination-year fixed effect; and ε_{ipjt} is a mean zero error term. The product-destination-year effects capture all common factors that affect the price of a particular good sold in a destination across firms in a given year. The firm-destination-year effects are therefore identified through comparisons with other firms selling the same product in the same destination in the same year. Thus, the OLS estimate of λ_{ijt} reflects average log export prices (or log quantities) by firm-destination-year purged of effects due to the composition of products.¹⁰

Panel A in Table 4 examines the relationship between these average log export prices by firm-destination-year—estimated in (4)—and the measure of export experience in the destination. Panel B examines a similar relationship using average log export quantities as the dependent variable. Column (1) reports results from the comparison of average export prices across cohorts of exporters within destinations, obtained in a regression including destination-year effects, industry and region effects. The results indicate that more experienced exporters tend to sell larger quantities at lower prices. The regressions in column (2) include firm and year fixed effects. Hence they exploit within-firm variation in market experience (across destination and over time) to identify the relationship between average

¹⁰Kugler and Verhoogen (2012) and Bastos, Silva, and Verhoogen (2014) adopt a similar method to estimate average input and output prices at the firm-year level. Donald and Lang (2007) offer a discussion on how this method compares with related estimators. In this model, identification of firm-destination-year effects requires that firms belong to a connected “network” of firms, where a firm is connected if it exports a product to a destination that is also exported to that market by at least another firm in the network. A similar issue arises in the literature using employer-employee data to identify person and firm effects (Abowd, Creecy, and Kramarz, 2002). For this reason, we drop observations for unconnected firms in our estimation sample.

export prices (quantities) and market experience. Column (3) includes also destination effects to account for potential direct effects of destination attributes on export prices. The results in both columns suggest that as export experience in a destination increases, firms tend to ship larger quantities at lower average prices.

We now turn to the behavior of average wages and inputs prices across and within firms. We first compute firm-year average log input prices (and quantities) by running regressions of the form:

$$\log z_{ipt} = \alpha_{pt} + \gamma_{it} + \varepsilon_{ipt}, \quad (5)$$

where i indexes firm, p product and t year; z_{ipt} is the unit value (or physical quantity) of purchases by firm i in product category p and year t ; α_{pt} is a product-year fixed effect; γ_{it} is a firm-year fixed effect; and ε_{ipt} is a mean zero error term. The product-year effects capture all common factors that affect the price (or quantity) of a particular input across firms in a given year. The firm-year effects are therefore identified by comparisons with other firms purchasing the same product in the same year. Hence the OLS estimate of γ_{it} reflects average log input prices (or log quantities) at the firm-year level purged of effects due to the composition of products. We estimate (5) separately for import prices (quantities) and manufactured inputs prices (quantities) using data at the firm-product-year level from the FTS and IAPI data sets, respectively.

The results in Table 5 examine the behavior of average wages (labor costs per worker) and average log import prices—estimated in (5)—across cohorts of exporters. The estimates in column (1) reveal that older exporters tend to pay higher wages, on average.¹¹ The results in column (2) show that a similar relationship holds for import prices: firms with longer spells of export activity tend to pay higher prices for their imported inputs, on average.¹²

Table 6 examines how average input prices and quantities evolve with firm sales over time, within surviving firms. Panel A reports estimates for three different measures of input prices paid by firms: average wages, average imported input prices, and average manufactured input prices. Panel B reports estimates for the three corresponding quantity measures. All regressions include firm and year effects, and thus identification comes from within-firm variation over time, while accounting for effects common to all firms in a given year.¹³ The results suggest that prices and quantities of inputs tend to increase with

¹¹This finding generalizes the well-known fact that older manufacturing firms tend to pay higher wages (Brown and Medoff, 2003).

¹²As noted in Section 2, the IAPI sampling procedure makes it difficult to undertake meaningful cross-sectional comparisons between input prices and export experience in a given year. For this reason, the average input prices estimated in (5) using IAPI data are not included among the set of dependent variables in Table 5. They are solely considered in Table 6 below which focuses on within-firm changes over time, conditional on firms being sampled.

¹³An alternative approach for examining the relationship between input prices and firm growth is to regress directly average input prices on average physical quantities of inputs. However, as emphasized by Kugler and Verhoogen (2012) care must be exercised in examining such relationships. Since unit values are

sales withing surviving firms over time. This pattern holds for labor inputs (column (1)), imported inputs (column (2)), and all manufactured material inputs (column (3)).

4 The model

In this section we develop a learning model with quality choice to jointly explain the evolution of firm growth rates, and input and output prices over the firm life cycle. To capture the conditional age-dependence of growth rates documented in section 3.3 we consider a model of learning by Arkolakis, Papageorgiou, and Timoshenko (2015). To explain the pricing patterns documented in section 3.4, we introduce input and output quality choice as in Kugler and Verhoogen (2012).

4.1 Set-up

Time is discrete and is denoted by t . There are N countries. Each country j is populated by L_j identical infinitely-lived consumers. There are two sectors in each economy: a final goods sector and an intermediate inputs sector. The final goods sector is populated by a mass of monopolistically competitive firms. Those firms supply horizontally differentiated varieties of various qualities. The intermediate inputs sector is perfectly competitive and uses a constants-returns-to-scale production technology. Every period there exists an exogenous mass of entrants J_j . There are no sunk costs of entry.

4.2 Consumers

Consumer preferences in country j over the consumption of the composite final good are described by the expected utility function U_j given by

$$U_j = E \sum_{t=0}^{+\infty} \beta^t \ln Q_{jt}, \quad (6)$$

where β is the discount factor and Q_{jt} is the consumption of the composite final good. Q_{jt} is given by

$$Q_{jt} = \left(\sum_{i=1}^N \int_{\omega \in \Omega_{ijt}} \left(e^{a_{jt}(\omega)} \right)^{\frac{1}{\sigma}} (\lambda_{jt}(\omega) q_{jt}(\omega))^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}},$$

where $q_{jt}(\omega)$ is the consumption of variety ω in the final-goods sector, Ω_{ijt} is the total set of varieties in the final goods sector sold in country j originating from country i , and σ is the elasticity of substitution across varieties.

computed as the ratio between input expenditures and physical quantities, measurement error in physical quantities will generate a spurious negative correlation between physical quantities and unit values. In line with their proposed solution for this problem, we relate both input prices and physical quantities to firm sales in separate regressions.

Each variety ω is subject to two sources of demand heterogeneity. First, as in Kugler and Verhoogen (2012), $\lambda_{jt}(\omega)$ is the quality of variety ω in country j at time t . $\lambda_{jt}(\omega)$ captures characteristics of variety ω which are chosen by a firm. If chosen, those characteristics increase the utility of a consumer. $\lambda_{jt}(\omega)$ is known to both consumers and firms.

Second, as in Arkolakis, Papageorgiou, and Timoshenko (2015), $a_{jt}(\omega)$ is the demand shock for variety ω in country j at time t . The demand shock captures inherent variation in preferences across varieties irrespective of the varieties' quality. The demand shock is given by

$$a_{jt}(\omega) = \theta + \epsilon_{jt}(\omega),$$

where θ is the time-invariant component of the shock, a product ‘‘appeal’’ index. The appeal index is subject to the transient preference shocks $\epsilon_{jt}(\omega)$ which are i.i.d. $N \sim (0, \sigma_\epsilon^2)$. In contrast to quality, the demand shock is known to consumers, but not to firms.

Each consumer is endowed with a unit of labor which he inelastically supplies to the market, and owns a share of profits of domestic monopolistically-competitive firms. Given their income, consumers minimize the cost of acquiring the aggregate consumption bundle yielding the demand for variety ω given by

$$q_{jt}(\omega) = \lambda_{jt}(\omega)^{\sigma-1} e^{a_{jt}(\omega)} \frac{p_{jt}(\omega)^{-\sigma}}{P_{jt}^{1-\sigma}} Y_{jt},$$

where $p_{jt}(\omega)$ is the price of variety ω , P_{jt} is the aggregate price index, and Y_{jt} is the aggregate spending level in country j at time t . The aggregate price index is given by

$$P_{jt} = \left(\sum_{i=1}^N \int_{\omega \in \Omega_{ijt}} \lambda_{jt}(\omega)^{\sigma-1} e^{a_{jt}(\omega)} p_{jt}(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}. \quad (7)$$

4.3 Intermediate inputs sector

The intermediate inputs sector is characterized by perfect competition and a constant-return-to-scale production technology. The sector uses labor l to produce intermediate inputs of varying quality c : production of x units of an intermediate input of quality c requires cx units of labor. Notice that such production technology implies that production of higher quality material inputs requires more labor resources.¹⁴ The profit of a firm producing an intermediate input of quality c is given by

$$\pi_{jt}(c) = p_{jt}^c(c) x_{jt} - w_{jt} c x_{jt},$$

¹⁴The intermediate inputs sector can also be thought of as an education or training sector, which converts units of effective labor into workers of different skill levels, who are then employed in the final goods sector. Under this interpretation, production of higher-skill workers requires more labor from the education or training sector.

where w_{jt} is the wage rate and $p_{jt}^c(c)$ is the price of an intermediate input of quality c in country j at time t . Perfect competition leads to zero profit yielding to the price of an intermediate input equal to its marginal cost:

$$p_{jt}^c(c) = cw_{jt}. \quad (8)$$

4.4 Final goods sector

The final goods sector consists of a continuum of monopolistically competitive firms.

Production technology

Each firm produces one good which it can supply to multiple markets in varying qualities. The production of q physical units of the final good requires $x = \frac{q}{\varphi}$ units of an intermediate input, where φ is the productivity level of the firm.

The productivity parameter φ is drawn from a Pareto distribution with the shape parameter ξ and the scale parameter φ_{\min} and is known to the firm since entry.¹⁵ In this set-up, the productivity parameter φ measures the efficiency with which the firm can convert units of an intermediate input into units of the final good. A more productive firm can produce the same quantity of output with less units of an input, irrespective of the quality of the intermediate input used.

The quality of an intermediate input, however, is intimately linked to the quality of the final good: an intermediate input of quality c delivers the final good of quality $\lambda = c^\gamma$. In addition to the quality of an intermediate input, the production of λ units of quality of the final good requires incurring $f^\lambda = \lambda^{\frac{1}{\alpha}}$ quality-upgrading costs (measured in the units of labor), where $\alpha \geq 0$. The quality-upgrading costs f^λ can be interpreted as an investment in R&D or product design necessary to deliver outputs of higher quality. With this interpretation, α measures the effectiveness of such spending: an increase in α requires incurring less costs to deliver the same level of output quality.¹⁶

Finally, selling to market j from market i requires incurring a fixed overhead production cost f_{ij} and an iceberg transportation cost τ_{ij} , all measured in units of labor.

Belief updating

The profitability of a firm in market j depends on the firm's appeal index θ_j . The firm never observes its product-appeal index in a given market and must make all of its decisions based on beliefs about θ_j .

¹⁵The probability density of Pareto distribution is given by $(\xi\varphi_{\min}^\xi)/\varphi^{\xi+1}$.

