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ABSTRACT

We develop a model of international trade with heterogeneous firms and endogenous quality choices. Producing higher quality involves returns to scale, it is intensive in skilled labor and high-quality inputs. Firms' quality choices are interrelated because firms sell their goods to consumers and to other firms. We estimate the model using data on manufacturing plants in Colombia before the trade liberalization, simulate a counterfactual liberalization and compare the results to post-liberalization data. Like other unilateral trade liberalizations in developing countries, the skill premium and skill intensity in manufacturing increased, and the size of firms decreased in Colombia. In the model, lower tariffs lead importers and exporters to upgrade quality, increasing the domestic demand and supply of high-quality inputs. Other firms then upgrade their own product quality, thereby amplifying these effects of domestic inputs. Relative demand for skilled labor increases in a wide range of firms, despite a contraction in sales.

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During the 1980s and 1990s, the numerous developing countries that unilaterally decreased their trade barriers after decades of import-substitution experienced a broad transformation in their manufacturing sector: Measured productivity, investment, skill intensity, the quality of inputs and of outputs all increased while firm size decreased or remained unchanged. Skill premia typically also rose abruptly by 10% to 20%.[1] The rise in demand for skill is particularly puzzling from the perspective of a standard factor-proportions model. Bilateral trade data suggest that developing countries have a comparative advantage in producing unskill-intensive, low-quality goods.[2] So, a trade liberalization should shift their production toward low-quality goods and decrease the relative demand for skilled workers.

We develop a model that brings together and extends several mechanisms used to explain this puzzle in the literature. In the model, heterogeneous firms endogenously choose the quality of their products. The production of high-quality goods exhibits economies of scale, it is intensive in skilled labor and high-quality inputs. A trade liberalization leads exporters to upgrade quality if their scale increases or if they face a higher relative demand for high-quality goods abroad.[3] Importers upgrade because high-quality foreign inputs make it cheaper for them to produce higher-quality goods.[4] Since producing higher-quality is skill intensive, trade increases the demand for skills *within* importing and exporting firms.

Beyond these existing mechanisms, the model brings domestic firms into the picture. *Across* firms, quality choices are interrelated because firms sell their goods to final consumers and to

[1]These changes are unlikely to come only from other reforms because they are typically larger in sectors with larger tariff decreases. For productivity changes, see Aw, Roberts and Xu (2011), Eslava et al. (2013), Khandelwal and Topalova (2004), Pavcnik (2002), Trefler (2004) and references there surveyed. Goldberg and Pavcnik (2004, 2007) survey labor market changes, and Tybout (2003) surveys firm size. See Kugler and Verhoogen (2009, 2012), Tovar (2012) and Verhoogen (2008) for quality improvements, and Das et al. (2013) and Holmes and Schmitz (2010) for case studies. The patterns are well-documented for middle-income countries, and they are less clear for low-income countries. The main trade partners of these middle-income countries were at the time high-income countries—not yet China.

[2]Within product categories, high-income countries systematically sell their goods at higher unit prices. See Schott (2004) and Khandelwal (2010) for example. Our argument and model are also applicable to higher-technology, capital-intensive goods that may appear as separate product categories in the data.

[3]See Bustos (2011a) and Helpman et al. (2010, 2012) for the economies of scale hypothesis. Here, differences in wages occur across firms only because of unobservable differences in skill. We do not address labor market imperfections in Helpman et al (2010, 2012). The demand for skill intensive goods is higher abroad in models of quality-differentiation, e.g. Verhoogen (2008) and Faber (2013), and of offshoring, e.g., Feenstra (2010) and Feenstra and Hanson (1997).

[4]See Burstein et al. (2013), Burstein and Vogel (2012) and Kugler and Verhoogen (2012). We interpret inputs as materials only through most of the paper, but we allow them to include capital inputs in section 5. See also Goldberg et al. (2009, 2010, 2012) for trade in intermediate inputs.

other firms. As importers and exporters upgrade, they increase the supply and demand for high-quality inputs in the domestic market. The increased supply makes the domestic production of high-quality goods cheaper, and the increased demand boosts their sales relative to low-quality goods. Both effects lead other firms to upgrade their own product quality and thereby magnify these supply and demand effects. Like in the data, the rise in demand for skills following a trade liberalization may be widespread. Also like in the data, a higher demand for skill may coexist with a reduction in scale due to increased competition.[5]

Through quality choices, the model also provides a unified explanation for well-documented cross-sectional correlations between firms' sales, wages, skill intensity, prices, and participation in international trade.[6] Economies of scale imply that more productive firms endogenously choose higher quality, become larger and more skill intensive. They sell their output and buy their inputs at higher prices. These larger firms are also more likely to trade because importing and exporting require a fixed cost. If, as our parameter estimates suggest, the relative demand and supply of high-quality goods is higher abroad, then importers and exporters are also more skill intensive and pay higher wages even after controlling for size.

Our application is the Colombian trade liberalization in 1991. We estimate the model to a cross-section of manufacturing plants in Colombia in 1988, simulate a counterfactual liberalization and compare the results to post-liberalization 1994 data. Since the model better represents patterns within sectors, we estimate it separately for two large sectors, chemicals and machinery. We believe this exercise is illustrative because the Colombian experience was typical and patterns in chemicals and machinery are similar to other sectors in Colombia.[7]

The model captures well the cross-sectional joint distribution of sales, wages, skill intensity, and import and export participation and intensity. The counterfactual liberalization, in turn, matches the data qualitatively well: Sales decrease, demand for skilled labor increases and large firms increase their sales and skill intensity relative to small firms.[8] Empirical studies

[5]Inputs also have an amplification effect in Markusen and Venables (1999) and Jones (2011), but there amplification only occurs if firm size increases, which doesn't occur in unilateral trade liberalizations.

[6]See Abowd, Kramarz and Margolis (1999) and Davis and Haltiwanger (1991) for wages, skill and size, and Bernard and Jensen (1995, 1997) and Bernard, Jensen, Redding and Schott (2007) for importing and exporting.

[7]See studies in footnote 1 for other countries and appendix A for other sectors. Chemicals and machinery sectors both contain final and intermediate goods (see section 3).

[8]In the counterfactual, we allow for only two parameters to change—one controlling trade deficits

of trade liberalizations document comprehensive changes in manufacturing firms—measured productivity, investment, skill intensity, and quality all improved. Similarly in the counterfactual, firms that upgrade their output quality also invest, become more skill intensive and upgrade the quality of their inputs. At the same time, their profits shrink, a prediction consistent with the strong opposition of industry associations to unilateral trade liberalizations in Colombia and elsewhere.[9]

This, perhaps counterintuitive, combination of decreasing sales and increasing skill intensity arises in the counterfactual for two reasons. First, the parameter estimates attribute a minor role for economies of scale in determining a firm's quality and skill intensity. Because exporters are generally large, recent theories propose economies of scale as the driver of these firms' decisions on investment, productivity improvements and skill intensity. To our knowledge, we are the first to use the joint distribution of sales and wages, and sales and skill intensity, to estimate the role of economies of scale in a trade model. Our results do not support the economies-of-scale hypothesis: Exporters are large even before the trade liberalization, and the positive relation between sales and other firm outcomes is noisy.[10]

Second, the amplification effect of domestic inputs is necessary for counterfactual increases in skill intensity to be large enough to match the data and to extend to domestically-oriented firms. In chemicals, for example, the model predicts that sales drop in 99% of firms, while skill intensity increases in 61% of firms, including 14% of firms that neither import nor export. Sales drop by 14% on average, and the share of skilled workers goes from 28% to 35%. In machinery, a comparative disadvantage sector, drops in sales are larger, 34%, and increases in skill intensity are smaller, from 19% to 25%. The domestic amplification effect accounts for roughly two-thirds of the rise in sectoral skill intensity in chemicals, and one-third in machinery.

The magnitude of these counterfactual changes is comparable to the data, where skill in-

and the other controlling non-tariff barriers—to exactly match changes in aggregate imports and exports. Large firms increase their size and skill intensity relative to other firms in Bustos (2011), Kugler and Verhoogen (2012), and Lileeva and Trefler (2010).

[9]See Edwards (2001) for the politics of the structural reforms in Colombia, and Milgrom and Roberts (1990) for a description of broad firm transformations in modern manufacturing.

[10]This was previously noted by Tybout (2003). He adds that firm size does not increase, if anything, it decreases with import competition, but we do not use post-liberalization data in the estimation. Helpman et al (2012) also estimate a quantitative trade model with economies of scale, but since they do not observe sales, they use export dummies. Export dummies, however, may reflect a firm's ability to compete with foreign firms in the domestic market, and the export activities and scale per se need not drive firms' behavior. See Lileeva and Trefler (2010) and footnote 3 for other theories.

tensity increased by 7.9 percentage points in chemicals and 2.4 percentage points in machinery. Changes in the data, however, occurred while the skill premium in Colombia increased by 12%, whereas our baseline counterfactuals are obtained under the assumption of inelastic wages.[11] So, our quantitative results suggest that, existing mechanisms, even when magnified by domestic input-output linkages, cannot fully account for the rise in demand for skill in data. In section 5, we extend the model to narrow this gap.

The model is in section 1. A description of Colombian reforms and the data is in section 2. We estimate the model in section 3 and simulate the trade liberalization in section 4. Section 5 considers other explanations and section 6 concludes.

1 The model

Preferences are in section 1.1, technologies in section 1.2, and equilibrium in section 1.3. The model extends Melitz (2003). The key theoretical innovation, from which the results follow, is a production function where high-quality goods involve economies of scale and are intensive in skilled labor and high-quality inputs. The assumptions on environment are guided by our empirical application.

The set up is static. There are two countries, Home and Foreign. Foreign variables are denoted with an asterisk. Since Colombia is a small country, we assume all Foreign variables are exogenous. Our focus is the medium-run effects of the trade liberalization: The five years in which most of the changes in the labor market arguably occur. During the period, imports increased faster than exports in Colombia as it is typical with unilateral trade liberalizations. Also, average sales decreased and there was some exit—a change inconsistent with free entry and constant markups, where average sales must increase whenever the probability of surviving decreases. We view free entry and balanced trade as long-run tendencies. In 1999, nearly ten years after the liberalization, a large devaluation of Colombian pesos increased exports and probably firm size. But to study the medium run, we allow for unbalanced trade and take

[11] Our counterfactual assumes that labor is perfectly elastic, and hence wages do not change. Appendix C.1 assumes that labor is perfectly inelastic and finds that the skill premium increases by 4% in chemicals and 8% in machinery. The Colombian skill premium is from Attanasio et al. (2004, table 4) who observe education and earnings of households. We only observe skills with error. See section 2.

the set of potentially active firms as exogenous. These assumptions make it harder for trade to increase the demand for skills in the model since sales are allowed to drop and there are economies of scale in the production of high-quality, skill-intensive goods. Exit may occur because there is a fixed cost of production.

