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Multi-product firms and product quality☆

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ABSTRACT

We examine the global operations of multi-product firms. We present a flexible heterogeneous-firm trade model with either limited or strong scope for quality differentiation. Using customs data for China during 2002–2006, we empirically establish that firms allocate activity across products in line with a product hierarchy based on quality. Firms vary output quality across their products by using inputs of different quality levels. Their core competence is in varieties of superior quality that command higher prices but nevertheless generate higher sales. In markets where they offer fewer products, firms concentrate on their core varieties by dropping low-quality peripheral goods on the extensive margin and by shifting sales towards top-quality products on the intensive margin. The product quality ladder also governs firms' export dynamics, both in general and in response to the exogenous removal of MFA quotas on textiles and apparel. Our results inform the drivers and measurement of firm performance, the effects of trade reforms, and the design of development policies.

1. Introduction

How firms organize production and sales across multiple product lines has important micro and macro implications. At the micro level, bigger and more productive firms sell more products, with the majority of their sales, exports and profits coming from a few core products (e.g. Arkolakis and Muendler, 2010; Bernard et al., 2009). Moreover, reallocations across products improve firm productivity and performance in response to shocks such as trade reforms or exchange rate movements (e.g. Bernard et al., 2010, 2011; Chatterjee et al., 2013; Gopinath and Neiman, 2014). At the macro level, multi-product firms capture an overwhelming and disproportionately large share of production, trade, and employment. Reallocations across heterogeneous firms shape aggregate productivity, the welfare gains from trade, and the aggregate impact of idiosyncratic and systemic shocks, especially with granularities in the firm size distribution (e.g. Arkolakis et al., 2012; Di Giovanni et al., 2014; Gabaix, 2011; Gaubert and Itskhoki, 2016; Melitz and Redding, 2015; Pavcnik, 2002). Yet despite its implications for firm performance, aggregate welfare and inequality, the allocation of activity across products within multi-product firms remains poorly understood.

Prima facie evidence for China suggests that product quality differentiation may be important (Appendix Table 1). Firms that export

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products at higher average prices and firms that vary prices more across their product range attain higher exports. Controlling for initial trade activity, such firms also achieve faster export growth. Although output prices may not directly reflect product quality, similar patterns hold when output quality is inferred from data on export prices and quantities, or proxied with the price or inferred quality of imported inputs. In addition, firms with higher productivity, employment, skill-, capital-, advertising and R&D intensity have higher average prices and quality, as well as greater price and quality dispersion across products.[1] These findings indicate that quality differentiation across firms and across products within firms may be key to understanding firms' export performance and the differential effects of trade reforms across the firm size and worker skill distribution.

This paper examines the global operations of multi-product firms in light of the motivating facts. We present a flexible heterogeneous-firm trade model that characterizes the behavior of multi-product firms with either limited or strong scope for quality differentiation. Using rich customs data for China during 2002–2006, we empirically establish that firms allocate activity across products in line with strong quality differentiation. They observe a product hierarchy governed by quality which determines how they participate in different markets and how they respond to changes in economic conditions over time. First, multi-product firms vary output quality across their product range by using inputs of different quality levels. Second, firms' core competence is in varieties of superior quality that command higher prices but nevertheless generate higher sales than cheaper goods of lower quality. Third, in markets where they offer fewer products, firms concentrate activity in their core varieties by dropping low-quality peripheral goods on the extensive margin and by shifting sales towards top-quality products on the intensive margin. Finally, the systematic reallocation of activity across the product quality ladder guides firms' export dynamics, both in general and in response to the exogenous removal of MFA quotas on textiles and apparel.

Our theoretical framework illustrates how the possibility for vertical differentiation affects the production and sales decisions of multi-product firms, relative to a world with only horizontal differentiation. We refer to these economic environments as *quality sorting* and *efficiency sorting*, respectively. In the model, firm-level ability and firm-product-specific expertise draws create exogenous variation in production efficiency across firms and across products within firms. Under *quality sorting*, firms can choose to make products of higher quality at a higher marginal cost by assembling more expensive inputs of higher quality. The exogenous variation in production efficiency induces endogenous variation in quality across firms and products, as well as in product scope and sales profile across firms. Abler companies offer higher quality of any given good, sell more goods, enter more markets, and earn higher revenues. Within a firm, more expensive varieties of higher quality generate higher bilateral and worldwide sales. Firms vary their product scope across heterogeneous country markets, and expand their product range by progressively adding goods in decreasing order of price and quality. Under *efficiency sorting* by contrast, there is no quality differentiation in the market place, and higher productivity is associated with lower marginal costs, lower prices, and higher sales. Firms now follow product hierarchies based on production efficiency, and all predictions for input and output prices are reversed.

Guided by this conceptual framework, we analyze the operations of multi-product firms using firm-level data for China on the universe of export and import transactions during 2002–2006. An important advantage of these data is that we observe the price and sales for all of a firm's exports by destination and product, as well as the price of all of its imported intermediate inputs. On the sales side, this allows us to examine the relationship between product scope and the distribution of product prices and sales across the different markets in which the same firm operates. On the production side, we are able to implement a new methodology we develop for matching multiple inputs (and their prices) to multiple output products (and their prices).

We perform four empirical exercises, and conclude that multi-product firms organize operations in a manner consistent with quality sorting but not with efficiency sorting. First, we establish evidence for the most distinctive prediction of quality sorting: the price-sales profile of multi-product firms. We show that export prices are positively correlated with worldwide exports across products within a firm-year and with bilateral sales across products within firm-destination-years. Model-consistent estimates of product quality are likewise positively associated with export revenues across a firms' product range, where we infer unobserved quality from observed price and quantity data as in Khandelwal (2008). These results do not appear to be driven by variable mark-ups: They are robust to controlling for firms' market power with their share of the relevant (country-)product market. They are also stronger for differentiated goods and for advertising- and R&D intensive industries with greater scope for quality upgrading.[2]

Second, we provide empirical support for the idea that firms use inputs of varying quality in order to manufacture products of varying quality. We document that input prices are positively correlated with output prices across products within a firm-year, even when we account for firms' market share in input and output markets. In the absence of detailed information on domestic inputs or direct measures of product quality, we use the prices that producers pay for imported intermediates to proxy the quality of their inputs.[3] We exploit detailed input-output tables for China to allocate firms' multiple imported inputs to the production of their multiple outputs, and we thereby obtain an input price index for each output product. Our results are stable across several variants of this assignment technique.

Third, we demonstrate that firms' product scope and allocation of activity across products are directly linked through a product hierarchy characterized by quality.[4] We rank the products of each firm based on their global sales, price, or inferred quality. Looking across the different markets that an exporter serves, we find that firms systematically shift activity towards their core top-ranked varieties in markets where they offer fewer products. On the extensive margin, they drop cheaper, lower-quality goods that place lower in their product ladder. On the intensive margin, they skew sales towards their best-selling, most expensive, highest-quality products.

Finally, we show that quality sorting governs multi-product firms' response to changes in economic conditions over time. We agnostically study the export dynamics of all firms surviving from the

[1] Inferring unobserved product quality is an important methodological contribution of our analysis that we discuss below. We calculate the average and the standard deviation of observed prices and inferred quality across products after first demeaning by product fixed effects. We describe the data sample, variable definition, and empirical specifications behind these conditional correlations in the notes to Appendix Table 1.

[2] Variable mark-ups are unlikely to drive our results on theoretical grounds either, because the correlation between prices and revenues remains positive (negative) under quality (efficiency) sorting under various demand and market structures. See Section 2.2.1 for more details.

[3] This is consistent with evidence in Kugler and Verhoogen (2009) of a positive correlation between the prices that Colombian plants pay for their imported and domestic inputs.

[4] Differential demand shocks across products and markets can induce firms to deviate from perfectly observing a fixed product hierarchy. Several checks we perform in Sections 5.3.1 and 5.4 suggest that such deviations are indeed present. See Armenter and Koren (2014), Eaton et al. (2011), and Head et al. (2017) for related work on the stability of destination and product hierarchies across firms and cities.

beginning to the end of our panel, without taking a stance on why they choose to adjust their trade activity. We also examine how surviving exporters in the textiles and apparel industry respond to a specific exogenous trade shock, namely the removal of export quotas under the Multi-Fiber Agreement in 2005. Both exercises reveal that firms expand (contract) their product scope and global exports by adding (dropping) lower-ranked varieties along the quality ladder and by reducing (increasing) the concentration of sales in top-ranked products.

We contribute to the international trade literatures on multi-product firms and on firm heterogeneity in efficiency and quality (e.g. Baldwin and Harrigan, 2011; Bernard et al., 2010, 2011; Eckel and Neary, 2010; Hallak and Sivadasan, 2013; Iacovone and Javorcik, 2012; Kugler and Verhoogen, 2012; Manova and Zhang, 2012; Melitz et al., 2014; Verhoogen, 2008). We build on insights from both literatures, and emphasize how their interaction enriches our understanding of multi-product firms. Theoretically, we highlight the role of quality sorting by presenting a general conceptual framework with minimal assumptions about consumer preferences and market structure. Methodologically, we propose novel strategies for proxying product quality and for mapping multiple inputs to multiple outputs within firms. Empirically, we corroborate and extend concurrent evidence in Eckel et al. (2015) that Mexican firms earn higher domestic and global revenues from their more expensive varieties.

We also shed light on the economic impact of globalization. Reallocations across firms and within-firm productivity upgrading mediate welfare gains from trade, with reallocations across products key to the latter (e.g. Bernard et al., 2011; Burstein and Melitz, 2013; Bustos, 2011; Mayer et al., 2016; Melitz and Redding, 2015). However, financial and labor market frictions distort the pattern of trade activity within and across firms and their response to trade reforms (e.g. Cosar et al., 2016; Helpman et al., 2010; Manova, 2013). Separately, more successful exporters hire more skilled workers and pay higher wages, while sophisticated inputs and skilled labor are complementary in the production of output quality (e.g. Bernard et al., 2012; Verhoogen, 2008). In light of this, our findings suggest that quality-driven reallocations across products within firms are important in understanding how trade liberalization impacts firm performance and aggregate welfare, as well as inequality through differential adjustments along the firm size and worker skill distribution.

More broadly, we speak to fundamental questions in industrial organization about firms' production and sales decisions. Standard balance-sheet data make it difficult to study these questions because they report total firm revenues and input purchases, with no price series or break-down by product and market. By exploiting customs records on the universe of firms' export and import transactions, we add three insights to IO evidence based on case studies of specific industries and markets. First, our findings for the relationship between product scope and sales distribution across products are inconsistent with constant mark-ups featured in models with CES preferences and monopolistic competition. Instead, they point to variable mark-ups that emerge for example in models with CES preferences and linear demand or in models with cross-product synergies or cannibalization (e.g. Dhingra, 2013; Eckel and Neary, 2010; Melitz et al., 2014). Second, the variation in marginal costs, quality, mark-ups and prices across firms and across products within firms complicates the measurement of firm productivity and mark-ups, and validates recent work that aims to address it (e.g. De Loecker et al., 2016; De Loecker and Warzynski, 2012). Third, this implies that micro and macro analyses that rely on price data need to take quality and mark-up variation into account. For instance, this applies to studies of exchange rate pass-through to producer and consumer prices (e.g. Gopinath et al., 2011) and to the design and implementation of anti-dumping and competition policies.

Lastly, we inform policy-relevant questions about export promotion in developing countries as a means to economic growth. While policy debates often center on improving cost competitiveness, our analysis indicates that quality upgrading is key to firms' export success. This suggests that policy makers may want to encourage investment not only in production efficiency, but also in quality capabilities. Recent evidence on the effects of import liberalization is consistent with the role we document for imported intermediates in producing high-quality products: Access to a wider range of foreign inputs and to foreign inputs of superior quality than those domestically available enables firms to expand product scope, productivity and quality (e.g. Amiti and Konings, 2007; Bas and Strauss-Kahn, 2015; De Loecker et al., 2016; Fan et al., 2015; Goldberg et al., 2010; Gopinath and Neiman, 2014; Halpern et al., 2015). Equally important is access to skilled labor and effective management practices (e.g. Bloom et al., 2016; Verhoogen, 2008).

The remainder of the paper is organized as follows. Sections 2 and 3 develop the model and its testable predictions. Sections 4 and 5 introduce the data and present the empirical results. The last section concludes.

2. Conceptual framework

How do multi-product firms organize their global production and sales activities when there is potential for both horizontal and vertical differentiation in the market space? In this section, we characterize multi-product firms' behavior when they simultaneously compete on production efficiency and product quality. We focus on three decisions that firms make in order to maximize profits: the optimal range of products and markets, the optimal quality of each product, and the optimal distribution of quality, prices, and sales across products and markets. We identify the key economic mechanisms that govern these decisions, and derive empirically testable predictions that allow us to validate them in the data. We emphasize that both the presence and the scope for quality differentiation critically affect observable firm outcomes. While the nature of consumer demand and firm competition matter, they do not qualitatively impact the role of quality differentiation.

We examine multi-product, multi-quality firms in a stylized conceptual framework with minimal assumptions about the underlying demand, production and market structure. This flexible specification illustrates the generality of our theoretical predictions in a transparent manner. We show in an Online Appendix how our main propositions can be formally derived from closed-form solutions under concrete assumptions about consumer preferences (CES and linear demand), production technology (quantity and quality production functions with fixed and variable costs), and market structure (monopolistic competition).[5] Our theoretical results, and the interpretation of our empirical findings in their light, would thus be valid both in more general settings than we consider here and in fully specified frameworks such as those in the Online Appendix.

2.1. Production efficiency and product quality

Consider a world with $J+1$ countries in which heterogeneous firms can produce multiple horizontally and vertically differentiated goods.[6] Let consumers' utility in country j be increasing in product

[5] In the Online Appendix, we incorporate efficiency and quality variation across firms and across products within firms into two existing models of multi-product firms: Bernard et al. (2010) and Melitz et al. (2014). In the former case we follow closely the analysis in Bloom et al. (2016).

[6] Our theoretical propositions hold whether firms manufacture a granular set or a continuum of products. We consider the former in this section for expositional purposes and in the interest of a transparent mapping between theory and empirics; the Online Appendix illustrates the robustness of our predictions to the latter scenario. Measurement error resulting from the aggregation of unobserved varieties at the barcode level to observed product categories can bridge theoretical predictions for product continua to empirical patterns for product granularity.

variety, product quantity and product quality, such that demand x_{ji} for variety i is increasing in its quality q_i, decreasing in its price p_{ji}, and increasing in aggregate demand R_j and a quality-adjusted aggregate price index P_j, $x_{ji}\left(\underset{-}{p_{ji}}, \underset{+}{q_i}, \underset{+}{R_j}, \underset{+}{P_j}\right)$. We define quality as any intrinsic characteristic or taste preference that improves the consumer appeal of a product given its price. This implies that observed output prices will reflect the combined effect of both objective and subjective dimensions of product quality, while observed input prices will capture only the former. Our empirical analysis will encompass both interpretations as we will examine evidence on both output and input prices.