¹⁶The assumed production technology for the quality of the final good corresponds to the Kugler and Verhoogen (2012) fixed-cost-of-upgrading Leontief production function which can equivalently be written as $\lambda = \min\{(f^\lambda)^\alpha, c^\gamma\}$. The parameter α can therefore be interpreted as the scope for quality differentiation. If the value of α is low, it would be expensive for firms to upgrade quality, and hence the equilibrium will exhibit little variation in the quality of intermediate and final goods. By contrast, if the value of α is high, quality upgrading is relatively inexpensive and the equilibrium will exhibit large heterogeneity in product quality.

The prior belief about θ_j is given by the initial distribution from which the appeal index is drawn, $N(\bar{\theta}, \sigma_\theta^2)$. The posterior belief is given by the normal distribution with mean $\mu_{nj}(\bar{a}_j, n)$ and variance v_n^2 , where n is the number of demand shocks $a_{jt}(\theta_j)$ that the firm has observed prior to making a current decision and \bar{a}_j is the mean of those observed demand shocks.¹⁷ We assume that a firm observes one shock per period, hence we also interpret n as a firm's age. In the limit, as $n \rightarrow \infty$, the posterior distribution converges to a degenerate distribution centered at θ_j .

The static problem of a firm

At the start of each period, a firm from country i decides on whether to sell to market j or not, and, conditional on selling to market j , the firm chooses the quantity q_{ijt} and the quality λ_{ijt} of its final good to be sold to market j , and the quantity x_{ijt} and the quality c_{ijt} of its intermediate input to maximize per-period expected profit. The problem of the firm is given by

$$E\pi_{ijt}(\varphi, \bar{a}_j, n) = \max_{\{q_{ijt}, \lambda_{ijt}, x_{ijt}, c_{ijt}\}} E_{a_{jt}|\bar{a}_j, n} \left[p_{ijt}q_{ijt} - p_{it}^c(c_{ijt})\tau_{ij}x_{ijt}(c_{ijt}) - w_{it}f_{ijt}^\lambda - w_{it}f_{ij} \right], \quad (9)$$

subject to the following five constraints

$$p_{ijt} = q_{ijt}^{\frac{-1}{\sigma}} \lambda_{ijt}^{\frac{\sigma-1}{\sigma}} e^{\frac{a_{jt}}{\sigma}} P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}}, \quad (10)$$

$$p_{it}^c(c_{ijt}) = c_{ijt}w_{it}, \quad (11)$$

$$x_{ijt}(c_{ijt}) = \frac{q_{ijt}}{\varphi}, \quad (12)$$

$$f_{ijt}^\lambda = \lambda_{ijt}^{\frac{1}{\alpha}}, \quad (13)$$

$$\lambda_{ijt} = c_{ijt}^\gamma. \quad (14)$$

We close the model in a standard way as described in Timoshenko (2015b) and Arkolakis, Papageorgiou, and Timoshenko (2015). The details are outlined in Appendix D.

4.5 Properties of the solution

In this section we examine properties of the stationary equilibrium and demonstrate how learning about demand affects the quality choice of inputs, the quality of the final good, and the evolution of prices and quantities of inputs and outputs.

From the static problem of a firm (9), the optimal quality of an intermediate input c_{ij} is given by

$$c_{ij}(\varphi, b_j) = \left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \left[\frac{\varphi^{\sigma-1} b_j(\bar{a}_j, n)^\sigma Y_j P_j^{\sigma-1}}{w_i^\sigma \tau_{ij}^{\sigma-1}} \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \quad (15)$$

¹⁷As proven in DeGroot (2004), $\mu_{nj} = \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + n\sigma_\theta^2} \bar{\theta} + \frac{n\sigma_\theta^2}{\sigma_\epsilon^2 + n\sigma_\theta^2} \bar{a}_j$ and $v_n^2 = \frac{\sigma_\epsilon^2 \sigma_\theta^2}{\sigma_\epsilon^2 + n\sigma_\theta^2}$.

where $b_j(\bar{a}_j, n) = E_{a_{jt}|\bar{a}_j, n} \left(e^{\frac{a_{jt}}{\sigma}} \right)$ is the expected demand level.¹⁸ Proposition 1 establishes four properties of the input quality choice.

Proposition 1 *Properties of the quality of intermediate inputs.*

Provided $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$, $\gamma > 1$ and all else equal

- (a) c_{ij} is increasing in Y_j ;*
- (b) c_{ij} is increasing in φ ;*
- (c) c_{ij} is increasing in b_j ;*
- (d) c_{ij} is increasing in n if $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$, and is declining in n otherwise.*

The proofs to all Propositions are included in Appendix F. Proposition 1 states that, provided the investment in quality upgrading is sufficiently effective, i.e. α is low enough, firms will chose higher quality of intermediate inputs and thus supply final goods of higher quality (by equation (14)) to larger markets. Similarly, by part (b) of Proposition 1, more productive firms will chose higher quality of an intermediate input and thus the final output.

While parts (a) and (b) of Proposition 1 are known from Kugler and Verhoogen (2012), parts (c) and (d) are novel to the literature and describe how quality choice varies within firms over time. Part (c) states that quality choice is intimately related to a firm's idiosyncratic expected demand level. Conditional on the aggregate market size Y_j , firms with higher expected demand b_j will choose higher quality inputs and thus will supply higher quality outputs.

More important, however, is that a firm's expected demand varies over time. As firms learn, they update their beliefs. Thus, firms will upgrade product quality if expected demand is growing, and downgrade quality if expected demand is shrinking, potentially leading to an exit from a market.

As stated in part (d) of Proposition 1, provided that the expected true appeal index \bar{a}_j is high enough, the quality of intermediate inputs will rise with a firm's age n . The intuition is straightforward. Every firm starts with the same prior $\bar{\theta}$ regarding its true appeal index. If the realized posterior \bar{a}_j is greater than the prior (more specifically greater than $\bar{\theta} + \sigma_\theta^2/(2\sigma)$), a firm will grow in its expected demand b_j . This growth will lead to the improvement in the good's quality and ultimately to an increase in sales.¹⁹ In contrast, firms which overestimated their demand and discover that their true appeal index is below the prior, $\bar{a}_j < \bar{\theta} + \sigma_\theta^2/(2\sigma)$ to be precise, gradually adjust their expected demand downwards and shrink in size. Hence, the quality of intermediate inputs of shrinking firms will decline over time.

The data available to us are not sufficient to explicitly measure product quality or demand and test predictions in Proposition 1. We can however examine the model's

¹⁸The complete solution to the firm's maximization problem is presented in Appendix E.

¹⁹This mechanism is intuitive and supported by anecdotal evidence. Consider, for example, the production of the iPhone by Apple. As the firm learns about the growing popularity of its product, it continues to invest in R&D and systematically releases new and upgraded versions of the product.

implications for the behavior of input and output prices. From equation (11) we see that the price of an intermediate input p_{it}^c faced by a final goods producer is linear in the quality of an intermediate input. By part (d) of Proposition 1, over time growing firms tend to increase the quality of intermediate inputs used. Hence surviving firms will pay increasing prices for intermediate inputs as they age. These predictions are consistent with the evidence presented in Tables 5 and 6. The price of the final good charged by a firm is given by

$$p_{ijt} = \frac{\sigma}{\sigma-1} e^{\frac{a_{jt}}{\sigma}} \frac{c_{ij}(\varphi, b_j) w_i \tau_{ij}}{b_j \varphi}. \quad (16)$$

Proposition 2 below establishes properties of the final goods prices.

Proposition 2 *Properties of the final goods prices.*

Provided $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$, $\gamma > 1$ and all else equal

(a) p_{ijt} is increasing in φ if $\alpha > \frac{1}{\sigma-1}$, and is declining in φ otherwise;

(b) p_{ijt} is increasing in b_j if $\alpha > \frac{\gamma}{\sigma+(\gamma-1)(\sigma-1)}$, and is declining in b_j otherwise;

(c) for $\alpha > \frac{\gamma}{\sigma+(\gamma-1)(\sigma-1)}$, p_{ijt} is increasing in n if $\bar{a}_j > \bar{\theta} + \frac{\sigma_{\theta}^2}{2\sigma}$, and is declining in n otherwise.

(d) for $\alpha < \frac{\gamma}{\sigma+(\gamma-1)(\sigma-1)}$, p_{ijt} is declining in n if $\bar{a}_j > \bar{\theta} + \frac{\sigma_{\theta}^2}{2\sigma}$, and is increasing in n otherwise.

Similarly to Kugler and Verhoogen (2012), parts (a) and (b) of Proposition 2 state that more profitable firms (as measured by either high productivity or high demand expectations) charge higher prices for their outputs if the scope for quality differentiation is high enough.²⁰

Parts (c) and (d) of Proposition 2 indicate that, in contrast with input prices, the behavior of output prices depends on parameter configuration. Part (c) of Proposition 2 states that if α is high enough, $\alpha > \frac{\gamma}{\sigma+(\gamma-1)(\sigma-1)}$ to be precise, output prices will increase with age for growing firms. As discussed above, a growing firm is the firm which underestimated its true appeal index and learned that the mean of the observed demand shocks \bar{a}_j is greater than the prior. Similarly, shrinking firms, i.e when $\bar{a}_j < \bar{\theta} + \frac{\sigma_{\theta}^2}{2\sigma}$, output prices will decline with age. In contrast, part (d) of Proposition 2 states that when α is below the threshold value of $\frac{\gamma}{\sigma+(\gamma-1)(\sigma-1)}$, output prices will decline with age for growing firms, and increase with age for shrinking firms.

Another way to understand the intuition behind the ambiguity in the final goods pricing behavior is to consider the trade-off between the effect of quality upgrading versus the increase in profitability on prices. In the context of equation (16), suppose that a firm keeps the quality of an intermediate input unchanged. In this case, the price dynamics are solely driven by changes in demand beliefs, b_j . Since demand beliefs enter multiplicatively

²⁰A similar relation between output prices and productivity holds in the model of Antoniadis (2015) who introduces quality choice in the model of Melitz and Ottaviano (2008).

with productivity into prices, revenues, and profits, the effect of an increase in beliefs is equivalent to an increase in productivity, or an increase in profitability, or a decline in marginal cost. Since price is a mark-up over marginal cost, more profitable firms (either due to falling costs or rising expected demand) will charge lower prices over time. The quality of an intermediate input (hence output) either does not vary or increases by an amount which is insufficient to compensate for falling marginal cost. In the model, the extent of quality adjustment is governed by α . For low values of α , high fixed costs of quality adjustment f^λ deter firms from varying the quality of intermediate inputs. As a result, prices decline over time as firms age.

When quality upgrading is cheap (α is high), an increase in demand beliefs is accompanied by a corresponding increase in the quality of an intermediate input (equation (15)). If the quality of an intermediate input increases by more than one-to-one with respect to beliefs, the price of the final good increases. This occurs exactly when $\alpha > \gamma/(\sigma + (\gamma - 1)(\sigma - 1))$.