1.1 Demand

There is a continuum of goods indexed by ω. The set of goods is Ω in Home and Ω^* in Foreign, with $|\Omega| = |\Omega^*| = 1$. Consumers take prices $p(\omega)$ and qualities $\tilde{q}(\omega)$ as given, and choose quantities $x(\omega)$ to maximize a demand function with constant elasticity of substitution (CES):

$$X(Q) = \left[\int_{\Omega\cup\Omega^*} x(\omega)^{(\sigma-1)/\sigma}\tilde{q}(\omega)^{1/\sigma}d\omega\right]^{\sigma/(\sigma-1)} \tag{1}$$

where $\sigma > 1$ is the elasticity of substitution. We change the quality scale to q defined through

$$\tilde{q} = \Phi(q, Q)$$
$$\text{where} \quad \Phi(q, Q) = \frac{\exp(q - Q)}{1 + \exp(q - Q)} \tag{2}$$

and $Q = 0$. Since quality is an ordinal concept, the change of scale has no bearing on the results. It is convenient because, in section 1.2.1 below, it allows us to capture the demand for high-quality goods in Foreign relative to Home consumers with a single parameter. We henceforth refer to firm ω's quality level as $q(\omega)$ defined by $\tilde{q}(\omega) = \Phi(q(\omega), Q)$, and to Q as the consumer's reference quality. The CES price index is

$$\overline{P}(Q) = \left[P(Q)^{1-\sigma} + P^*(Q)^{1-\sigma}\right]^{1/(1-\sigma)}, \quad \text{where} \tag{3}$$
$$P(Q) = \left[\int_{\Omega} p(\omega)^{1-\sigma}\Phi(q(\omega), Q)d\omega\right]^{1/(1-\sigma)} \quad \text{and} \quad P^*(Q) = \left[\int_{\Omega^*} p(\omega)^{1-\sigma}\Phi(q(\omega), Q)d\omega\right]^{1/(1-\sigma)}$$

are the indices of the Home and Foreign varieties, respectively. Let Y be the consumer aggregate spending. Then, his spending on a good with price p and quality q is

$$r_c(q, p) = \left[\frac{p}{\overline{P}(Q)}\right]^{1-\sigma} \Phi(q, Q)Y. \tag{4}$$

1.2 Production

Each good $\omega \in \Omega$ is potentially produced by a monopolistically competitive firm. All goods have final and intermediate usage. Firms use skilled and unskilled labor, and material inputs for production. To produce quality q, firm ω pays a fixed cost $f(q)$. After incurring this cost, the output of firm ω when producing quality q with import status $1_M \in \{0,1\}$ is

$$\tilde{\alpha} z(q,\omega) L(q)^{\alpha} X(q)^{1-\alpha} \tag{5}$$

$$\text{where} \quad L(q) = \left[\sum_{\varsigma \in \{s,u\}} l_{\varsigma}^{(\sigma_L - 1)/\sigma_L} \Phi_L(\varsigma, q)^{1/\sigma_L} \right]^{\sigma_L/(\sigma_L - 1)},$$

$$X(q) = \left[\int_{\Omega \cup \Omega^*(1_M)} x(\omega')^{(\sigma-1)/\sigma} \Phi[q(\omega'), q]^{1/\sigma} d\omega' \right]^{\sigma/(\sigma-1)},$$

$\tilde{\alpha} = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$ is a constant, $z(q,\omega)$ is a firm- and quality-specific productivity parameter, l_s and l_u are the quantities of skilled and unskilled labor, $x(\omega')$ is the quantity of variety ω', and $\Phi_L : (\{s,u\} \times \mathbb{R}_+) \to \mathbb{R}_+$ is a productivity shifter. The set $\Omega^*(0) = \varnothing$ and $\Omega^*(1) = \Omega^*$.

Production is a Cobb-Douglas function of labor $L(q)$ and material inputs $X(q)$. Function $L(q)$ is a CES aggregate of skilled and unskilled labor. Denote with w_s and w_u the wages of skilled and unskilled labor. Then, the firm's demand for skilled relative to unskilled workers is

$$\frac{l_s}{l_u} = \left(\frac{w_s}{w_u} \right)^{-\sigma_L} \frac{\Phi_L(s,q)}{\Phi_L(u,q)}. \tag{6}$$

Skill intensity decreases in the skill premium $\frac{w_s}{w_u}$ and increases in output quality if $\frac{\Phi_L(s,q)}{\Phi_L(u,q)}$ is increasing in q. Section 3 below estimates the ratio $\frac{\Phi_L(s,q)}{\Phi_L(u,q)}$ as a function of q.

Function $X(q)$ is the CES aggregate of material inputs, where $\Phi(q',q)$ is the productivity shifter of an input of quality q' when the output quality is q. Function Φ, defined in equation (2) above, has three key properties. It is increasing in the first argument and decreasing in the second. Higher quality inputs are more efficient, and higher-quality output is more difficult to produce. It is also log-supermodular. Then, the firm's relative demand for any two inputs 1 and 2 with qualities $q_1 > q_2$,

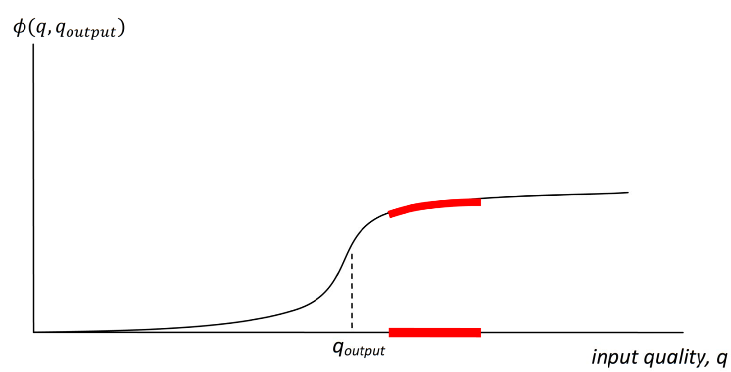
$$\frac{x(1)}{x(2)} = \left(\frac{p_1}{p_2} \right)^{-\sigma} \frac{\Phi(q_1,q)}{\Phi(q_2,q)},$$

is increasing in the output quality q: Firms of higher output quality demand relatively more inputs of higher quality.[12]

1.2.1 Firms in international trade

Firm ω pays a fixed cost $f_M(\omega)$ to import Foreign varieties $\omega \in \Omega^*$.[13] Log-supermodularity of Φ implies that higher-quality firms gain more from importing high-quality inputs. This point is also made clear in figure 1, which plots the productivity shifter $\Phi(q, q_{output})$ as a function of input quality q when the firm's output quality is q_{output}. The firm would like to concentrate its input purchases in the interval marked with a bold red line. These inputs are efficient—i.e., $\Phi(q, q_{output})$ is high—but probably not as expensive or scarce as inputs of higher quality. But if the firm is among the highest quality firms in Home, these inputs are not available domestically and Home inputs are inefficient—i.e., $\Phi(q, q_{output})$ is low when $q < q_{output}$. The firm will then be more willing to pay a fixed cost to import higher-quality inputs than a low-quality firm will.

Figure 1: Productivity shifter $\Phi(q, q_{output})$ as a function of input quality q.



Firm ω pays a fixed cost $f_X(\omega)$ to access the Foreign market with demand

$$r^*(q, p) = p^{1-\sigma}\Phi(q, Q^*)Y^*. \tag{7}$$

[12]Function Φ is log-supermodular if $\frac{\partial^2 \ln \Phi(q', q)}{\partial q' \partial q} > 0$, or equivalently, $\frac{\Phi(q_1, q)}{\Phi(q_2, q)}$ is increasing in q whenever $q_1 > q_2$. See Costinot (2009).

[13]Consumers access foreign markets freely but firms pay a fixed cost. This asymmetry can be eliminated by assuming all firms and consumers can access foreign markets freely but they pay an additional markup for distribution costs. Firms can choose to pay a fixed cost to forgo these distribution costs.

Demand in Foreign may arise from consumers or firms. Parameter Y^* captures the size of the Foreign market, while parameter Q^* captures the relative demand of high- to low-quality goods. If $Q^* > Q$, Foreign's relative demand for high-quality goods is higher than Home consumer's. That is, for any two goods 1 and 2 with $q_1 > q_2$,

$$\left[\frac{r^*(q_1, p_1)}{r^*(q_2, p_2)}\right] \Big/ \left[\frac{r_c(q_1, p_1)}{r_c(q_2, p_2)}\right] = \left[\frac{\Phi(q_1, Q^*)}{\Phi(q_2, Q^*)}\right] \Big/ \left[\frac{\Phi(q_1, Q)}{\Phi(q_2, Q)}\right] > 1.$$

Firms with higher-quality output are then more likely to export. The fixed costs of importing and exporting imply that larger, more productive firms are also more likely to trade. We allow these costs $f_X(\omega)$ and $f_M(\omega)$ to be firm-specific because participation in trade varies across firms with similar characteristics in the data.

1.2.2 The firm's problem

We use standard CES aggregation to derive demand and set up the firm's problem. A bundle of labor and material inputs for producing quality q with import status 1_M costs

$$C(q, 1_M) = w(q)^\alpha P_I(q, 1_M)^{1-\alpha},$$

where $w(q) = [\sum_{i=s,u} w_i^{(1-\sigma_L)} \Phi_L(\varsigma, q)]^{1/(1-\sigma_L)}$ is the CES price of labor, and $P_I(q, 1) = \overline{P}(q)$ and $P_I(q, 0) = P(q)$ in equation (3) above are the CES prices of materials. These prices are functions of output quality q through productivity shifters Φ_L and Φ. Firm ω's total revenue is $r_T(\omega) = \{r[q(\omega), p(\omega)] + 1_X(\omega) r^*[q(\omega), p(\omega)]\}$, where $r(q, p)$ is Home's demand function in equation (10) below. The firm's demand for skilled and unskilled labor is then

$$w_\varsigma l_\varsigma(\omega) = \left\{\frac{w_\varsigma}{w[q(\omega)]}\right\}^{1-\sigma_L} \Phi_L[\varsigma, q(\omega)] R_L(\omega) \qquad \text{for } \varsigma = s, u \tag{8}$$

where $R_L(\omega) = (\alpha/\mu) r_T(\omega)$ is the firm's total spending on labor and μ is the markup. The firm's spending on an input with quality q and price p is

$$r_I(q, p, \omega) = \left\{\frac{p}{P_I[q(\omega), 1_M(\omega)]}\right\}^{1-\sigma} \Phi[q, q(\omega)] R_I(\omega) \tag{9}$$

where $R_I(\omega) = [(1-\alpha)/\mu] r_T(\omega)$ is total spending on inputs. Aggregating over consumers and firms (equations (4) and (9)), spending on a variety with price p and quality q in Home is

$$r(q,p) = r_c(q,p) + \int_\Omega r_I(q,p,\omega)d\omega = p^{1-\sigma}\chi(q) \tag{10}$$
$$\text{where} \quad \chi(q) = \Phi(q,Q)P(Q)^{\sigma-1}Y + \int_\Omega \Phi[q,q(\omega)]P_I[q(\omega),1_M(\omega)]^{\sigma-1}R_I(\omega)d\omega.$$

Function $\chi(q)$ summarizes the country-wide demand for quality q: Each type of spending, consumers' Y and firms' $R_I(\omega)$, is weighted by its own relative demand for quality q captured by shifters Φ. If Φ were constant in its second argument, all agents would have the same relative demand for high- and low-quality goods, and $\chi(q)$ would reduce to a function of aggregate prices, absorption and a demand shifter associated with q.

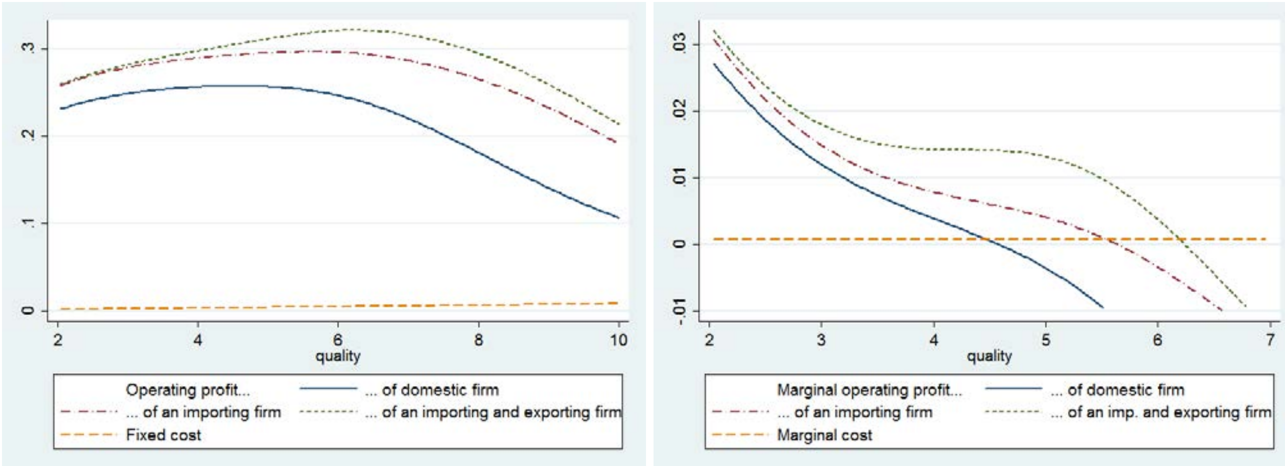
Firm ω sets price $p = \mu C(q, 1_M)/z(q,\omega)$ where $\mu = \frac{\sigma}{\sigma-1}$ is the markup. It chooses quality q, entry 1_E, import status 1_M and export status 1_X to maximize profits:

$$\pi(\omega) = \max_{q,1_E,1_M,1_X} 1_E \left\{ \sigma^{-1}\left[r(q,p) + 1_X r^*(q,p)\right] - \left[f(q) + 1_M f_M(\omega) + 1_X f_X(\omega)\right] \right\}. \tag{11}$$

A firm's operating profit $\sigma^{-1}\left[r(q,p) + 1_X r^*(q,p)\right]$ is proportional to its productivity $z(q,\omega)$ and the cost of producing higher quality $f(q)$ is fixed. So, more productive firms endogenously choose higher quality. The decisions of output quality, import and export statuses cannot be disentangled. Exporting increases the scale of production rendering imports more profitable, and importing decreases variable costs rendering exports more profitable. Importing and exporting also yield higher profits from quality upgrading. Similarly intertwined are other firms' choices, since they determine input costs C and demand function χ. Before closing the model, we illustrate these choices.