In order to begin production, firms have to incur sunk entry costs associated with research and product development. Firms face ex-ante uncertainty about their production efficiency, and discover it only after completing this irreversible investment. The success of R&D will generally differ across potential product lines within a firm. A firm's production efficiency in variety i can therefore be thought of as the product $\varphi\lambda_i$ of a firm-wide ability draw φ and a firm-product specific expertise draw λ_i, assumed independent of each other.

Two factors determine firms' marginal production cost c_i: their capacity $\varphi\lambda_i$ to assemble given inputs efficiently and the marginal cost of their inputs w_i, where $c_i = \frac{w_i}{\varphi\lambda_i}$. In the absence of quality differentiation across inputs, all producers would face the same input cost. This will no longer be the case in the presence of quality differentiation, as firms can endogenously choose to use different inputs.

When there is scope for vertical differentiation, we assume that the technology for quality production exhibits two properties. First, manufacturing goods of higher quality is associated with higher marginal input costs because it requires the use of high-quality intermediate inputs, specialized equipment, and skilled workers.[7] Second, there is complementarity between production efficiency and input quality. Such complementarity could be attributed, for example, to the heightened importance of minimizing production errors and ensuring quality control when processing more sophisticated intermediates. These minimal assumptions will be sufficient to generate rich predictions. They are moreover consistent with prior evidence of positive correlations among product quality, output prices, input prices, wages, and management competence across firms within narrow industries (Bloom et al., 2016; Crozet et al., 2011; Iacovone and Javorcik 2010; Kugler and Verhoogen, 2012; Manova and Zhang, 2012; Verhoogen, 2008).

Finally, firms face fixed operation costs of headquarter services f and fixed management costs f_p for each active product line. This will imply that companies with different ability draws will choose to produce a different number of products. Entering each foreign market j necessitates additional headquarter services f_j associated with customs, regulatory compliance, and the maintenance of distribution networks. As a result, some low-ability domestic sellers will not become exporters or will supply some but not all countries. Finally, exporting entails additional destination-product specific fixed costs f_{jp}, which reflect market research, advertising, product customization and standardization. There are also iceberg transportation costs such that τ_j units of a good need to be shipped for 1 unit to arrive. Trade costs are bilateral but we have suppressed the subscripts indicating the exporting country for simplicity. Because of these trade costs, firms will not offer every product they sell at home in every foreign market they enter.

[7] In turn, higher-quality intermediate inputs and more specialized equipment are presumably more expensive because they are produced by more skilled workers that earn a higher wage.

2.2. Firm behavior

2.2.1. Quality and price setting

Upon entry, firms observe their full vector of draws $\{\varphi; \lambda_i, i \in \Omega_i\}$, and decide whether to exit immediately or to commence production. If they begin operations, they determine which products i to manufacture, which country markets j to serve, and which products to offer in each market. To build intuition, we consider a static world in which firms produce a single quality version of each product in their portfolio and there are no supply or demand interdependencies across destination-products within firms. This allows us to illustrate the key mechanisms at play in a tractable environment that reduces the firms' profit maximization problem to a series of separable decisions.

A manufacturer will maximize total profits by separately maximizing the global profits that it could potentially generate from each product. In particular, a firm with ability φ and product expertise λ_i will simultaneously choose the optimal input cost w_i and thereby output quality q_i; whether to enter market j (i.e. $Z_{ji} = 1$) or not (i.e. $Z_{ji} = 0$); and the optimal price p_{ji} and quantity x_{ji} to offer in country j. This maximization problem can be represented as follows:

$$\begin{aligned} \max_{\{w_i, Z_{ji}, p_{ji}, x_{ji}\}} \pi_i(\varphi, \lambda_i) &= \sum_j \pi_{ji}(\varphi, \lambda_i) = \\ &= \sum_j Z_{ji}\left[p_{ji}(\varphi, \lambda_i, w_i)\, x_{ji}(\varphi, \lambda_i, w_i)\right. \\ &\quad \left. - C_{ji}(c_i, x_{ji}, f_{pj}, \tau_j)\ \right] \end{aligned} \tag{1}$$

$$\text{s.t. } x_{ji} = x_{ji}(p_{ji}, q_i, R_j, P_j), \quad c_i = \frac{w_i}{\varphi\lambda_i} \text{ and } q_i = q_i(\varphi, \lambda_i, w_i).$$

Firms are atomistic and take aggregate demand R_j and price indices P_j as given. The total cost of manufacturing and delivering quantity x_{ji} to market j is denoted $C_{ji}\left(\underset{+}{c_i}, \underset{+}{x_{ji}}, \underset{+}{f_{pj}}, \underset{+}{\tau_j}\right)$. It is assumed to increase with marginal costs c_i, quantity x_{ji}, fixed and variable production and distribution costs f_{pj} and τ_j . In the case of domestic sales, $\tau_d = 1$, and fixed costs correspond to the product-specific overhead costs f_p. Recall that *ceteris paribus*, demand x_{ji} is increasing in quality q_i and decreasing in price p_{ji}. Moreover, quality is increasing and supermodular in input costs w_i and production efficiency $\varphi\lambda_i$, while marginal costs c_i are increasing in input costs and decreasing in production efficiency. Although general, these properties allow us to characterize key aspects of firm behavior in equilibrium.

In this environment, the technological complementarity between firm capability and input quality in the production of output quality implies that firms with exogenously higher production efficiency $\varphi\lambda_i$ will endogenously choose to use more expensive, higher-quality inputs and thereby assemble higher-quality products, such that $w_i\left(\underset{+}{\varphi\lambda_i}\right)$ and $q_i\left(\underset{+}{\varphi\lambda_i}, \underset{+}{w_i}\right)$ in the spirit of Kugler and Verhoogen (2012).[8] This will generate quality differences across firms competing in the same product category, and induce each firm to vary input and output quality across its product range in response to the exogenous variation in its expertise λ_i across products.

To fix ideas, it is conveninent to express the endogenous input costs as a function of the exogenous production efficiency $w_i(\varphi, \lambda_i) = (\varphi\lambda_i)^{\theta+1}$, $\theta \geq -1$, whereby marginal costs become $c_i(\varphi, \lambda_i) = (\varphi\lambda_i)^{\theta}$.

[8] Kugler and Verhoogen (2012) and Johnson (2012) show that economies of scale in quality production would generate similar predictions. Manufacturing a higher-quality product might entail higher fixed costs if it requires more complex assembly processes, more expensive equipment, stricter quality control or more managerial oversight. More productive firms that expect to capture a bigger market share by charging lower quality-adjusted prices would then be incentivized to produce higher-quality goods.

This formulation permits a transparent examination of the implications of quality differentiation for various firm outcomes. It is without loss of generality as any monotonic transformation of these functions would preserve our qualitative results. The parameter θ governs the sensitivity of production costs and implicitly of output quality with respect to input quality and production capacity. It can be thought of as the scope for quality differentiation from the consumer's perspective or the return to quality differentiation from the producer's perspective.

Consider the variation across firms manufacturing the same product category. Exogenously more efficient firms will have endogenously (weakly) lower marginal costs if either (i) products are not vertically differentiated (i.e. $\theta = -1$) or (ii) products are vertically differentiated and more efficient firms use higher-quality inputs, but marginal costs do not increase sufficiently quickly with quality (i.e. $-1 < \theta \leq 0$). Conversely, exogenously more efficient firms will have endogenously higher marginal costs if (iii) products are vertically differentiated, more efficient firms use higher-quality inputs, and marginal costs rise sufficiently quickly with quality (i.e. $\theta > 0$). This also applies to the variation in production efficiency and marginal costs across products within firms.

Adopting the nomenclature in the prior literature, we will describe scenarios (i) and (ii) as *efficiency sorting* and scenario (iii) as *quality sorting*. Note that while quality sorting implies the presence of quality differentiation, efficiency sorting does not imply its absence.

In any given market j, firms will charge a price equal to their marginal cost plus an optimal mark-up that generally depends on the nature of consumer demand and market competition. In the absence of dynamic strategic interaction among firms, a seller has no incentive to underprice a competitor with lower marginal costs. In a wide class of standard models, the equilibrium ranking of prices across firm-products will therefore inherit the underlying ranking of marginal costs despite the possibility of variable mark-ups, $p_{ji}\left(\underset{+}{c_i}, \underset{+}{\tau_j}\right)$.

We illustrate this point with three concrete examples. Under CES demand and monopolistic competition as in Melitz (2003), all firms extract the same constant mark-up above marginal cost, determined by the demand elasticity of substitution across varieties. Deviating from either assumption about the market structure creates incentives for variable mark-ups. Under CES demand and Bertrand competition as in Bernard et al.(2003), the most efficient supplier of a good captures the entire market by pricing either at the monopolistically competitive level or at the marginal cost of the second most efficient potential supplier, whichever is lower. Under linear demand and monopolistic competition as in Melitz and Ottaviano (2008), firms' optimal mark-up depends on their marginal cost relative to a choke price at which demand falls to zero, which is governed by demand elasticities and the overall competitiveness in a market.

In all three set-ups, firm-products with exogenously higher production efficiency will sell at lower prices under efficiency sorting and at higher prices under quality sorting. In other words, $p_{ji}\left(\underset{-}{\varphi\lambda_i}\right)$ if $\theta \leq 0$ and $p_{ji}\left(\underset{+}{\varphi\lambda_i}\right)$ if $\theta > 0$. With constant mark-ups, this directly reflects the variation in marginal costs across firms and products. With variable mark-ups, abler producers extract higher mark-ups than less able competitors selling varieties of the same product. Across products within a firm, core goods with higher expertise receive higher mark-ups than peripheral goods with lower expertise. In the case of quality sorting, a firm's higher-quality products thus sell at higher prices both because they entail higher marginal costs and because they secure bigger mark-ups. In the case of efficiency sorting, a firm's more efficiently produced goods sell at lower prices despite receiving higher mark-ups because of their lower marginal costs.[9]

This framework demonstrates how quality differentiation importantly affects the relationship between prices, revenues and profits across active firms and products in a given market j. Since consumer demand decreases with quality-adjusted prices, varieties associated with higher production efficiency will always generate higher sales revenues and profits, such that $r_{ji}\left(\underset{+}{\varphi\lambda_i}\right)$ and $\pi_{ji}\left(\underset{+}{\varphi\lambda_i}\right)$ regardless of the scope for quality differentiation. Under efficiency sorting (i.e. $\theta \leq 0$), firm-products with lower marginal costs $\varphi\lambda_i$ thus command lower prices and earn higher revenues and profits as in Bernard et al. (2010) and Melitz et al. (2014). By contrast, these patterns are reversed under quality sorting (i.e. $\theta > 0$): Within a given product category, more successful firms now enjoy bigger revenues and profits despite charging higher prices because they offer products of superior quality. Across products within a firm, more expensive varieties are of better quality and bring higher revenues and profits.

We have abstracted away from the possibility for cross-product interdependencies in production or consumption in order to emphasize the distinction between efficiency and quality sorting. While cross-product synergies or cannibalization could affect firms' product scope, pricing strategy and sales profile, they would not reorder products in firms' product hierarchy in terms of production efficiency or product quality. As a result, they would not qualitatively change the key predictions for firm behavior in Propositions 1–4 that we take to the data.[10]

2.2.2. Activity across multiple products

The variation in exogenous production efficiency and endogenous product quality across firms and products gives rise to systematic patterns in firms' market entry decisions Z_{ji}. A key feature of this extensive margin is the observance of a product hierarchy from core to peripheral goods that is governed by the scope for quality differentiation.

Consumer love of variety and the presence of product-specific overhead costs f_p imply that no firm will export a product without also selling it at home. Firms will therefore manufacture only goods for which they can earn non-negative profits domestically. Since profits increase in production efficiency $\varphi\lambda_i$, there is a zero-profit expertise cut-off $\lambda^*(\varphi)$ for each ability level φ, below which firm φ will not make product i. This cut-off is defined by $\pi_{di}(\varphi, \lambda^*(\varphi)) = 0$.

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[9] Allowing for dynamic strategic pricing behavior might nuance these theoretical predictions, but it would not affect the interpretation of our empirical results. If firms strategically lower or raise all mark-ups across their product range, our results for the variation across products within firms would still hold. If firms strategically increase the spread of mark-ups between core and peripheral goods, this would amplify forces that we already account for. Finally, if firms strategically decrease the spread of mark-ups between core and peripheral goods, the predicted correlation between prices and revenues across products within firms would be less positive or more negative. This would work against us finding evidence for quality differentiation as we do.

[10] Cross-product synergies or cannibalization effects would generate respectively centrifugal or centripetal forces in firms' product portfolio. For example, Eckel and Neary (2010) study cross-product cannibalization in consumption that arises because an increase in the sales of one variety in a firm's portfolio reduces demand for its other varieties. On the production side, there may be synergies in fixed costs such as equipment or managerial supervision across product lines, or, conversely, diseconomies of scope due to capacity constraints or span of control issues in managerial supervision. Intuitively, centrifugal (centripetal) forces would lead firms to offer more (fewer) products than in our baseline. They may also introduce additional motives for variable mark-ups. If so, any centrifugal (centripetal) force that incentivizes firms to widen (narrow) their product scope would also induce them to concentrate sales away from (towards) their top varieties. Relative to peripheral goods, firms' core products would still generate higher sales, sell at lower (higher) prices under efficiency (quality) sorting, and receive weakly higher mark-ups.

Since φ and λ_i are independent draws, higher-ability firms will have a lower threshold $\lambda^*\left(\underset{-}{\varphi}\right)$ and offer more products.

Turning to trade, firms will only enter a given destination-product market if they expect to earn positive profits there. Given that $\pi_{ji}\left(\underset{+}{\varphi\lambda_i}\right)$, a firm with ability φ will export product i to country j if its expertise draw λ_i is no lower than a zero-profit cut-off $\lambda_j^*(\varphi)$ determined by $\pi_{ji}\left(\varphi, \lambda_j^*(\varphi)\right) = 0$. Following the same logic as before, $\lambda_j^*\left(\underset{-}{\varphi}\right)$ and abler firms will sell a bigger number of products $n_j\left(\underset{+}{\varphi}\right)$ than less able firms to any given destination. Prior evidence indicates that there is selection into exporting such that firms sell only a subset of their domestically-marketed products to country j. Similarly, only a subset of domestically active firms in a given product category export abroad. This is consistent with $\lambda_j^*(\varphi) > \lambda^*(\varphi)$ for all j.

Firms will generally adjust their product range across destinations because $\lambda_j^*(\varphi)$ depends on market-specific aggregate demand R_j, price index P_j, variable τ_j and fixed f_{pj} trade costs. However, sellers will observe a strict hierarchy of products that is stable across destinations. In each market it enters, exporter φ will start with the same core variety and add more goods in decreasing order of expertise λ_i until it reaches the marginal product that brings zero profits.[11]

The nature of this product ladder is the main dimension along which the behavior of multi-product firms changes when there is sufficient scope for vertical differentiation in production. Under efficiency sorting (i.e. $\theta \leq 0$), firms' core competences lie in their cheapest varieties. Sellers therefore expand their product range by adding products in increasing order of marginal cost and price. Under quality sorting by contrast (i.e. $\theta > 0$), a firm's best-selling variety is its most expensive, highest-quality item. Producers now widen their product scope by adding goods in decreasing order of marginal cost and price.

