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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) the volatility of output and input prices tends to decline with export 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.

JEL Classification: F12; F14; L11; O14

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

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; (3) the volatility of output and input prices tends to decline with export experience; and (4) 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 firm-level dynamics of input and output prices 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, Forthcoming) 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, an increase in input prices raises the cost of production and therefore leads to higher output prices. On the other hand, an increase in beliefs about demand leads to an increase in the quantity supplied. Given a downward sloping demand curve, the increase in quantity supplied leads to a reduction in the market-clearing output price.[1] Furthermore, the interaction between learning about demand and endogenous quality choice leads to a reduction in price volatility among older firms. As firms learn about the demand for their output, beliefs converge over time to their corresponding true values, which leads to a slower growth and therefore lower volatility of input and output prices. 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. We then check the ability of the model to predict moments which are not directly targeted in the calibration. The calibrated model correctly predicts that export prices decline with export-market age within firms, and that successful exporters are on average larger than other entrants in their first year and experience substantial growth thereafter. The model further accounts for about a third of the (conditional) size-dependence of growth rates and at most a quarter of the decline in price volatility with export experience that emerges from the data.[2]

Armed with the calibrated model, we assess implications of regulations that impose minimum product quality standards on traded goods. We first find that this policy leads to a reallocation of productive resources from old and large towards young and small firms.

[1] The effect of a reduction in output price due to an increase in beliefs about demand is distinct from the effects of an increase in output price due to a positive realization of an intra-temporal demand shock. In the latter case, since the quantity sold is held fixed, any subsequent positive demand shock realization leads to a higher market clearing price.

[2] Alternative mechanisms which can potentially account for the remainder of the (conditional) size-dependence of growth rates may include financial constraints as in Cooley and Quadrini (2001) or random productivity evolution as in Arkolakis (2016).

As a consequence, we further find that most of the burden of the policy falls onto younger generations of exporters who start small and gradually grow over time when they update their beliefs upwards. Lastly, in our model the quality constrained firms are not always low productivity firms, but instead low *profitability* firms. A low productivity firm may be a large and successful exporter if it has a product with sufficiently high demand. A firm's profitability in a market is jointly determined by its productivity and its expected demand level. This implication is in sharp contrast to that arising from from static models of quality choice along the lines of Kugler and Verhoogen (2012) that unambiguously predict a reallocation of resources from high to low productivity firms.

Altogether, we find that a minimum quality requirement on exported goods 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 (sub-optimally) choosing higher quality inputs. The extensive and intensive margin distortions lead to lower levels of welfare in equilibrium.

We contribute to several strands of existing research. A recent body of literature focuses on learning about unobserved demand as a fundamental source of firm dynamics (Albornoz, Corcos, Ornelas, and Pardo, 2012; Chaney, 2014; Eaton, Eslava, Jinkins, Krizan, and Tybout, 2014; Ruhl and Willis, 2014; Timoshenko, 2015a,b; Arkolakis, Papageorgiou, and Timoshenko, Forthcoming). While the microfoundations of the learning process vary across models, this body of work makes it possible to rationalize the age-dependence of various firms' life cycle patterns (conditional on size) observed in the data. For example, Albornoz et al. (2012) find that, consistently with market experimentation, new exporter-entrants grow the fastest in the first market they enter. The within-market growth in destinations that exporters enter thereafter gradually declines. Ruhl and Willis (2014) find that, consistent with a model where a firm's demand gradually increases over time, a firm's conditional survival rate increases with cohort age. Arkolakis, Papageorgiou, and Timoshenko (Forthcoming) find that, consistent with learning about unobserved demand, firm growth rates decline in age, conditional on size, and decline in size, conditional on age. Timoshenko (2015b) further finds that older exporters switch products less frequently than new exporters. In a contribution to this literature, we find that, consistent with a learning mechanism, the volatility of input and output prices declines with export experience.[3]

Models of firm dynamics that introduce idiosyncratic productivity shocks into Melitz (2003), including Luttmer (2007), Impullitti, Irarrazabal, and Opromolla (2013) and Arkolakis (2016), would have difficulty predicting the age-dependence of various firms' life cycle patterns. In these models, productivity dynamics follows a Brownian motion process. A peculiar feature of this process is that firms with the same productivity level have identical growth patterns regardless of their age. As a result, even if modified to allow for quality choice (as in Kugler and Verhoogen (2012)), these models would predict the volatility of input and output prices to be constant with respect to firm age. In contrast, as we show in this paper, the interaction of learning with quality choice allows us to rationalize the dynamics of price volatility with age.[4]

Our findings further contribute 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, 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 (Forthcom-

[3]We 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, 2016; Timoshenko, 2015a). 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.

[4]A complementary set of literature employs models of firm dynamics whereby a firm's current investment decision influences the firm's future profitability. These models are also referred to as models of active learning. Ericson and Pakes (1995) are the first to develop such a model. Subsequent trade literature has incorporated variants of Ericson and Pakes (1995) mechanism to study firm dynamics (Foster, Haltiwanger, and Syverson, 2015). In the follow up paper, Ericson and Pakes (1998) test whether the data follows passive learning of Jovanovic (1982) or active learning of Ericson and Pakes (1995). The authors find that each of the mechanisms has merit in the data. In this paper we do not seek to differentiate between different learning mechanisms, but rather explore dynamic implications of a plausible Jovanovic (1982) mechanism whereby firms learn about their unobserved demand via longer experience.

ing) 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.[5] Our paper contributes to this 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.[6]

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.[7]

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

[5]Other 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.

[6]Our 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).

[7]Our 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.

concludes the paper.

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).[8]

We have further used FTS data spanning a longer period (1990-2009) to compute

[8]In 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.

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.[9] 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).[10] All nominal variables 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.

[9] Since 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).

[10] Firms 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.

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.[11] 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.[12] The patterns displayed in 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 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

[11] A 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.

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

an equation of the form:

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

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. Using the sample mean of firm age as the reference point, the estimates in columns (1)-(2) reveal that, among all manufacturing firms, one extra year of age is associated with a rise of 2.9% in total employment and 3.6% 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)-(8) reveal that export revenue increases systematically with the length of activity in export markets. Using the sample means as reference points, the estimate in column (5) indicates that one extra year of export-age among exporters is associated with a 19.2% increase in export revenue, while the estimate in column (8) reveals that if export-destination-age increases by one year, export revenue in that market rises by 23.4% 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 follow 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 as 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:

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

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:

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

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 exporter size. As emphasized by Arkolakis, Papageorgiou, and Timoshenko (Forthcoming) 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:

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

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. We then relate these average prices (and quantities) to firm-destination-year measures of export experience.[13]

We adopt an anlogous two-step estimation procedure to examine the behavior of inputs prices across and within firms. In a first step, we estimate firm-year average log input prices (and quantities) by running regressions of the form:

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

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 comparison 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-

[13]Kugler and Verhoogen (2012) and Bastos, Silva, and Verhoogen (Forthcoming) 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. Note that the estimation of (4) is simply a first-step to obtain firm-destination-year average export prices (and quantities) and is not reported.

year level from the FTS and IAPI data sets, respectively. In a second step, we relate these estimates to measures of market experience and firm performance.[14]

Panel A in Table 4 examines the relationship between the 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, 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-year and destination effects. Hence they exploit within-firm variation in market experience across destination to identify the relationship between average export prices (quantities) and market experience, while accounting for potential direct effects of destination attributes on export prices. The results reveal that as export experience in a destination increases, firms tend to ship larger quantities at lower average prices.[15]

Turning to input prices, 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.[16] 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.[17]

We further show that export experience is also systematically associated with the volatility of output and input prices within firms. In column (1) of Table 6, we observe that the absolute value of export price growth within a firm-destination cell is negatively associated with export experience in that market. In the other two columns, we find

[14]Note that the estimation of (5) is simply a first-step to obtain firm-year average input prices (and quantities) and is not reported.

[15]Similar results are obtained if we include as controls destination-specific variables (that are standard in gravity regressions) instead of destination fixed effects.