1.2.3 Choice of output quality: An example

Consider the problem of a firm in choosing its output quality. Assume that its productivity is $z(q,\omega) = z$ for all q. If the firm is not engaged in international trade $1_M = 1_X = 0$, its profit as



(a) components of profit (b) first order conditions

Figure 2: A firm's choice of output quality

a function of its output quality q is

$$z^{\sigma-1}[\mu C(q,0)]^{1-\sigma}\chi(q)/\sigma - f(q). \tag{12}$$

The first term is the firm's operating profit and the second, its fixed cost. Figure 2(a) graphs the two terms (solid line for operating profit), where $\{[\mu C(q,0)]^{1-\sigma}\chi(q)/\sigma\}$ and $f(q)$ are taken from the estimates in section 3 below.[14] Higher quality has two opposing effects on the operating profit—it increases demand $\chi(q)$ and input cost $C(q,0)$. Demand dominates for low-quality levels, but eventually as high-quality inputs become expensive or unavailable, the cost effect dominates. So, the operating profit is initially increasing in q, peaks at $q = 4.6$ and then declines. The fixed cost is linear by parametric assumption.

Figure 2(b) shows the firm's first order conditions, the derivative of equation (12) with respect to q. The firm chooses quality $q = 4.5$, where its marginal operating profit equals marginal cost. Its total profit is the area between the two curves minus $f(0)$. An increase in the firm's productivity z shifts the marginal profit curve upward and increases the optimal quality—more productive firms choose higher quality.

The figure also compares the choice of quality for different import and export statuses. Parameter estimates below are such that Foreign has a higher relative demand and supply

[14] We use estimates from the chemical sector here.

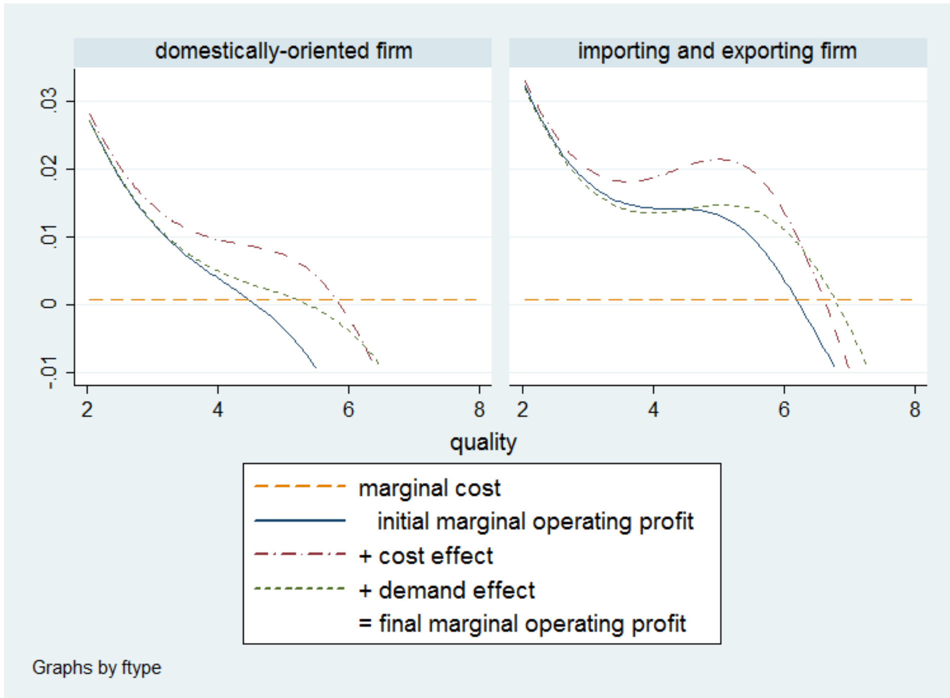
of high-quality goods than Home. Then, importing decreases the relative cost of producing high-quality, and exporting increases the relative demand for high-quality goods. Graphically, importing and exporting shift the marginal profit curve rightward due to these relative cost and demand effects and upward due to standard effects of increase in scale and decrease in cost. Both shifts increase the firm's optimal quality and operating profit. The firm engages in international trade if the additional profit exceeds the fixed cost of importing or exporting.

To illustrate the interconnection between firms' quality choices, we exogenously increase all firms' quality by one. Aggregate prices $P(q)$ and demand $\chi(q)$ change accordingly, but we do not allow firms to update their choices of output quality or of import and export status. Figure 3(a) shows the changes in the problem of the firm in figure 2(b) that neither imports nor exports. The effects of cost $C(q, 0)$ and demand $\chi(q)$ are separated. The cost effect shifts the marginal operating profit up and to the right. The aggregate cost of inputs $C(q, 0)$ decreases, especially for the production high-quality goods whose adequate materials are initially not available in Home. Demand shifts the marginal operating profit down and to the right. The downward shift occurs because the price index decreases—competition tightens—and the rightward shift occurs because firms shift demand from low- to high-quality materials. The overall effect of the experiment is large: The firm's quality choice increases from 4.5 to 5.2, more than half of the 1.0 exogenous increase in other firms' quality.[15]

Figure 3(b) shows the effect of the experiment on a firm that imports and exports. The cost effect is much smaller because the firm already has access to high-quality Foreign inputs, and the demand shift is now positive because the firm's marginal profit intercepts the x-axis at a higher quality level. The counterfactual trade liberalization in section 4 below leads most firms to upgrade their product quality, and so its Home-market effects are akin to this experiment: Reductions in the cost of producing high-quality goods leads to quality upgrades among all firms, especially non-importers, and shifts in demand lead to quality upgrading only among *ex ante* high-quality firms.

[15]The potential for multiplicity of equilibria is discussed in appendix D.

Figure 3: Effect of other firms on quality choice



1.3 Tariffs, trade and equilibrium

The price $p(\omega)$ that agents at Home pay for $\omega \in \Omega^*$ includes an *ad valorem* tariff τ: $p(\omega) = (1+\tau)p^*(\omega)$ where $p^*(\omega)$ is the unit price of a Foreign variety $\omega \in \Omega^*$ after trade costs.[16] Home's imports from Foreign is $R_{HF} = R^{\tau}_{HF}/(1+\tau)$ where R^{τ}_{HF} is after-tariff spending on Foreign goods,

$$R^{\tau}_{HF} = \left[\frac{P^*(Q)}{\overline{P}(Q)}\right]^{1-\sigma} Y + \int_{\Omega} 1_M(\omega) \left\{\frac{P^*[q(\omega)]}{\overline{P}[q(\omega)]}\right\}^{1-\sigma} R_I(\omega) d\omega.$$

Tariff revenues $T = \tau R_{HF}$ are redistributed to consumers through a lump sum transfer. Home's exports to Foreign are

$$R_{FH} = \int_{\Omega} 1_X(\omega) r^*[q(\omega), p(\omega)] d\omega.$$

To close the model, we take a stance on the factor(s) used for fixed costs f, f_M and f_X. The data do not distinguish fixed from variable production costs, and we assume that fixed costs use a separate factor (labor or capital) that differs from the skilled and unskilled labor used in production function (5). When matching the model to data in section 3 below, we then take

[16] We make the standard assumption that Foreign factors are used to transport Foreign goods.

variable labor $\frac{l_s(\omega)}{l_s(\omega)+l_u(\omega)}$ to be firm ω's skill intensity, and in the counterfactuals, we assume that the supply of the factor used in fixed costs is perfectly elastic so that fixed costs do not change.[17] Without loss of generality, let its price be one so that f, f_M and f_X are the costs and the parameters describing the technologies to produce, to import and to export. Let D_H be Home's exogenous trade deficit, $L_s(w)$ and $L_u(w)$ be the supply of skilled and unskilled labor when wages are $w = (w_s, w_u)$. Then, consumer spending is

$$Y = w_s L_s(w) + w_u L_u(w) + F + \int_\Omega \pi(\omega) d\omega + T + D_H \tag{13}$$
$$\text{where } F = \int_\Omega 1_E(\omega) \left[f(q(\omega)) + 1_M(\omega) f_M(\omega) + 1_X(\omega) f_X(\omega) \right] d\omega$$

is firms' total spending on fixed costs. By Walras' law, $R_{HF} = R_{FH} + D_H$. Labor markets clear if

$$L_\varsigma(w) = \int_\Omega l_\varsigma(\omega) d\omega \qquad \text{for } \varsigma = s, u. \tag{14}$$

To summarize, an economy is defined by Home's labor supply $L_s(w)$ and $L_u(w)$, fixed production costs $f(q)$, tariffs τ, deficit D_H; the set of firms Ω each with its productivity $z(q, \omega)$, its fixed cost of importing $f_M(\omega)$ and exporting $f_X(\omega)$, and by Foreign, itself described by demand shifters Q^* and Y^*, and set of goods Ω^* each with its price $p^*(\omega)$ and quality level $q(\omega)$. An equilibrium is a set of wages w that clears the labor markets.

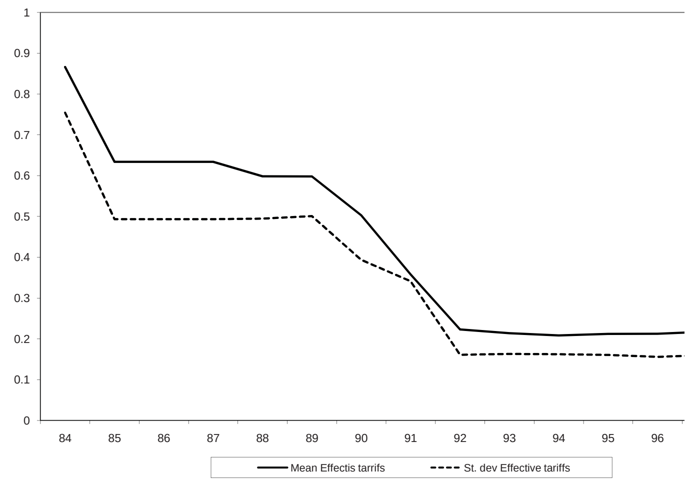
2 Data and the Colombian Trade Liberalization

Following international trends, Colombia significantly reduced trade barriers in a broad set of industries between 1985 and 1991 after decades of import-substitution policies.[18] Non-tariff barriers, which affected 99.6% of industries in 1984, were removed, and the average tariff in manufacturing decreased from 50% to 13%. Figure 4 shows the evolution of effective tariff rates

[17] This assumption is innocuous for the benchmark counterfactual where labor is perfectly elastic and wages do not change. In appendix C.2, the results barely change when we let fixed costs change with wages in the case of inelastic labor supply.

[18] Attanasio et al (2004) and Edwards (2001) describe reforms in Colombia. The trade liberalization was accompanied by reforms in the labor and financial markets, but these were less comprehensive because they stalled for political reasons. See also Lora (2001).

Figure 4: Effective tariffs, mean and standard deviation 1984-1996



between 1984 and 1996. The sharp decreases in 1991 were arguably unexpected.[19] In 1990, the newly-elected Gaviria administration designed a four-year plan to reduce trade barriers, but it abruptly implemented the whole plan after a few months under the impression that uncertainty was holding back changes in firms.