When firms adjust their product range across markets, they can modify not only their product mix on the extensive margin, but also the sales distribution across inframarginal products. This will however depend on the market structure. With CES demand and monopolistic competition, for example, the ratio of a supplier's expertise in two varieties uniquely determines the ratio of their sales in a given market, regardless of the supplier's product scope there. This is no longer the case with variable mark-ups. Consider for instance linear demand with monopolistic competition or, alternatively, CES demand with Bertrand competition. In both cases, firms respond to increased market competition by shifting activity towards their core competences along both the extensive and the intensive margins: They sell fewer varieties by dropping peripheral products, and they also skew the sales distribution across their surviving products towards their top varieties. In more general demand structures with variable mark-ups, any centripetal force that incentivizes firms to narrow their product scope will intuitively also induce them to concentrate sales towards their top varieties. This includes demand structures that allow for cross-product interdependencies in production or consumption.

We summarize the solution to firms' maximization problem at the product level in Eq. (1) as follows: Within a multi-product firm, core goods will be sold to more markets, earn higher revenues in each market, and generate higher worldwide sales than peripheral goods. Within the firm's product portfolio, core goods are always the ones produced with most expertise. However, while they are the cheapest varieties in the absence of quality differentiation, they represent the most expensive, highest-quality ones in its presence.

2.2.3. Activity across multiple markets

A firm with ability φ will enter destination market j if its expected profits there from all varieties i with expertise $\lambda_i > \lambda_j^*(\varphi)$ exceed the fixed headquarters cost of exporting f_{hj}, i.e. if $\pi_j(\varphi) = \sum_{i:\lambda_i > \lambda_j^*(\varphi)} \pi_{ji}(\varphi, \lambda_i) - f_{hj} \geq 0$. Export profits $\pi_j(\varphi)$ increase with ability because abler firms sell more products to j and earn higher revenues from each product, compared to competitors with the same expertise draws but lower ability. Thus only firms with ability above a cut-off level φ_j^* will service destination j, where φ_j^* satisfies $\pi_j\left(\varphi_j^*\right) = 0$.

With asymmetric countries, φ_j^* varies across destinations and abler firms enter more markets because they are above the export threshold for more countries. Abler exporters thus outperform less able producers along all three export margins: number of export destinations, product range in each destination, and sales in each destination-product market.

Finally, not all firms that incur the sunk cost of entry survive. Once they observe their ability and expertise draws, firms begin production only if their expected profits from all domestic and foreign operations are non-negative, i.e. $\pi(\varphi) = \sum_j \pi_j(\varphi) - f_h \geq 0$, where f_h is the firm-level fixed cost of headquarter services. Total profits increase in φ because abler firms manufacture and sell more products domestically, earn higher domestic revenues for each product, and have superior export performance as described above. Companies below a minimum ability level φ^* are therefore unable to break even and exit immediately upon learning their attributes. This cut-off is defined by the zero-profit condition $\pi(\varphi^*) = 0$.

3. Empirical predictions

Section 2 delivers a number of testable predictions that make it possible to empirically distinguish between models of multi-product firms with and without quality differentiation, as well as between models with constant and with variable mark-ups. We now summarize these predictions.

3.1. Variation across firms within a product

Within a given product category, the correlation between price and revenue across firms depends on the extent of quality differentiation. This is a central result in the prior literature and not novel to our framework, but we restate it here for completeness.

Proposition 1. *Across firms within a destination-product market, export prices and export revenues are positively correlated under quality sorting ($\theta > 0$), but negatively correlated under efficiency sorting ($\theta \leq 0$).*

3.2. Variation across products within a firm

In the absence of vertical differentiation across products, firms' core products have low marginal costs and prices. By contrast, when there is scope for quality upgrading, firms' best-selling varieties are associated with superior quality, higher marginal costs, and higher prices.

Proposition 2. *Across products within a firm and across products within a firm-destination, export prices and export revenues are positively correlated under quality sorting ($\theta > 0$), but negatively correlated under efficiency sorting ($\theta \leq 0$).*

[11] Product hierarchies will generally vary among producers because the expertise draws are i.i.d. across firms and goods. In practice, the product ranking might also vary across countries within a manufacturer if there are idiosyncractic taste or cost shocks at the firm-destination-product level. Such idiosyncracies would work against us finding empirical support for our theoretical propositions.

3.3. Variation across destinations within a firm

3.3.1. Product scope and product hierarchies

Multi-product firms observe a product hierarchy. Firms focus on their core competences and drop their peripheral goods in destinations where they sell fewer products. With constant mark-ups, this has clear implications for a firm's average price $\bar{p}_j(\varphi)$ across the products it offers in market j. Under quality sorting, exporters add varieties in decreasing order of marginal cost and quality. Firm φ will thus offer lower average quality at a lower average price in countries where it exports more products. Under efficiency sorting by contrast, product scope $n_j(\varphi)$ and $\bar{p}_j(\varphi)$ are instead positively correlated across destinations within firms, because exporters add products in increasing order of marginal cost.

The relationship between firms' product range and average price is more nuanced in environments with variable mark-ups. It is still the case that firms offer more cheaper (expensive) varieties when they expand their product scope under quality (efficiency) sorting. At the same time, sellers might also charge higher mark-ups depending on the market structure. In the case of linear demand and monopolistic competition, for example, firms export more products to markets where they face less competition and where they can therefore set higher mark-ups. Under efficiency sorting, variable mark-ups can thus amplify the positive correlation between product scope and $\bar{p}_j(\varphi)$ across destinations within a firm. Under quality sorting, by contrast, variable mark-ups can make this correlation less negative and possibly even positive.

Note that across markets within a firm, the correlation between the number of exported products $n_j(\varphi)$ and the simple average product price $\bar{p}_j(\varphi)$ is driven by the extensive margin of product selection. The corresponding correlation between $n_j(\varphi)$ and the revenue-weighted average product price $\tilde{p}_j(\varphi)$ reflects both product selection and the relative sales of different products in the firm's portfolio. Since core varieties generate higher sales, $\tilde{p}_j(\varphi) > \bar{p}_j(\varphi)$ under quality sorting and $\tilde{p}_j(\varphi) < \bar{p}_j(\varphi)$ under efficiency sorting. This implies that the correlation between $n_j(\varphi)$ and $\tilde{p}_j(\varphi)$ is smaller than the correlation between $n_j(\varphi)$ and $\bar{p}_j(\varphi)$ in absolute terms, and its precise sign is theoretically ambiguous.

Proposition 3. *Firms observe a product hierarchy. They expand product scope by adding more peripheral products of lower price under quality sorting ($\theta > 0$) and by adding more peripheral products of higher price under efficiency sorting ($\theta \leq 0$). Across destinations within a firm, product scope and the simple average product price are positively correlated under efficiency sorting; either negatively or positively correlated under quality sorting; and less correlated than product scope and the revenue-weighted average product price.*

3.3.2. Product scope and sales distribution

All else constant, firms earn higher revenues in destinations where they export more goods. Depending on the market structure, the distribution of sales across products may or may not change with the number of varieties sold. These relationships hold regardless of the presence and scope for quality differentiation in production.

Proposition 4. *Across destinations within a firm, export product scope and export revenues are positively correlated. Across destinations within a firm, the distribution of revenues across products is independent of product scope under constant mark-ups, but its skewness towards the firm's core products decreases with product scope under variable mark-ups.*

4. Data

Our analysis exploits proprietary data from the Chinese Customs Office on the universe of Chinese firms that participated in international trade over the 2002–2006 period.[12] These data report the free-on-board value of all export and import transactions in U.S. dollars by firm, product and trade partner for 239 destination/source countries and 8,908 different products in the 8-digit Harmonized System.[13] They also record the quantities traded in one of 12 different units of measurement (such as kilograms, square meters), which makes it possible to construct unit values. Trade volumes for each HS-8 digit product category are consistently documented in a unique unit of measurement.

In principle, unit values should precisely reflect producer prices. Since trade datasets rarely contain direct information on prices, the prior literature has typically relied on unit values as we do. The level of detail in our data is an important advantage as the unit prices we observe are not polluted by aggregation across firms or across markets and products within firms. We have confirmed that all of our results are robust to excluding potential outliers with price levels below the 1st percentile or above the 99th percentile.

While we observe all trade transactions at the monthly frequency, we work with annualized exports for two reasons. First, there is a lot of seasonality and lumpiness in the monthly data, and most companies do not sell the same product to a given market in every month. By focusing on annual data, we avoid this issue and related concerns with sticky prices. Second, outliers are likely to be of greater concern in the monthly data.

Some state-owned enterprises in China are pure export-import businesses that do not engage in manufacturing but act exclusively as intermediaries between domestic producers (buyers) and foreign buyers (suppliers). Following standard practice in the literature, we identify such wholesalers using keywords in firms' names and exclude them from our sample.[14] We do so in order to focus on the operations of companies that both make and trade goods since we are interested in how production efficiency and product quality affect export activity. Showing direct evidence on the prices firms pay for imported inputs is thus an important part of our analysis as they proxy input quality. We cannot apply this approach to intermediaries because we do not observe their suppliers and cannot interpret their import transactions as input purchases.

We study the variation in the scope for quality differentiation across products using three relatively standard proxies in the literature. These measures are meant to capture technological characteristics of the manufacturing process that are exogenous from the perspective of an individual firm. The first indicator is the Rauch (1999) dummy for differentiated goods that are not traded on an organized exchange or listed in reference manuals. It is available for SITC 4-digit categories, which we concord to the Chinese HS 8-digit classification. We also employ continuous measures of R&D intensity or combined advertising and R&D intensity from Klingebiel et al. (2007) and Kugler and Verhoogen (2012), respectively. These are based on U.S. data for 3-digit ISIC sectors, which we match to the HS-8 products in our data.

[12] Manova and Zhang (2008) describe these data and provide an overview of Chinese trade patterns. While the raw data covers the 2000–2006 period, the HS 8-digit product classification changed in 2002. Given our interest in the operations of multi-product firms, we focus on the 2002–2006 period for which products are consistently coded.

[13] Product classification is consistent across countries at the 6-digit HS level. The number of distinct product codes in the Chinese 8-digit HS classification is comparable to that in the 10-digit HS trade data for the U.S.

[14] We drop 23,073 wholesalers who mediate a quarter of China's trade. Using the same data, Ahn et al. (2011) identify intermediaries in the same way in order to study wholesale activity.

4.1. Comparing prices across products

Our empirical strategy critically rests on the comparison of prices across a firm's product range. Conceptually, we are interested in how quality differs across products, where quality is interpreted as the utility consumers derive from a single physical unit of a product. This poses an obvious challenge: Given both horizontal and vertical differentiation across products, we cannot characterize the quality of different goods in a firm's production portfolio in absolute terms. We can, however, rate them in relative terms based on how they compare to the average variety available on the market in their respective product category.

As an illustrative example, consider a firm that sells both printers and cell phones. Let its printer be q_p times better than the average printer on the market and its cell phone be q_c times better than the average cell phone on the market, where $q_p > q_c$. Through the lens of our model, we would ascribe q_p and q_c as the quality levels of the firm's printer and cell phone, respectively. We would moreover expect that the firm's core competence is in manufacturing printers, while cell phones are its peripheral good.

We implement this approach by demeaning every export (import) unit value by the average observed across all firms exporting (importing) that HS 8-digit product category. For example, if firm f charges $logprice_{fp}$ for HS 8-digit product p, and the average log export price across all Chinese firms selling p is $\overline{\log price_p}$, then we use $\log price_{fp} - \overline{\log price_p}$ as a standardized price that we can compare across f's different HS 8-digit products. When we examine f's operations in a particular destination d, we are careful to demean its export prices by the relevant averages across Chinese exporters to that specific market. In other words, if f ships products p and p' to country d, we will compare $\log price_{fpd} - \overline{\log price_{pd}}$ to $\log price_{fp'd} - \overline{\log price_{p'd}}$. Our results for bilateral exports are however not sensitive to this choice of demeaning, and also obtain if we subtract the global $\overline{\log price_p}$ and $\overline{\log price_{p'}}$ averages instead.

Working with log prices instead of prices is motivated by two reasons. First, it is what theory calls for, given that we will estimate model-based equations in their log-linear form with Ordinary Least Squares. Second, by demeaning log prices we obtain the distance between a firm's price from the market average in percentage terms rather than in absolute levels. This facilitates the comparison of prices across products by accounting for differences across product categories in both the first and the second moments of the price distribution.

4.2. A first glance at the data

Table 1 illustrates the substantial variation in export prices across the 176,116 Chinese manufacturers, 7,481 export products, and 239 destination countries in the unbalanced 2002–2006 panel. Consider first the average price of each firm-product-year triplet, constructed as the ratio of annual worldwide sales and quantities across all destinations served d, $price_{fpt} = \frac{\sum_d revenue_{fpdt}}{\sum_d quantity_{fpdt}}$. After removing product-year pair fixed effects, the mean log price in the data is 0.00 (by construction), with a standard deviation of 1.32 across goods and manufacturers. There is comparable dispersion at the firm-product-destination-year level, with an average log price of 0.00 (by construction) and standard deviation of 1.24.

Prices vary considerably across Chinese producers selling the same HS 8-digit product, to the same country, in a given year: The standard deviation of firm prices in the average destination-product-year market is 0.89. This highlights the extent of firm heterogeneity in the data.

There is also a lot of variation in unit values across products within firms. The standard deviation of demeaned log prices across goods within a firm-year is 0.84 on average when we consider worldwide exports. This number remains high at 0.75 when we instead look at the spread of bilateral export prices across products for the average firm-destination-year triplet. This demonstrates the heterogeneity in product attributes across an exporter's merchandise.

Table 2 indicates that the variation in unit values across products within multi-product firms is not random: Export prices and revenues are in fact systematically positively correlated across a manufacturer's product range. For each year in our sample, we rank each firm's products twice, once based on their worldwide sales and once based on their export price. The best selling or most expensive good is ranked first, the second most receives second rank, etc. We thus obtain every firm's *global* product ranking by sales and by price.

Table 2 shows that firms' top-selling varieties tend to be their most expensive ones. Each cell in the table reports what fraction of all firm-product pairs receive a certain rank by price (rows) and sales (columns), averaging across years in the panel. A firm's leading product by export revenues is often also its most or second-most expensive product (45%=5.47/12.19 and 19%=2.27/12.19 of the time, respectively). Similarly, a firm's most expensive product is usually ranked first or second by export revenues (45% and 18% of the time, respectively). Moreover, the entries along the diagonal contain the biggest fraction of firm-product pairs in any row or column. In other words, across all products in a firm's output basket, the price rank of a given product is most likely to exactly coincide with its sales rank. We view these patterns as suggestive of quality differentiation across products within a firm. In particular, exporters' core expertise appears to lie in expensive, high-quality goods that generate the most revenues, whereas peripheral products are cheap, of low quality and contributing little to sales.