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

[17]As 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 7 below which focuses on within-firm changes over time, conditional on firms being sampled.

similar patterns for the volatility of input prices within firms: column (2) reveals that the absolute value of wage growth within firms is negatively associated with export experience, while in column (3) we observe that the absolute value of the growth of imported input prices also declines with export-age.[18] In sum, the data reveal that the volatility of output and input prices within firms tends to decline with export experience.

The analysis of firm-level input prices above relies solely on cross-sectional comparisons across cohorts of firms.[19] In order to characterize more fully the dynamic behavior of input prices within surviving firms, Table 7 examines how average input prices and quantities evolve with firm sales over time. 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.[20] The results suggest that prices and quantities of inputs tend to increase with sales within surviving firms over time. In other words, aging firms that expand relatively more tend to purchase larger quantities of productive inputs at higher unit prices. This pattern holds for labor inputs (column (1)), imported inputs (column (2)), and all manufactured material inputs (column (3)).

[18]For consistency, the main quantitative analysis in the paper focuses on the period 2005-2009, which makes it possible to link all the available data sets. As noted above, however, the FTS data are available for a longer period. In Tables A3-A6 in the Appendix we show that the main results on the age-dependency of export growth and prices are qualitatively similar when focusing on the period 1996-2009. (The FTS data do not include information on location and hence region effects are not included.)

[19]Note that including firm effects in Table 5 would not provide a suitable source of variation for identifying the relationship between market experience and input prices within firms. This is because variation over time in export-age within surviving exporters cannot generally be distinguished from other macroeconomic factors that are common to all surviving exporters.

[20]An alternative approach for examining the relationship between input prices and firm performance 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 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.

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 (Forthcoming). 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 constant-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

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

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

$$Q_{jt} = \left(\sum_{i=1}^{N} \int_{\omega\in\Omega_{ijt}} \left(e^{a_{jt}(\omega)}\right)^{\frac{1}{\sigma}} \left(\lambda_{jt}(\omega)q_{jt}(\omega)\right)^{\frac{\sigma-1}{\sigma}} d\omega\right)^{\frac{\sigma}{\sigma-1}}, \tag{7}$$

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.

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 (Forthcoming), $a_{jt}(\omega)$ 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

$$P_{jt} = \left(\sum_{i=1}^{N} \int_{\omega \in \Omega_{ijt}} \lambda_{jt}(\omega)^{\sigma-1} e^{a_{jt}(\omega)} p_{jt}(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}. \quad (8)$$

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.[21] The profit of a firm producing an intermediate input of quality c is given by

$$\pi_{jt}(c) = p^{c}_{jt}(c)x_{jt} - w_{jt}cx_{jt},$$

where w_{jt} is the wage rate and $p^{c}_{jt}(c)$ 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:

$$p^{c}_{jt}(c) = cw_{jt}. \tag{9}$$

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 $\varphi_{\min}$ and is known to the firm since entry.[22] 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

[21] The 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.

[22] The probability density of Pareto distribution is given by $\left(\xi\varphi^{\xi}_{\min}\right)/\varphi^{\xi+1}$.

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 $\lambda = c^{\gamma}$. Parameter γ therefore governs the elasticity of the output quality with respect to the input quality. 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.[23]

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.

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 υ_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.[24] We assume that a firm observes one shock per period, hence we also interpret n as a firm's age. In the limit, as $n \to \infty$, the posterior distribution converges to a degenerate distribution centered at θ_j.

[23]The 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 foods. By contrast, if the value of α is high, quality upgrading is relatively inexpensive and the equilibrium will exhibit large heterogeneity in product quality.

[24]As 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 $\upsilon_n^2 = \frac{\sigma_{\epsilon}^2\sigma_{\theta}^2}{\sigma_{\epsilon}^2 + n\sigma_{\theta}^2}$.

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

$$E\pi_{ijt}(\varphi,\bar{a}_j,n)=\max_{\{q_{ijt},\lambda_{ijt},x_{ijt},c_{ijt}\}} E_{a_{jt}|\bar{a}_j,n}\left[p_{ijt}q_{ijt}-p^c_{it}(c_{ijt})\tau_{ij}x_{ijt}(c_{ijt})-w_{it}f^{\lambda}_{ijt}-w_{it}f_{ij}\right],\quad(10)$$

subject to the following five constraints

$$\begin{aligned}p_{ijt} &= q_{ijt}^{-\frac{1}{\sigma}}\lambda_{ijt}^{\frac{\sigma-1}{\sigma}}e^{\frac{a_{jt}}{\sigma}}P_{jt}^{\frac{\sigma-1}{\sigma}}Y_{jt}^{\frac{1}{\sigma}}, &(11)\\ p^c_{it}(c_{ijt}) &= c_{ijt}w_{it}, &(12)\\ x_{ijt}(c_{ijt}) &= \frac{q_{ijt}}{\varphi}, &(13)\\ f^{\lambda}_{ijt} &= \lambda_{ijt}^{\frac{1}{\alpha}}, &(14)\\ \lambda_{ijt} &= c^{\gamma}_{ijt}. &(15)\end{aligned}$$

We close the model in a standard way as described in Timoshenko (2015b) and Arkolakis, Papageorgiou, and Timoshenko (Forthcoming). 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 (10), the optimal quality of an intermediate input c_{ij} is given by

$$c_{ij}(\varphi,b_j) = \left[\frac{(\gamma-1)\alpha}{\gamma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}}\left[\frac{\varphi^{\sigma-1}b_j(\bar{a}_j,n)^{\sigma}}{w_i^{\sigma}\tau_{ij}^{\sigma-1}}Y_jP_j^{\sigma-1}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}}\quad(16)$$

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.[25] 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;*

(e) $\left|\frac{\partial \ln c_{ij}}{\partial \ln n}\right|$ *is increasing in* α.

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 (15)) 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), (d) and (e) 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

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

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.[26] 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.

Part (e) of Proposition 1 further establishes a crucial connection between properties of the quality production function and firm dynamics. Namely, (the absolute value of) the elasticity of input quality with respect to age increases with the scope for quality differentiation. The intuition for this relationship is as follows. The greater is the scope for quality differentiation, the smaller is the fixed cost of quality upgrading. As the cost of quality upgrading declines, firms will change the quality of intermediate inputs by more. Hence, in response to the same change in underlying beliefs over time, firms will make greater adjustments in quality, yielding a higher elasticity of input quality with respect to age. This result is crucial for identifying parameter α, which measures the scope for quality differentiation. It implies that α can be identified using a dynamic, as opposed to a cross-sectional, moment from the data. Hence, the interaction between learning about demand and quality upgrading provides a novel way of identifying a quality production function parameter, notably by linking it to the elasticity of input prices with respect to age.

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 implications for the behavior of input and output prices. From equation (12) we see that the price of an intermediate input p_{it}^c faced by a final goods producer is linear in the quality of the input. By part (d) of Proposition 1, over time growing firms tend to increase the quality of inputs used. Hence surviving firms will pay increasing prices for inputs as they age. These predictions are consistent with the evidence presented in Tables 5 and 7. The

[26]This 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.

price of the final good charged by a firm is given by

$$p_{ijt} = \frac{\sigma}{\sigma-1} e^{\frac{a_{jt}}{\sigma}} \frac{c_{ij}(\varphi, b_j) w_i \tau_{ij}}{b_j \varphi}. \quad (17)$$

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.*

As in 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.[27]

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

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

increase in profitability on prices. In the context of equation (17), suppose that a firm keeps the quality of inputs unchanged. In this case, the price dynamics are solely driven by changes in demand beliefs, b_j. Since demand beliefs enter multiplicatively 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, and more profitable firms (either due to falling costs or rising expected demand) will charge lower prices over time.[28] 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 input quality (equation (16)). If input quality increases by more than one-to-one with respect to beliefs, the output price 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

$$q_{ijt} = \left(\frac{\sigma - 1}{\sigma}\right)^\sigma \left(\frac{\varphi b_j}{w_{it}\tau_{ij}}\right)^\sigma c_{ijt}^{\gamma(\sigma-1)-\sigma} P_{jt}^{\sigma-1} Y_{jt}. \tag{18}$$

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 (13), the quantity of inputs x_{ijt} is linear in the quantity of the final good. Hence, consistent with the evidence presented in Table 7, 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

[28]Appendix G provides a greater intuition on the relationship between price and expected versus realized demand.

of the model and show that the calibrated parameter values satisfy this restriction. 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.[29]

Following the argument in Arkolakis, Papageorgiou, and Timoshenko (Forthcoming), 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.