We use the Colombian Annual Manufacturing Survey which comprises all manufacturing plants in Colombia with 10 or more workers. A plant is interpreted as a firm in the model.[20] We use two sample years. We estimate the model with pre-liberalization 1988 data and compare the counterfactual results to 1994 post-liberalization data. For each plant in 1988, the data contain the value of domestic and export sales, and spending on domestic and imported materials. The number of workers and wage bill are reported separately for managers, technicians and production workers. We take managers and technicians to be white-collar workers, but below, measurement error distinguishes them from unobservable skilled workers.

The survey changed during the years of interest. In 1994, there is no plant-specific data on imports and exports. We use only total imports and exports by sector from Feenstra et al. (2005). Plant identification numbers changed in 1990. So, we cannot infer exit or within-firm changes.[21] Last, our measure of white-collar workers is not available after 1994 because the

[19]The figure is from Eslava et al. (2013).

[20]Plants report whether they belong to a firm with multiple plants, but not the plant(s) to which they are linked. Six percent of plants are from multi-plant firms, and moments in the data look similar if these plants are excluded.

[21]The number of firms decreases slightly in 1991, but there is a long term trend in increasing number

classification of employees changed in 1995.

Our model is suitable to study patterns within sectors. A within-sector emphasis is consistent with recent papers that find large systematic variations within and not across sectors, and more specifically, with Helpman et al.'s (2012) finding that worker inequality and changes in inequality occur mostly within sectors.[22] The structure of the model where all goods are recycled as inputs within sectors is also apt since input-output matrices generally have large diagonal elements, especially in developing countries. Accordingly, we choose two sectors for our empirical analysis and estimate the model separately for each sector. The chemical sector with 438 plants and the machinery sector with 557 plants are among the largest in Colombia. The chemical sector contains intermediate and final goods such as pharmaceutics, cosmetics and household cleaning products, and about 53% of its material inputs are themselves chemicals. The machinery sector contains electrical and non-electrical machinery and final goods such as household appliances, computers and televisions. Intra-sector purchases amount to about 20% of intermediate goods in the sector.[23]

3 Pre-liberalization cross-section

As we turn to the estimation, we clarify the objectives of our quantitative analysis. Quality choices in the model provide a unified explanation for well-documented cross-sectional correlations between sales, wages, skill intensity, import and export participation and intensity. In estimating the model to a pre-liberalization cross-section, we show that the model can quantitatively match the joint distribution of these firm characteristics, and that this joint distribution allows for the identification of parameters governing demand for skilled and unskilled labor. So, changes in firm behavior due to the counterfactual trade liberalization are quantitatively consistent with the cross section.

Numerous studies associate trade liberalization episodes in developing countries with in-

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of firms as the economy grows, making it hard to quantify exit.

[22]Helpman et al.'s (2012) data are from Brazil and cover the period of trade liberalization. See also Bernard, Eaton, Jensen and Kortum (2003) for cross-sectional patterns.

[23]The figures for intra-sector intermediate consumption come from the 1988 input-output matrices, whose sector classification differs from the manufacturing survey. For chemicals intermediate consumption, we use the figure corresponding to "Chemicals and Rubber," and for machinery, we use "Machinery and Equipment."

creases in the demand for skills in manufacturing—both the skill premium and the skill intensity increased. In unilateral liberalizations, firm sales also decreased significantly in the short and medium run as imports flooded the market. Together, these changes are inconsistent with models where firms' demand for skills depends only on economies of scale. Our model combines economies of scale with other elements in the literature and input-output linkages.[24] Quantitatively, the counterfactual results suggest how far (or close) the main mechanisms linking trade to demand for skills in the literature are to explaining changes in the data and whether the novel feature of input linkages is economically relevant. Our application is then intended to illustrate events from a broad set of countries and sectors. So, we exploit only patterns in the data that are well documented elsewhere, and we show in appendix A that they occur in other sectors in Colombia.

Still, one contrast between sectors is worth highlighting. Like other developing countries, Colombia has a comparative disadvantage in producing machines.[25] So, the extent to which the model predicts an increase in demand for skills even when the exports of machines do not grow suggests whether our mechanism is consistent with documented increases in demand for skills in a wide range of manufacturing firms and sectors.

The estimation uses the method of simulated moments, where the chosen moments describe the joint distribution of firm sales, wages, skill intensity, imports and exports. There are 15 parameters and 47 moments. The parametrization is in section 3.1.1, the simulation in section 3.1.2 and the moments in section 3.1.3. Section 3.1.4 discusses identification. Results are in section 3.2. Monte Carlo simulations are in appendix D.

[24]The patterns in the data cannot be generated by firms shedding their least skill-intensive products during the trade liberalization—an alternative explanation suggested to us by Jon Vogel. In our data, the average number of products by firm increased from 3.6 to 4.4 between 1988 and 1994 and it increased within all sectors. These changes are consistent with quality upgrading since a firm's product scope may be a reasonable proxy for its product quality. See Bernard et al. (2012).

[25]See Eaton and Kortum (2001).

Table 1: List of parameters

description	model variable	parametrization	parameter
firm-quality productivity	$z(q,\omega)$	$= \max\{0, z_1(\omega) + z_2(\omega)q\}$	
		$z_1(\omega) \sim$ log-normal	μ_1, σ_1
		$z_2(\omega) \sim$ normal with mean 0	σ_2
fixed cost of production	$f(q)$	$= f_1 q$	f_1
productivity of skilled to unskilled workers	$\Phi_L(s,q)/\Phi_L(u,q)$	$= \exp(l_1 + l_2 q)$	l_1, l_2
fixed cost of importing	$f_M(\omega)$	$\sim$ log-normal	μ_M, σ_M
fixed cost of exporting	$f_X(\omega)$	$\sim$ log-normal	μ_X, σ_X
skill premium	w_s/w_u		w_s/w_u
quality of Foreign firms	q^*		q^*
ref. quality of Foreign demand	Q^*		Q^*
size of Foreign market	Y^*		Y^*
measurement error in skills	-	logistic, truncated in $[0,1]$ and mean parameter 0	σ_π

Fixed parameters are $Y = p^* = w_u = 1$, $\sigma = 5$, $\sigma_L = 1.6$, $\alpha = 0.7$, $\tau_{\text{chemicals}} = 0.415$, $\tau_{\text{machinery}} = 0.210$.

3.1 Estimation procedure

3.1.1 Parametrization

Table 1 summarizes the parametrization. We fix parameters that are not identified. The elasticity of substitution across skilled and unskilled labor σ_L is not separately identified from Φ_L since they both enter the model only through the demand for labor in equation (8). Similarly, the elasticity of substitution across goods σ is not separately identified from $z(q,\omega)$ since it enters only as an exponent of $z(q,\omega)$ in demand. We take $\sigma = 5$ from Broda and Weinstein (2006), and $\sigma_L = 1.6$ from Acemoglu and Autor (2010). The average tariff on chemicals in 1988 in Colombia is $\tau = 41.5\%$ and in machines it is $\tau = 21.0\%$. The share of labor in production is $\alpha = 0.7$. We assume all foreign firms have the same price and quality, and set $p^*(\omega) = 1$ for all $\omega \in \Omega^*$. We also set $w_u = 1$ because our moments only include relative wages, not wages in pesos. Similarly, we set $Y = 1$ because we do not match firm sales in pesos, only sales normalized by domestic absorption. Appendix C.2 experiments with alternative values for σ, σ_L and α.

We parameterize technologies $z(q,\omega)$, fixed costs $f(q)$, $f_M(\omega)$ and $f_X(\omega)$, productivity shifters for labor $\Phi_L(\varsigma, q)$ and measurement errors for skills. Let

$$z(q,\omega) = \max\{0, z_1(\omega) + z_2(\omega)q\} \tag{15}$$

where $z_1(\omega)$ is independently drawn from a log-normal with mean parameter μ_1 and variance parameter σ_1, and $z_2(\omega)$ is drawn from a normal distribution with mean zero and variance σ_2. We allow for the rate at which productivity changes with quality $z_2(\omega)$ to be firm-specific because the model would otherwise predict a perfect correlation between sales and wages.[26]

Let $f(q) = f_1 q$ where f_1 is a parameter to be estimated. We assume $f(0) = 0$ because we cannot estimate it without observing exit.[27] Firms' fixed costs of importing $f_M(\omega)$ are independently drawn from a log-normal with mean parameter μ_M and variance parameter σ_M, and their fixed costs of exporting $f_X(\omega)$ are drawn from a log-normal with parameters μ_X and σ_X. Assume

$$\begin{aligned} \frac{\Phi_L(s,q)}{\Phi_L(u,q)} &= \exp(l_1 + l_2 q) \\ \Phi_L(u,q) &= \bar{\phi}_L(q; l_1, l_2) \end{aligned} \tag{16}$$

where l_1 and l_2 are parameters to be estimated and $\bar{\phi}_L(q)$ is judiciously adjusted for every parameter guess so that the CES price of labor $w(q) = 1$ for all q.[28] Without $\bar{\phi}_L$, l_2 increases the efficiency of producing high-quality goods and affects quality choices. With $\bar{\phi}_L$, l_1 and l_2 only affect skill intensity, as per equation (6).

The data report the share of white- and blue-collar workers, not their skill. Firm characteristics such as sales, importing and exporting are much more correlated with wages than with the share of white-collar workers. Our interpretation is that firms observe skill better than we econometricians and that wages reflect the true ranking of skill intensity across firms better than the share of white-collars. Accordingly, we assume measurement error in skills. A share $\pi_u(\omega)$ of firm ω's unskilled workers are misclassified as white-collars, where $\pi_u(\omega)$ is inde-

[26] These two dimensions of firm heterogeneity are akin to those in Hallak and Sivadasan (2013).

[27] Allowing for $f(0)$ to match a 10% exit, barely changes the counterfactual results below. The decrease in firm sales is slightly lower and the increase skill intensity is slightly higher than the benchmark.

[28] $\bar{\phi}_L(q; l_1, l_2) = \left[w_u^{1-\sigma_L} + \exp(l_1 + l_2 q) w_s^{1-\sigma_L}\right]^{-1}$

pendently drawn from a logistic distribution truncated in [0,1] with mean parameter zero and variance parameter σ_π. All skilled workers are white-collars.[29] Other estimated parameters are the quality of Foreign goods q^*, and Foreign's demand shifters Q^* and Y^*.

3.1.2 Simulation

We simulate the behavior of 5000 firms. Each firm has a fixed vector of five independent standard normal random variables. For each parameter guess, we transform these vectors to get firm-specific productivity parameters $z_1(\omega)$ and $z_2(\omega)$, fixed costs $f_X(\omega)$ and $f_M(\omega)$ and measurement error $\pi_u(\omega)$. Firms may exit or enter the market. If they enter, they choose a quality level from a grid with 200 choices $q \in [0, 10]$. Together with the four choices on participation of international trade—to import only, to export only, to import and export, or to do neither—firms have 801 discrete choices over which we iterate.[30]

Given firms' discrete choices and wages, the vector of price indices $P(q)$ is a fixed point calculated iteratively for each quality level in the grid. Price indices are fixed points because they enter into firms' prices through material inputs. Given price indices, the demand function $\chi(q)$ in equation (10) is also iteratively calculated as a fixed point for each quality in the grid. Demand is a fixed point because firms' demand for materials enter into $\chi(q)$ thereby affecting sales and demand for materials.[31] Given P and χ, we calculate the profit of each firm for each of its 801 discrete choices and update its optimal choice. The equilibrium is attained when no firm changes its choice. We then calculate each firm's average wage, share of white-collar workers, imports, exports, and sales. The parameter estimates minimize the squared distance between the moments from these generated data and the observed moments, weighted by the inverse of their variance.[32] Implicitly, this procedure takes labor supply $L(w)$ to equal firms' demand

[29] We assume that skilled workers are not misclassified for several reasons. First, in the data, the wages of white-collars vary a lot more than that of blue-collars across firms, suggesting that the presence of college graduates among blue-collars is not common. Second, if classification errors also applied to skilled workers, their share in the industry would be close to the white-collar share, which is about 50%, much higher than the share of college graduates in Colombian manufacturing.