Table 1
This table summarizes the variation in f.o.b. export prices across firms, products, and destinations in the 2002–2006 panel. Line 1 (Line 2): summary statistics for firm-product-year (firm-product-destination-year) log prices, after taking out product-year pair fixed effects. Line 3: for each destination-product-year market with multiple Chinese exporters, we record the standard deviation of log prices across firms, after taking out destination-product-year triple fixed effects. Line 3 shows how this standard deviation varies across destination-product-year triplets. Line 4 (Line 5): for each multi-product firm, we record the standard deviation of log prices across products by year (by destination-year). Line 4 (Line 5) shows how this standard deviation varies across firm-year (firm-destination-year) observations.

	# Obs	Average	St Dev	Min	5th Percentile	95th Percentile	Max
Panel A. Variation across firms within products							
1. Firm-product-year prices (product-year FE)	6,185,641	0.00	1.32	−15.30	−2.01	2.16	14.07
2. Firm-product-dest-year prices (product-year FE)	14,351,836	0.00	1.24	−16.59	−1.92	2.01	14.30
3. St dev of prices across firms within dest-product-year triplets (dest-product-year FE)	1,071,478	0.89	0.73	0.00	0.07	2.28	10.02
Panel B. Variation across products within firms							
4. St dev of prices across products within firm-year pairs (firm-year FE, product-year FE)	547,534	0.84	0.63	0.00	0.12	2.05	9.29
5. St dev of prices across products within firm-dest-year triplets (firm-dest-year FE, product-year FE)	2,200,442	0.75	0.63	0.00	0.07	1.94	9.77

Table 2
This table ranks products within multi-product firms based on either worldwide export revenues (columns) or export price (rows), separately for each year in the 2002–2006 panel. The product with the highest sales (price) in each firm-year is ranked first, the second highest receives rank 2, etc. For each firm-product-year triplet, we construct the export price as the ratio of worldwide export revenues and quantities, demeaned by its product-year average across firms. Each cell in the table shows what percent of all firm-product pairs receive a certain rank by price and revenue, averaged across all years.

Product rank by sales	1	2	3	4	5	> 5	Total
Product rank by price							
1	**5.47%**	2.15%	1.18%	0.75%	0.51%	2.13%	12.19%
2	2.27%	**2.30%**	1.14%	0.69%	0.47%	1.99%	8.86%
3	1.23%	1.22%	**1.26%**	0.71%	0.46%	1.91%	6.79%
4	0.76%	0.74%	0.76%	**0.81%**	0.48%	1.88%	5.43%
5	0.51%	0.50%	0.51%	0.51%	**0.55%**	1.87%	4.45%
>5	1.95%	1.95%	1.95%	1.96%	1.97%	**52.51%**	62.28%
Total	12.19%	8.86%	6.79%	5.43%	4.45%	62.28%	100.00%

Appendix Table 2 provides additional summary statistics for the variation in export revenues across firms, destinations, products and years, as well as in export quality which we infer from the data on export prices and quantities as described below.

5. Empirical results

Our empirical analysis proceeds in three steps. In Section 5.1, we first revisit evidence in the prior literature that constitutes a starting point for our analysis and informs Proposition 1. We document a positive correlation between export prices and revenues across manufacturers of the same product category, which we interpret as consistent with quality differentiation across firms.

We next turn to our novel contribution, and examine the variation in market activity across products within firms. In Section 5.2, we test the central predictions of Proposition 2. We establish several empirical results which together suggest that multi-product firms use inputs of different quality levels in order to produce goods of different quality levels. Moreover, a firm's core competence is determined by product quality, such that its higher-quality goods command higher prices and generate higher revenues. In Section 5.3, we then study the relationship between product scope, export revenues, average price, and sales skewness across destinations within a firm, as per Propositions 3 and 4. Our findings indicate that firms concentrate activity towards their core, high-quality goods in markets where they offer fewer products and earn lower export revenues. This occurs through adjustments both on the extensive margin of product scope and on the intensive margin of product sales.

Our baseline analysis considers the cross-sectional variation in export activity across firms and products in the 2002–2006 panel. This allows us to directly project theoretical predictions onto the data. In Section 5.4, we provide additional corroborative evidence based on multi-product firms' export dynamics. This time-series evidence is consistent with firms' expected response to changes in the econonomic environment within our conceptual framework, and helps validate the economic mechanisms of interest.

5.1. Variation across firms within a product

Past work has documented that export prices and revenues are positively correlated across firms within narrow segments of the global economy, such as finely disaggregated product categories or country-product markets. In light of Proposition 1, this is indicative of quality differentiation across firms, with more successful exporters offering better-quality goods at higher prices.

Appendix Table 3 confirms that these patterns hold in our data as well. In the spirit of Manova and Zhang (2012) who study the cross-section of China's trade transactions in 2005, we regress log export unit values on log export revenues by firm, product, destination, and year. Controlling for destination-product-year triple fixed effects, we find a positive and significant coefficient. The point estimates suggest that a one-standard-deviation increase in export revenues is accompanied by 20% higher free-on-board export prices. This association is moreover stronger for products with arguably greater scope for quality differentiation, such as differentiated goods and sectors intensive in R&D and advertising. Column 6 shows that a theoretically-motivated proxy for product quality is likewise positively correlated with export revenues across firms in a given market; we describe this proxy in more detail below.

5.2. Variation across products within a firm

5.2.1. Export prices and export revenues

We now turn to the variation in export activity across products within multi-product firms as informed by Proposition 2. We first consider the relationship between exporters' global sales and prices by product. For each year, we aggregate the data to the firm-product level by summing trade revenues and quantities across markets. We then take their ratio and construct firm f's average export price for product p across all destinations d it serves in year t as $price_{fpt} = \frac{\sum_d revenue_{fpdt}}{\sum_d quantity_{fpdt}}$. In order to make these prices comparable across goods, we demean them by their product-year specific average across firms. For notational simplicity, ln $price_{fpt}$ below always refers to these demeaned log prices.

We estimate the following specification:

$$\ln price_{fpt} = \alpha + \beta \ln revenue_{fpt} + \delta_{ft} + \varepsilon_{fpt}, \qquad (2)$$

where $revenue_{fpt} = \sum_d revenue_{fpdt}$. As per our model, we include firm-year fixed effects δ_{ft} to account for systematic differences in ability across exporters, as well as for changes in this ability level within firms over time. These fixed effects also control for all observed and unobserved firm characteristics outside our model that affect trade outcomes symmetrically across the product range, such as productivity, managerial competence, fixed capital equipment, worker skill, distribution networks, or experience in foreign markets. At this level of aggregation, the sample comprises 4,127,779 observations spanning 175,949 firms and 7,477 products. We cluster errors by firm throughout the paper, to allow for correlated shocks within firms over time.[15] Our results are robust to alternative treatments of the error term, such as clustering by product, by both firm and product, or by destination (where relevant).

We are primarily interested in β, which reflects the sign of the conditional correlation between export price and revenues across goods within a firm. The sign of this correlation allows us to evaluate the importance of product quality for the operations of multi-product exporters. In particular, $\beta > 0$ would be consistent with quality sorting and $\theta > 0$ in the model, while $\beta < 0$ would correspond to efficiency sorting and $\theta < 0$. We emphasize that we

[15] This is motivated by the likely structure of the error term. The δ_{ft} account for supply and demand shocks that might be correlated across products within a firm at a given point in time, while demeaning the left-hand side variable by product-year accommodates possible correlated shocks across firms exporting the same product in the same year. Clustering by firm addresses the potential additional correlation in supply and demand shocks within firms over time. For example, firms with more effective management might be less affected by negative aggregate shocks than firms with weaker management subject to the same shocks.

Table 3
This table examines the relationship between worldwide export prices and revenues across products within firm-years. For each firm-product-year triplet, the log export price is the log ratio of worldwide export revenues and quantities, demeaned by its product-year average across firms. In Column 2 market power is proxied by the firm's share of total Chinese exports by product-year. Product scope for quality differentiation is proxied by the Rauch dummy for differentiated goods (Column 3), sectors' R&D intensity (Column 4), or sectors' combined advertising and R&D intensity (Column 5). Column 6 uses products' rank by price and revenues across products within each firm-year instead of log price and log revenues. In Column 7 log price is replaced by a proxy for log quality constructed from data on export prices and quantities. All regressions include a constant term and firm-year pair fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% level.

Dependent variable: (log) export price by firm, product and year	Baseline (1)	Market power (2)	Rauch dummy (3)	R&D intensity (4)	Adv + R&D intensity (5)	Product rank (6)	(log) Quality (7)
(log) Sales	0.038***	0.040***	0.026***	0.035***	0.038***	0.055***	1.006***
	(61.07)	(62.28)	(19.75)	(47.91)	(44.61)	(3.79)	(385.57)
Market share		−0.415***					
		(−17.58)					
(log) Sales x Quality differentiation			0.019***	0.270***	0.065**		
			(13.94)	(9.94)	(2.28)		
Quality differentiation			−0.206***	−4.767***	0.336		
			(−15.93)	(−18.95)	(1.48)		
Firm-Year FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.43	0.43	0.46	0.43	0.43	0.72	0.56
# Observations	4,127,779	4,127,779	2,857,087	3,995,973	4,013,020	4,127,779	4,127,779
# Firms	175,949	175,949	156,088	170,785	171,608	175,949	175,949

cannot and do not want to give β a causal interpretation, since unit values and sales are joint outcomes of producers' profit maximization and are both determined by firm ability and product expertise.

The results in Table 3 lend strong support to quality differentiation across a firm's products. Within firms, more expensive goods generate systematically higher global sales. The estimates in Column 1 imply that a one-standard-deviation increase in exports is associated with 10.6% higher prices. Column 2 confirms that this result is unrelated to the variation in a company's market power across products, which could influence its pricing strategy for reasons outside our model. For instance, strategic interactions among firms could lead them to charge variable mark-ups that depend on their market presence relative to competitors. For each product p and year t, we proxy firm f's market power with its share of total Chinese exports of p, $\frac{revenue_{fpt}}{\sum_f revenue_{fpt}}$, where the sum in the denominator is taken over all firms exporting p.

We conduct two further sensitivity analyses to ensure that our findings are not driven by measurement error (ME) in export values or quantities that could bias β.[16] First, we explore the variation in the scope for quality differentiation across products using three common measures for θ in the model. In Column 3, we regress export prices on export revenues, the Rauch (1999) indicator for differentiated goods, and the interaction of the two. The rational for this diff-in-diff approach is that while ME might be present, it arguably does not vary systematically across industries. ME is thus more likely to affect β than the coefficient on the interaction term. Indeed, the positive correlation between export prices and revenues is 73% higher for differentiated products. Similar results obtain in Columns 4 and 5 when we instead proxy θ with sectors' R&D intensity or combined advertising and R&D intensity. For example, prices increase 5.4 percentage points faster with revenues in an industry with 20% higher R&D intensity. All of these patterns are highly significant at 1% or 5%.

As a second specification check, we study the *rank* of firms' export price and revenues instead of their *level*. This allows us to rely much less directly on the construction of unit prices. We order each manufacturer's products based on its worldwide sales, such that the top-selling good is ranked first, the second-most receives rank 2, etc. We also array firms' products by their demeaned unit values. We allow for changes in firms' product hierarchy over time by calculating these rankings separately for each year. As Column 6 illustrates, there is a strong positive correlation between products' global rank by price and by revenue across goods within exporters. In unreported regressions, we have confirmed that this correlation increases with sectors' scope for quality differentiation. These results reinforce our conclusion that $\beta > 0$ is not driven by ME bias, since such bias would have to be severe to systematically distort product rankings.

We next perform a more stringent test of the model and examine the variation across exporters' goods within specific destination markets. We estimate an expanded version of Eq. (2) with the firm-product-country-year quadruplet as the unit of observation:

$$\ln price_{fpdt} = \alpha + \beta \ln revenue_{fpdt} + \delta_{fdt} + \varepsilon_{fpdt}. \tag{3}$$

Here ln $price_{fpdt}$ is firm f's log price for product p in destination d in year t, after it has been demeaned by the product-country-year specific average price. Similarly, bilateral instead of global trade values enter on the right-hand side. We include firm-destination-year triple fixed effects δ_{fdt}, which implicitly account for the variation in total expenditure, trade costs, consumer price indices, and market toughness across countries as directed by theory. The δ_{fdt} dummies additionally control for cross-country differences in consumer preferences and other institutional frictions that are outside our model, as well as for firms' market-specific distribution networks and export experience. For simplicity, we use the same coefficient notation in all estimating equations, although the coefficients differ conceptually across specifications.

As evidenced in Table 4, exporters earn higher revenues from their more expensive products not only in terms of worldwide sales, but also within each destination. This correlation is not driven by differences in market power across a firm's product lines, which we now proxy with bilateral market shares $\frac{revenue_{fpdt}}{\sum_f revenue_{fpdt}}$. The relationship is also significantly stronger for goods with greater scope for quality upgrading. It is furthermore robust to using products' price and revenue ranks instead of levels, where these ranks have been constructed separately for each firm, year, and importing country based on bilateral sales.

Overall, the point estimates in Table 4 and their statistical significance are very similar to those for global exports in Table 3. For example, a one-standard-deviation increase in bilateral exports is accompanied by 9.5% higher bilateral unit values. This comovement

[16] See Manova and Zhang (2012) for a discussion of why the direction of such bias is ex-ante ambiguous and depends on the nature of ME in revenues and/or quantities. They also show that the correlation of price and revenue is not mechanically positive by construction.

Table 4
This table examines the relationship between bilateral export prices and revenues across products within firm-destination-years. For each firm, product, destination and year, the log price is demeaned by its product-destination-year average across firms. In Column 2 market power is proxied by the firm's share of total Chinese exports by product-destination-year. Product scope for quality differentiation is measured as in Table 3. Column 6 uses products' rank by price and revenues across products within each firm-destination-year triplet instead of log price and log revenues. In Column 7 log price is replaced by inferred log quality as in Table 3. All regressions include a constant term and firm-destination-year triple fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dependent variable: (log) export price by firm, product, destination and year	Baseline (1)	Market power (2)	Rauch dummy (3)	R&D intensity (4)	Adv + R&D intensity (5)	Product rank (6)	(log) Quality (7)
(log) Sales	0.038***	0.040***	0.032***	0.031***	0.034***	0.065***	0.898***
	(41.24)	(41.99)	(19.95)	(28.64)	(27.68)	(3.40)	(219.13)
Market share		−0.072***					
		(−6.94)					
(log) Sales x Quality differentiation			0.012***	0.396***	0.188***		
			(7.09)	(11.45)	(5.12)		
Quality differentiation			−0.178***	−6.331***	−1.570***		
			(−12.35)	(−20.21)	(−5.47)		
Firm-Dest-Year FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.53	0.53	0.57	0.54	0.54	0.72	0.61
# Observations	9,481,443	9,481,443	6,533,138	9,247,765	9,290,452	9,481,443	9,481,443
# Firm-dest pairs	175,949	175,949	156,088	170,785	171,608	175,949	175,949

in export sales and prices across products within firms amounts to half of the corresponding comovement across firms within product markets reported in the previous section. This signals the empirical relevance of the model in rationalizing both patterns in the data.