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

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. The identification argument is as follows. As stated in Proposition 1 part (e), the elasticity of input prices with respect to age increases in α. Hence, a faster increase in input prices with respect to age indicates a greater scope for quality differentiation. We use this relationship to identify parameter α. The identification of γ relies on the parameter's definition as the elasticity of output quality with respect to input quality, as can be seen from equation (15). Since sales are increasing in output quality, the elasticity of sales with respect to the input quality is also increasing in γ: $\partial \ln r_{ijt}/\partial \ln c_{ijt} = \gamma/\alpha$. Hence, the equation implies that for any underlying change in the quality of intermediate inputs, the resulting change in sales will be larger for larger values of γ. A larger growth in sales within firms over time implies that the share of total sales accounted for by entrants is smaller. Given the inverse relationship between parameter γ and the share of sales from entrants, we can therefore implicitly identify parameter γ by targeting the share of sales from entrants.

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.[30] 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.[31]

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 domestic market, f_d, is computed to yield the ratio of average domestic sales of firms to

[30] It is important to note that our quantitative results on within firm dynamics do not depend on the magnitudes of the fixed cost parameters. We therefore normalize the values of fixed costs to values that deliver the average value of export and domestic sales as that in the data. The chosen values of the fixed costs should not be interpreted as the actual values of fixed costs Portuguese firms face. For a rigorous empirical work on the estimation of fixed costs see Irarrazabal, Moxnes, and Opromolla (2015).

[31] For other applications of the simulated method of moments to parametrize a model see Eaton, Kortum, and Kramarz (2011), Eaton et al. (2014), Ruhl and Willis (2014).

average export sales of exporters, which is equal to 0.35.

5.2 Calibration results

Table 8 displays the simulated and data moments and Table 9 reports the corresponding calibrated parameter values. As can be seen from Table 8, 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 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, the success of exporters in the model 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 10 reports the growth regression results based on the simulated data. Comparison of the size coefficients in Tables 3 and 10 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, 2016).

Finally, to stress the interaction between learning and price dynamics we further compare predictions of the model and the data about the volatility of input and output prices with respect to age. Table 11 replicates the results in Table 6 using the simulated data. Notice from equations (16) and (17) that the growth of input and output price over time is driven by the evolution of beliefs about expected demand, b_j. As firms learn about their product demand, beliefs converge to their corresponding true values. The convergence in beliefs over time leads to a slower growth in input and output prices over time. As a result, the model implies a decline in price volatility, namely the absolute value of the growth rates of input and output prices, with export experience. Comparison of the age coefficients between Table 11 and Table 6 reveals that the learning mechanism considered in this paper accounts for at most a quarter of a decline in the price volatility with export experience.

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 $\bar{c}$.[32] The corresponding problem of the firm is described in Appendix H.

The quality standard 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,

[32] Bown 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.

as a result, choose higher quality inputs. Production of higher quality 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 5. Panels 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 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 the 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.

Further, the burden of a quality standard falls largely on young exporters. Figure 6 depicts the share of firms that are constrained by a quality requirement, among all firms in a given cohort. Consider a quality standard which leads to a 1 percent increase in average export quality. For this policy, almost 90 percent of entrants are constrained, while by the fifth year the share of constrained exporters drops to about 43 percent. In a static quality choice model of Kugler and Verhoogen (2012) this relationship is flat and the economic burden of a quality standard is equally distributed across cohorts. In contrast, when firms face demand uncertainty, the burden of a standard falls disproportionately on the young and uncertain firms. As surviving entrants learn about their potentially high demand, they gradually update their beliefs upward and increase the quality of exported goods above a minimum requirement. Our model therefore highlights that, due to the initial uncertainty about demand, young firms are the most vulnerable to potential economic policies and are more constrained in the early years of their life-cycle.

Firms that are constrained by the minimum quality requirement are not always the low productivity firms as would be implied by a static model of quality choice along the lines of Kugler and Verhoogen (2012). Using simulated data for a given quality standard, Figure 7 depicts a productivity distribution among firms that are constrained by the quality requirement and a productivity distribution among firms that are not constrained by the requirement.[33] As can be seen in Figure 7, the two productivity distributions overlap. Consistent with the static framework of Kugler and Verhoogen (2012), the average productivity of constrained firms is smaller than the average productivity of unconstrained firms. In contrast to predictions of the static framework, the learning equilibrium also exhibits relatively low productivity firms which are not constrained and high productivity firm which are constrained. This difference in the predictions across the two modeling environments results from the interaction of firm-level supply and demand side parameters that ultimately determine a firm's response to a quality standard in a learning model. Notice from equation (16) that a firm's optimal quality choice depends on the interaction of productivity, φ, and the expected demand, b_j, i.e. on $\varphi^{\sigma-1}b_j^{\sigma}$. We refer to the product of the two firm-level supply and demand side parameters as a firm's profitability. From equation (16), the optimal quality is increasing in profitability. Hence, a minimum quality requirement affects the low profitability firms. Low profitability does not necessarily imply low productivity. In fact, a low productivity firm may supply a high quality product if expected demand is sufficiency high. As a result, in contrast to implications from a static model, a quality standard does not necessarily imply a reallocation of resources from high to low productivity firms. It is the interaction between firm-level demand and supply side parameters that determines the redistribution of resources.

Next, Figure 8 describes the effect of minimum quality requirements on the general equilibrium variables. In all panels of Figure 8, 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.[34]

Panel A of Figure 8 plots the effect of a quality standard on welfare. Welfare is given by the real consumption and is defined in equation (7). There are two channels through which a quality standard may affect welfare. Holding all else constant, a restrictive standard reduces the number of varieties available to consumers, Ω_{ijt}, as not all firms are be able to

[33]In Figure 7 we consider a quality standard that increases the average export quality by 5 percent. The results are similar across alternative policies and are available upon request.

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

comply with a higher quality standard. As a consequence, consumers have access to less varieties and their welfare declines. On the other hand, surviving varieties are supplied in higher qualities, $\lambda_{jt}(\omega)$, which it turn raises the welfare of consumers. The model does not admit a closed form characterization of the effect of a quality standard on welfare, and we therefore adhere to quantitative results presented in Figure 8.

As is evident from Panel A of Figure 8, 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).

Finally, as can be seen in Panel E of Figure 8, 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 9.

Figure 9 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 9. As can be seen from Panel A in Figure 9, 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 9, 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; (3) the volatility of output and input prices tends to decline with export experience; and (4) 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. Moreover, the interaction between learning about demand and endogenous quality choice leads to a reduction in price volatility among older firms. As firms learn about the demand for their product, beliefs converge over time to their corresponding true values, which reduces the volatility of input and output prices. 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