[30] Our results are robust to increasing the number of firms and quality choices. See appendix D.

[31] In estimating P and χ, instead of aggregating over 5000 firms, we use the results in Melitz (2003) to aggregate over the representative firm in each of the 800 discrete choices. This significantly speeds up computation, since less than one-quarter of the possible choices are picked in a typical iteration.

[32] The variance of moments is calculated by randomly drawing the set of firms with replacement and recalculating the moments. To calculate moments on market shares, we multiply generated shares by 5000/438 where 438 is the number of chemical plants in the data.

Table 2: List of moments

	# of moments
10%, 25%, 50%, 75%, 90% of the unconditional distribution of ...	
... log(normalized domestic sales)	5
... white-collar workers/total number of workers	5
By quartile of domestic sales, ...	
... average white-collar workers/total number of workers	4
... share of plants exporting	4
... share of plants importing	4
... spending on imported inputs/total spending on materials	4
... export sales/total sales	4
% of firms in the n^{th} quartile of domestic sales and the m^{th} quartile of wages for $n, m = 1, ..., 4$	16
average wage of white-collars/average wage of blue-collars	1
total	47

for labor and trade deficit D_H to equal the difference between estimated imports and exports.

3.1.3 Moments

The list of moments is on table 2. We match the 10%, 25%, 50%, 75%, 90% of the unconditional distributions of the log of normalized domestic sales (market shares) and share of white-collar workers.[33] We classify firms according to their quartile of domestic sales, and for each quartile, we match: The average of firms' share of white-collar workers; the percentage of firms importing and exporting; the spending on imported materials divided by total spending on materials, and export sales divided by total sales. We classify firms into quartiles of domestic sales and quartiles of average wages, and match the percentage of firms in each combination of quartiles. That is, we match the percentage of firms in each of the sixteen bins in figure 6(a) and (c). The classification of firms by quartile of wage in the model reflects firms' actual skill

[33] This normalization of sales by absorption is standard (see Tybout (2003)). Between 1988 and 1994 the Colombian economy grew, but since this growth is generally not associated with the trade liberalization, normalizing sales by absorption eliminates growth. We calculate absorption as total sales plus sectoral imports minus exports, where Colombian imports and exports of chemicals and machinery are taken from Feenstra et al (2005).

intensity without measurement error. Finally, we match the ratio of the average wage of white- to blue-collar workers. In all, these are 47 moments.

3.1.4 Identification

While the formal estimation procedure is above, we informally discuss parameter identification here. The distribution of firm productivity $z(q, \omega)$ captures primarily the distribution of market shares, whose overall level depends on import penetration. And since $p^* = 1$, parameter μ_1 governs import penetration by increasing the productivity in Home relative to Foreign. Parameter σ_1 governs the variance of market shares. By allowing some firms to be relatively more productive at skill-intensive high-quality goods, σ_2 governs the joint distribution of sales and wages. Given the size of the Home market, approximately Y/α with $Y = 1$, parameter Y^* governs export intensity.

Fixed trade costs $f_X(\omega)$ and $f_M(\omega)$ govern firms' import and export status and their correlation with sales. The assumption that $\Phi(q, Q) = \frac{\exp(q-Q)}{1+\exp(q-Q)}$ with $Q = 0$ normalizes the quality scale, by eliminating the variance and mean of the logistic distribution. The fixed cost of production $f(q) = f_1 q$ governs the dispersion of quality choices across firms. If quality choices are similar, firms' import and export intensities do not depend on size or skill intensity. So, systematic differences in these intensities help identify f_1. Given quality choices, the quality of foreign imports q^* governs how import intensity varies with sales and skill intensity, and the shifter of Foreign demand Q^* governs how export intensity varies with sales and skill intensity.

Given quality choices, l_1 and l_2 capture the distribution of shares of white-collar workers. The smaller dispersion in the distribution of sales and wages relative to sales and shares of white-collar workers help identify σ_π. Parameter σ_π also pins down the total share of unskilled workers misclassified as white-collar workers. This share together with the wages of white- to blue-collar workers helps identify the unobserved skill premium w_s/w_u.

Finally, it may seem odd that we do not use prices to estimate a model of quality differentiation. But for the same reasons as in Melitz (2003), the model has no implications for unit prices. Function Φ captures only one agent's valuation of a good of quality level q relative to other agents', and a firm's productivity $z(q, \omega)$ can be decomposed into its productivity *and*

Table 3: Parameter estimates

	chemicals		machinery	
parameter	estimate	std. error	estimate	std. error
μ_1	-0.22	0.01	-0.08	0.01
σ_1	0.66	0.01	0.66	0.01
σ_2	0.002	0.001	0.004	0.001
f_1	2.3e-5	6.7e-6	9.9e-6	6.5e-6
l_1	-3.4	0.6	-4.5	0.6
l_2	0.66	0.10	0.89	0.15
μ_M	-7.1	0.2	-5.8	0.1
σ_M	1.4	0.1	1.1	0.1
μ_X	-5.7	0.2	-2.9	0.3
σ_X	1.0	0.1	2.0	0.1
w_s/w_u	2.70	0.13	2.17	0.11
q^*	9.0	0.3	6.9	0.2
Q^*	5.5	0.3	6.2	0.2
Y^*	0.19	0.01	0.20	0.03
σ_π	0.29	0.02	0.16	0.01

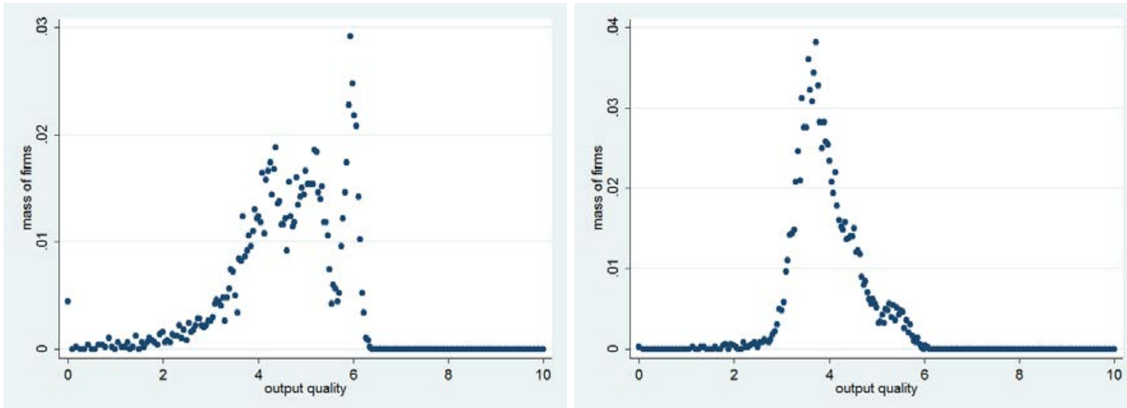
a demand for its quality agreed upon by all agents.[34] Technically, the model assumes only that goods that are produced with increasing returns to scale use intensively inputs that are themselves produced with increasing returns to scale. The estimated parameters suggest that these goods are skill intensive and that their relative demand and supply are higher abroad. We call these goods high-quality for exposition given our within-sector focus, but they can be interpreted more broadly as high-tech or capital-intensive goods.

3.2 Results

The parameter estimates are on table 3. In both sectors, the relative demand and supply of high-quality goods are higher abroad. In chemicals, the quality of Foreign goods $q^* = 9.0$ is well above 6.7, the highest-quality of Home firms, and the Foreign reference quality $Q^* = 5.5$

[34]To match the overall relation between firm size and prices, we can also multiply $\Phi(q, q')$ everywhere by another function $\bar{\phi}(q)$ that captures all agents' common valuation for quality q, and multiply productivity parameters $z(q, \omega)$ everywhere by a common parameter $\bar{z}(q)$ capturing all firms' efficiency in producing quality level q. If $\bar{\phi}(q)\bar{z}(q)^{\sigma-1} = 1$, revenues and hence firm choices would not change, but unit prices would generally increase in q if $\bar{z}(q)$ decreased fast enough.

Our data contain unit prices but sectoral definitions are too broad. Within sectors, the correlation between unit prices and other firm characteristics, such as sales, skill intensity and wages, are generally positive but statistically insignificant. Statistical significance arises if we pool across all sectors as Kugler and Verhoogen (2012) do.



(a) Chemicals (b) Machinery

Figure 5: Distribution of quality choices

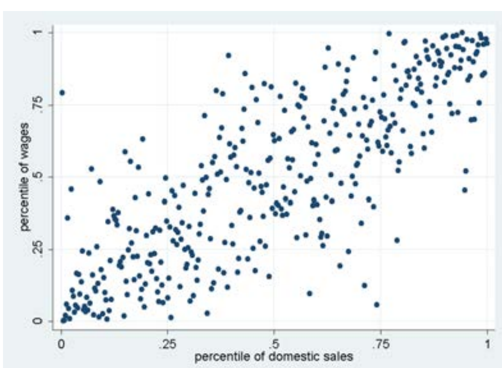
is well above the reference quality for Home consumer and most firms. In machinery, $q^* = 6.9$, $Q^* = 6.2$ and the highest quality in Home is 6.0. The distribution of quality levels is in figure 5. It displays several peaks because of the discrete choices of importing and exporting, and it is more spread for chemicals where the share of firms trading abroad is larger.

Skill upgrading associated with international trade is large in both sectors. For example, if we change the fixed costs of trading of a typical firm in chemicals, its skill intensity increases by 8 percentage points if it switches from not trading to importing only, by 6 points if it switches to exporting only, and by 17 points if it switches to importing and exporting. In 2000 US$, the average fixed cost of importing chemicals is 315,000 and of exporting is 238,000. Since firms with lower costs self-select into importing and exporting, the average cost paid is 51,000 for importing and 112,000 for exporting. For machinery where firms are generally smaller, the average fixed cost paid for importing is 30,000, and for exporting, it is 15,000.[35] The estimated variance of fixed importing costs is large in chemicals because in the data small and large firms import, and only large firms export (see table 5). The opposite holds in machinery. These variances govern the probability that a firm switches to importing or exporting in the counterfactual trade liberalization, and the largest increases in skill intensity come from switchers. If increases in trade occur only at the intensive margin, then changes in skill intensity are smaller.

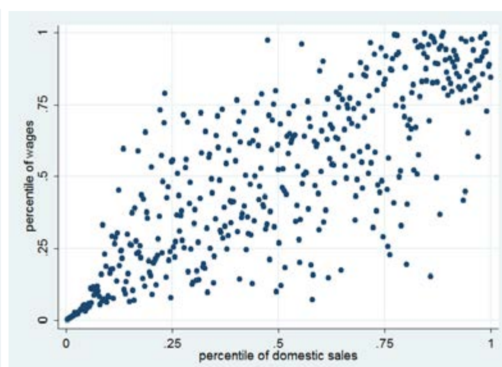
[35]Estimated fixed costs of trading are in line with Cherkashin et al. (2012) and Das et al. (2007). They are large because they reflect the expected profits from importing and exporting. We infer fixed costs in US$ in the model through the estimated ratio of average sales to fixed costs assuming that average sales is the same as in the data, since average sales in the model are fixed through the normalization $Y = 1$.