5.2.2. Inferred export quality and export revenues

The results in Tables 3 and 4 show that firms' best-selling products are their most expensive varieties. In our model, this outcome obtains only when there is quality variation across goods within a firm, and when it is sufficiently powerful to dominate the price effects of efficiency heterogeneity, i.e. $\theta > 0$. It is thus possible that firms actively vary quality across their product range, but this force is overpowered by the correlated variation in production efficiency across goods. A separate concern is that theoretical frameworks other than the ones we have considered might generate a positive relationship between prices and revenues without the quality mechanism.

The systematic patterns that we document across sectors with different potential for quality upgrading go a long way towards establishing our quality interpretation. Nevertheless, we would ideally like to show corroborative evidence using direct measures of product quality. In the absence of such information, we first construct an indicator $\hat{q}_{fpt}$ for unobserved product quality q_{fpt} from observed data on export quantities x_{fpt} and prices p_{fpt}. We proxy quality with $\ln \hat{q}_{fpt} = \sigma \ln x_{fpt} + \ln p_{fpt}$, where we set the elasticity of substitution across varieties at the commonly used value $\sigma = 5$; our results are robust to alternative choices over σ. This quality proxy can be structurally motivated in theoretical models that feature CES preferences and constant mark-ups such as Khandelwal (2010), and it has been used for example in Khandelwal et al. (2013) and Fan et al. (2015). We remove product-year fixed effects from this calculation to ensure that prices and quantities are comparable across products.

The results in Column 7 of Table 3 reveal that export revenues are positively correlated with inferred quality $\ln \hat{q}_{fpt}$ across products within a firm. In Column 7 of Table 4, we similarly find a strong positive correlation between bilateral export revenues and quality across products within a firm-destination, where we impute market-specific product quality as $\ln \hat{q}_{fpdt} = \sigma \ln x_{fpdt} + \ln p_{fpdt}$. We obtain substantially higher point estimates than in our baseline price regressions in Column 1, suggesting that firms' core products feature both high quality and high production efficiency as manifested in low quality-adjusted prices. A one-standard-deviation rise in bilateral export revenues is on average attained with 280% higher product quality. While this evidence is consistent with the quality channel we emphasize, an important caveat is that $\hat{q}_{fpt}$ and $\hat{q}_{fpdt}$ would not accurately proxy product quality in theoretical frameworks with variable mark-ups.

5.2.3. Export prices and imported-input prices

To more conclusively establish the quality mechanism, we exploit the rich nature of our data to obtain measures for the quality of firms' inputs in production. A large number of Chinese exporters use imported inputs (59% of all exporters and 57% of all exporter-year observations), and the customs files record all such input purchases. While we do not observe manufacturers' use of domestic materials, inputs, and labor, we can therefore use the prices they pay for imported parts as an indicator for the quality of all of their inputs. A positive correlation between this indicator and export prices across a firm's products would then signal that producers vary the quality of their outputs by using inputs of different quality levels.[17]

Combining information on input and output prices has two additional advantages. From an economics perspective, input prices in principle capture the objective quality of an input and, by extension, its resultant output; output prices by contrast reflect both products' objective quality and consumers' subjective quality valuation. From an econometrics perspective, input and output prices are obtained from independent data series, such that their relationship is not subject to ME concerns that could bias the correlation between output sales and prices.

Operationalizing this methodology poses some challenges. We are interested in exporters that make multiple products using multiple intermediates. For each firm f and product p at time t, we would thus like to calculate ln *input price*$_{fpt}$, the average input price across all imported inputs that f uses to manufacture p. We therefore need to allocate inputs to outputs in order to develop quality proxies that vary across products within a firm. We pursue two different strategies, and find very similar results that are consistent with quality differentiation.

We first focus on foreign inputs in the same broad industry classification as the output product. For example, if a firm buys tyres and steering wheels and sells cars, both its exports and imports would

[17] If such a positive correlation instead reflected producers passing on cost shocks to consumers for reasons outside our model, we would have observed a negative correlation between export prices and revenues, because in that case higher export prices would have implied less efficient production rather than higher quality.

be recorded in the automobile industry. The average price across the tyres and wheels that it uses would then proxy the quality of the cars that it makes. If the company also manufactures cell phones, the price that it pays for SIM cards would enter the measured quality of its cell phones but not that of its cars.

Recall that we observe trade flows by HS 8-digit product. For every producer *f*, we construct a weighted average log input price across all materials that *f* imports (e.g. tyres, steering wheels) in a given HS 3-digit category (e.g. vehicles), which we label $\ln input\ price^{HS3}_{fpt}$. We use import values as weights, but our results are robust to taking an unweighted average instead.[18] We assign $\ln input\ price^{HS3}_{fpt}$ to all HS 8-digit products *p* that *f* exports in a given HS 3-digit industry (e.g. cars and trucks). This allows us to obtain input quality proxies for 25% of the observations at the firm-export product-year level in our data, for a sample of 1,031,424 observations.

Our second approach to matching firms' imported inputs to exported products relies on detailed input-output tables for China. These tables report the total value of inputs used from one sector for production in another sector, in a matrix of 139 sectors. The relative contribution of two inputs varies significantly across output sectors. For example, manufacturing a car might require tyres, multiple LED displays and some cloth for upholstery; assembling a cell phone might demand only one display, no tyres and no cloth; and sewing a dress might need only cloth.

For each firm, we can therefore apply the input-output tables to allocate some part of its every imported input to each of its exported products. Let u_{ij} be the value of input *i* used in the production of sector *j* in the IO tables. Let the set of sectors *j* exported by firm *f* be *J*. We assume that a share $\frac{u_{ij}}{\sum_{j \in J} u_{ij}}$ of *f*′s total imports of *i* are employed in manufacturing *j*. Using these inferred input values as weights, we construct the weighted average input price for firm *f*'s output *j* across its inputs *i* in year *t*.[19] We refer to this measure as $\ln input\ price^{IO}_{fpt}$, and assign it to all HS-8 digit products that *f* exports in IO sector *j*. This generates input quality proxies for 58% of the observations at the firm-export product-year level in our data, for a sample of 2,403,309 observations.

We believe that parsing out inputs to outputs in this way is informative if imperfect. It gauges the variation in marginal costs across a firm's products in a more comprehensive way than focusing only on inputs within the same narrow sector as the output, as we did for $\ln input\ price^{HS3}_{fpt}$. At the same time, companies need not necessarily combine intermediates in the same proportion as in the IO tables. To the extent that individual firms' input sourcing strategy and production process deviate from the aggregate patterns reflected in the IO tables, this would introduce classical measurement error and bias our results downwards. For robustness, in unreported regressions we have considered a slightly different formula for $\ln input\ price^{IO}_{fpt}$ and reassuringly obtained very similar results.[20]

We examine the relationship between producers' output and input prices by estimating:

$$\ln price_{fpt} = \alpha + \beta \ln input\ price_{fpt} + \delta_{ft} + \varepsilon_{fpt}, \tag{4}$$

where $\ln price_{fpt}$ is firm *f*′s demeaned export price for product *p* in year *t* based on worldwide sales. We measure $\ln input\ price_{fpt}$ with either $\ln input\ price^{HS3}_{fpt}$ (Panel A of Table 5) or $\ln input\ price^{IO}_{fpt}$ (Panel B); the two deliver point estimates of comparable magnitude and significance. As before, we exploit purely the variation across output goods within a manufacturer by including firm-year pair fixed effects δ_{ft}. We are once again interested in β as a conditional correlation that does not permit a causal interpretation: The choices of input and output quality are intimately related in exporters' profit maximization problem in a framework with endogenous quality choice.

Consistently with our theoretical predictions for $\theta > 0$, we find a highly statistically and economically significant positive association between input and output prices across products within a firm. Our baseline in Column 1 indicates an elasticity of 0.11 to 0.13. These results are robust to explicitly controlling for manufacturers' market power both in the output market for their export goods and in the input market for their imported parts (Column 2). As earlier, we capture the former with *f*′s share of total Chinese exports of output product *p* in year *t*, $\frac{revenue_{fpt}}{\sum_f revenue_{fpt}}$. To measure the latter symmetrically, for each year we average *f*′s share of total Chinese imports across all of its inputs that are matched to its output product *p* and used in the calculation of $\ln input\ price_{fpt}$.[21]

Through the lens of our model, we interpret this as strong evidence that Chinese exporters use inputs of different quality levels to produce goods of different quality levels. To shed more light on this mechanism, we re-estimate Eq. (4) separately for homogeneous and differentiated export products in Columns 3 and 4. Firms' export prices rise substantially more quickly with their input prices when the output product is differentiated. This is in line with the model's prediction that output price and quality increase faster with marginal cost and input quality in sectors with greater scope for quality differentiation (i.e. higher θ).

Our results survive two additional sensitivity checks. All Chinese customs transactions are recorded as occurring under one of two main trade regimes: processing and ordinary trade.[22] Processing firms import inputs specifically for further processing, assembly, and re-exporting. Ordinary exporters may or may not use imported materials when producing for foreign markets. Since we have removed all trade intermediaries from our sample, we can interpret the import transactions of both ordinary and processing exporters as purchases of foreign inputs. We have nevertheless confirmed that all patterns in Table 5 hold when we focus on processing imports only. Column 5 replicates our baseline regression for this subsample.

We also verify that our results are not driven by potential aggregation bias in the matching of inputs to outputs. By design, the two algorithms we use can map multiple HS 8-digit export products to the same imported-input price (at the HS 3-digit or IO-sector level). In Column 6, we collapse the data such that output prices on the left-hand side are at the same level of aggregation as input prices on the right-hand side. Our results continue to hold, with the point estimate for β increasing. All findings in Columns 2–5 also obtain at this level of aggregation.

Finally, Column 7 shows that a strong positive relationship holds not only between input and output prices, but also between inferred input and output quality across products within a firm. Following the same methodology as in Section 5.2.2, we back out proxies for

[18] Before this manipulation, we demean all import prices by their product-year specific average across firms. This makes import prices comparable across inputs and parallels our standardization of export prices.

[19] As before, we use import prices demeaned by their product-specific average import price across firms.

[20] In particular, we constructed the weighted average input price using the ratios $\frac{u_{ij}}{\sum_{i \in I} u_{ij}}$ as weights without exploiting information on firms' import values. These weights implicitly assume that all firms use different inputs *i* in the same proportion when making a given product *j*. This is the counterpart to the assumption behind $\ln input\ price^{IO}_{fpt}$ that all firms allocate a given input *i* in the same proportion across different outputs *j*.

[21] It is not obvious ex ante whether and how market power would enter. Manufacturing more of a certain product requires bigger input quantities. A bigger export market share might thus allow firms to charge higher mark-ups and to negotiate lower input prices. This would tend to bias β downwards. On the other hand, input scarcity or convexity in production costs might bias β upwards.

[22] See Manova and Yu (2016) among others for more details on these regimes.

Table 5
This table examines the relationship between firms' export prices and imported-input prices across products within firm-years. The outcome variable is firms' log export price by HS 8-digit product and year, except in Column 6 where it is the weighted average annual log export price by HS 3-digit product or by IO sector using export revenues as weights. The input price is the weighted average of log import prices for inputs matched to the output product, using import values as weights. It is based on imports in the same HS 3-digit product category (Panel A) or on all inputs using input-output tables (Panel B). All prices have been demeaned by their product-year average across firms before any further manipulation. In Column 2 market power in output markets is proxied by the firm's share of total Chinese exports by product category and year; market power in input markets is proxied by the firm's average share of total Chinese imports across all inputs matched to the output product, by year. Column 3 (4) restricts the sample to homogeneous (differentiated) export products. In Column 5 only processing imports enter the calculation. In Column 7 the export and imported-input log prices are replaced by inferred export-product and imported-input log quality as in Table 3. All regressions include a constant term and firm-year pair fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dependent variable: (log) export price by firm, product category and year	Baseline (1)	Market power (2)	Hom goods (3)	Diff goods (4)	Proc imports (5)	HS3 product (6)	(log) Quality (7)
Panel A. Input price based on imports in same HS-3 product category							
(log) Input price	0.134***	0.134***	0.088***	0.111***	0.176***	0.191***	0.120***
	(30.66)	(30.69)	(7.25)	(29.89)	(20.88)	(34.89)	(27.35)
Input market share		0.275					
		(1.55)					
Output market share		−0.120***					
		(−4.60)					
Firm-Year FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.43	0.43	0.53	0.41	0.45	0.58	0.40
# Observations	1,031,424	1,031,424	60,165	621,297	534,580	393,820	1,031,424
# Firms	68,925	68,925	12,748	53,240	40,508	68,925	68,925
# Product categories	7,039	7,039	1,283	3,026	6,231	171	7,039
Panel B. Input price based on all imports and IO tables							
(log) Input price	0.118***	0.118***	0.032**	0.110***	0.142***	0.161***	0.109***
	(17.86)	(17.86)	(2.04?	(14.00)	(11.81)	(25.35)	(14.12)
Input market share		−0.165					
		(−0.76)					
Output market share		2.473					
		(1.26)					
Firm-Year FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.40	0.40	0.58	0.43	0.38	0.50	0.39
# Observations	2,403,309	2,403,309	153,737	1,519,333	1,487,247	818,560	2,403,309
# Firms	99,694	99,694	27,540	83,356	61,035	99,694	99,694
# Product categories	6,418	6,418	1,275	2,759	6,175	92	6,418

the quality of every imported input at the firm-product-country level from the available information on import prices and quantities. For each of a firm f's output products p, we construct $\ln input\ quality_{fpt}^{HS3}$ and $\ln input\ quality_{fpt}^{IO}$ as the weighted average quality of f's imported inputs used in the production of p, based on the same assignment of inputs to output products as above. In line with our quality interpretation, we observe $\beta > 0$ when we re-estimate Eq. (4) replacing input and output price levels with their respective imputed quality.

5.3. Variation across destinations within a firm

The analysis so far has established robust positive correlations between export prices, export revenues, input prices, and inferred quality across a manufacturer's product range. As per Proposition 2, these results are consistent with quality differentiation across products within multi-product firms, whereby exporters earn higher revenues from their core expensive goods that are of superior quality.

We next examine how exporters adjust their product scope and sales distribution across destinations. Our interest here is not in the underlying differences across markets that trigger such adjustments, but rather in the attributes of the goods that firms choose to offer and to sell more of when they adjust their product range. This analysis is guided by Propositions 3 and 4.

5.3.1. Product scope and product hierarchies

We first study how firms vary their export activity across destination countries along the extensive margin of product entry. Specifically, we assess the extent to which exporters observe a product hierarchy by introducing their core products in all markets and progressively adding goods that they have less expertise in when they enlarge the set of products on offer. We also study how average prices and average inferred quality change with the number of traded products, to gauge to what extent firms' product hierarchy is determined by efficiency vs. quality sorting.

We begin with the joint variation in product scope, average price and export revenues across destinations within a company. For each firm f, country d and year t, we obtain total bilateral exports, $revenue_{fdt} = \sum_p revenue_{fpdt}$, and record the number of products shipped, $Nproducts_{fdt}$. We construct the simple average log price across the products that f sells to d at time t, after these prices have been demeaned by their product-destination-year average. We likewise compute the weighted average of these demeaned prices, using firms' bilateral exports as weights.