	all firms		exporters					
Dep.variable:	log empl (1)	log sales (2)	log empl (3)	log sales (4)	log exp (5)	log exp-dest (6)	log exp-dest (7)	log exp-dest (8)
log age	0.429***	0.533***	0.546***	0.508***				
	[0.003]	[0.004]	[0.009]	[0.011]				
log export-age					1.593***	0.468***		
					[0.013]	[0.012]		
log export-destination-age							1.125***	1.150***
							[0.008]	[0.008]
N (obs.)	178,697	178,697	29,804	29,804	29,804	155,015	155,015	155,015
R-squared	0.218	0.206	0.263	0.247	0.478	0.244	0.387	0.54
industry-year effects	Y	Y	Y	Y	Y			
region effects	Y	Y	Y	Y	Y	Y	Y	
destination-year effects						Y	Y	Y
industry effects						Y	Y	
firm effects								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:	log $empl_t$-log $empl_{t-1}$			log $sales_t$-log $sales_{t-1}$		
	(1)	(2)	(3)	(4)	(5)	(6)
log age_{t-1}	-0.041***		-0.035***	-0.066***		-0.065***
	[0.001]		[0.001]	[0.001]		[0.001]
log $empl_{t-1}$		-0.026***	-0.016***			
		[0.001]	[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:	log exports$_t$–log exports$_{t-1}$			log exports-dest$_t$–log exports-dest$_{t-1}$		
	(1)	(2)	(3)	(4)	(5)	(6)
log export-age$_{t-1}$	-0.049***		-0.023***			
	[0.006]		[0.006]			
log exports$_{t-1}$		-0.026***	-0.021***			
		[0.002]	[0.003]			
log export-age-destination$_{t-1}$				-0.068***		-0.033***
				[0.003]		[0.003]
log exports-dest$_{t-1}$					-0.048***	-0.042***
					[0.001]	[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			
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)
log export-age-destination	-0.037***	-0.020***
	[0.005]	[0.005]
N (obs.)	131,585	131,585
R-squared	0.192	0.524
B. Dep. variable:	**avg. log export quantity**	
	(1)	(2)
log export-age-destination	0.556***	0.571***
	[0.011]	[0.014]
N (obs.)	131,585	131,585
R-squared	0.186	0.460
destination-year effects	Y	
industry effects	Y	
region effects	Y	
firm-year effects		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***	0.021***
	[0.002]	[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 log 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: Price volatility and export experience, 2005-2009

Dep. variable:	absolute value of growth of avg. log export price (1)	log avg. wage (2)	avg. log import price (3)
log export-age-destination$_{t-1}$	-0.043***		
	[0.003]		
log export-age$_{t-1}$		-0.085***	-0.073***
		[0.005]	[0.007]
N (obs.)	72,398	16,680	14,146
R-squared	0.839	0.057	0.114
destination-year effects	Y		
region effects	Y	Y	Y
industry effects	Y		
industry-year effects		Y	Y

Notes: The estimation sample is composed of manufacturing exporters in the period 2005-2009. Data are at the firm-destination-year level in column (1) and at the firm-year level in columns (2) and (3). In column (1) dependent variable is the absolute value of the growth of the firm-destination-year average log export price, which was estimated using the FTS data set at the firm-product-destination-year level. In column (2) the dependent variable is the absolute value of the growth of the firm-year average log wage obtained from the EIAS data set. In column (3) the dependent variable is the absolute value of the growth of 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 7: Input prices (quantities) and firm growth, 2005-2009

A. Dep. variable:	log avg. wage	avg. log import price	avg. log input price
	(1)	(2)	(3)
log sales	0.227***	0.024*	0.041*
	[0.004]	[0.013]	[0.022]
N (obs.)	178,697	31,281	14,602
R-squared	0.846	0.742	0.787
B. Dep. variable:	**log employment**	**avg. log import quantity**	**avg. log input quantity**
	(1)	(2)	(3)
log sales	0.346***	0.289***	0.603***
	[0.004]	[0.026]	[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 EIAS 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 8: 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
	Criterion		*0.0002*

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

[a]Source: The age coefficient in Table 5, column (2).

[b]Source: The age coefficient in Table 3, column (3).

[c]Source: The empirical estimate of the tail index is presented in Appendix I.

Table 9: 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 10: 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$\leq$20

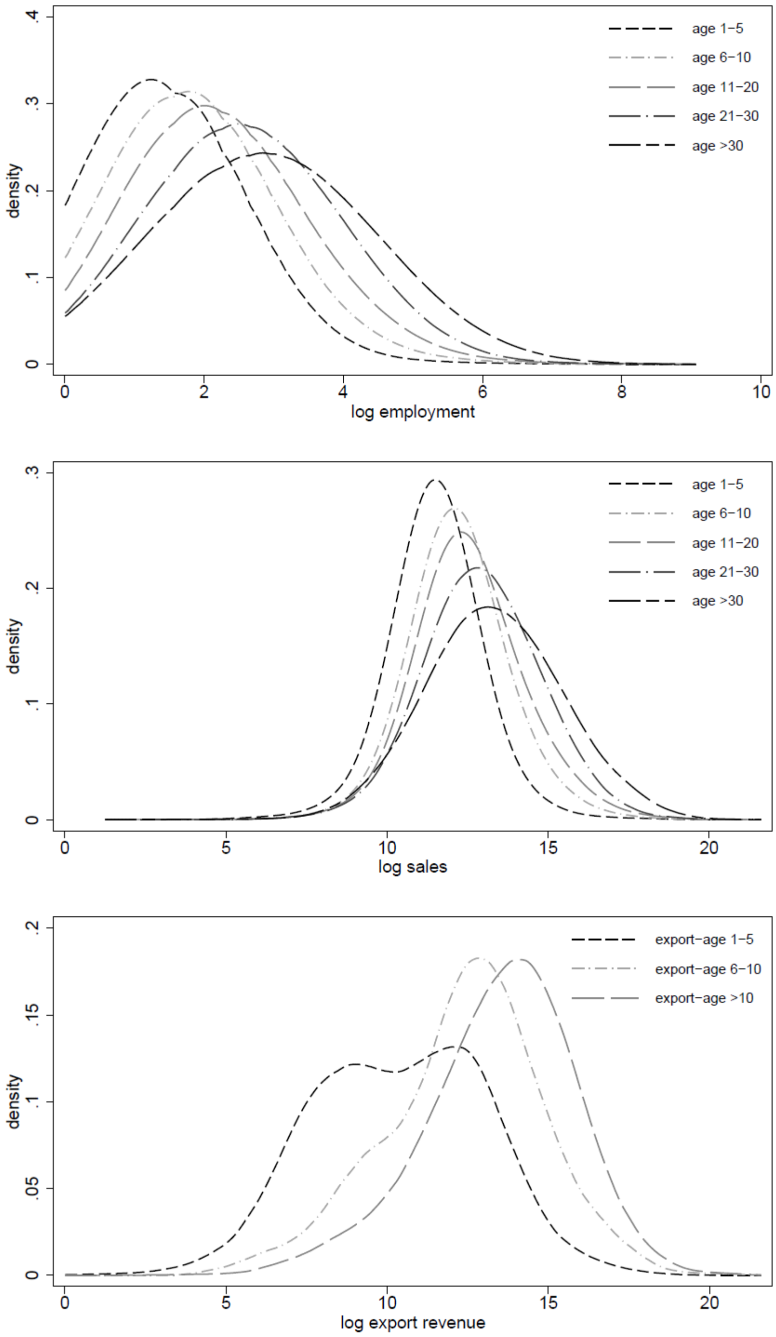
Notes: The table reports OLS regressions based on the simulated firm-level sample. Robust standard errors in brackets. ***1% level, **5% level, *10% level.