In line with the behavior of quantities as a function of export-age reported in Table 4, Proposition 3 establishes the behavior of the optimal quantity of the final good given by

$$q_{ijt} = \left(\frac{\sigma - 1}{\sigma}\right)^\sigma \left(\frac{\varphi b_j}{w_{it}\tau_{ij}}\right)^\sigma c_{ijt}^{\gamma(\sigma-1)-\sigma} P_{jt}^{\sigma-1} Y_{jt}. \quad (17)$$

Proposition 3 *Property of the final-goods quantities.*

Provided $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$, $\gamma > 1$ and all else equal, for $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$, q_{ijt} is increasing in n if $\alpha < \gamma$, and is declining in n otherwise.

From equation (12), the quantity of an intermediate input x_{ijt} is linear in the quantity of the final good. Hence, consistently with the evidence presented in Table 6, the model also delivers input prices and quantities increasing with firm growth. Notice that, as discussed in Appendix E, the solution to a firm's problem only exists when $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$. Hence, the model always delivers optimal quantity increasing with export-age as suggested by Table 4, as long as $(\gamma - 1)(\sigma - 1) > 1$. In the next section, we turn to the quantitative analysis of the model and show that the calibrated parameter values satisfy this restriction. Hence, the quantitative exercise will demonstrate that the model is able to deliver the behavior of output and input prices and quantities suggested by the data.

5 Quantitative analysis

In this section we calibrate a symmetric two-country model to match the average domestic and export behavior of Portuguese firms over the period 2005-2009, and next explore the quantitative ability of the model to predict the data.

5.1 Parameter identification

Three parameters of the model can be pinned down independently. The discount factor β is taken to be 0.9606 which corresponds to a quarterly interest rate of 1 percent. As estimated by Amador and Soares (2014) in the context of the Portuguese economy, the elasticity of substitution σ is taken to be 6.16. The exogenous death rate δ is taken to be 2.98%, which corresponds to the average death rate of Portuguese firms in the top 5 percent of the export revenue distribution.²¹

Following the argument in Arkolakis, Papageorgiou, and Timoshenko (2015), the standard deviation of the transient preference shocks, σ_θ , is identified by the extent of the conditional age dependence of firms' growth rates. Specifically, we target the age coefficient in a regression of the log of export revenue growth on export-age and size, as reported in Table 3, column (3). All else equal, the larger is the standard deviation, the more dispersion there is in the observed distribution of export revenue. The magnitude of σ_ϵ relative to the standard deviation of the "appeal" index draw, σ_θ , determines the rate at which firms update their beliefs, and thus the rate at which firms grow. The higher is the variance of the appeal relative to the variance of the shock, the more weight firms attribute towards updating their beliefs in favor of the posterior mean of the observed demand shocks, the faster they grow. Thus, σ_ϵ is pinned down by the average growth rate of exporter-entrants.

The two parameters governing the quality production function, α and γ , are pinned down by the export-age coefficient in the input price regression in Table 5, and the share of sales from export entrants. From equation (33), parameter α directly governs the extent of the age dependence of the quality of intermediate inputs, hence prices of intermediate inputs. From equation (14), parameter γ governs the rate at which the quality of intermediate inputs translates into the quality of the final good and thus total sales. Given the selection of incumbents based on higher productivity or expected demand (hence quality), the size of an export-entrant relative to an average firm declines in γ , and hence the share of export sales accounted for by entrants declines.

Finally, the shape parameter of the Pareto distribution of productivity draws, ξ , is identified by the tail index of the export revenue distribution of exporting firms, and the fixed cost of selling in the export market, f_x , is identified by the average revenue of exporters. All else equal, the higher are the fixed costs, the higher is the productivity entry threshold. As a result, more productive exporting firms earn larger revenues yielding higher average sales of exporters. The six parameters, σ_ϵ , σ_θ , α , γ , ξ , and f_x are jointly calibrated to minimize the sum of the squared deviations of the simulated versus the data moments.

Having calibrated these parameters, the variable trade cost τ is computed to yield the proportion of exporters in the Portuguese data (16.7%). The fixed cost of selling in the

²¹The identifying assumption is that the largest firms in an economy are likely to exit due to exogenous reasons.

domestic market, f_d , is computed to yield the ratio of average domestic sales of firms to average export sales of exporters, which is equal to 0.35.

5.2 Calibration results

Table 7 displays the simulated and data moments and Table 8 reports the corresponding calibrated parameter values. As can be seen from Table 7, the moments identify parameters fairly well with the criterion equal to 0.0002. The calibrated parameter values fall within the range of part (d) of Proposition 2, whereby the profitability effect dominates the quality upgrading effect and output prices decline with age for growing firms. Next we compare the predictions of the model to the facts documented in Section 3.

Figure 3 replicates the results in the lower panel of Figure 1 using simulated data, and depicts non-parametric estimates from a kernel density of the steady state cross-sectional distribution of export sales. The model is able to capture a key feature of the data: the distribution of export revenue shifts systematically to the right reflecting the growth in export sales of surviving exporters. The model explains this growth with the learning mechanism. An average surviving exporter updates its beliefs upwards, increases the quality of intermediate inputs used, increases the quantity sold and the quality of the final good, and as a result experiences growth in sales.

To further examine the difference between growth and selection on initial size discussed in Section 3.2, Figure 4 replicates the results in the bottom panel of Figure 2 using simulated data. As can be seen by comparing the figures, the model is able to capture both mechanisms. As is in the data, in the model the success of exporters is partially determined by their initial size. Recall that in the model all exporter-entrants share the same beliefs about their expected demand. Hence, the main source of variation in export sales in the first period, and hence selection, is productivity heterogeneity. More productive firms are able to absorb less favorable demand shocks, and hence have a higher probability of surviving in the long run. Subsequent growth is then determined by the evolution of firms' beliefs about their demand.

The model is calibrated to match the conditional age-dependence of growth rates and input prices. Table 9 reports the growth regression results based on the simulated data. Comparison of the size coefficients in Tables 3 and 9 reveals that the model slightly over-predicts the extent of the conditional size dependence of growth rates. The less strong size-dependence of growth observed in the data may arise due to alternative mechanisms considered in the literature such as financial constraints (Cooley and Quadrini, 2001) or random productivity evolution (Arkolakis, 2015).

5.3 Counterfactual experiments

In this section we use the calibrated two-country model to explore the implications of imposing minimum quality standards on trade in final goods. Due to the quality standard,

any exporting firm in each country must choose the quality of intermediate inputs above a given threshold \bar{c} .²² The corresponding problem of the firm is described in Appendix G, and Figure 5 describes the effect on the general equilibrium variables. In all panels of Figure 5, the horizontal axis measures the percent improvement in the average quality of exported goods that results from the imposition of a given minimum quality requirement. All depicted values on the vertical axis are normalized by their corresponding values in the calibrated non-constrained equilibrium.²³

As is evident from Panel A of Figure 5, a quality standard is not welfare improving. For example, a minimum standard leading to 25 percent improvement in the average quality of exported goods reduces real consumption by 2 percent. The intuition for the result is as follows. As can be seen from Panel C, the export-quality standard increases the productivity threshold for entry in the export market and thus reduces the number of exporters (Panel D). The decline in the number of exporters reduces the degree of competition in the domestic market, leading to a higher equilibrium price level (Panel B). Furthermore, the decline in foreign competition leads to entry of less efficient firms in the domestic market: as can be observed in Panels C and D, the domestic entry threshold declines and the mass of domestic varieties rises. At the extensive margin, therefore, the effect of the minimum quality standard on exports is qualitatively equivalent to an increase in the iceberg transportation cost τ , which also leads to a reduction in the number of exporters, an increase in the number of domestic varieties, and an increase in the price level (Melitz, 2003). Our model is therefore able to match recent evidence indicating that standards reduce entry in export markets and lead to an increase in product prices, especially among small exporters (Fontagné et al., 2015).

The quality standard additionally distorts the intensive margin of firm adjustment. For the firms located close to the entry threshold, i.e. either small or young firms, the quality constraint binds. Hence, in order to export, these firms are forced to comply with the standard and, as a result, choose higher quality intermediate inputs. The production of higher quality intermediate inputs requires more labor. Hence, the imposition of the minimum quality standard leads to the reallocation of resources among exporters towards young and small firms. This effect is demonstrated in Figure 6. Panel A and B depict the proportion of labor employed in the production of exports allocated between the bottom 10 and top 10 percent of exporters in the export-sales distribution (including the units

²²Bown and Crowley (forthcoming) provide several examples of product standards imposed in practice, and note that it is typical for foreign suppliers to allege that such standards are either too restrictive or applied in way that discriminates against foreign relative to domestic production, potentially forcing them to undertake additional costly investments to meet compliance requirements. Fontagné et al. (2015) offer a detailed empirical treatment of restrictive Sanitary and Phyto-Sanitary (SPS) standards on imports, and note that such standards may require exporting firms to upgrade their products or substitute more costly inputs from those previously used. Chen, Wilson, and Otsuki (2008) note that standards and technical regulations set in importing countries have become a rising concern to exporters, and examine the importance of various types of standards in developing-country firms' export decisions.

²³Naturally, a stronger improvement in the average quality of exported goods corresponds to a higher minimum quality constraint on intermediate inputs embodied in exports.

of labor embodied in the intermediate inputs purchased by these firms). In Panel A, we observe that as the minimum quality standard increases, the proportion of labor accounted for by the bottom 10 percent of exporters rises from about 0.8 to 1.2 percent. In contrast, the share of labor among top 10 percent of exporters declines from around 63 to 60 percent. In a similar way, Panels C and D show that there is a reallocation of labor units from old to young exporters.

Finally, as can be seen in Panel E of Figure 5, while the policy raises export quality it leads at best to a small improvement in the overall quality of goods available to consumers. For example, a standard leading to an increase in the quality of exported goods by about 8 percent raises the overall quality of goods available to consumers by less than one percent. Thus, consumers face higher prices and experience almost no difference in the quality of goods available to them. This effect is primarily driven by the rapid decline in the number of exporters relative to domestic firms. Although export quality rises, the proportion of exporting firms declines much faster (as seen in Panel D) yielding a small contribution of higher export quality to the overall quality of goods available to consumers. The latter effect may even dominate: a standard leading to a relatively large improvement in the average quality of exported goods (over 15 percent) leads to a decline in the overall quality of goods available to consumers.

5.4 Sensitivity analysis

In this section we explore the sensitivity of the welfare implications to the changes in the scope for quality differentiation determined by parameter α . Recall that the higher is the value of α , the smaller is the fixed cost of quality upgrading. Hence, we would expect welfare losses imposed by the quality standard to be smaller. The results are depicted in Figure 7.

Figure 7 plots the real consumption (Panel A) and the average quality of all goods (Panel B) as a function of the average improvement in the quality of exported goods for three different values for the scope for quality differentiation. All other parameters are kept unchanged at their calibrated values reported in Table 8. As can be seen from Panel A in Figure 7, while consumers in both countries still experience welfare losses due to a quality standard, the magnitude of the losses is smaller the less costly (higher α) is the quality upgrading technology. The cheaper is the quality upgrading technology, the less costly it is for the constrained firms to comply with the standard, the less resources are disposed in paying the fixed costs, hence the smaller are welfare losses. As can be seen from Panel B in Figure 7, this mechanism also leads to the higher potential maximum improvement in the overall quality of all goods.