We evaluate the implications of Propositions 3 and 4 for the extensive margin of multi-product firms' exports by estimating:

$$\ln revenue_{fdt} = \alpha + \beta \ln Nproducts_{fdt} + \delta_{ft} + \varepsilon_{fdt} \text{ and} \quad (5)$$
$$\ln avg\ price_{fdt} = \alpha + \beta \ln Nproducts_{fdt} + \delta_{ft} + \varepsilon_{fdt}.$$

Given the firm-year pair fixed effects δ_{ft} in these regressions, β is identified purely from the cross-sectional variation across countries within manufacturers. As before, it reflects conditional correlations of interest and does not support a causal interpretation: In the model, product scope, export revenues and average prices are jointly pinned down by a producer's ability draw and characteristics of the destination market.

Table 6
This table examines the relationship between bilateral export revenues, average export price, average quality, and product scope across destinations within firm-years. Product scope is measured by the log number of products a firm exports to a given destination, by year. For each firm, product, destination and year, we first demean the log price by its product-destination-year average across firms. We then construct the average log export price at the firm-destination-year level as the arithmetic average of these demeaned prices (Columns 2-5) or their weighted average using the firms' export revenues in that destination and year as weights (Column 6). In Column 3 market power is proxied by the firm's average share of total Chinese exports across all its products by destination-year. Column 4 (5) restricts the sample to homogeneous (differentiated) goods. In Columns 7-8 log price is replaced by inferred log quality as in Table 3. All regressions include a constant term and firm-year pair fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% level.

Dep variable	(log) Sales	Avg (log) price					Avg (log) Quality	
		Baseline	Market power	Hom goods	Diff goods	Weighted Avg	Baseline	Weighted Avg
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(log) # Products	1.714***	−0.020***	−0.020***	0.001	−0.024***	−0.002	−0.035***	0.899***
	(333.42)	(−15.53)	(−15.69)	(0.28)	(−15.90)	(−1.35)	(−5.65)	(124.08)
Market share			−0.011**					
			(−2.48)					
Firm-Year FE	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.54	0.57	0.57	0.62	0.59	0.58	0.54	0.56
#Observations	3,236,020	3,236,020	3,236,020	388,613	2,272,354	3,236,020	3,236,020	3,236,020
# Firms	175,949	175,949	175,949	50,659	142,559	175,949	175,949	175,949

In line with our theoretical predictions, exporters earn systematically higher revenues in countries where they sell more products (Column 1 of Table 6). At the same time, product scope is negatively correlated with the average price across products (Column 2). This pattern is not driven by cross-country differences in a firm's market power, as proxied by the average market share across its products in a destination-year (Column 3). Moreover, it holds in the sample of differentiated goods with potential for quality upgrading, but is absent among homogeneous commodities (Columns 4 and 5). Finally, the theoretically ambiguous relationship between product scope and the revenue-weighted average price is markedly less negative and not statistically different from 0 (Column 6).

These relationships are economically significant. The typical firm generates 85% higher bilateral revenues and lowers its average bilateral f.o.b. price by 1% when it exports 50% more products to a given destination. The latter correlation is 20% higher for differentiated varieties.

Through the lens of our model, these results suggest that exporters expand (restrict) their product offering across markets by consistently exporting core expensive varieties of high quality and adding (dropping) peripheral cheaper goods of inferior quality. In particular, Proposition 3 indicates that a firm's number of products and their average price would be negatively associated only with quality sorting ($\theta > 0$), but not with efficiency sorting. This conclusion is further bolstered by the results in Columns 7–8, where we re-estimate Eq. (5) for the average inferred output quality across a firm's products, rather than their average price. Moreover, compared to the simple average quality, the weighted average quality is not only less negatively correlated, but it is in fact significantly positively correlated with product scope across destinations within a firm-year. In light of Proposition 3, this illustrates the large adjustments that firms make across markets, both along the extensive margin of product scope and along the intensive margin of product sales.

While the evidence in Table 6 points to the validity of Propositions 3 and 4 for the case of quality sorting, it does not directly establish whether firms adhere to the same global product hierarchy in all destinations. We next present empirical patterns consistent with an important role for such a hierarchy. While the exact rankings of products by export sales, by price, and by inferred quality do differ to some degree across the multiple markets that a firm serves, the data suggest that such deviations from a strict product hierarchy are small in magnitude.

We begin with informative summary statistics. For each firm-destination pair, we obtain the cross-product correlation between the global and the bilateral revenue rank of products in the firm's export portfolio. We record the average and the standard deviation of these correlations across destinations within each firm. For the median firm, the average correlation is 0.69, with a standard deviation of 0.30. We then ask how much of the total variation in product ranks across products and destinations within a firm can be ascribed to fixed factors at the firm-product level. In particular, we regress the bilateral rank of product p exported by firm f to destination d on firm-product pair fixed effects. The R-squared from this regression is very high at 0.85 in the cross-section for year 2006, and increases further to 0.93 when we control for the number of firms' bilaterally exported products.

We next systematically examine the relationship between the number of products that a firm sells in a given market and where these products enter in the firm's global product ranking. We first consider the agnostic ranking of firm f's products based on their global sales, ignoring the underlying cause for this ranking. For each company and year, the good that generates the highest revenues worldwide receives rank 1, the second-highest revenues - rank 2, etc. We record the average, minimum and maximum ranks observed across the products that f sells to destination d in year t. If the exporter follows a strict product ladder in all countries, then the minimum global product rank would be 1 in every market. The maximum rank, on the other hand, would equal the number of products shipped, $Nproducts_{fdt}$. Thus, product scope would be uncorrelated with the minimum product rank across destinations within a firm-year, but it would be positively correlated with the maximum and with the average product rank. Deviations from these patterns would signal that firms do not maintain a strict product hierarchy, and instead re-order products across markets. In practice, we work with the 10th and 90th percentiles instead of the minimum and the maximum to guard against idiosyncratic outliers.[23]

We evaluate these predictions by regressing each of the three rank measures on the number of bilaterally traded products in specifications at the firm-destination-year level. Firm-year pair fixed effects ensure that the conditional correlation β is estimated from

[23] Qualitatively similar results obtain if we instead use these extreme values.

Table 7
This table shows that firms focus on their core, expensive, high-quality products in markets where they export fewer products. Product scope is measured by the log number of products a firm exports to a given destination, by year. For each firm-year, we rank products globally based on the firm's worldwide export revenues (Panel A), worldwide export prices (demeaned by their product-year average across firms) (Panel B), or inferred worldwide quality as in Table 3 (Panel C). The top product receives rank 1 and the bottom product - a rank equal to the number of products the firm exports. Using these global product rankings, we record the average, 10th percentile and 90th percentile rank observed across the products a firm exports to a given destination-year. Column 2 (3) restricts the sample to homogeneous (differentiated) goods. Columns 4-5 restrict the sample to firm-destination-years with 2 or more products. All regressions include a constant term and firm-year pair fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dep variable	Average rank			10th Perc	90th Perc
	All (1)	Hom goods (2)	Diff goods (3)	All (4)	All (5)
Panel A. Products ranked by global sales					
# Products	0.450***	0.351***	0.440***	−0.018***	0.851***
	(39.67)	(14.70)	(39.39)	(−2.45)	(34.81)
Firm-Year FE	Y	Y	Y	Y	Y
R-squared	0.72	0.67	0.70	0.30	0.83
# Observations	3,236,020	388,613	2,272,355	1,445,003	1,445,003
# Firms	175,949	50,659	142,559	130,631	130,631
Panel B. Products ranked by global price					
# Products	0.030**	−0.000	0.036***	−0.319***	0.367***
	(2.11)	(−0.05)	(3.38)	(−19.80)	(30.48)
Firm-Year FE	Y	Y	Y	Y	Y
R-squared	0.91	0.86	0.90	0.69	0.96
# Observations	3,236,020	388,613	2,272,355	1,445,003	1,445,003
# Firms	175,949	50,659	142,559	130,631	130,631
Panel C. Products ranked by global quality					
# Products	0.235***	0.013***	0.227***	−0.147***	0.585***
	(15.24)	(6.11)	(17.74)	(−13.32)	(30.66)
Firm-Year FE	Y	Y	Y	Y	Y
R-squared	0.85	0.77	0.84	0.57	0.91
# Observations	3,236,020	388,613	2,272,355	1,445,003	1,445,003
# Firms	175,949	50,659	142,559	130,631	130,631

the variation across markets within an exporter at a given point in time:

$$\{avg\ rank_{fdt}, \min rank_{fdt}, \max rank_{fdt}\} = \alpha + \beta N\ products_{fdt} + \delta_{ft} + \varepsilon_{fdt}. \quad (6)$$

As Panel A of Table 7 shows, the average sales product rank indeed rises significantly with product scope. This pattern is more pronounced among differentiated goods, although it is also present among homogeneous varieties. Moreover, the 90th percentile rank increases about twice as fast with the number of goods shipped as the average, whereas the 10th percentile rank is essentially unaffected.

We next impose more structure on the origin of product hierarchies in firms' export portfolios, and rank products based on their global price (i.e. global sales/global quantities) instead of their global sales. Now in each year, exporters' most expensive product receives rank 1, their second-most expensive product - rank 2, etc. We similarly develop a global product ladder for each firm and year based on inferred product quality.

In Panels B and C of Table 7, we re-estimate Eq. (6) using exporters' global price and quality product rankings. We obtain qualitatively similar results as in Panel A with two exceptions. The average rank becomes independent of or very weakly correlated with product scope for non-differentiated products, which strengthens our conclusions. While the 10th percentile now falls with $Nproducts_{fdt}$, the important observation for our purposes is that the 90th percentile rises faster than that in absolute terms.

Together, Tables 6 and 7 suggest that exporters' core competence lies with their expensive products, which correspond to their highest-quality goods. In destinations where firms choose to offer fewer varieties, they focus on these high-quality, core products. At the same time, product hierarchies are not perfectly observed across destinations as per the baseline model. This is consistent with unobserved supply and demand shocks at the product-destination or firm-product-destination level, such as variation in transportation costs and in consumer tastes as in Bernard et al. (2010).[24]

5.3.2. Product scope and sales distribution

We next examine how firms vary their export activity across destination countries along the intensive margin. We consider the distribution of sales across products within a firm, and assess if and how product scope relates to the concentration of sales towards core goods. This is informative because according to Proposition 4, such a systematic relationship would emerge only in frameworks with variable mark-ups, but not in environments with constant mark-ups and monopolistic competition.

For each firm f, destination d and year t, we measure export sales concentration with the log ratio of the revenues generated by f's top and second-best product in d at time t, $\ln(revenue_{fdt,1}/revenue_{fdt,2})$.[25] We identify these top two products in three different ways, based on bilateral export sales, prices, or inferred qualities. We rely on firms' bilateral trade activity to account for the fact that they may not observe the same product hierarchy in all markets. We regress each concentration ratio on the exporter's log number of products sold in destination d and year t. Since we are interested in the variation across importing countries within a firm, we include firm-year pair fixed effects δ_{ft}:

$$\ln(revenue_{fdt,1}/revenue_{fdt,2}) = \alpha + \beta \ln N\ products_{fdt} + \delta_{ft} + \varepsilon_{fdt}. \quad (7)$$

As Table 8 shows, firms skew their exports more towards their top-selling, most expensive, and highest-quality good in markets where they sell fewer varieties (Columns 1, 4, 7). Halving the product range is associated with a 21% rise in revenues from the best-selling product relative to the second-best. This number reaches 8.5% when we consider the concentration of sales towards the most expensive good, and 15.5% when we instead focus on the concentration of sales towards the highest-quality product. In the rest of Table 7 we estimate Eq. (7) separately for firms' homogeneous and differentiated products, and document that qualitatively similar results hold for both categories.[26]

In unreported regressions, we have confirmed that similar results obtain when we use an alternative measure of sales concentration: the Herfindahl index for the distribution of bilateral exports across all of f's products sold to destination d. An advantage of this measure is that it takes into account the complete sales distribution across f's full product range, rather than the relative sales of the top two

[24] For completeness, we have checked that the results for the variation across destinations within firms in Tables 6 and 7 also apply to the variation across firms within a destination-year. We do so by re-estimating the relevant equations with destination-year instead of firm-year fixed effects. This implies that within a market, firms exporting more products have higher revenues and focus on their core expensive goods. These findings are consistent with the model and further corroborate our interpretaion.

[25] As Melitz et al. (2014), we use the log ratio in order to capture the relative contribution of different products in percentage terms.

[26] Of note, the concentration of sales towards expensive and towards high-quality products falls faster with product scope for differentiated varieties than for homogeneous goods. On the other hand, the opposite is true of the concentration of sales towards the best-selling product.

Table 8
This table shows that firms concentrate sales in their core, expensive, high-quality products in markets where they export fewer products. The outcome variable is the log ratio of the sales of a firm's top-ranked product to the sales of its second-ranked product, by destination-year. For each firm-destination-year, we rank products bilaterally based on the firm's bilateral export revenues (Columns 1-3), bilateral export prices (demeaned by their product-destination-year average across firms) (Columns 4-6), or bilateral inferred quality as in Table 3 (Columns 7-9). Columns 2, 5 and 8 (3, 6 and 9) restrict the sample to homogeneous (differentiated) goods. All regressions include a constant term and firm-year pair fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dependent variable: (log) ratio of exports of top-ranked to second-ranked product, by firm, destination and year									
Product rank by	Bilateral sales			Bilateral price			Bilateral quality		
	All (1)	Hom goods (2)	Diff goods (3)	All (4)	Hom goods (5)	Diff goods (6)	All (7)	Hom goods (8)	Diff goods (9)
(log) # Products	−0.419***	−0.628***	−0.415***	−0.169***	−0.189***	−0.205***	−0.314***	−0.144***	−0.301***
	(−99.11)	(−26.81)	(−83.44)	(−27.00)	(−24.31)	(−17.22)	(−49.82)	(−4.97)	(−42.40)
Firm-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.50	0.60	0.53	0.28	0.51	0.34	0.32	0.53	0.36
# Observations	1,445,003	95,380	954,562	1,445,003	95,380	954,562	1,445,003	95,380	954,562
# Firms	130,631	21,640	98,684	130,631	21,640	98,684	130,631	21,640	98,684

products alone. However, it provides a consistency check only for Column 1, where products are ranked based on sales. It cannot shed light on the attributes (production efficiency, product quality) of the products that generate high revenues.

These findings imply that in tougher markets where firms opt to sell fewer products, they shift activity towards their core, high-quality goods both along the extensive margin (by dropping lower-quality varieties) and along the intensive margin (by concentrating sales further towards high-quality products). In light of Proposition 4, these patterns are inconsistent with the constant mark-ups implied by the combination of CES demand and monopolistic competition. Instead, they suggest that variable mark-ups importantly affect the sales decisions of multi-product firms, where such variable mark-ups may arise from deviations from CES demand, monopolistic competition, and/or cross-product independence in production or consumption.