Table 11: Price volatility and export experience in the simulated data

Dep. variable:	absolute value of growth of log export price (1)	absolute value of growth of log input price (2)
log export-age$_{t-1}$	-0.009***	-0.005***
	[0.001]	[0.000]
N (obs.)	185,111	185,111
R-squared	0.001	0.267
sample	age≤20	age≤20

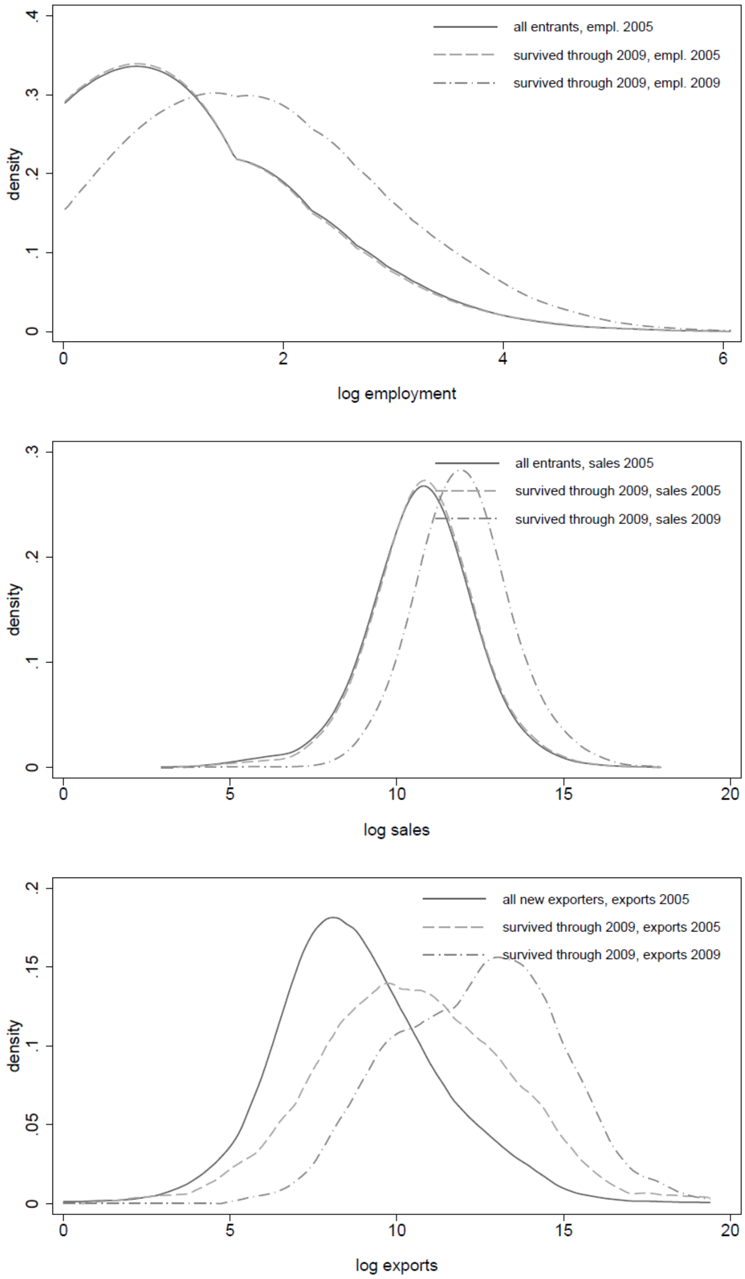
Notes: The table reports OLS regressions based on the simulated firm-level sample. Robust standard errors in brackets. ***1% level, **5% level, *10% level.

Figure 1: Firm performance across cohorts, 2005



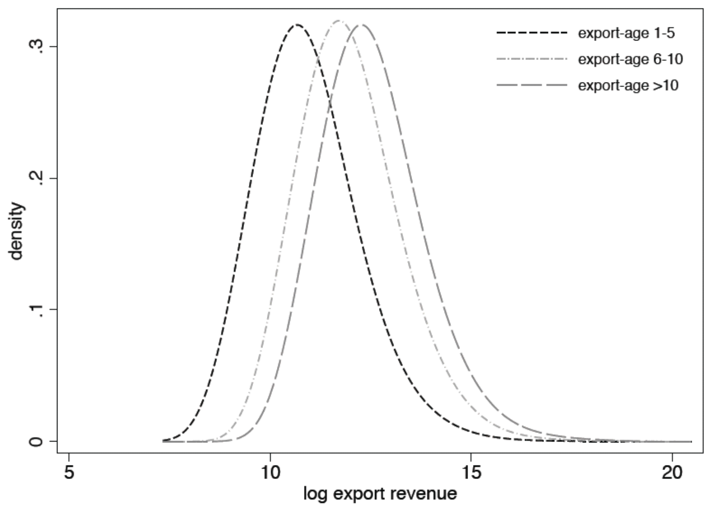
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7, using data from 2005. Age is the number of years since birth of the firm. Export-age is the number of consecutive years the firm has recorded positive export revenue.

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



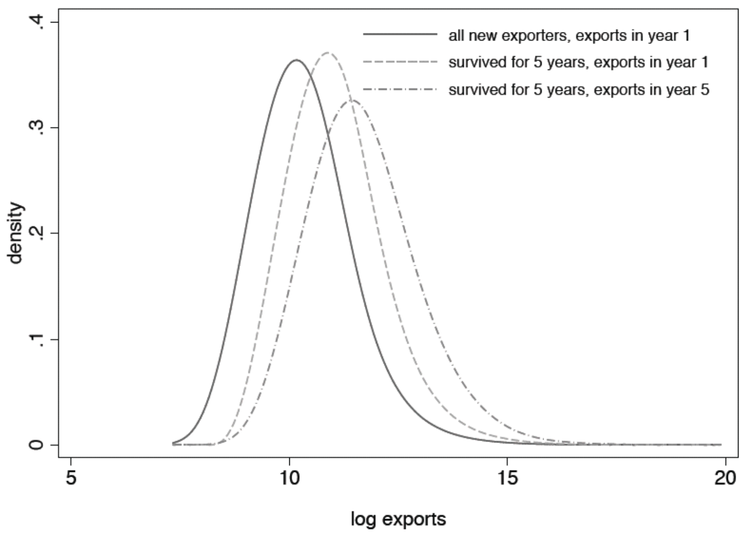
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7, using data from 2005 and 2009.

Figure 3: Firm performance across cohorts, simulated data



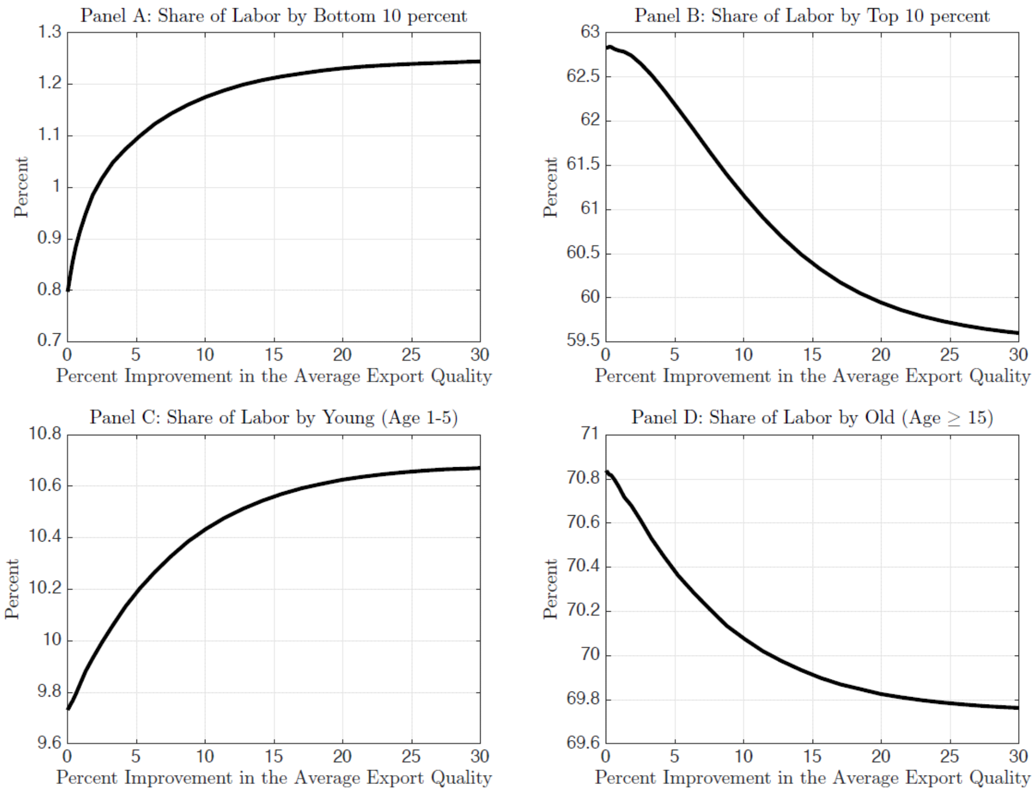
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7. Authors calculations on model simulation.