6 Conclusion

We used detailed micro data from the Portuguese manufacturing sector to document new facts about the joint evolution of firm performance and prices over the life cycle: (1) firms with longer spells of activity in a destination tend to export larger quantities at lower prices to that market; (2) more experienced exporters tend to use more expensive inputs; and (3) input prices and quantities tend to rise with sales within firms over time. In line with previous research, we also reported evidence that the positive relationship between export revenue and market experience reflects growth, not just market selection based on initial size; and that revenue growth within destinations (conditional on initial size) tends to decline with export-age.

To account for the joint observation of these patterns in the data, we developed a theory of endogenous input and output quality choices in a learning environment. In the model, firms supply products of varying quality based on their beliefs about idiosyncratic expected demand. Through the life-cycle, an average surviving firm updates its demand expectations upwards, grows, and, as a result, finds it optimal to upgrade the quality of outputs, which requires using higher quality inputs. Because higher quality inputs are more expensive, average input prices increase with export experience. The evolution of output prices is less clear-cut. On the one hand, quality upgrading leads to a higher price. On the other hand, an increase in demand expectations increases profitability and causes a price reduction. Hence the model is able to rationalize the varying behavior of input and output prices over the firm life cycle observed in the data.

Calibrated to match the observed age-dependence of export growth and input prices, our model slightly over predicts the conditional size-dependence of growth rates that emerges from the data. Using the calibrated model, we examined the implications of regulations imposing minimum product quality standards on exports. We found that the imposition of these standards reduces welfare through two distinct channels. First, it lowers entry in export markets and therefore the number of export varieties available to consumers. Second, it distorts an intensive margin of adjustment. To participate in the export market, marginal exporters are forced to comply with the minimum standard by choosing intermediate inputs of higher quality. This choice leads to a reallocation of productive resources from large and old towards small and young firms, leading to a further decline in welfare.

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Table 1: Firm performance across cohorts, 2005-2009

Dep.variable:	all firms			exporters			
	log empl (1)	log sales (2)	log empl (3)	log sales (4)	log exp (5)	log exp-dest (6)	log exp-dest (7)
log age	0.429*** [0.003]	0.533*** [0.004]	0.546*** [0.009]	0.508*** [0.011]			
log export-age					1.593*** [0.013]	0.468*** [0.012]	1.125*** [0.008]
log export-destination-age							
N (obs.)	178,697	178,697	29,804	29,804	29,804	155,015	155,015
R-squared	0.218	0.206	0.263	0.247	0.478	0.244	0.387
industry-year effects	Y	Y	Y	Y	Y		
region effects	Y	Y	Y	Y	Y	Y	Y
destination-year effects						Y	Y
industry effects						Y	Y

Notes: In columns (1)-(2) the estimation sample is composed of manufacturing firms in the period 2005-2009. In columns (3)-(7) the estimation sample is composed of manufacturing exporters in the period 2005-2009. In columns (1)-(5) data are at the firm-year level. In columns (6)-(7) data are the the firm-destination-year level. In column (5) the dependent variable is the log of total export revenue of the firm in all destinations. In columns (6) and (7) the dependent variable is the log of export revenue by destination. Robust standard errors in brackets, clustered by firm-year. ***1% level, **5% level, *10% level.

Table 2: Firm growth, size and age, 2005-2009

Dep variable:	(1)	(2)	(3)	(4)	(5)	(6)
	log empl _{t-1}	log empl _{t-1}	log sales _{t-1}	log sales _{t-1}	log sales _{t-1}	log sales _{t-1}
log age _{t-1}	-0.041*** [0.001]		-0.035*** [0.001]	-0.066*** [0.001]		-0.065*** [0.001]
log empl _{t-1}		-0.026*** [0.001]	-0.016*** [0.001]			
log sales _{t-1}					-0.013*** [0.001]	-0.001 [0.001]
N (obs.)	122,695	122,695	122,695	122,695	122,695	122,695
R-squared	0.030	0.023	0.033	0.068	0.041	0.068
industry-year effects	Y	Y	Y	Y	Y	Y
region effects	Y	Y	Y	Y	Y	Y

Notes: The estimation sample is composed of manufacturing firms in the period 2005-2009. Data are at the firm-year level. Robust standard errors in brackets, clustered by firm-year. ***1% level, **5% level, *10% level.

Table 3: Exports growth, revenue and experience, 2005-2009

Dep variable:	(1)	(2)	(3)	(4)	(5)	(6)
	log exports _t -log exports _{t-1}					
log export-age _{t-1}	-0.049*** [0.006]		-0.023*** [0.006]			
log exports _{t-1}		-0.026*** [0.002]	-0.021*** [0.003]			
log export-age-destination _{t-1}				-0.068*** [0.003]		-0.033*** [0.003]
log exports _t -dest _{t-1}					-0.048*** [0.001]	-0.042*** [0.001]
N (obs.)	16,680	16,680	16,680	75,137	75,137	75,137
R-squared	0.061	0.065	0.066	0.039	0.050	0.052
industry-year effects	Y	Y	Y	Y	Y	Y
region effects	Y	Y	Y	Y	Y	Y
destination-year effects				Y	Y	Y
industry-effects				Y	Y	Y

Notes: The estimation sample is composed of manufacturing exporters in the period 2005-2009. In columns (1)-(3) data are at the firm-year level. In columns (4)-(6) data are at the firm-destination-year level. Robust standard errors in brackets, clustered by firm-year. ***1% level, **5% level, *10% level.

Table 4: Export prices (quantities) and export experience, 2005-2009

A. Dep. variable:	avg. log export price		
	(1)	(2)	(3)
log export-age-destination	-0.037*** [0.005]	-0.009** [0.004]	-0.024*** [0.005]
N (obs.)	131,585	131,585	131,585
R-squared	0.192	0.418	0.420
B. Dep. variable:	avg. log export quantity		
	(1)	(2)	(3)
log export-age-destination	0.556*** [0.011]	0.631*** [0.011]	0.558*** [0.012]
N (obs.)	131,585	131,585	131,585
R-squared	0.186	0.360	0.370
destination-year effects	Y		
industry effects	Y		
region effects	Y		
firm effects		Y	Y
year effects		Y	Y
destination effects			Y

Notes: The estimation sample is composed of manufacturing exporters in the period 2005-2009. Data are at the firm-destination-year level. The dependent variable is the firm-destination-year average log export price (quantity), which was estimated using the FTS data set at the firm-product-destination-year level. Robust standard errors in brackets, clustered by firm-year. ***1% level, **5% level, *10% level.

Table 5: Input prices and export experience, 2005-2009

Dep. variable:	log avg. wage (1)	avg. log import price (2)
log export-age	0.087*** [0.002]	0.021*** [0.006]
N (obs.)	29,804	19,767
R-squared	0.305	0.233
industry-year effects	Y	Y
region effects	Y	Y

Notes: The estimation sample is composed of manufacturing exporters in the period 2005-2009. Data are at the firm-year level. In column (1) the dependent variable is the firm-year average wage obtained from the EIAS data set. In column (2) the dependent variable is the firm-year average log import price, which was estimated using the FTS data set at the firm-product-year level. Robust standard errors in brackets. ***1% level, **5% level, *10% level.

Table 6: Input prices (quantities) and firm growth, 2005-2009

A. Dep. variable:			
	log avg. wage (1)	avg. log import price (2)	avg. log input price (3)
log sales	0.227*** [0.004]	0.024* [0.013]	0.041* [0.022]
N (obs.)	178,697	31,281	14,602
R-squared	0.846	0.742	0.787
B. Dep. variable:			
	log employment (1)	avg. log import quantity (2)	avg. log input quantity (3)
log sales	0.346*** [0.004]	0.289*** [0.026]	0.603*** [0.040]
N (obs.)	178,697	31,281	14,602
R-squared	0.966	0.831	0.916
firm effects	Y	Y	Y
year effects	Y	Y	Y

Notes: The estimation sample is composed of manufacturing firms in the period 2005-2009. Data are at the firm-year level. In column (1) the dependent variable is the firm-year average wage (employment) obtained from the ELIAS data set. In column (2) the dependent variable is the firm-year average log import price (quantity), which was estimated using the FTS data set at the firm-product-year level. In column (3) the dependent variable is the firm-year average log material input price (quantity), which was estimated using the IAPI data set at the firm-product-year level. Robust standard errors in brackets. ***1% level, **5% level, *10% level.

Table 7: Data and simulation moments, 2005-2009

Calibration moments	data (1)	simulation (2)
1. The mean of the logarithm of export sales	11.96	11.96
2. The growth rate of export entrants	31.08%	30.81%
3. The share of sales from export entrants	1.42%	1.41%
4. The age coefficient in the input price regression ^a	0.021	0.021
5. The age coefficient in the exports growth regression ^b	-0.023	-0.023
6. The tail index of the export sales distribution ^c	-1.238	-1.245
<i>Criterion</i>		<i>0.0002</i>

Notes: Moments correspond to the average export behavior of Portuguese manufacturing firms over the period 2005-2009.

^aSource: The age coefficient in Table 5, column (2).

^bSource: The age coefficient in Table 3, column (3).

^cSource: The empirical estimate of the tail index is presented in Appendix H.