5.4. *Export dynamics within firms over time*

The analysis so far has examined the cross-sectional variation in export activity across firms, products, and destinations. This elucidates how firms make decisions about their optimal product scope and revenues in each consumer market, given the prevailing market conditions at a certain point in time. It also informs how firms determine the level and cross-sectional distribution of product quality, prices, and sales across country-product markets.

In this section, we provide complementary evidence on how multi-product, multi-quality firms adjust their export activity in response to changes in economic conditions over time. In particular, we examine the pattern of reallocation across products within firms along the extensive margin of product entry and exit, as well as along the intensive margin of changes in sales levels and concentration among surviving products.

The static conceptual framework in Section 2 can be generalized to accommodate exogenous supply and demand shocks. Consider first shocks that affect all products symmetrically, such as aggregate expenditure growth in a given destination which raises demand proportionately for all varieties. Propositions 3 and 4 would have clear predictions for exporters' optimal response: Conditional on expanding export activity and sales, firms will enlarge their export product scope by going down their product ladder and adding more of their peripheral goods. Compared to surviving varieties, these newly introduced products will generate lower revenues and sell at higher (lower) prices under efficiency (quality) sorting. In addition, firms will preserve the concentration of sales among inframarginal varieties in the case of constant mark-ups, but reduce it under variable mark-ups. Conversely, negative shocks would induce firms to contract total exports by narrowing their product range, dropping marginal varieties that occupy the bottom of the product hierarchy, and possibly skewing sales further towards the top inframarginal products that survive.

Consider next supply and demand shocks that differentially affect products, such as exogenous shifts in product-specific input costs or consumer tastes. Such shocks would reorder the ranking of products by profitability in a firm's output portfolio. As a result, should firms optimally choose to increase total exports (for example because of a large positive shock across the board), they might introduce new varieties that generate higher sales and rank higher in terms of efficiency or quality than incumbent products in their export basket. Moreover, firms might simultaneously add and drop products. While the predictions of Proposition 4 regarding product scope and sales concentration would still hold, the implications of Proposition 3 regarding product hiearchies would remain qualitatively valid but quantitatively less relevant.

The analysis of firms' export dynamics thus serves several purposes. First, it allows us to assess how important the allocation of activity across products is to the operations of multi-product firms, not only in the cross-section but also for export dynamics.

Second, export dynamics reveal to what extent firms' product hierarchy is stable over time and governed by the same factors as in the cross-section. As discussed above, product-specific shocks can reshuffle products' relative profitability. Firms may also actively upgrade their production technology to improve efficiency and/or quality, but the associated costs and returns may vary across products. Either force could lead to product hierarchies changing significantly within firms over time. Moreover, quality sorting might characterize the pattern of export activity in the cross section in line with our results above, but reallocations across products over time might be determined by differential adjustments in production efficiency.

Finally, panel analysis can inform how multi-product companies respond to trade reforms that affect export opportunities. We can document how product characteristics prior to exogenous policy shocks shape export behavior following reforms. In addition to being policy-relevant, this exercise allows us to overcome outstanding concerns with endogeneity or omitted variable bias.

We perform our analysis in two different ways. We first study the export dynamics of all firms surviving from the beginning to the end of our panel, and consider the change in their trade behavior from 2002 to 2006. We can thus agnostically identify the roles of production efficiency and product quality in guiding adjustments across products

Table 9
This table examines how firms adjust activity across products over time. Panel A considers adjustments within surviving firms from 2002 to 2006. Panel B considers adjustments within surviving firms in the textiles and apparel industries from 2004 to 2006 in response to the removal of MFA quotas in 2005. In Columns 1-3 the sample includes all firm-products exported at t=0, and the dependent variable is a binary indicator equal to 1 if the firm does not export the product at t=1. In Columns 4-6 the sample includes all firm-products exported at t=1, and the dependent variable is a binary indicator equal to 1 if the firm did not export the product at t=0. In Columns 7-9 the sample includes all firm-products exported at both t=0 and t=1, and the dependent variable is the change in log export revenues from t=0 to t=1. The product attribute on the right-hand side is worldwide log revenues, log price or log quality by firm-product at t=0 or t=1 as indicated in the column heading. All regressions include a constant term and firm fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dep variable (Sample)	Drop dummy, t=1 (Products traded at t=0)			Add dummy, t=1 (Products traded at t=1)			Δ (log) Sales (Products traded at t=0 & t=1)		
Product attribute	(log) Sales t=0 (1)	(log) Price t=0 (2)	(log) Quality t=0 (3)	(log) Sales t=1 (4)	(log) Price t=1 (5)	(log) Quality t=1 (6)	(log) Sales t=0 (7)	(log) Price t=0 (8)	(log) Quality t=0 (9)
Panel A. Full panel, 2002–2006									
Product attribute	−0.061***	−0.002**	−0.012***	−0.056***	0.004***	−0.010***	−0.421***	−0.126***	−0.142***
	(−96.13)	(−2.10)	(−48.18)	(−117.55)	(5.92)	(−53.26)	(−92.64)	(−11.02)	(−55.06)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.37	0.29	0.31	0.35	0.26	0.27	0.48	0.35	0.40
# Observations	347,288	347,288	347,288	407,412	407,413	407,414	143,881	143,882	143,883
# Firms	42,521	42,521	42,522	42,521	42,522	42,523	37,867	37,868	37,869
Panel B. MFA reform, 2004–2006									
Product Attribute	−0.075***	−0.013***	−0.022***	−0.068***	−0.003	−0.022***	−0.449***	−0.115***	−0.186***
	(−57.15)	(−3.39)	(−26.23)	(−66.63)	(−0.80)	(−32.01)	(−37.33)	(−3.47)	(−27.57)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.39	0.31	0.33	0.37	0.29	0.31	0.51	0.38	0.44
# Observations	46,625	46,625	46,625	63,828	63,828	63,828	24,178	24,178	24,178
# Firms	8,682	8,682	8,682	8,682	8,682	8,682	7,226	7,226	7,226

in the medium run, without taking a stance on why firms choose to adjust export activity in the first place.

We then exploit the removal of export quotas under the Multi-Fiber Agreement (MFA) in 2005, and explore the export dynamics of surviving firms in the textiles and apparel industry in the short run from 2004 to 2006. We focus on the HS 6-digit product categories that are considered affected by the reform because they faced binding quotas (i.e. exports prior to the reform exceeded 90% of the quota level) and on the export destinations for which these quotas applied (US and all EU countries). Although this reform impacted only 8.7% of the firm population in 2004, exploring its effects has two benefits compared to the full-panel analysis. First, it constituted a large, exogenous shock to foreign demand from the perspective of individual producers, and indeed triggered rapid growth in aggregate exports of textiles and apparel. The MFA episode thus identifies a precise rather than agnostic reason for exporters to expand trade activity, and it has been exploited as an exogenous shock for identification purposes in several studies (cf. Khandelwal et al., 2013; Manova and Yu, 2016). Second, focusing on the textiles and apparel industries serves as a case study of manufacturers that operate in a well-defined product space and use relatively transparent production technologies.[27]

5.4.1. Adjustment across products within firms

We first evaluate how exporters reallocate activity across products by dropping some varieties from their export portfolio, introducing new ones, and adjusting the sales of surviving goods. We estimate the following three specifications at the firm-product level:

$$Drop_{fp,t=1} = \alpha + \beta\ Product\ Attribute_{fp,t=0} + \delta_f + \varepsilon_{fp}, \tag{8a}$$

$$Add_{fp,t=1} = \alpha + \beta\ Product\ Attribute_{fp,t=1} + \delta_f + \varepsilon_{fp}, \tag{8b}$$

$$\Delta \ln revenue_{fp} = \alpha + \beta\ Product\ Attribute_{fp,t=0} + \delta_f + \varepsilon_{fp}. \tag{8c}$$

[27] See Upward and Wang (2013) for complementary evidence that the MFA reform induced firms to expand their product scope. We study instead the differential adjustments that firms made across their product range.

In Eq. (8a), the sample comprises all products p that firm f exports at time $t = 0$, and the outcome variable $Drop_{fp,t=1}$ is an indicator set to 1 if the firm does not export p at time $t = 1$. In (8b), the sample comprises all products p that f exports at time $t = 1$, and the outcome variable $Add_{fp,t=1}$ is an indicator set to 1 if the firm did not export p at time $t = 0$. In (8c), the sample comprises all surviving products p that f exports at both $t = 0$ and $t = 1$, and the outcome variable is the change in log export revenues from $t = 0$ to $t = 1$, $\Delta \ln revenue_{fp} = \ln revenue_{fp,t=1} - \ln revenue_{fp,t=0}$. The explanatory variables of interest, $Product\ Attribute_{fp,t=0}$ and $Product\ Attribute_{fp,t=1}$, refer to the log export revenue, price, or quality of a firm's product at time $t = 0$ and $t = 1$ respectively. We include firm fixed effects, such that β is estimated from the variation in export dynamics across varieties within a firm.

The results in Table 9 reveal patterns strongly consistent with the implications of Proposition 3 for the evolution of multi-product firms' exports over time. In Panel A, we study the balanced panel of surviving firms in our data, such that t_0 and t_1 correspond to years 2002 and 2006. We find that exporters are more likely to discontinue products that generate lower revenues, that sell at lower prices, and that feature lower quality (Columns 1–3). In the quality-sorting version of our conceptual framework, these are precisely the goods that would be classed as peripheral and most prone to being cut when firms scale down operations. Likewise, the new varieties that exporters introduce tend to have lower sales and quality than incumbent products, but they do attain slightly higher prices (Columns 4–6). This is consistent with firms expanding their product range by going further down their product ladder, if there is both quality and efficiency differentiation across varieties and prices reflect their net effect on marginal costs.

These adjustments on the extensive margin of product scope are accompanied by reallocations on the intensive margin of sales levels for inframarginal products: Goods that initially rank higher on the product hierarchy in terms of sales, price, or quality experience less revenue growth over time (Columns 7–9). In light of Proposition 4, this is in line with companies concentrating their exports less in core varieties when they expand their product range. Having said that, these findings are also consistent with product-specific shocks that re-order the product hierarchy and generate mean reversion in product-level exports. The analysis in the next subsection, however, provides more direct evidence in support of the former interpretation.

We obtain qualitatively and quantitatively similar results when we turn to the MFA reform in Panel B. We now restrict the sample to firms in the textiles and apparel industries that enjoyed a large exogenous increase in foreign demand in 2005, and set t_0 and t_1 to years 2004 and 2006, respectively. In response to this policy shock, exporters systematically added (and occasionally dropped) products that rank lower on their product hierarchy as reflected in export sales, prices and quality, while also flattening the distribution of sales across their product range. Of note, the coefficient on initial product price turns from positive to negative and insignificant, lending further support to quality sorting.

As a robustness check, in Appendix Table 4 we replicate this analysis using ordinal ranks instead of continuous measures for the product attributes of interest (sales, price, quality). We observe the same, highly significant patterns. (Note that as expected, β flips sign since a core product with high attribute values receives a lower rank number by construction.) We further establish that firms not only tend to add/drop products from the lower end of their product hierarchy, but they also generally preserve the ranking of inframarginal products in their export basket: There is a strong positive correlation between the initial and end ranks of surviving varieties. This correlation is the strongest when we rank products by sales (48.8%, 61.1%), but remains high when we rank them by quality (40.8%, 45.6%) or price (32.4%, 35.4%).

5.4.2. Adjustment across destinations within firms

We next assess how firms adjust their export activity differentially across destination markets. Changes in aggregate economic conditions that affect all products in an exporter's output portfolio are not perfectly correlated across countries. Similarly, product-level supply and demand shocks can be destination-specific. We can thus exploit the variation across countries to further evaluate the empirical relevance of Propositions 3 and 4 for export dynamics. We estimate the following three specifications:

$$\Delta \ln revenue_{fd} = \alpha + \beta \Delta \ln N\ products_{fd} + \delta_f + \varepsilon_{fd}, \quad (9a)$$

$$\Delta \ln \left(revenue_{fd,1}/revenue_{fd,2}\right) = \alpha + \beta\, \Delta \ln N\ products_{fd} + \delta_f + \varepsilon_{fd}, \quad (9b)$$

$$\Delta\ avg\ rank_{fd} = \alpha + \beta\, \Delta\ N\ products_{fd} + \delta_f + \varepsilon_{fd}. \quad (9c)$$

The unit of observation in these specifications is now the firm-destination pair, and the sample comprises all destination markets d that firm f serves at both $t = 0$ and $t = 1$. The explanatory variable of interest is the change in the (log) number of products that f exports to d from $t = 0$ to $t = 1$. We include firm fixed effects to identify β from the variation in export patterns across countries within a firm. We report our findings for the 2002–2006 long difference in the full panel in Panel A of Table 10, and for the 2004–2006 short-term response to the MFA reform in Panel B of Table 10.

Eqs. (9a) and (9b) speak to the validity of Proposition 4. In (9a), the outcome variable is the change in firm f's log exports to destination d, $\Delta \ln revenue_{fd} = \ln revenue_{fd,t=1} - \ln revenue_{fd,t=0}$. As Column 1 indicates, expanding their product scope in a given market indeed allows firms to generate higher sales there. In (9b), the outcome variable is the change in sales concentration in f's core products, $\Delta \ln (revenue_{fd,1}/revenue_{fd,2}) = \ln (revenue_{fd1,t=1}/revenue_{fd2,t=1}) - \ln (revenue_{fd1,t=0}/revenue_{fd2,t=0})$. As in Table 8, we measure sales concentration with the log ratio of exports of the top and second-best product, where these two products are ranked based on bilateral export sales, prices, and inferred qualities. Columns 2–4 show that widening the product range is accompanied by flattening the sales distribution across products, as indirectly implied by the evidence for product-level sales in Table 9.