Table 4: Unconditional distribution of sales and of skill intensity

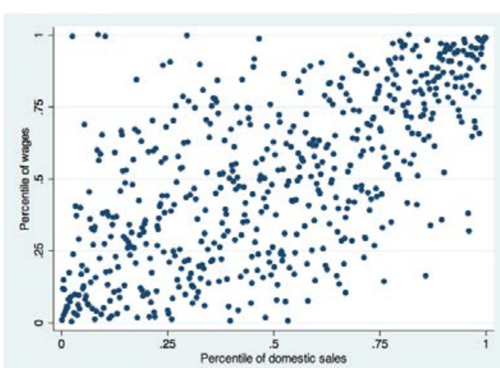
	percentiles				
CHEMICAL SECTOR	10%	25%	50%	75%	90%
ln(normalized domestic sales)					
data	-10.0	-9.3	-8.1	-6.7	-5.6
model	-10.2	-9.1	-7.9	-6.7	-5.6
white-collar workers/total number of workers					
data	0.18	0.29	0.46	0.61	0.73
model	0.20	0.30	0.42	0.58	0.77
	percentiles				
MACHINERY SECTOR	10%	25%	50%	75%	90%
ln(normalized domestic sales)					
data	-9.9	-9.3	-8.6	-7.5	-6.2
model	-10.4	-9.3	-8.1	-6.9	-5.8
white-collar workers/total number of workers					
data	0.11	0.19	0.28	0.38	0.50
model	0.12	0.18	0.27	0.39	0.52



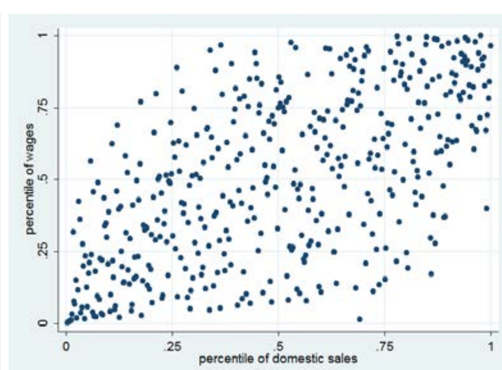
(a) Data, chemical sector



(b) Model, chemical sector



(c) Data, machinery sector



(d) Model, machinery sector

Figure 6: Distribution of firm domestic sales and wage

Table 5: Joint distributions of sales with other characteristics

	quartiles of domestic sales			
CHEMICAL SECTOR	1	2	3	4 (largest)
average share of white-collar workers				
data	0.39	0.45	0.49	0.52
model	0.38	0.43	0.48	0.52
share of importing plants				
data	0.25	0.49	0.72	0.90
model	0.18	0.49	0.71	0.92
share of exporting plants				
data	0.02	0.09	0.19	0.66
model	0.002	0.02	0.19	0.72
spending on imported materials/total				
data	0.07	0.20	0.25	0.50
model	0.09	0.21	0.31	0.46
export sales/total sales				
data	0.02	0.01	0.01	0.09
model	0.00	0.00	0.02	0.07

	quartiles of domestic sales			
MACHINERY SECTOR	1	2	3	4 (largest)
average share of white-collar workers				
data	0.23	0.29	0.29	0.38
model	0.25	0.28	0.32	0.35
share of importing plants				
data	0.17	0.32	0.50	0.85
model	0.02	0.20	0.48	0.89
share of exporting plants				
data	0.05	0.09	0.14	0.37
model	0.04	0.09	0.15	0.30
spending on imported materials/total				
data	0.06	0.11	0.19	0.43
model	0.01	0.09	0.21	0.41
export sales/total sales				
data	0.03	0.04	0.06	0.03
model	0.00	0.00	0.01	0.03

Table 6: Estimated and observed skill intensities and premia

MEASURED SKILL	premium[†] = $w_{\mathbf{white}}/w_{\mathbf{blue}}$		intensity = $L_{\mathbf{white}}/(L_{\mathbf{white}}+L_{\mathbf{blue}})$	
	data	model	data	model
chemicals	1.93	1.92	49%	51%
machinery	1.62	1.56	33%	35%
UNOBSERVED SKILL	**premium** = w_s/w_u		**intensity** = $L_s/(L_s+L_u)$	
	Colombian avg.*	model	Colombian avg.*	model
chemicals	1.9 - 2.6	2.7	10%	28%
machinery	1.9 - 2.6	2.2	10%	19%

* The Colombian average is from Attanasio et al. (2004). Their numbers are expected to be lower than ours because manufacturing is generally more skill intensive than services and agriculture. † Measured skill premium is the only moment on this table directly targeted.

The model matches very well the unconditional distributions on table 4 and the conditional distributions on table 5. Only for machinery, the model slightly overestimates the spread of the unconditional distribution of sales and underestimates imports and exports in the lower quartiles of sales. In both sectors, firms in the upper quartiles of sales generally have higher shares of white-collar workers, they are more likely to import and export, they export a higher share of their output and import a higher share of their inputs. The model also replicates well the increasing relation between sales and wages in figure 6.[36] The large spread in this distribution suggests that economies of scale are not important determinants of skill intensity, especially in the machinery sector where the spread is larger.

Table 6 presents measures of skill intensity and premium. Targeted wages of white- to blue-collar workers are similar in the data and in the model. Considering that manufacturing is generally more skill intensive than services and agriculture, the model's predictions on non-target, unobservable skill are very well aligned with Attanasio et al. (2004) who use Colombian household survey data. They document that about 10% of heads of households in Colombia had a college degree during the trade liberalization, and that the skill premium in 1988 was $w_s/w_u = 2.6$ for university to elementary school and 1.9 for university to secondary school. Our estimated skill intensity is 28% and skill premium is 2.7 in chemicals, a particularly skill-intensive sector. For machinery, these numbers are 19% and 2.2, respectively.

[36] There are 5000 firms in the model. To avoid cluttering figures 6(b) and (d), we randomly select firms in the model, 438 for chemicals and 557 for machinery, so that the number of observations in the model and in the data figures are the same.

4 Pre- versus post-trade liberalization

4.1 Counterfactual procedure

The procedure to simulate the trade liberalization is here and the results are in section 4.2. We exogenously decrease tariffs to match the Colombian average in 1988 and 1994. In chemicals, τ goes market from 41.5% to 16.6%, and in machinery, from 21.0% to 10.1%. Although the trade liberalization is unilateral, exports may expand for various reasons: The Colombian peso may depreciate, or imported inputs may decrease the price and increase the quality of domestic goods, making them more competitive abroad.

The model, however, cannot predict changes in imports and exports without information on non-tariff barriers, elasticity of labor supply and trade deficit. So, we allow Foreign prices p^* and market-size parameter Y^* to change to exactly match the aggregate change in imports and exports. To be specific, between 1988 and 1994, chemical imports expanded from 21.5% to 35.2% of total absorption in Colombia, and exports expanded from 7.1% to 9.7%. We match this 13.7% points expansion of imports and 2.6% points expansion of exports. We similarly match changes in trade flows for machinery, where imports expanded by 26.7% of absorption, from 46% to 73%, and exports expanded only by 0.3%, from 3.0% to 3.3%. So, *the counterfactual studies the model's changes in demand for skills given observed changes in trade flows*. Changes in Y^* may, for example, reflect movements in real exchange rates, and changes in p^*/Y^* reflect non-tariff barriers.

The cross-sectional data contain no information on the elasticity of labor supply, only on the supply of white- and blue-collar labor given pre-liberalization wages. To clearly understand the workings of the model, we assume that labor is perfectly elastic and wages (w_u, w_s) do not change. This assumption is reasonable given our within-sector focus, but if we consider manufacturing as a whole, between 1988 and 1994, both the skill premium and the skill intensity increased in Colombia, suggesting that labor supply is imperfectly elastic. Then, to explore the implications of inelastic labor in the model, appendix C.1 makes the extreme opposite assumption that labor is perfectly inelastic and labor supply (L_u, L_s) does not change.[37]

[37]Relative wages of skilled workers increase confirming the positive link between trade and skills in the model. Relative to the elastic labor case, these wage changes dampen the incentives for firms to upgrade quality and decrease the indirect Home-market effects, but the general messages do not change.

4.2 Counterfactual results

Consistent with the data, the model predicts large decreases in sales combined with large increases in skill intensity. In chemicals, sales drop by 14% on average (-0.15 log-points), and skill intensity goes from 28% to 35%. In machinery, sales drop by 34% (-0.42 log-points), and skill intensity goes from 19% to 25%. Table 7 reports changes in the distribution of sales and skill intensity. Both in the data and in the model, sales and white-collar shares increase in the upper tail relative to the rest of the distribution. Machinery, the comparative disadvantage sector, displays larger decreases in sales and smaller increases in skill intensity.

Quantitatively, changes in normalized sales are well aligned with the data because we directly target changes in import penetration and export expansion, and absorption is total sales plus imports minus exports.[38] In chemicals, the model underestimates changes in skill intensity—the share of white-collar workers goes from 51% to 56% in the model and from 49% to 57% in the data. Changes in unobserved skill intensity are larger, but still short of the data.[39] In machinery, increases in the share of white-collar workers are larger than in the data, but if we consider that the Colombian skill premium increased by 12% between 1988 and 1994, the model also underestimates the data. This underestimation occurs even though the model puts together the literature's most prominent explanations for the rise in demand for skills following trade liberalizations in developing countries, and we show next that the effect of trade is significantly amplified through domestic input linkages.

[38] More specifically, let S_1 and S_0 be total normalized sales before and after the counterfactual, respectively. Then, $S_1 = S_0 - \Delta\frac{\text{imports}}{\text{absorption}} + \Delta\frac{\text{exports}}{\text{absorption}}$, where $\Delta\frac{\text{imports}}{\text{absorption}}$ and $\Delta\frac{\text{exports}}{\text{absorption}}$ are exactly matched to the data in the counterfactual. The only reason why log-changes in sales in machinery diverge from the data is because initial total normalized sales is 57% of absorption in the data and 77% in the model. This discrepancy arises because, in the data, import penetration of machinery by final consumers and other sectors is much larger than the targeted import penetration of materials in the machinery sector on table 5. One way to mend the model to match initial normalized sales is to directly target this moment and allow for the price of Foreign goods faced by consumers to differ from the price faced by firms.

[39] The labor market in the model is excessively simplified, with just two types, but some of the changes in quality and skill intensity in the model may be reflected in the data. If there is more than two types of workers, some of the mid-level workers, previously classified as blue- and white-collars, may have been substituted for highly skilled workers who are less likely to be classified as blue-collars. Such an extension of the model and its identification is beyond the scope of the paper.

Table 7: Changes in the distributions of sales and skill intensity

CHEMICAL SECTOR	percentiles 10%	25%	50%	75%	90%	**total†**
ln(normalized sales), $\Delta = 1994 - 1988^{*}$						
data	-0.42	-0.25	-0.26	-0.22	-0.15	**-0.14**
model	-0.24	-0.24	-0.20	-0.17	-0.15	**-0.15**
skill intensity, $\Delta = 1994 - 1988$ **in %**						
data, white-collar shares	0.0	3.2	7.5	12.1	11.7	**7.9**
model, white-collar shares	0.1	2.7	3.8	2.7	1.9	**5.1**
model, skilled labor shares	-0.9	-0.7	3.7	9.0	7.4	**7.4**

MACHINERY SECTOR	percentiles 10%	25%	50%	75%	90%	**total†**
ln(normalized sales), $\Delta = 1994 - 1988$						
data	-0.58	-0.62	-0.66	-0.46	-0.63	**-0.63**
model	-0.57	-0.56	-0.50	-0.45	-0.43	**-0.42**
skill intensity, $\Delta = 1994 - 1988$ **in %**						
data, white-collar shares	1.0	2.0	2.9	4.8	9.0	**2.4**
model, white-collar shares	-1.8	-1.1	-0.2	2.5	1.6	**5.0**
model, skilled labor shares	-1.7	-1.8	-2.2	0.0	7.7	**6.3**

*A firm's normalized sales are its total sales divided by the sales of domestic and foreign firms in the Home market. † Changes in total skill intensity are larger than shifts in percentiles because labor shifts from less to more skill-intensive firms. See appendix B.

4.2.1 Decomposition of changes in skill intensity

The model brings together various mechanisms through which trade affects the demand for skills—the direct mechanisms proposed in the literature and the indirect effect of input-output linkages. To get a sense of the relative importance of these mechanisms, we decompose the counterfactual changes in skill intensity above into various effects. Results are on table 8. The numbers are didactic but rough since all effects interact.