Table 8: Parameter values

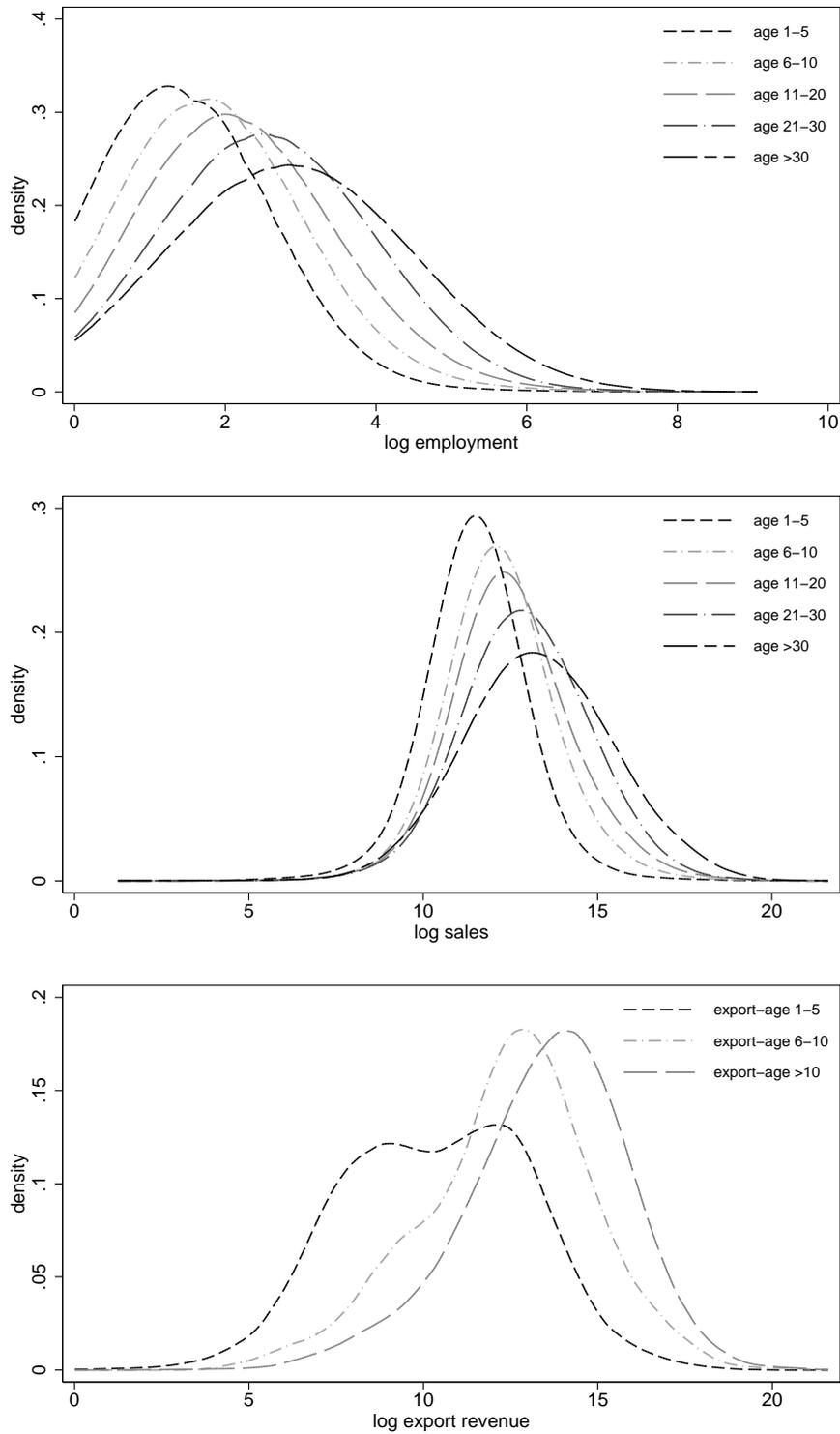
Parameter	Value
β	0.9606
σ	6.160
δ	0.0298
σ_θ	1.45
σ_ϵ	2.51
α	0.06
γ	1.97
ξ	7.69
f_x	12,064.58
f_d	4,262.52
τ	1.05

Table 9: Export growth, revenue, and experience in the simulated data

Dep. variable:	log exports _t -log exports _{t-1}
log export-age _{t-1}	-0.023*** [0.001]
log exports _{t-1}	-0.032*** [0.001]
N (obs.)	185,111
R-squared	0.01
sample	age ≤ 20

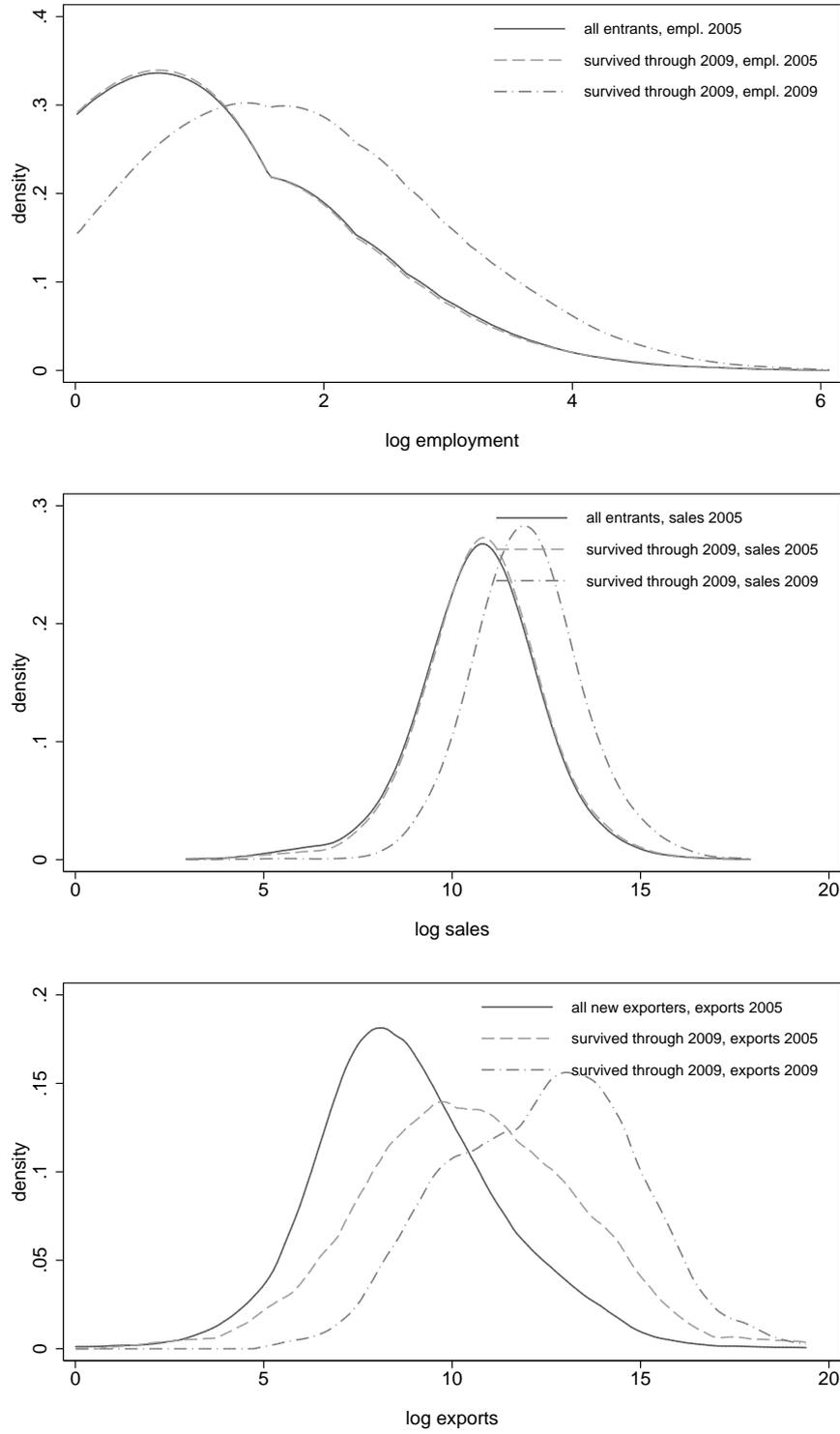
Notes: The table reports OLS regressions based on the simulated firm-level sample. Robust standard errors in brackets. ***1% level, **5% level, *10% level.

Figure 1: Firm performance across cohorts, 2005



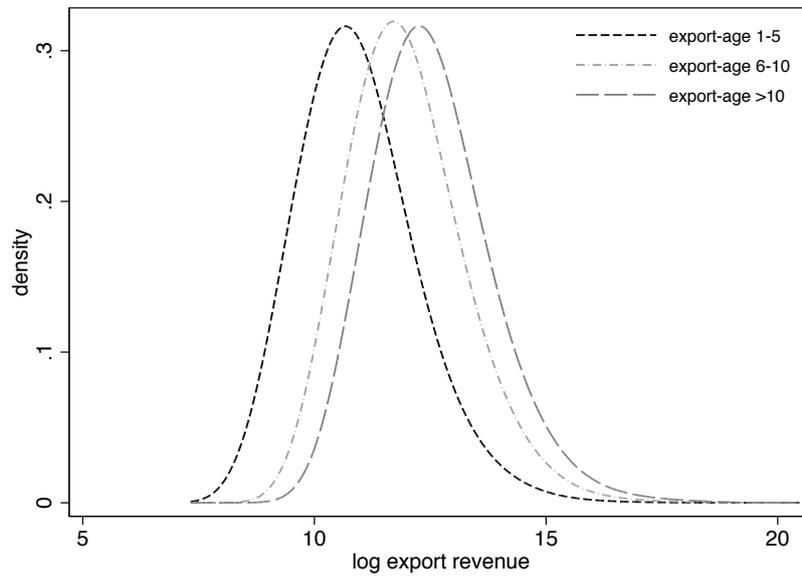
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7, using data from 2005. Age is the number of years since birth of the firm. Export-age is the number of consecutive years the firm has recorded positive export revenue.

Figure 2: Growth versus selection on initial size, 2005-2009



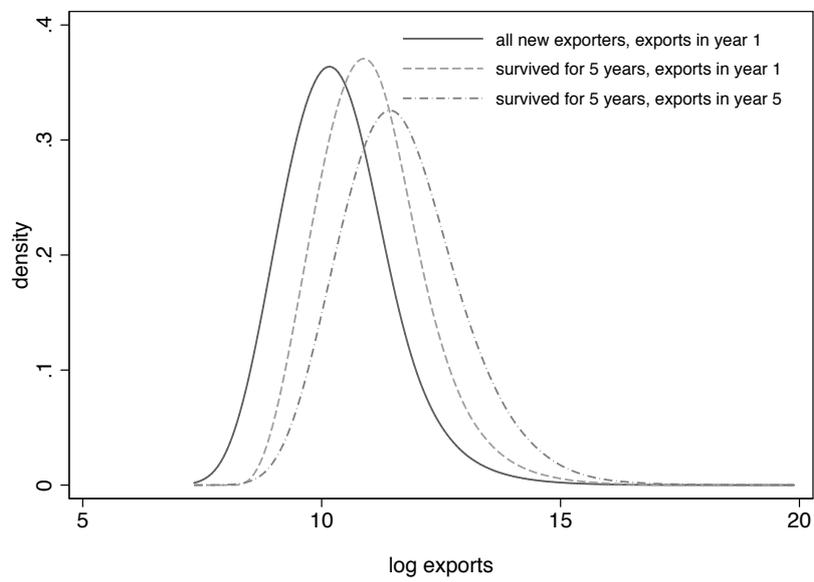
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7, using data from 2005 and 2009.