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



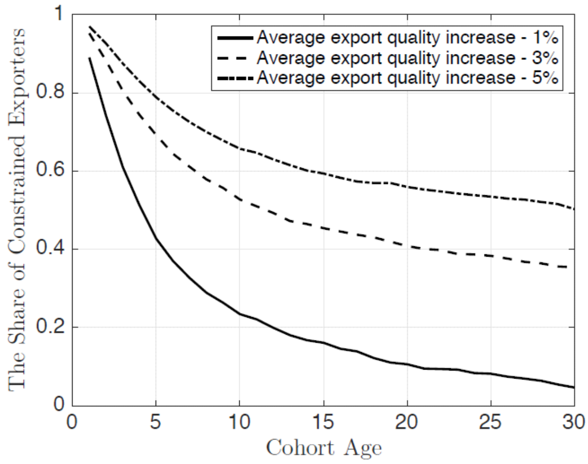
Notes: The figure depicts non-parametric estimates from a kernel density smoother with bandwidth 0.7. Authors calculations on model simulation.

Figure 5: Labor reallocation caused by minimum quality standards



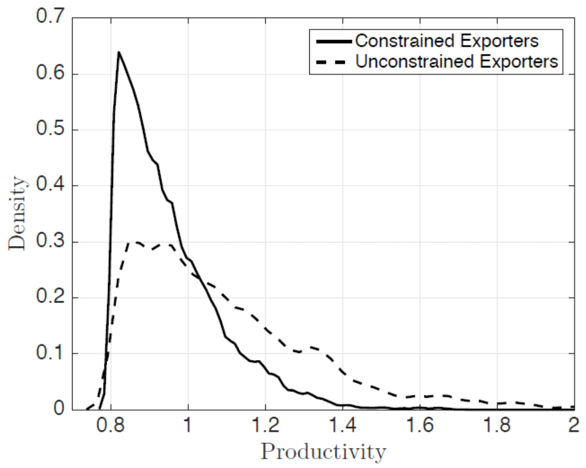
Notes: Authors calculations on model simulation.

Figure 6: The share of quality constrained exporters by cohort



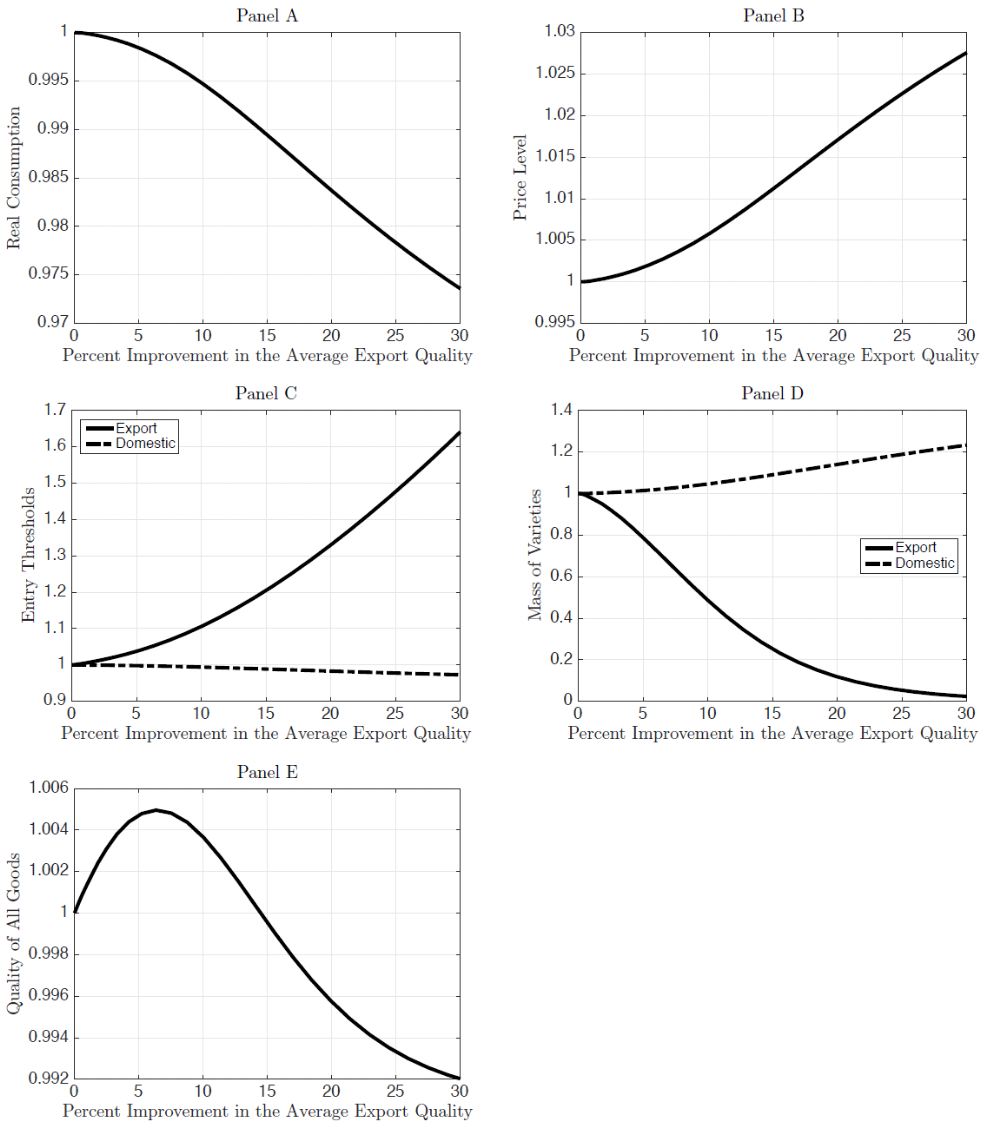
Notes: Authors calculations on model simulation.

Figure 7: Productivity distribution



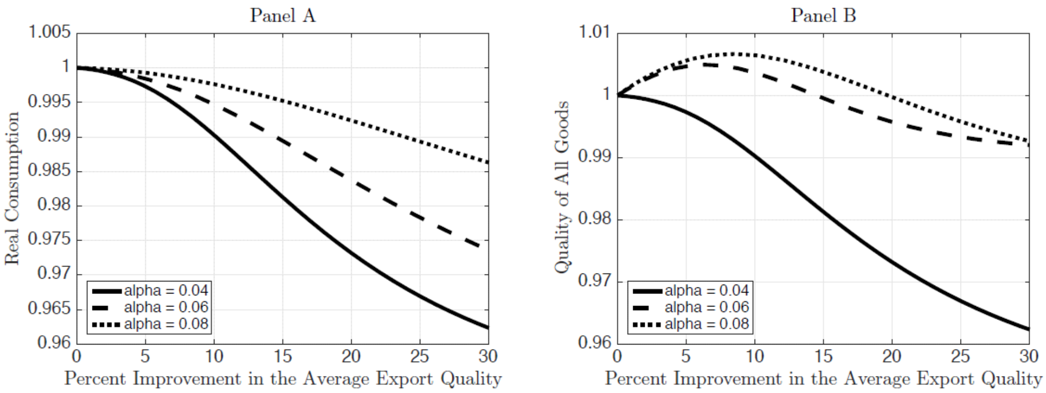
Notes: The considered quality standard increases the average export quality by 5 percent. The productivity values on the horizontal axis are normalized by the average productivity across all exporters. Authors calculations on model simulation.

Figure 8: 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 9: 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

$$V_{ijt}(\varphi, \bar{a}_j, n) \;=\; \max\left\{E\pi_{ijt}(\varphi, \bar{a}_j, n) + \beta(1-\delta)E_{\bar{a}'_j|\bar{a}_j,n}V_{ijt+1}(\varphi, \bar{a}'_j, n+1); 0\right\}, \quad (19)$$

where δ is the exogenous death rate of firms. The solution to problem (19) 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 $V^E_{ijt}(\varphi, 0, 0) =$

$E\pi_{ijt}(\varphi,0,0)+\beta(1-\delta)E_{\bar{a}'_j|\bar{a}_j,1}V_{ijt+1}(\varphi,\bar{a}'_j,1)$. 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 $p^c_j(c)$; 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 $q^c_j(\omega)$; 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: $q^c_j(\omega)$ maximizes utility in (6).