The procedure is as follows. Given import status 1_M and export status 1_X, firm ω chooses quality q to maximize its profit

$$\frac{1}{\sigma} z(q,\omega)^{\sigma-1}[\mu C(q,1_M)]^{1-\sigma}\left[\chi(q) + 1_X \Phi(q,Q^*)Y^*\right] \tag{17}$$

$$\text{where} \quad C(q,1_M) = w(q)^{\alpha}\left[P(q)^{1-\sigma} + 1_M P^*(q)^{1-\sigma}\right]^{\frac{1-\alpha}{1-\sigma}} \tag{18}$$

$$\text{and} \quad \chi(q) = \Phi(q,Q)P(Q)^{\sigma-1}Y + \int_{\Omega} \Phi[q,q(\omega')]P_I[q(\omega'),1_M(\omega')]^{\sigma-1}R_I(\omega')d\omega'. \tag{19}$$

To construct table 8, we incrementally change each firm's profit-maximization problem by replacing the pre-liberalization functions with post-liberalization ones. There are two effects on input costs C in line (18). The effect of "cost of Home inputs" is a change in $P(q)$ and the effect of "cost of Foreign inputs" is a potential change in the firm's import status 1_M and a change in function $P^*(q)$ due to exogenous tariffs and Foreign price p^*. There are three demand effects. In Home demand function $\chi(q)$, line (19), the effect of "Home market size" is a change in market tightness through price indices $P(Q)$ and $P_I[q(\omega'),1_M(\omega')]$ and demand for materials $R_I(\omega')$, and the "Home demand shift" is a change in the relative valuation of different quality levels through $\Phi[q,q(\omega')]$ as other firms ω' change their quality choices $q(\omega')$. In line (17), the "export market" effect is a potential change in the firm's export status 1_X and in exogenous Y^*. Functions $z(q,\omega)$, $\Phi(q,Q)$, and $\Phi(q,Q^*)$ do not change with the counterfactual.

For each firm and each of these incremental changes, we re-calculate optimal quality, and demand for skilled and unskilled labor. We partition firms according to their participation in international trade and report on table 8 changes in total skill intensity $\frac{\int l_s(\omega)}{\int l_s(\omega)+\int l_u(\omega)}$ for each subset of firms. Since wages do not change, a firm's skill intensity increases if and only if it upgrades its quality. The overall changes in skill intensity on table 7—of 7.4 percentage points in chemicals and 6.3 percentage points in machinery—correspond to the sum of the different channels explored in table 8.

Results. Increases in the skill-intensity of new importers, new exporters and continuing exporters are large—16, 17 and 7 percentage points respectively in chemicals for example.[40] In chemicals, new importers are few because the estimated variance of fixed importing costs is large (see section 3 above). New and continuing exporters, together, are 29% of firms and their skill intensity increases by 8 percentage points, while new and continuing importers are 32% of firms and their skill intensity increases by 5% points. So, even though chemical exports increase by only 2.6% of domestic absorption they have a much larger impact in the Home market than imports which increase by 14% of absorption. In machinery, new importers and exporters are few, and Home-market effects are smaller.

These Home-market effects are illustrated in the theory section 1.2.3 above: As importers and exporters upgrade their product quality, they decrease aggregate cost of materials $P(q)$ and increase demand $\chi(q)$ for high-quality goods in Home. Cost effects are larger for firms without access to foreign inputs. In chemicals, they add 6.4 percentage points to the skill intensity of domestically-oriented firms and 3.0 points to sectoral skill intensity. Demand shifts add 2.1 percentage points to sectoral skill intensity, and they are positive only for the 41% highest-quality firms. In machinery, where exports do not grow, Home-market effects account for a 2.2 (= 1.7 + 0.5) percentage-point rise in skill intensity compared to 5.1 (= 3.0 + 2.1) points in chemicals.

Trade also directly affects skill intensity. As Foreign inputs get cheaper, skill intensity increases by 9.6 percentage points in machinery and by 3.7 points in chemicals. This effect is much larger in machinery where the import intensity of firms grew by 25% points, from 37% to 63%, compared to 11% points in chemicals, from 43% to 54%. Import competition decreases domestic demand. An 18% drop in domestic sales is associated with a decrease in skill intensity of 2.5 percentage points in chemicals. The expansion of export sales, in turn, increases skill intensity by 0.6% for continuing exporters and 11% for new exporters. Perhaps counterintuitively,

[40] The finding that exporters, especially new exporters, disproportionately increase their skill-intensity and innovation is in Bustos (2011b) and Lileeva and Trefler (2010). Larger firms disproportionately increase their skill intensity in Kugler and Verhoogen (2012).

Table 8: Decomposition of changes in skill intensity (in %)

CHEMICALS	domestic	continuing importers	continuing exporters*	new importers†	new exporters*	all firms
% of firms	38%	31%	23%	1%	6%	100%
initial skill intensity	**12**	**21**	**30**	**16**	**21**	**28**
+ cost of Home inputs	6.4	5.1	2.4	6.2	5.2	3.0
+ cost of Foreign inputs	-	4.3	3.7	12	4.4	3.7
+ Home market size	-4.4	-6.0	-1.9	-3.4	-5.7	-2.5
+ Home demand shift	-1.9	-0.5	2.5	1.9	0.6	2.1
+ export market	-	-	0.6	0.5	11	1.1
$\Sigma =$ **final skill intensity**	**12**	**25**	**37**	**33**	**36**	**35**
$\Delta =$ *final - initial*	*0.1*	*4.0*	*7.3*	*17*	*16*	*7.4*
log change in sales	-0.25	-0.20	-0.14	-0.01	-0.06	-0.15

MACHINERY	domestic	continuing importers	continuing exporters*	new importers†	new exporters*	all firms
% of firms	54%	30%	13%	3%	0.1%	100%
initial skill intensity	**8.0**	**14**	**26**	**8.4**	**8.4**	**19**
+ cost of Home inputs	1.6	1.4	2.0	2.0	1.7	1.7
+ cost of Foreign inputs	-	8.6	11	16	14	9.6
+ Home market size	-3.4	-9.1	9.0	-3.3	-9.2	2.4
+ Home demand shift	-0.2	-0.7	1.1	-0.1	-1.0	0.5
+ export market	-	-	-11	-4.5	25	-8.0
$\Sigma =$ **final skill intensity**	**6.0**	**14**	**38**	**18**	**39**	**25**
$\Delta =$ *final - initial*	*-2.0*	*0.3*	*11.5*	*9.6*	*30.4*	*6.3*
log change in sales	-0.57	-0.42	-0.39	-0.28	-0.19	-0.42

† includes firms that initially export only and start importing after the liberalization.

* includes firms that import and export.

the signs of these two effects reverse for machinery. Continuing exporters experience two opposing effects when domestic sales fall. On the one hand, they downgrade quality because scale of production decreases. On the other hand, exports as a share of their sales increase, and Foreign has a higher relative demand for high-quality goods.

The "export market" effect is negative in machinery. Decreases in tariffs and in the price of Foreign inputs make Home goods more competitive abroad because their cost falls and quality rises. To prevent exports from growing, the counterfactual then predicts that Y^*, the parameter governing Foreign demand in equation (7), drops by 42%.[41] Continuing exporters downgrade because their scale decreases and because they face a lower relative demand for high-quality goods. For these firms, the lines "Home market size" and "export market" are best seen together since their export intensity increases from 7% to 23% with the "Home market size" effect and back to 12% with the "export market" effect. In all, changes in scale and composition of sales between Home and Foreign add up to -2.2% = 9.0%-11.2% for continuing exporters. Last, we note that in both sectors, the firms that decrease their skill intensity the most are *ex ante* medium-quality firms that do not engage in international trade. These firms compete in the same segment of the input market as new importers and exporters.

Although table 8 show multifarious effects, general messages can be drawn. First, domestic spillovers are large. In chemicals, the indirect effects of Home inputs account for an increase in sectoral skill-intensity of 5.1 (=3.0 + 2.1) percentage points, while the direct effects of economies of scale, Foreign sales and Foreign inputs exploited in previous papers together account for 2.4 (=3.7 -2.5 + 1.1) percentage points. Second, economies of scale play a minor role. Although sales drop in 99% of chemical firms, skill intensity increases in 61% of firms, including 14% of domestically-oriented firms. The average skill intensity of domestically-oriented firms does not change despite a 22% drop in sales. In machinery, sales of continuing exporters drop by 33% and their skill intensity goes from 26% to 38%. Third, the model's link between international trade and skill intensity is very robust. It explains sizable increases in skill intensity that spread to domestically-oriented firms and to a comparative-disadvantage sector, machinery.

[41]This drop is consistent with an increase in Colombian absorption of machines by 85% due to an investment boom between 1988 and 1994. See section 5 below for changes in Y^* and p^*.

5 Scale, exports, and capital goods

The benchmark counterfactuals above under predict the effects of trade in the demand for skilled workers, suggesting that other forces are at work. This section modifies the counterfactuals to consider three other explanations: Economic growth, anticipation of future exports, and capital inputs.[42] Results are on tables 9 and 10.

First, although normalized sales—i.e., sales/domestic absorption—decreased by 13% (0.14 log-points) in the chemical sector in Colombia between 1988 and 1994, there was economic growth and real absorption increased by 30%. We repeat the counterfactual but allow Home consumer spending Y to exogenously increase to match the 30% absorption growth. Results are labeled as $A1$. Aggregate sales increase by 12%, but *normalized* sales are the same as in the benchmark. The distribution of skill intensity shifts to the right but total skill intensity increases by only 0.2 percentage points relative to the benchmark. In machinery, the increase in domestic absorption was even larger, 85%, as Colombia underwent an investment boom between 1988 and 1994. But its effect on skill intensity is again negligible, confirming that economies of scale have a small effect on skill intensity in the estimated model.

Second, imports expand faster than exports between 1988 and 1994, but exports expand faster thereafter. If firms invest and hire in anticipation of exports, our benchmark will underestimate increases in skill intensity. As a crude exercise, we simulate a counterfactual with an export expansion of 5.1% of domestic absorption in chemicals, instead of 2.6%, where 5.1% is the increase in exports between 1988 and 1995. Results, labeled as $A2$, confirm the large spillovers from exports in the model. Normalized sales increase relative to the benchmark due to additional export sales. Sectoral skill intensity increases by 10.4 percentage points, well above the benchmark's 7.4 points. Among domestically-oriented firms, 40% of firms upgrade quality, sales drop by 22%, skill intensity goes from 11.6% to 13.0%.

For machinery, exports did not expand until a large real depreciation of Colombian pesos in 1999. Just for didactic purposes, we match the export expansion of 6.1% of domestic absorption, from 3.0% to 9.1%, between 1988 and 2000. The indirect effects of exports are again huge.

[42] An additional explanation is a tendency in the data for the skill premium and skill intensity to rise over time in Colombia, like in the United States and other countries. But estimating the long-run trend, absent other changes, is difficult.

Table 9: Changes in the distribution of sales and measured skill intensity, alternative specifications

	percentiles					total
CHEMICAL SECTOR	10%	25%	50%	75%	90%	
ln(normalized sales), $\Delta = 1994 - 1988^{*}$						
data	**-0.42**	**-0.25**	**-0.26**	**-0.22**	**-0.15**	**-0.14**
model						
benchmark	-0.24	-0.22	-0.20	-0.17	-0.15	-0.15
A1: growth	-0.22	-0.21	-0.18	-0.14	-0.15	-0.15
A2: exports 1995	-0.24	-0.22	-0.18	-0.11	-0.11	-0.11
A3: $\alpha = 0.5$	-0.27	-0.25	-0.21	-0.17	-0.14	-0.15
share of white-collar workers, $\Delta = 1994 - 1988$ **in %**						
data	**0.0**	**3.2**	**7.5**	**12.1**	**11.7**	**7.9**
model						
benchmark	0.1	2.7	3.8	2.7	1.9	5.1
A1: growth	1.5	4.0	4.5	3.4	2.1	5.1
A2: exports 1995	1.4	5.0	6.0	4.5	2.6	7.0
A3: $\alpha = 0.5$	0.8	7.9	14	11	5.9	16

	percentiles					total
MACHINERY SECTOR	10%	25%	50%	75%	90%	
ln(normalized sales), $\Delta = 1994 - 1988^{*}$						
data	**-0.58**	**-0.62**	**-0.66**	**-0.46**	**-0.63**	**-0.63**
model						
benchmark	-0.57	-0.56	-0.50	-0.45	-0.43	-0.42
A1: growth	-0.57	-0.52	-0.45	-0.41	-0.41	-0.41
A2: exports 2000	-0.53	-0.50	-0.43	-0.37	-0.32	-0.31
A3: $\alpha = 0.5$	-0.72	-0.70	-0.62	-0.53	-0.42	-0.42
share of white-collar workers, $\Delta = 1994 - 1988$ **in %**						
data	**1.0**	**2.0**	**2.9**	**4.8**	**9.0**	**2.4**
model						
benchmark	-1.8	-1.1	-0.2	2.5	1.6	5.0
A1: growth	-0.6	0.2	1.4	3.4	2.5	5.1
A2: exports 2000	0.4	2.3	5.5	15.1	12.2	20
A3: $\alpha = 0.5$	-1.8	-1.4	0.0	3.6	6.8	11

Table 10: Changes in skill intensity by participation in international trade

	final - initial skill intensity (in %)					
	domestic	continuing importers	continuing exporters*	new importers†	new exporters*	**all firms**
CHEMICALS						
benchmark	0.1	4.0	7.3	17	16	**7.4**
A1: growth	0.4	4.0	7.1	17	16	**7.6**
A2: exports 1995	1.4	6.8	9.9	20	18	**10**
A3: $\alpha = 0.5$	1.5	19	24	41	34	**24**
MACHINERY						
benchmark	-2.0	0.3	12	9.6	30	**6.3**
A1: growth	-1.8	0.1	9.2	8.6	23	**6.4**
A2: exports 2000	0.4	4.7	29	26	41	**25**
A3: $\alpha = 0.5$	-1.7	4.2	16	2.0	29	**13**

† includes firms that initially export only and start importing after the liberalization

* includes firms that import and export

Average skill intensity increases for domestically-oriented firms, and for the sector, it goes from 19% to 43%. Indirect Home-market effects account for more than half of this sectoral change.