Figure 3: Firm performance across cohorts, simulated data



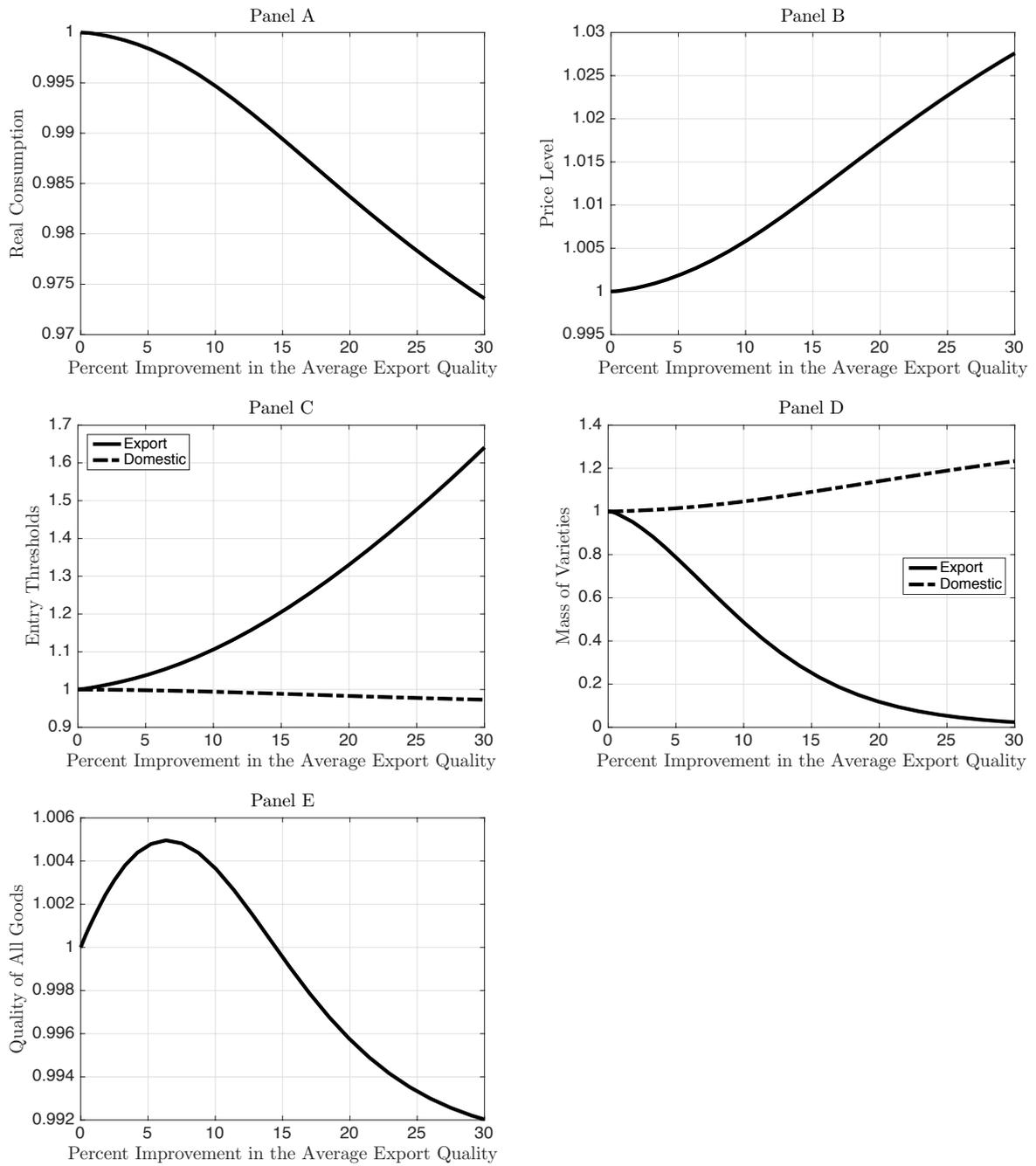
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7. Authors calculations on model simulation.

Figure 4: Growth versus selection on initial size, simulated data



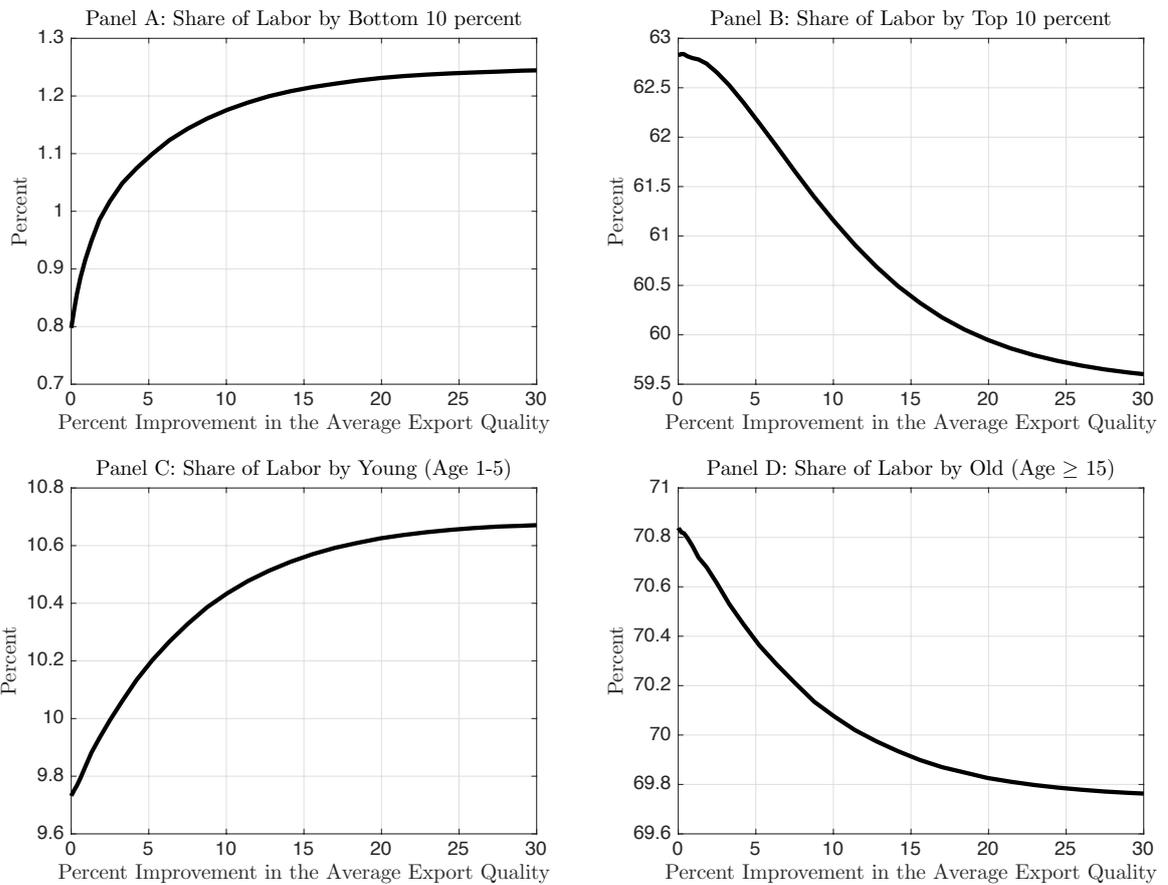
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7. Authors calculations on model simulation.

Figure 5: Effects of minimum quality standards



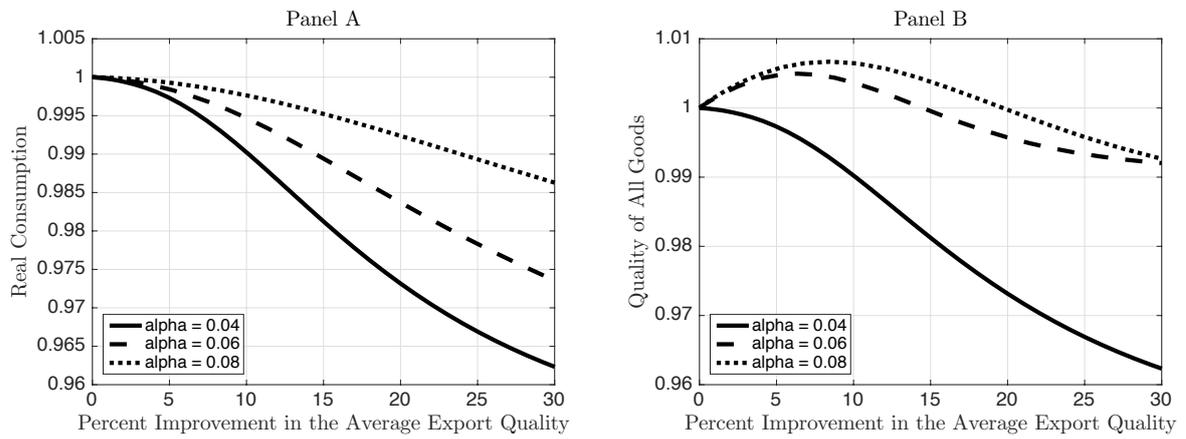
Notes: All depicted values on the vertical axis are normalized by their corresponding values in the calibrated non-constrained equilibrium. Authors calculations on model simulation.

Figure 6: Labor reallocation caused by minimum quality standards



Notes: Authors calculations on model simulation.

Figure 7: Effects of minimum quality standards, robustness



Notes: All depicted values on the vertical axis are normalized by their corresponding values in the calibrated non-constrained equilibrium. Authors calculations in model simulation.

Appendix

A Variable definitions

Here we describe in more detail the variables used in the analysis:

Employment: Number of employees during the reference year.

Sales: Total value of sales (in Portugal and abroad) during the reference year.

Avg. wages: Ratio between the wage bill (including wages, social security contributions, benefits, etc.) and the number of paid employees. It corresponds to the average gross earnings per paid worker.

Capital stock per worker: Book value of assets (tangible and intangible) divided by employment. The book value of tangible and intangible assets corresponds to the difference between the acquisition price of the assets and the cumulative of amortizations.

Value added per worker: Value added created by a firm during the reference year divided by employment.

Age: Number of years passed since a firm was first registered in Portugal.

Export-age: Number of consecutive years a firm has been an exporter. This variable is truncated at the difference between the reference year and 1990.

Export-destination-age: Number of consecutive years the firm has recorded positive export flows to the reference destination. This variable is truncated at the difference between the reference year and 1990.

Exports: Export revenue of a firm during the reference year.

Number of destinations served: Number of different export destinations served by a firm during the reference year.

Number of product categories exported: Number of different product categories exported by a firm during the reference year. Products are classified according to the Combined Nomenclature (CN) of the European Union at the 8-dig level.

Export prices: Ratio between the FOB euro value of an export flow (by firm-product-destination) and its weight measured in kilograms.

Export quantities: Weight in kilograms of an export flow (by firm-product-destination).

Imports: Import expenditure of a firm during the reference year.

Number of source countries: Number of different countries from which a firm sourced products during the reference year.

Number of product categories imported: Number of different product categories sourced by a firm during the reference year. Products are classified according to the Combined Nomenclature (CN) of the European Union at the 8-dig level.

Import prices: Ratio between the FOB euro value of an import flow (by firm-product-source) and its weight measured in kilograms.

Import quantities: Weight in kilograms of an import flow (by firm-product-source).

Input purchases: Expenditure in manufactured material inputs of a firm during the reference year.

Number of material inputs used: Number of different product categories of manufactured material inputs sourced by a firm during the reference year. Product categories of material inputs are classified according to the PRODCOM at the 12-dig level.

Input prices: Ratio between the FOB euro value of manufactured input purchases (by firm-product) and its physical quantity (measured in kilos or other unit).

Input quantities: Physical quantity of manufactured input purchases (by firm-product).

All monetary variables are in euros and have been deflated to constant 2005 prices using the Portuguese GDP deflator from the World Development Indicators of the World Bank.

B Data description and processing

The data used in this paper come from the *Enterprise Integrated Accounts System* (EIAS) and the *Foreign Trade Statistics* (FTS) of Portugal. The EIAS is an annual census of firms that is available for the years 2005 to 2009. We use this data set to obtain information on the number of employees, date of constitution, wage bill, capital stock, value-added, total sales, location and industry affiliation for each firm-year. We restrict the analysis to firms whose main activity is in the manufacturing sector excluding the Petroleum industry. We impose these restrictions using the firm's self-reported industry code in the EIAS data set, where industries are defined by the Revision 2.1 of the National Classification of Economic Activities (CAE). There are 99 manufacturing industry codes (3-dig level, excluding the petroleum industry) and 7 different regions, based on which we define the categorical variables included in the regressions.