Finally, Eq. (9c) provides further support for Proposition 3. The outcome variable is now the change in the average global rank across the products that firm f sells in country d, $\Delta avg\ rank_{fd} = avg$

Table 10
This table examines how firms adjust activity across destinations over time. Panel A considers adjustments within surviving firms from 2002 to 2006. Panel B considers adjustments within surviving firms in the textiles and apparel industries from 2004 to 2006 in response to the removal of MFA quotas in 2005. In Column 1 the outcome variable is the change in bilateral log export revenues from t=0 to t=1. In Columns 2-4 the outcome variable is the change in the log ratio of the sales of a firm's top-ranked product to the sales of its second-ranked product, where product rank is based on firms' bilateral export revenues, price and quality as in Table 8. In Columns 5-7 the outcome variable is the change in the average global product rank across the products a firm exports to a given destination, where product rank is based on firms' worldwide export revenues, price and quality as in Table 7. All regressions include a constant term and firm fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dep variable	Δ (log) Sales	Δ Concentration ratio			Δ Average rank		
Product rank by		Bilateral sales	Bilateral price	Bilateral quality	Global sales	Global price	Global quality
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Full panel, 2002–2006							
Δ (log) # Products	1.234***	−0.551***	−0.175***	−0.455***			
	(121.85)	(−29.65)	(−4.30)	(−11.44)			
Δ # Products					0.532***	0.028	0.346***
					(15.48)	(0.94)	(9.17)
Firm FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.47	0.49	0.39	0.39	0.40	0.72	0.55
# Observations	170,083	68,538	68,538	68,538	170,083	170,083	170,083
# Firms	39,701	24,206	24,206	24,206	39,701	39,701	39,701
Panel B. MFA reform, 2004–2006							
Δ (log) # Products	1.183***	−0.503***	−0.231*	−0.470***			
	(40.31)	(−10.39)	(−1.87)	(−4.69)			
Δ # Products					0.762***	0.165	0.550***
					(9.93)	(1.03)	(5.63)
Firm FE	Y	Y	Y	Y	Y	Y	Y
R-squared	0.61	0.59	0.48	0.49	0.39	0.69	0.48
# Observations	20,569	8,988	8,988	8,988	20,569	20,569	20,569
# Firms	7,474	4,034	4,034	4,034	7,474	7,474	7,474

$rank_{fd,t=1} - avg\ rank_{fd,t=0}$. As in Table 7, for each year $t = 0$ and $t = 1$, we first rank f's products globally based on their worldwide sales, price, and inferred quality. We then take the average of these global ranks across the varieties exported bilaterally to d. If firms observe the same global product hierarchy in all markets at a given point in time, then $\Delta avg\ rank_{fd}$ will increase with $\Delta\ N\ products_{fd}$, even if this global product hierarchy changes over time because of aggregate or product-level shocks that are not destination-specific. This is in fact what we find in Columns 5–7. By contrast, if firms experienced destination-product specific shocks that dominated any aggregate or product-level shocks, they would differentially adjust their product hierarchy across countries and $\Delta avg\ rank_{fd}$ would be unrelated to $\Delta\ N\ products_{fd}$. Through the lens of our conceptual framework, the combined evidence in Tables 9 and 10 therefore indicates that firm-product level characteristics (production efficiency, product quality) are powerful enough to generate stable product hieararchies within multi-product firms, both in the cross-section of countries and in the time-series within countries.

6. Conclusion

This paper establishes that product hierarchies and quality differentiation govern the operations of multi-product firms. We present a general conceptual framework in which manufacturers draw different production efficiencies across products and optimally choose the distribution of prices, quality, and sales across their product range. This framework delivers a set of predictions that allow us to empirically assess how efficiency and quality sorting interact with the product margin inside firms.

Using detailed customs data for China, we empirically establish that firms allocate activity across products in line with strong quality differentiation. Multi-product firms vary output quality across their products by using inputs of different quality levels. Their core competence is in varieties of superior quality that command higher prices but nevertheless generate higher sales. In markets where they offer fewer products, firms concentrate activity in these core varieties by dropping low-quality peripheral goods on the extensive margin and by shifting sales towards top-quality products on the intensive margin. Finally, firms' export dynamics follow systematic reallocations of activity across the product quality ladder, both in general and in response to exogenous trade reforms such as the removal of MFA quotas on textiles and apparel.

Our results inform the determinants of firms' export success and the design of export-promoting policies in developing economies. They also have implications for the measurement of multi-product firms' productivity and performance in environments with efficiency, quality, and mark-up variation across firms and products. More broadly, we shed light on the impact of trade reforms and other economic shocks such as exchange rate fluctuations at the firm and aggregate levels, as well as on the adjustment process mediating this impact. An important avenue for future research is understanding how quality differentiation across firms and across products within firms affects the welfare and distributional consequences of international trade. Two key considerations in this context are the production complementarities between input quality, worker skill, and managerial capacity, and frictions in the allocation of resources across firms and across product lines within firms.

Appendix A

Appendix Table 1

This table examines the relationship between firms' trade activity, production attributes and product profile. In Panel A the sample comprises all exporters in 2002, and the outcome variable is firms' log worldwide exports in 2002. In Panel B the sample comprises all firms that exported in both 2002 and 2006, and the outcome variable is the 2002-2006 change in firms' log worldwide exports. In Panels C and D the sample comprises all exporter-years with balance-sheet data on firm production attributes, and the outcome variable is indicated in the column heading. For each firm, the average and standard deviation of log export price, log export quality, log imported-input price, and log imported-input quality are taken over the firm's export products and imported inputs, after these have been demeaned by their product-year average. Capital intensity is log fixed capital per worker. Skill intensity is the share of employees with a high-school degree. R&D + Advert Intensity is the share of R&D and advertising expenditures in total sales. All regressions include a constant term and fixed effects for firms' primary industry of activity, province and ownership type. Panel D also includes year fixed effects. Robust T-statistics in parentheses. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Panel A. Export sales, prices and quality across firms, 2002

Dep variable	Log exports$_{2002}$							
Firm Attribute	Avg export price (1)	Avg export quality (2)	Avg import input price (3)	Avg import input quality (4)	St dev export price (5)	St dev export quality (6)	St dev import input price (7)	St dev import input quality (8)
Firm attribute$_{2002}$	0.055***	0.099***	0.078***	0.054***	0.105***	0.072***	0.346***	0.081***
	(5.88)	(43.86)	(7.74)	(23.67)	(6.59)	(19.53)	(9.45)	(9.87)
R-squared	0.05	0.09	0.04	0.05	0.03	0.04	0.04	0.04
# Observations	67,416	67,416	43,180	43,180	48,466	48,466	22,731	22,731

Panel B. Export growth, prices and quality across firms, 2002-2006

Dep variable	Log exports$_{2006}$ - Log exports$_{2002}$							
Firm Attribute	Avg export price (1)	Avg export quality (2)	Avg import input price (3)	Avg import input quality (4)	St dev export price (5)	St dev export quality (6)	St dev import input price (7)	St dev import input quality (8)
Firm attribute$_{2002}$	0.046***	0.002	0.168***	0.041***	0.108***	0.019***	0.108***	0.019***
	(4.99)	(1.02)	(16.9)	(17.98)	(6.73)	(5.09)	(6.73)	(5.09)
Log exports$_{2002}$	−0.376***	−0.377***	−0.349***	−0.357***	−0.288***	−0.290***	−0.288***	−0.290***
	(−72.32)	(−71.95)	(−54.19)	(−54.68)	(−46.39)	(−46.37)	(−46.39)	(−46.37)
R-squared	0.20	0.20	0.18	0.18	0.12	0.12	0.12	0.12
# Observations	42,521	42,521	29,549	29,549	32,548	32,548	32,548	32,548

(*continued on next page*)

Appendix Table 1 (*continued*)

Panel C. Production attributes, prices and quality across firms, 2004

Dep variable	Avg export price (1)	Avg export quality (2)	Avg import input price (3)	Avg import input quality (4)	St dev export price (5)	St dev export quality (6)	St dev import input price (7)	St dev import input quality (8)
Productivity	0.022***	0.173***	0.054***	0.389***	0.008**	0.071***	0.007*	0.012
(Levinsohn-Petrin)	(4.08)	(7.25)	(7.56)	(12.19)	(2.10)	(4.00)	(1.87)	(0.75)
Log employment	0.009*	0.176***	0.087***	0.589***	0.027***	0.207***	0.028***	0.130***
	(1.93)	(8.50)	(14.12)	(21.60)	(8.70)	(14.41)	(8.72)	(9.40)
Capital intensity	0.017***	0.144***	0.126***	0.624***	0.011***	0.070***	0.017***	0.047***
	(3.67)	(7.04)	(20.41)	(22.61)	(3.69)	(4.87)	(5.61)	(3.41)
Skill intensity	0.249***	0.724***	0.275***	1.118***	0.107***	0.494***	0.056***	0.210***
	(12.30)	(7.92)	(9.84)	(9.06)	(7.81)	(7.82)	(4.12)	(3.47)
Log avg wage	0.258***	0.970***	0.240***	1.062***	0.087***	0.414***	0.026***	0.131***
	(21.77)	(18.25)	(16.63)	(16.68)	(11.00)	(11.17)	(3.54)	(4.10)
R-squared	0.17	0.14	0.25	0.23	0.28	0.23	0.16	0.15
# Observations	44,086	44,086	28,009	28,009	34,158	34,158	16,673	16,673

Panel D. Production attributes, prices and quality across firms, 2002, 2005, 2006

Dep variable	Avg export price (1)	Avg export quality (2)	Avg import input price (3)	Avg import input quality (4)	St dev export price (5)	St dev export quality (6)	St dev import input price (7)	St dev import input quality (8)
Productivity	0.013***	0.133***	0.009***	0.096***	0.057***	0.425***	0.010***	0.022**
(Levinsohn-Petrin)	(4.07)	(9.22)	(4.07)	(9.12)	(13.57)	(22.60)	(4.47)	(2.28)
Log employment	0.024***	0.238***	0.024***	0.188***	0.089***	0.595***	0.023***	0.112***
	(8.49)	(19.07)	(12.98)	(21.88)	(23.82)	(35.87)	(12.46)	(13.73)
Capital intensity	0.029***	0.187***	0.013***	0.092***	0.142***	0.686***	0.015***	0.040***
	(11.03)	(15.67)	(6.93)	(10.69)	(40.05)	(43.43)	(8.24)	(4.94)
R&D + Advert	1.000***	2.950***	0.704***	2.970***	1.033***	3.546***	0.269***	1.104***
Intensity	(2.61)	(2.97)	(2.97)	(3.44)	(3.53)	(3.73)	(2.89)	(3.03)
Log avg wage	0.244***	0.900***	0.093***	0.429***	0.264***	1.169***	0.035***	0.150***
	(35.5)	(29.65)	(21.01)	(20.97)	(31.85)	(31.95)	(8.30)	(8.11)
R-squared	0.15	0.13	0.27	0.22	0.24	0.23	0.14	0.12
# Observations	122,272	122,272	96,909	96,909	77,146	77,146	47,548	47,548

Appendix Table 2

This table summarizes the variation in f.o.b. log export revenues, prices and inferred quality across firms, products, and destinations in the 2002–2006 panel. The unit of observation is the firm-product-year triplet in Panel A and the firm-product-destination-year quadruplet in Panel B. Log prices and log quality have been demeaned by product-year pair fixed effects in Panel A and by destination-product-year triple fixed effects in Panel B.

	# Obs	Average	St dev	Min	Max
Panel A. Unit of observation: firm-product-year					
Log exports	4,127,779	9.42	2.78	0.00	22.51
Log price	4,127,779	0.00	1.32	−12.62	13.71
Log quality	4,127,779	0.00	6.28	−56.18	58.21
Panel B. Unit of observation: firm-destination-product-year					
Log exports	9,508,299	9.17	2.50	0.00	21.99
Log price	9,481,443	0.00	1.09	−12.90	13.68
Log quality	9,481,443	0.00	5.08	−56.81	59.39

Appendix Table 3

This table examines the relationship between export prices and revenues across firms within a destination-product-year market in the spirirt of Manova and Zhang (2012). Product scope for quality differentiation is measured as in Table 3. All regressions include a constant term and destination-product-year triple fixed effects. Robust T-statistics in parentheses based on standard errors clustered by destination-product. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dependent variable: (log) export price by firm, product, destination and year	Baseline (1)	Rauch dummy (2)	R&D intensity (3)	Adv + R&D intensity (4)	(log) Quality (5)
(log) Sales	0.083***	0.038***	0.079***	0.068***	1.332***
	(70.38)	(10.57)	(54.58)	(36.40)	(282.50)
(log) Sales x		0.055***	0.216***	0.581***	
Quality differentiation		(13.99)	(3.43)	(9.90)	
Dest-Product-Year FE	Y	Y	Y	Y	Y
R-squared	0.024	0.028	0.025	0.025	0.285
# Observations	9,481,443	6,533,138	9,247,765	9,290,452	9,481,443
# Dest-product pairs	1,156,681	737,451	1,109,223	1,118,503	1,156,681

Appendix Table 4

This table examines how firms adjust activity across products over time as in Table 9, but focuses on the role of product ranks instead of continuous values for export revenues, price and quality. Panel A considers adjustments within surviving firms from 2002 to 2006. Panel B considers adjustments within surviving firms in the textiles and apparel industries from 2004 to 2006 in response to the removal of MFA quotas in 2005. In Columns 1-3 the sample includes all firm-products exported at t=0, and the dependent variable is a binary indicator equal to 1 if the firm does not export the product at t=1. In Columns 4-6 the sample includes all firm-products exported at t=1, and the dependent variable is a binary indicator equal to 1 if the firm did not export the product at t=0. In Columns 7-9 the sample includes all firm-products exported at both t=0 and t=1, and the dependent variable is the change in log revenues from t=0 to t=1. In Columns 10-12 the sample includes all firm-products exported at both t=0 and t=1, and the dependent variable is the change in product rank from t=0 to t=1. Product rank is based on firms' worldwide log revenues, log price or log quality at t=0 or t=1 as indicated in the column heading. All regressions include a constant term and firm fixed effects. Robust T-statistics in parentheses based on standard errors clustered by firm. ***, **, and * indicate significance at the1%, 5%, and 10% levels.

Dep variable (Sample)	Drop dummy, t=1 (Products traded at t=0)			Add dummy, t=1 (Products traded at t=1)			Δ (log) Sales (Products traded at t=0 & t=1)			Rank, t=1 (Products traded at t=0 & t=1)		
Product rank	Sales Rank, t=0 (1)	Price Rank, t=0 (2)	Quality Rank, t=0 (3)	Sales Rank, t=1 (4)	Price Rank, t=1 (5)	Quality Rank, t=1 (6)	Sales Rank, t=0 (7)	Price Rank, t=0 (8)	Quality Rank, t=0 (9)	Sales Rank, t=0 (10)	Price Rank, t=0 (11)	Quality Rank, t=0 (12)
Panel A. Full panel, 2002-2006												
Product rank	0.0007***	0.0001***	0.0004***	0.0009***	-0.0000	0.0004***	0.0122***	0.0006	0.0069***	0.488***	0.354***	0.408***
	(12.58)	(3.53)	(11.43)	(10.12)	(-0.40)	(10.06)	(4.18)	(1.40)	(4.36)	(17.46)	(15.98)	(19.01)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.30	0.29	0.29	0.27	0.26	0.26	0.37	0.35	0.35	0.79	0.76	0.77
# Observations	347,288	347,288	347,288	407,412	407,413	407,414	143,881	143,882	143,883	143,881	143,882	143,883
# Firms	42,521	42,522	42,523	42,521	42,522	42,523	37,867	37,868	37,869	37,867	37,868	37,869
Panel B. MFA Reform, 2004–2006												
Product rank	0.0037***	0.0025***	0.0004***	0.0040***	-0.0001***	0.0026***	0.0111***	0.0004	0.0074***	0.611***	0.324***	0.456***
	(6.22)	(7.98)	(3.77)	(5.38)	(-59.94)	(6.66)	(3.14)	(0.58)	(3.32)	(13.48)	(20.01)	(20.92)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.33	0.32	0.31	0.31	0.36	0.30	0.40	0.38	0.42	0.82	0.76	0.78
# Observations	46,625	46,625	46,625	63,828	63,828	63,828	24,178	24,178	24,178	24,178	24,178	24,178
# Firms	8,682	8,682	8,682	8,682	8,682	8,682	7,226	7,226	7,226	7,226	7,226	7,226

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jinteco.2017.08.006.

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