2. Given the equilibrium values, firms in the intermediate-goods sector break even: $p^c_j(c)$ satisfies equation (9).

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 (10) and (19).

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 (8) 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

$$E\pi_{ijt}(\varphi,\bar{a}_j,n) = \max_{\{q_{ijt},\lambda_{ijt},x_{ijt},c_{ijt}\}} E_{a_{jt}|\bar{a}_j,n}\left[p_{ijt}q_{ijt} - p^c_{it}(c_{ijt})\tau_{ij}x_{ijt}(c_{ijt}) - w_{it}f^\lambda_{ijt} - w_{it}f_{ij}\right] \quad (20)$$

subject to

$$\begin{aligned} p_{ijt} &= q_{ijt}^{-\frac{1}{\sigma}}\lambda_{ijt}^{\frac{\sigma-1}{\sigma}}e^{\frac{a_{jt}}{\sigma}}P_{jt}^{\frac{\sigma-1}{\sigma}}Y_{jt}^{\frac{1}{\sigma}} &(21)\\ p^c_{it}(c_{ijt}) &= c_{ijt}w_{it} &(22)\\ x_{ijt}(c_{ijt}) &= \frac{q_{ijt}}{\varphi} &(23)\\ f^\lambda_{ijt} &= \lambda_{ijt}^{\frac{1}{\alpha}} &(24)\\ \lambda_{ijt} &= c_{ijt}^\gamma &(25)\end{aligned}$$

Substitute constraints (21)-(25) into (20) to obtain

$$E\pi_{ijt}(\varphi,\bar{a}_j,n) = \max_{\{q_{ijt},c_{ijt}\}} q_{ijt}^{\frac{\sigma-1}{\sigma}}c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}}b_jP_{jt}^{\frac{\sigma-1}{\sigma}}Y_{jt}^{\frac{1}{\sigma}} - c_{ijt}w_{it}\tau_{ij}\frac{q_{ijt}}{\varphi} - w_{it}c_{ijt}^{\frac{\gamma}{\alpha}} - w_{it}f_{ij}, \quad (26)$$

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

$$\frac{\sigma-1}{\sigma}q_{ijt}^{-\frac{1}{\sigma}}c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}}b_jP_{jt}^{\frac{\sigma-1}{\sigma}}Y_{jt}^{\frac{1}{\sigma}} = \frac{c_{ijt}w_{it}\tau_{ij}}{\varphi} \tag{27}$$

$$\frac{\gamma(\sigma-1)}{\sigma}q_{ijt}^{\frac{\sigma-1}{\sigma}}c_{ijt}^{\frac{\gamma(\sigma-1)}{\sigma}-1}b_jP_{jt}^{\frac{\sigma-1}{\sigma}}Y_{jt}^{\frac{1}{\sigma}} = w_{it}\tau_{ij}\frac{q_{ijt}}{\varphi}+\frac{\gamma}{\alpha}w_{it}c_{ijt}^{\frac{\gamma}{\alpha}-1}. \tag{28}$$

Divide equation (27) by (28) to obtain

$$\begin{aligned}
\frac{c_{ijt}}{\gamma q_{ijt}} &= \frac{\frac{c_{ijt}\tau_{ij}}{\varphi}}{\tau_{ij}\frac{q_{ijt}}{\varphi}+\frac{\gamma}{\alpha}c_{ijt}^{\frac{\gamma}{\alpha}-1}}\\
\frac{\gamma q_{ijt}\tau_{ij}}{\varphi} &= \frac{q_{ijt}\tau_{ij}}{\varphi}+\frac{\gamma}{\alpha}c_{ijt}^{\frac{\gamma}{\alpha}-1}\\
q_{ijt} &= \frac{\gamma}{\alpha(\gamma-1)}\frac{\varphi}{\tau_{ij}}c_{ijt}^{\frac{\gamma}{\alpha}-1}
\end{aligned} \tag{29}$$

Substitute equation (29) into (27) to obtain

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

$$c_{ijt} = \left[\frac{(\gamma-1)\alpha}{\gamma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}}\left[\frac{\varphi^{\sigma-1}b_j^{\sigma}}{w_{it}^{\sigma}\tau_{ij}^{\sigma-1}}Y_{jt}P_{jt}^{\sigma-1}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}} \tag{30}$$

Substitute equations (25) and (27) into equation (21) to obtain

$$p_{ijt} = \frac{\sigma}{\sigma-1}e^{\frac{a_{jt}}{\sigma}}\frac{c_{ijt}w_{it}\tau_{ij}}{\varphi b_j}. \tag{31}$$

Substitute equation (31) and (25) into (21) to obtain

$$q_{ijt} = \left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\left(\frac{\varphi b_j}{w_{it}\tau_{ij}}\right)^{\sigma}c_{ijt}^{\gamma(\sigma-1)-\sigma}P_{jt}^{\sigma-1}Y_{jt}. \tag{32}$$

Substitute equation (29) into (23) to obtain

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

Using equations (30), (31) and (32), sales can be written as

$$r_{ijt} = \frac{\sigma}{\sigma-1}\frac{\gamma}{\alpha(\gamma-1)}c_{ijt}^{\frac{\gamma}{\alpha}}e^{\frac{a_t}{\sigma}}\frac{w_{it}}{b_j}. \tag{33}$$

The partial elasticity of sales with respect to input quality is therefore given by

$$\frac{\partial \ln r_{ijt}}{\partial \ln c_{ijt}} = \frac{\gamma}{\alpha}.$$

To ensure that the optimal c_{ijt} given by equation (30) maximizes the profit function in (26), 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 (16) 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

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

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 $\bar{a}_j > \bar{\theta} + \frac{\sigma_\theta^2}{2\sigma}$.

Part (e): Equation (34) can be written as

$$\frac{\partial \ln c_{ij}}{\partial \ln n} = \frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} \frac{n\sigma_\theta^2/\sigma_\epsilon^2}{2\sigma(1+n\sigma_\theta^2/\sigma_\epsilon^2)^2} \left[2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2\right]. \tag{35}$$

Notice that the first multiplier on the right hand side of equation (35) increases in α. The second and the third multiplier do not depend on α, but may be positive or negative depending on the sign of $\left[2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2\right]$. Hence, $\left|\frac{\partial \ln c_{ij}}{\partial \ln n}\right|$ is increasing in α. ∎

Proof of Proposition 2.

Part (a) and (b): Substitute equation (16) into (17) to obtain

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

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

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

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

$$\frac{\partial p_{ijt}}{\partial n} = p_{ijt}\left(\frac{1}{\frac{\gamma}{\alpha} - (\gamma-1)(\sigma-1)} - \frac{1}{\sigma}\right)\frac{\sigma_\theta^2/\sigma_\epsilon^2}{2\sigma(1+n\sigma_\theta^2/\sigma_\epsilon^2)^2}\left[2\sigma(\bar{a}_j - \bar{\theta}) - \sigma_\theta^2\right]. \quad (36)$$

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 (16) into equation (32) to obtain

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

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

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

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 Price adjustments due to changes in expected versus realized demand

In this appendix we provide a more detailed explanation on the relationship between output prices, expected demand, and realized demand. Recall that there are two separate variables in the model which are related to the notion of a demand shock. The first is the current demand shock realization denoted by a_{jt}, where j refers to a destination, and t refers to time. The second is the belief about demand denoted by $b_j(\bar{a}_j, n)$, where $\bar{a}_j$ is the average of the observed demand shock realizations, and n is the number of these observed demand shocks.

As we show below, a high (or positive) demand shock, a_{jt}, realization in period t leads to an increase in the output price in period t (holding $b_j(\bar{a}_j, n)$ constant). This mechanism is consistent with the common understanding of the relationship between output prices and demand shocks, and holds in our model as well. In contrast, an increase in belief about demand, $b_j(\bar{a}_j, n)$, leads to a decline in the output price (holding a_{jt} constant). This is the novel channel in the learning model, which is driven by firms choosing quantities based on the belief about demand and not the current demand shock realization.