The FTS are the country's official information source on international trade statistics, gathering export and import transactions (values and physical quantities) of firms located

in Portugal by product category (CN classification, 8-dig) and destination or source market. These data are available from 1990 to 2009. Two firms exporting or importing in the same 8-dig CN product category may belong to different 3-dig CAE industries. We use the FTS data on values and quantities to construct export prices by firm-product-destination, and import prices by firm-product. From this data set, we further obtain total exports and imports of the firm in each year, and the variables export-age and export-destination-age.

The IAPI survey is also run by the National Statistics Institute and collects information on values and physical quantities of outputs, material inputs, and energy sources of firms by product category. The data are reported by a version of the PRODCOM classification (12-digit), adapted by INE to reflect the specificity of the Portuguese industrial sector. In the period 2005-2009, the IAPI sampling scheme covered selected sectors. It ranked firms in descending order of sales and included them until 90% of total sales in the corresponding sector were covered, with some minor qualifications: (i) it included all firms with 20 or more employees; (ii) it included all firms in sectors with fewer than 5 firms; and (iii) and once included in the sample, firms were followed in subsequent years. The IAPI sampling scheme makes it difficult to make cross-sectional comparisons between different cohorts of firms or exporters in a given year, but is suitable for examining within-firm changes over time, conditional on a firms being sampled.

In line with Kugler and Verhoogen (2012) and Hallak and Sivadasan (2013), we implemented a number of cleaning procedures to the raw data in order to reduce the influence of measurement error and outliers:

1. In the firm-level files, we excluded all firm-year observations for which the values of sales, employment or labor costs were missing or equal to zero;
2. In the firm-level files, we excluded observations for which the value of a key variable (employment, sales, wages or export revenue) differed by more than a factor of 5 from the previous year;
3. In the firm-product-destination and firm-product-source files from FTS, we dropped observations with missing information on values (defined in euros) or quantity (measured in kilograms). We then winsorized export (import) prices and quantities by 1% on both tails of the distribution (within each product-year cell). We adopted a similar cleaning procedure for the IAPI firm-product files.

The results are robust to using different bounds for the winsorizing procedure (including no winsorizing) and exclusion of outliers. They also do not depend on the inclusion of observations from firms with missing values in a subset of key variables.

C Summary statistics

Tables A1 and A2 provides summary statistics on the 2005-2009 firm-level panel used in the analysis.

D Closing the model

Entry and Exit Decisions

Following Timoshenko (2015b), given the per-period optimal expected profit $E\pi_{ijt}(\varphi, \bar{a}_j, n)$, a incumbent firm decides whether to continue selling to market j from market i by maximizing the expected present discounted value of the future profit stream. Denote by $V_{ijt}(\varphi, \bar{a}_j, n)$ the continuation value of the option to export from country i to j . $V_{ijt}(\varphi, \bar{a}_j, n)$ solves the following Bellman equation

$$V_{ijt}(\varphi, \bar{a}_j, n) = \max \left\{ E\pi_{ijt}(\varphi, \bar{a}_j, n) + \beta(1 - \delta)E_{\bar{a}'_j | \bar{a}_j, n} V_{ijt+1}(\varphi, \bar{a}'_j, n + 1); 0 \right\}, \quad (18)$$

where δ is the exogenous death rate of firms. The solution to problem (18) yields a set of market-participation thresholds $\bar{a}_{ij}^*(\varphi, n)$ such that a firm decides to continue exporting to market j if $\bar{a}_j \geq \bar{a}_{ij}^*(\varphi, n)$, and exits the market otherwise.

A new entrant draws its productivity φ from a Pareto distribution and decides whether to sell to a given market by maximizing the value of entry given by $V_{ijt}^E(\varphi, 0, 0) = E\pi_{ijt}(\varphi, 0, 0) + \beta(1 - \delta)E_{\bar{a}'_j | \bar{a}_j, 1} V_{ijt+1}(\varphi, \bar{a}'_j, 1)$. Since there are no sunk market entry costs, the entry productivity threshold φ_{ij}^* from market i to market j is determined by equating the value of entry to zero.

General equilibrium

The stationary general equilibrium of the model is given by the market participation thresholds φ_{ij}^* and $\bar{a}_j \geq \bar{a}_{ij}^*(\varphi, n)$; the factor and goods prices w_j , $p_{ij}(\varphi, b_j)$ and $p_j^c(c)$; firm's optimal quantity and quality choices $q_{ij}(\varphi, b_j)$, $x_{ij}(\varphi, b_j)$, $c_{ij}(\varphi, b_j)$ and $\lambda_{ij}(\varphi, b_j)$; consumers' optimal consumption choice $q_j^c(\omega)$; the aggregate price index P_j ; the aggregate expenditure level Y_j ; the mass of firms selling from country i to j M_{ij} , and the probability mass function of firms $m_{ij}(\varphi, \bar{a}_j, n)$ such that

1. Given the equilibrium values, consumers maximize utility: $q_j^c(\omega)$ maximizes utility in (6).
2. Given the equilibrium values, firms in the intermediate-goods sector break even: $p_j^c(c)$ satisfies equation (8).
3. Given the equilibrium values, firms in the final-goods sector maximize profits: $q_{ij}(\varphi, b_j)$, $x_{ij}(\varphi, b_j)$, $c_{ij}(\varphi, b_j)$, $\lambda_{ij}(\varphi, b_j)$, φ_{ij}^* and $\bar{a}_j \geq \bar{a}_{ij}^*(\varphi, n)$ solve (9) and (18).
4. The goods market clears: $Y_j = L_j + \Pi_j$.

5. Trade is balanced: $Y_j = \sum_{i=1}^N \sum_n \int \int q_{ij}(\varphi, b_j) m_{ij}(\varphi, \bar{a}_j, n) d\varphi d\bar{a}_j$.
6. The aggregate behavior is consistent with the individual behavior: equilibrium prices satisfy equation (7) and $M_{ij} = \sum_n \int \int m_{ij}(\varphi, \bar{a}_j, n) d\varphi d\bar{a}_j$.

E Firm's static maximization problem

A firm's maximization problem is given by

$$E\pi_{ijt}(\varphi, \bar{a}_j, n) = \max_{\{q_{ijt}, \lambda_{ijt}, x_{ijt}, c_{ijt}\}} E_{a_{jt}|\bar{a}_j, n} \left[p_{ijt} q_{ijt} - p_{it}^c(c_{ijt}) \tau_{ij} x_{ijt}(c_{ijt}) - w_{it} f_{ijt}^\lambda - w_{it} f_{ij} \right] \quad (19)$$

subject to

$$p_{ijt} = q_{ijt}^{-\frac{1}{\sigma}} \lambda_{ijt}^{\frac{\sigma-1}{\sigma}} e^{\frac{a_{jt}}{\sigma}} P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} \quad (20)$$

$$p_{it}^c(c_{ijt}) = c_{ijt} w_{it} \quad (21)$$

$$x_{ijt}(c_{ijt}) = \frac{q_{ijt}}{\varphi} \quad (22)$$

$$f_{ijt}^\lambda = \lambda_{ijt}^{\frac{1}{\alpha}} \quad (23)$$

$$\lambda_{ijt} = c_{ijt}^\gamma \quad (24)$$

Substitute constraints (20)-(24) into (19) to obtain

$$E\pi_{ijt}(\varphi, \bar{a}_j, n) = \max_{\{q_{ijt}, c_{ijt}\}} q_{ijt}^{\frac{\sigma-1}{\sigma}} c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}} b_j P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} - c_{ijt} w_{it} \tau_{ij} \frac{q_{ijt}}{\varphi} - w_{it} c_{ijt}^{\frac{\gamma}{\alpha}} - w_{it} f_{ij}, \quad (25)$$

where $b_j = E_{a_{jt}|\bar{a}_j, n} \left(e^{\frac{a_{jt}}{\sigma}} \right)$. The first order conditions with respect to q_{ijt} and c_{ijt} are

$$\frac{\sigma-1}{\sigma} q_{ijt}^{-\frac{1}{\sigma}} c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}} b_j P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} = \frac{c_{ijt} w_{it} \tau_{ij}}{\varphi} \quad (26)$$

$$\frac{\gamma(\sigma-1)}{\sigma} q_{ijt}^{\frac{\sigma-1}{\sigma}} c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}-1} b_j P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} = w_{it} \tau_{ij} \frac{q_{ijt}}{\varphi} + \frac{\gamma}{\alpha} w_{it} c_{ijt}^{\frac{\gamma}{\alpha}-1}. \quad (27)$$

Divide equation (26) by (27) to obtain

$$\begin{aligned} \frac{c_{ijt}}{\gamma q_{ijt}} &= \frac{\frac{c_{ijt} \tau_{ij}}{\varphi}}{\tau_{ij} \frac{q_{ijt}}{\varphi} + \frac{\gamma}{\alpha} c_{ijt}^{\frac{\gamma}{\alpha}-1}} \\ \frac{\gamma q_{ijt} \tau_{ij}}{\varphi} &= \frac{q_{ijt} \tau_{ij}}{\varphi} + \frac{\gamma}{\alpha} c_{ijt}^{\frac{\gamma}{\alpha}-1} \\ q_{ijt} &= \frac{\gamma}{\alpha(\gamma-1)} \frac{\varphi}{\tau_{ij}} c_{ijt}^{\frac{\gamma}{\alpha}-1} \end{aligned} \quad (28)$$

Substitute equation (28) into (26) to obtain

$$\begin{aligned}
c_{ijt}^{1-\frac{\gamma(\sigma-1)}{\sigma}} &= \frac{\sigma-1}{\sigma} \left(\frac{\gamma}{(\gamma-1)\alpha} \frac{\varphi}{\tau_{ij}} c_{ijt}^{\frac{\gamma}{\alpha}-1} \right)^{-\frac{1}{\sigma}} \frac{\varphi b_j}{w_{it}\tau_{ij}} P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} \\
c_{ijt}^{\sigma-\gamma(\sigma-1)+\frac{\gamma}{\alpha}-1} &= \frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \frac{\varphi^{\sigma-1} b_j^\sigma}{w_{it}^\sigma \tau_{ij}^{\sigma-1}} P_{jt}^{\sigma-1} Y_{jt} \\
c_{ijt} &= \left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}} \left[\frac{\varphi^{\sigma-1} b_j^\sigma}{w_{it}^\sigma \tau_{ij}^{\sigma-1}} Y_{jt} P_{jt}^{\sigma-1} \right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}} \quad (29)
\end{aligned}$$

Substitute equations (24) and (26) into equation (20) to obtain

$$p_{ijt} = \frac{\sigma}{\sigma-1} e^{\frac{a_{jt}}{\sigma}} \frac{c_{ijt} w_{it} \tau_{ij}}{\varphi b_j}. \quad (30)$$

Substitute equation (30) and (24) into (20) to obtain

$$q_{ijt} = \left(\frac{\sigma-1}{\sigma} \right)^\sigma \left(\frac{\varphi b_j}{w_{it} \tau_{ij}} \right)^\sigma c_{ijt}^{\gamma(\sigma-1)-\sigma} P_{jt}^{\sigma-1} Y_{jt}. \quad (31)$$

Substitute equation (28) into (22) to obtain

$$x_{ijt} = \frac{\gamma}{\alpha(\gamma-1)} \frac{1}{\tau_{ij}} c_{ijt}^{\frac{\gamma}{\alpha}-1}.$$

Using equations (29), (30) and (31), sales can be written as

$$r_{ijt} = \frac{\sigma}{\sigma-1} \frac{\gamma}{\alpha(\gamma-1)} c_{ijt}^{\frac{\gamma}{\alpha}} e^{\frac{a_t}{\sigma}} \frac{w_{it}}{b_j}. \quad (32)$$

To ensure that the optimal c_{ijt} given by equation (29) maximizes the profit function in (25), we need to verify that $\frac{\partial^2 E\pi_{ijt}}{\partial c_{ijt}^2} \leq 0$ at the found optimum. This condition is satisfied whenever $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$.

F Proofs of Propositions

Proof of Proposition 1

Parts (a)-(c): Notice from equation (15) that the sign of the partial derivative of c_{ij} with respect to either Y_j , or φ , or b_j depends on the sign of the exponent $\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}$. The exponent is positive if and only if $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$.

Part (d): The derivative of c_{ij} with respect to n is given by

$$\frac{\partial c_{ij}}{\partial n} = c_{ij} \frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} \frac{\sigma_\theta^2 / \sigma_\epsilon^2}{2\sigma(1 + n\sigma_\theta^2 / \sigma_\epsilon^2)^2} [2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2]. \quad (33)$$

Provided $\alpha < \frac{\gamma}{(\gamma-1)(\sigma-1)}$, $\frac{\partial c_{ij}}{\partial n} > 0$ when $2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2 > 0$, or equivalently $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$. ■

Proof of Proposition 2.

Part (a) and (b): Substitute equation (15) into (16) to obtain

$$p_{ijt} = \frac{\sigma}{\sigma-1} \left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} e^{\frac{a_{ijt}}{\sigma}} w_i \tau_{ij} \left[\frac{Y_j P_j^{\sigma-1}}{w_i^\sigma \tau_{ij}^{\sigma-1}} \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \times \\ \times \varphi^{\frac{\sigma-1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - 1} (b_j^\sigma)^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - \frac{1}{\sigma}}.$$

Thus, the price is increasing in productivity φ when

$$\frac{\sigma-1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - 1 > 0 \iff \\ \alpha > \frac{1}{\sigma-1}.$$

The price is increasing in expected demand b_j^σ when

$$\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - \frac{1}{\sigma} > 0 \iff \\ \alpha > \frac{\gamma}{\sigma + (\gamma-1)(\sigma-1)}.$$

Part (c): The derivative of p_{ijt} with respect to n is given by

$$\frac{\partial p_{ijt}}{\partial n} = p_{ijt} \left(\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - \frac{1}{\sigma} \right) \frac{\sigma_\theta^2 / \sigma_\epsilon^2}{2\sigma(1 + n\sigma_\theta^2 / \sigma_\epsilon^2)^2} [2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2]. \quad (34)$$

Provided $\alpha > \frac{\gamma}{\sigma + (\gamma-1)(\sigma-1)}$, $\frac{\partial p_{ijt}}{\partial n} > 0$ when $2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2 > 0$, or equivalently $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$. ■

Proof of Proposition 3.

Substitute equation (15) into equation (31) to obtain

$$q_{ijt} = \left(\frac{\sigma-1}{\sigma} \right)^\sigma \left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{\gamma(\sigma-1)-\sigma}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \frac{1}{\tau_{ij}} \left[\frac{Y_{jt} P_{jt}^{\sigma-1}}{w_{it}^\sigma \tau_{ij}^{\sigma-1}} \right]^{\frac{\gamma(\sigma-1)-\sigma}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} + 1} \times \\ \times \varphi^{\frac{(\sigma-1)(\gamma(\sigma-1)-\sigma)}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} + \sigma} (b_j^\sigma)^{\frac{\frac{\gamma}{\alpha} - 1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}}.$$

The derivative of q_{ijt} with respect to n is given by

$$\frac{\partial q_{ijt}}{\partial n} = q_{ijt} \left(\frac{\frac{\gamma}{\alpha} - 1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} \right) \frac{\sigma_\theta^2 / \sigma_\epsilon^2}{2\sigma(1 + n\sigma_\theta^2 / \sigma_\epsilon^2)^2} [2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2].$$

Provided $\alpha < \gamma$, $\frac{\partial q_{ijt}}{\partial n} > 0$ when $2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2 > 0$, or equivalently $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$. ■

G Quality-constrained maximization problem of a firm

Denote by \bar{c} the minimum quality requirement for an intermediate input. The problem of the firm with the minimum quality standard can be written as

$$E\pi_{ijt}(\varphi, \bar{a}_j, n) = \max_{\{q_{ijt}, c_{ijt}\}} q_{ijt}^{\frac{\sigma-1}{\sigma}} c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}} b_j P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} - c_{ijt} w_{it} \tau_{ij} \frac{q_{ijt}}{\varphi} - w_{it} c_{ijt}^{\frac{\gamma}{\alpha}} - w_{it} f_{ij},$$

subject to $c_{ijt} > \bar{c}$. As shown in Appendix E, the unconstrained maximization yields

$$c_{ijt} = \left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \left[\frac{\varphi^{\sigma-1}}{w_{it}^\sigma \tau_{ij}^{\sigma-1}} Y_{jt} P_{jt}^{\sigma-1} b_j^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}}.$$

Provided that a firm's state triplet (φ, \bar{a}_j, n) satisfies

$$\left[\frac{(\gamma-1)\alpha}{\gamma} \left(\frac{\sigma-1}{\sigma} \right)^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} \left[\frac{\varphi^{\sigma-1}}{w_{it}^\sigma \tau_{ij}^{\sigma-1}} Y_{jt} P_{jt}^{\sigma-1} b_j^\sigma \right]^{\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)}} > \bar{c}, \quad (35)$$

the firm's optimal behavior under a quality standard will not be affected. Notice, that the left-hand side of inequality (35) is increasing in productivity φ and expected demand b^σ . Thus, the most productive firm and the firms with the highest demand are unaffected by the minimum-quality policy. If (φ, \bar{a}_j, n) are such that inequality (35) does not hold, the problem of the firm becomes

$$E\pi_{ijt}(\varphi, \bar{a}_j, n) = \max_{\{q_{ijt}\}} q_{ijt}^{\frac{\sigma-1}{\sigma}} \bar{c}^{\frac{\gamma(\sigma-1)}{\sigma}} b_j P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}} - \bar{c} w_{it} \tau_{ij} \frac{q_{ijt}}{\varphi} - w_{it} \bar{c}^{\frac{\gamma}{\alpha}} - w_{it} f_{ij},$$

The first order conditions with respect to q_{ijt} yield

$$q_{ijt} = \left(\frac{\sigma-1}{\sigma} \right)^\sigma \bar{c}^{\gamma(\sigma-1)} b_j^\sigma P_{jt}^{\sigma-1} Y_{jt} \left(\frac{\bar{c} w_{it} \tau_{ij}}{\varphi} \right)^{-\sigma}.$$

The resulting price charged by a firm is then given by

$$p_{ijt}(\bar{c}) = \frac{\sigma}{\sigma-1} e^{\frac{a_{jt}}{\sigma}} \frac{\bar{c} w_{it} \tau_{ij}}{\varphi b_j}.$$

Thus, surviving firms with (φ, \bar{a}_j, n) such that inequality (35) does not hold (the constrained firms), will choose a suboptimal quality level given by $\bar{c} > c_{ijt}$ yielding a higher price compared to the unconstrained equilibrium.

H Estimation of the tail index

To estimate the tail index of the distribution of export sales we use a method proposed by Gabaix and Ibragimov (2011). We estimate the tail index among exporters in the top

5 percent of export sales distribution for each year between 2005 and 2009 and target the average value in the calibration. The estimates are presented in Table A3.

Table A1: Summary statistics, FTS and EIAS data, 2005-2009

	all firms (1)	exporters (2)	non-exporters (3)
employment	18.7 [61.6]	63.7 [138.0]	9.6 [16.1]
sales	1653.4 [14768.9]	7694.0 [38586.8]	444.2 [2009.2]
avg. wages	10.9 [22.8]	14.7 [38.6]	10.1 [17.9]
capital stock per worker	48.2 [315.0]	85.2 [173.8]	40.8 [335.7]
value added per worker	15.6 [171.1]	23.7 [64.6]	14.0 [185.1]
age	14.8 [13.2]	21.9 [16.028]	13.4 [12.1]
export-age	1.4 [4.1]	8.3 [6.641]	
export-destination-age	0.8 [2.5]	4.9 [4.2]	
exports	575.5 [11707.3]	3451.5 [28493.4]	
number of destinations served	0.9 [3.8]	5.4 [7.9]	
number of product categories exported	1.4 [7.2]	8.3 [15.8]	
imports	399.7 [6574.3]	2234.6 [15919.9]	32.4 [577.5]
number of source countries	0.7 [2.5]	3.5 [4.8]	0.2 [0.9]
number of product categories imported	2.8 [13.9]	14.2 [30.5]	0.5 [3.7]
N (firm-year obs.)	178,697	29,804	148,893
N (distinct firms)	49,734	7,298	42,436

Notes: This table reports means and standard deviations (in brackets) of the firm-level panel from the FTS and EIAS data sets for the period 2005-2009. All monetary variables are in thousands of 2005 euros.

Table A2: Summary statistics, IAPI data, 2005-2009

	all firms (1)	exporters (2)	non-exporters (3)
sales	11938.6 [47766.4]	17171.1 [58957.5]	2943.6 [10035.5]
exports	6299.2 [44672.3]	9963.5 [55857.8]	
purchases of manufactured material inputs	4394.3 [28106.8]	6454.6 [35083.2]	852.5 [3521.803]
number of product categories of manuf. material inputs	7.7 [7.4]	8.1 [7.5]	6.9 [7.2]
N (firm-year obs.)	14,615	9,240	5,375
N (distinct firms)	4,100	2,678	1955

Notes: This table reports means and standard deviations (in brackets) of the firm-level panel from the IAPI data set for the 2005-2009 period. All monetary variables are in thousands of 2005 euros.

Table A3: Estimates of the tail exponent of the distribution of export sales

Dep. variable:	log exports _{<i>i</i>}				
	(1)	(2)	(3)	(4)	(5)
log (Rank _{<i>i</i>} - 1/2)	-1.191*** [0.018]	-1.196*** [0.018]	-1.197*** [0.018]	-1.250*** [0.020]	-1.357*** [0.013]
N (obs.)	331	302	306	281	272
R-squared	0.992	0.991	0.991	0.989	0.992
sample year	2005	2006	2007	2008	2009

Notes: This table reports estimates of the tail exponent of the distribution of export sales using Gabaix and Ibragimov (2011) method. The estimation sample is composed of manufacturing exporters in the top 5% of export sales distribution in the corresponding sample year. Standard errors in brackets. ***1% level, **5% level, *10% level.