Recall, that each period firms maximize expected profits by choosing the quantity supplied. The optimal quantity chosen by a firm is given by[35]

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

Notice three features of the optimal quantity. Firstly, optimal quantity is increasing in the firm's belief about demand, b_j. A firm which expects the demand for its product to be high, finds it optimal to supply a greater quantity to the market.

Secondly, productivity, φ, and belief about demand, b_j, enter multiplicatively into the optimal quantity equation. Hence, a firm with high demand behaves in the same way as a firm with high productivity: both of these firms find it optimal to supply greater quantity of a product to the market. This is the sense in which we write that "an increase in beliefs is equivalent to an increase in productivity, or an increase in profitability, or a decline in marginal cost." All of these changes lead to an increase in quantity supplied, an increase in revenue, and an increase in profits.

Thirdly and finally, the optimal quantity choice is independent of the current demand shock realization, a_{jt}. This occurs because firms make their decisions prior to observing current demand shock realizations: the fundamental premise of a learning environment.

Once firms have supplied their corresponding products to the market, current demand shocks are realized, and prices adjust to clear the markets according to the inverse demand function given by

$$p_{ijt} \quad = \quad q_{ijt}^{-\frac{1}{\sigma}} e^{\frac{a_{jt}}{\sigma}} P_{jt}^{\frac{\sigma-1}{\sigma}} Y_{jt}^{\frac{1}{\sigma}}.$$

The inverse demand equation demonstrates the opposite effects that the current demand shock realization, a_{jt}, versus the belief about demand, b_j, have on the market clearing price. Holding the quantity supplied (and therefore the belief about demand, b_j) constant, a product with a high (relative to a low) demand shock realization will be sold as a higher price. In contrast, consider two products with the same current demand shock realizations. A product with a higher belief about demand, b_j, will be supplied in greater quantity, and therefore will be sold at a lower price.

The evolution of within firm price over time is governed by the evolution of a firm's belief about demand, $b_j(\bar{a}_j, n)$. Positive and negative realizations of demand shocks, a_{jt}, generate a variation of the output price around the within firm time trend determined by the path of $b_j(\bar{a}_j, n)$. Given our interest in the inter-temporal within firm price behavior, our main analysis in the paper therefore focuses on the relationship between the output price and beliefs about demand, $b_j(\bar{a}_j, n)$.

[35] The considered relationship between demand shocks and price is independent of the quality upgrading mechanism. Hence, to make the explanation as clear and as transparent as possible, we are going to omit the quality upgrading component.

H 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 $(\varphi, \bar{a}_j, n)$ satisfies

$$\left[\frac{(\gamma-1)\alpha}{\gamma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}} \left[\frac{\varphi^{\sigma-1}}{w_{it}^{\sigma}\tau_{ij}^{\sigma-1}} Y_{jt} P_{jt}^{\sigma-1} b_j^{\sigma}\right]^{\frac{1}{\frac{\gamma}{\alpha}-(\gamma-1)(\sigma-1)}} > \bar{c}, \qquad (37)$$

the firm's optimal behavior under a quality standard will not be affected. Notice, that the left-hand side of inequality (37) 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 $(\varphi, \bar{a}_j, n)$ are such that inequality (37) 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 $(\varphi, \bar{a}_j, n)$ such that inequality (37) 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.

I 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 A7.

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

	all firms	exporters	non-exporters
	(1)	(2)	(3)
employment	18.7	63.7	9.6
	[61.6]	[138.0]	[16.1]
sales	1653.4	7694.0	444.2
	[14768.9]	[38586.8]	[2009.2]
avg. wages	10.9	14.7	10.1
	[22.8]	[38.6]	[17.9]
capital stock per worker	48.2	85.2	40.8
	[315.0]	[173.8]	[335.7]
value added per worker	15.6	23.7	14.0
	[171.1]	[64.6]	[185.1]
age	14.8	21.9	13.4
	[13.2]	[16.028]	[12.1]
export-age	1.4	8.3	
	[4.1]	[6.641]	
export-destination-age	0.8	4.9	
	[2.5]	[4.2]	
exports	575.5	3451.5	
	[11707.3]	[28493.4]	
number of destinations served	0.9	5.4	
	[3.8]	[7.9]	
number of product categories exported	1.4	8.3	
	[7.2]	[15.8]	
imports	399.7	2234.6	32.4
	[6574.3]	[15919.9]	[577.5]
number of source countries	0.7	3.5	0.2
	[2.5]	[4.8]	[0.9]
number of product categories imported	2.8	14.2	0.5
	[13.9]	[30.5]	[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	17171.1	2943.6
	[47766.4]	[58957.5]	[10035.5]
exports	6299.2	9963.5	
	[44672.3]	[55857.8]	
purchases of manufactured material inputs	4394.3	6454.6	852.5
	[28106.8]	[35083.2]	[3521.803]
number of product categories of manuf. material inputs	7.7	8.1	6.9
	[7.4]	[7.5]	[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: Exports growth, revenue and experience, 1996-2009

Dep variable:	log exports$_t$–log exports$_{t-1}$			log exports-dest$_t$–log exports-dest$_{t-1}$		
	(1)	(2)	(3)	(4)	(5)	(6)
log export-age$_{t-1}$	-0.053***		-0.027***			
	[0.003]		[0.004]			
log exports$_{t-1}$		-0.026***	-0.022***			
		[0.001]	[0.001]			
log export-age-destination$_{t-1}$				-0.074***		-0.032***
				[0.002]		[0.002]
log exports-dest$_{t-1}$					-0.050***	-0.045***
					[0.001]	[0.001]
N (obs.)	58,042	58,042	58,042	198,072	198,072	198,072
R-squared	0.053	0.057	0.058	0.031	0.043	0.045
industry-year effects	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 1996-2009. 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 A4: Export prices (quantities) and export experience, 1996-2009

A. Dep. variable:	avg. log export price	
	(1)	(2)
log export-age-destination	-0.019***	-0.010***
	[0.003]	[0.003]
N (obs.)	366,904	366,904
R-squared	0.184	0.525
B. Dep. variable:	**avg. log export quantity**	
	(1)	(2)
log export-age-destination	0.545***	0.569***
	[0.007]	[0.009]
N (obs.)	366,904	366,904
R-squared	0.223	0.443
destination-year effects	Y	
industry effects	Y	
firm-year effects	Y	Y
destination effects		Y

Notes: The estimation sample is composed of manufacturing exporters in the period 1996-2009. 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 A5: Input prices and export experience, 1996-2009

Dep. variable: avg. log import price	(1)
log export-age	0.024***
	[0.004]
N (obs.)	55,944
R-squared	0.373
industry-year effects	Y

Notes: The estimation sample is composed of manufacturing exporters in the period 1996-2009. Data are at the firm-year level. 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 A6: Price volatility and export experience, 1996-2009

Dep. variable:	absolute value of growth of avg. log export price (1)	avg. log import price (2)
log export-age-destination$_{t-1}$	-0.051***	
	[0.002]	
log export-age$_{t-1}$		-0.080***
		[0.006]
N (obs.)	231,128	43,198
R-squared	0.69	0.334
destination-year effects	Y	
industry effects	Y	
industry-year effects		Y

Notes: The estimation sample is composed of manufacturing exporters in the period 1996-2009. Data are at the firm-destination-year level in column (1) and at the firm-year level in column (2). In column (1) dependent variable is the absolute value of the growth of the firm-destination-year average log export price, which was estimated using the FTS data set at the firm-product-destination-year level. In column (3) the dependent variable is the absolute value of the growth of 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 A7: Estimates of the tail exponent of the distribution of export sales

Dep. variable:			log $exports_i$		
	(1)	(2)	(3)	(4)	(5)
log ($Rank_i$ -1/2)	-1.191***	-1.196***	-1.197***	-1.250***	-1.357***
	[0.018]	[0.018]	[0.018]	[0.020]	[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.