Third, in specification A3, we interpret non-labor inputs in the model more broadly to include capital equipment, not just materials. We decrease the labor share in production from $\alpha = 0.7$ in the benchmark to 0.5, which in principle provides more room for input linkages to affect quality choices.[43] In machinery, skill intensity increases by 13 percentage points, compared to 6.4 percentage-points benchmark. In chemicals, raising the input share magnifies domestic spillovers from trade. Estimated skill intensity increases from 30% to 54%. Of these 24 percentage points, a whopping 20 points is associated with indirect effects in the domestic input market. Rightward shifts in the distribution of white-collar shares are now larger than in the data, suggesting that capital plays a large role in explaining the link between trade and skills, especially if domestic spillovers are considered.[44]

Table 11 documents changes in Y^* and p^*, which are left as free parameters in all counterfactuals to match changes in imports and exports in the data. The results render themselves to interpretation even though the model is very stylized to capture all factors influencing sec-

[43]Parameter estimates are in appendix C.2 and the cross-sectional moments practically do not change.

[44]The model still under predicts the overall increase in demand for skills if we consider the 12% rise in the Colombian skill premium. With inelastic labor and $\alpha = 0.5$, a counterfactual liberalization increases the skill premium by 7.7% in chemicals.

Table 11: Counterfactual changes in Y^* and p^* (in %)

chemical sector	Y^*	Y^*/Y	p^*
benchmark	14	14	6
A1: growth	41	10	6
A2: exports 1995	41	41	5
A3: $\alpha = 0.5$	-18	-18	2
machinery sector	Y^*	Y^*/Y	p^*
benchmark	-42	-42	-21
A1: growth	2	-48	-22
A2: exports 2000	11	11	-21
A3: $\alpha = 0.5$	-61	-61	5

Parameter estimates are obtained with $Y = 1$ and $p^* = 1$.
Except for A1, $Y = 1$ in all counterfactuals.

toral trade in the period. Changes in foreign prices p^* reflect sector-specific non-tariff barriers and economy-wide movements in real exchange rates—p^* does not change much in chemicals and decreases in machinery. Since changes in Y^* govern growth in export demand relative to domestic absorption (approximately Y/α), the decrease in Y^* in the machinery benchmark by 42% is consistent with the large increase in Colombian absorption between 1988 and 1994. In chemicals, where absorption grows more in line with other manufacturing sectors, changes in Y^* reflect real exchange rate movements—a real depreciation of Colombian pesos increases Y^* relative to domestic absorption and wages.[45]

Looking across counterfactuals within a sector, predicted changes in Y^*/Y are similar between the benchmark and A1. To generate a more exports in A2, Y^*/Y increases in both machinery and chemicals. Case A3 is more relevant. Without intermediate inputs, trade models generally require a real depreciation of domestic currency (fall in domestic wages) in order for exports to increase at all in unilateral liberalizations. In contrast, counterfactual A3 in chemicals predicts an appreciation of 18%. The high share of intermediate inputs $(1 - \alpha) = 0.5$ leads to large Home-market effects, more quality upgrading and larger drops in costs relative to the benchmark. To prevent exports from growing further, Foreign demand Y^* falls by 18%. Between 1988 and 1994, Colombia experienced a real appreciation of its peso, and this counterfactual is consistent with the prevailing view that casts investment and capital flows as

[45]Differences in absorption growth do not fully explain the difference between sectors. Counterfactual relative changes in $Y^*_{machinery}/Y^*_{chemicals} = \frac{1-42\%}{1+14\%} = 0.51$ are smaller than the relative changes in domestic absorption in the data $\frac{1+30\%}{1+85\%} = 0.70$.

proximate causes.[46]

6 Conclusion

According to the infant-industry argument, trade barriers may act as coordination devices in the development of an industry and the adoption of advanced technologies. Here, it is the removal of trade barriers that acts as a coordination device: The direct effects of trade on a minority of plants percolate through the domestic economy through changes in cost and demand, leading to widespread investments in quality upgrading and rises in demand for skilled workers. All *ex ante* high-quality and some medium-quality firms upgrade their product quality while low-quality firms downgrade—a heterogeneous effect consistent with previous empirical findings.[47]

This interaction between firms' decision to adopt skill-biased technology arises from the assumption that skill- and unskill-intensive firms produce different types of goods—an assumption from the classic model of factor-proportions that explains well cross-sectional correlations of firm characteristics.[48] We focus on unilateral trade liberalizations in developing countries because the ensuing decrease in sales and increase in demand for skilled labor are together particularly puzzling. But we hope the model will find its way to other applications within and beyond the field of international trade.

[46]Counterfactual Y^*/Y and Y^*/w decrease by 18%, but movements in Y^* relative to Home prices $P(q)$ are smaller, because prices fall. Relative to the consumer price index $Y^*/P(0)$ decreases by 13% and relative to the material costs of the highest-quality firms $Y^*/P(6)$ decreases by 3%. These numbers are not far from the 11% appreciation of Colombian pesos reported by the central bank.

The investment boom is probably associated to capital liberalization reforms and to the trade liberalization itself since firms need to invest in product and process innovation to upgrade quality and adopt to the new economic environment. A dynamic model is required to study these movements.

[47]Amiti and Khandelwal (2013) find that decreasing tariffs leads to quality downgrading in sectors and countries that are far below the world technology frontier and upgrading otherwise. See also Amiti and Cameron (2012).

[48]Models of skill-bias technical change (e.g., Acemoglu (2002), Thoenig and Verdier (2003) and Wood (1995)) ignore that firms' products may change qualitatively when they adopt skill-biased technologies. This omission may matter if the markets for high- and low-tech goods are different.

The model is not necessarily at odds trade increasing the demand for skills in developed countries, but mechanisms other than foreign relative demand and supply of high-quality goods may be at play. Firms may upgrade their product quality to escape competition as in Aghion and Griffith (2005) and Aghion et al. (2005) or to ship the good apples out as in Hummels and Skiba (2004).

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A Moments from overall manufacturing

Our estimations and counterfactuals have focused on Chemical and Machinery sectors. We document here both aggregate and micro-level moments for pooled data across all sectors. The purpose is to show that the impact of trade liberalization is broad and skill intensity increases universally across sectors. Furthermore, data patterns of correlations between wage, skill intensity, export, import, and firm size are qualitatively similar in pooled data too. The primary reason we used specific sectors is to control for heterogeneity in input-output linkages and tariff reductions. It is also useful to contrast cross-industry differences in firm response and highlight alternative channels of skill upgrading.

As illustrated by Table A.1, manufacturing sectors in Colombia experienced an overall increase in the share of white collar workers by 4 percentage points. This is between the 8 percentage-point increase in Chemical and the 2 percentage-point increase in Machinery. In addition, aggregate manufacturing imports increased significantly between 1988 and 1994 too, from 23% to 35% of domestic absorption. This is comparable to Chemical and less than Machinery.

Table A.1: Data aggregates of pooled data vs. Chemical and Machinery

	Manufacturing	Chemical	Machinery
white collar share (1988)	0.31	0.49	0.33
white collar share (1994)	0.35	0.57	0.35
import penetration (1988)	23%	22%	46%
import penetration (1994)	35%	35%	73%

On table A.2, we report the key cross-sectional moments for pooled data of all manufacturing sectors. The unconditional distribution of white-collar share of manufacturing, as in aggregate, is close to that of Machinery and dominated by Chemical. Nevertheless, we find that, qualitatively, all correlations are very similar. A plant's domestic sales are positively correlated with its export/import status, white-collar worker share, and the intensive margins of exports/import. More importantly, we have illustrated that our model matches these patterns quantitatively well.

Table A.2: Cross-sectional moments of pooled data vs. Chemical and Machinery

	Manufacturing	Chemical	Machinery
unconditional distribution			
white-collar share $p10$	0.08	0.18	0.11
white-collar share $p25$	0.14	0.29	0.18
white-collar share $p50$	0.24	0.46	0.28
white-collar share $p75$	0.38	0.61	0.38
white-collar share $p90$	0.56	0.73	0.50
conditional on quartiles of domestic sales			
share of exporters $q1$	0.03	0.02	0.05
share of exporters $q2$	0.04	0.09	0.09
share of exporters $q3$	0.09	0.19	0.14
share of exporters $q4$	0.30	0.66	0.37
share of importers $q1$	0.06	0.25	0.17
share of importers $q2$	0.11	0.49	0.32
share of importers $q3$	0.23	0.72	0.50
share of importers $q4$	0.57	0.90	0.85
export/total sales $q1$	0.02	0.02	0.02
export/total sales $q2$	0.01	0.01	0.04
export/total sales $q3$	0.02	0.01	0.06
export/total sales $q4$	0.05	0.09	0.03
imported material/total $q1$	0.02	0.07	0.06
imported material/total $q2$	0.04	0.20	0.11
imported material/total $q3$	0.08	0.25	0.18
imported material/total $q4$	0.26	0.50	0.43

B Shifts in white-collar shares

We reconcile shifts in the distribution of white-collar shares with its aggregate changes on table 4. Consider the shifts in the unconditional distribution of the share of white-collar workers in the benchmark counterfactuals on table B.1 (copied from table 7). In both sectors, shifts in

Table B.1: Changes in distribution of white-collar shares

	percentiles					
	10%	25%	50%	75%	90%	**total**
chemical sector	0.1	2.7	3.8	2.7	1.9	**5.1**
machinery	-1.8	-1.1	-0.2	2.5	1.6	**5.0**

percentiles are smaller than the total. This appendix uses the example of chemicals to explain how shifts in employment, from the less to the more skill intensive firms can generate this result.

Table B.2 partitions firms by quartiles of white-collar shares. It reports the share of white-collar workers and the share of employment in each quartile. The sum of the product of lines (A) and (B) yields the total share of white-collar workers before the trade liberalization, 0.51. The sum of employment shares is 100%. Lines (C) and (D) repeats the exercise for the economy after the counterfactual liberalization, and the last two lines report the differences. In line (E), the difference between white-collar shares is smaller in each of the quartiles than the total—as per table B.1. This result is explained through line (F): Employment shares shift from less to more skill-intensive firms.

Table B.2: Decomposition of changes in skill intensity

	quartiles of white-collar shares				
	1	2	3	4	**total**
before liberalization					
avg. share of white-collars (A)	0.24	0.37	0.50	0.75	**0.51**
share of employment (B)	0.05	0.33	0.31	0.30	**1.00**
after liberalization					
avg. share of white-collars (C)	0.25	0.41	0.53	0.76	**0.56**
share of employment (D)	0.03	0.26	0.38	0.33	**1.00**
Δ = after - before					
avg. share of white-collars (E) = (A) - (C)	0.01	0.04	0.03	0.01	**0.05**
share of employment (F) = (B) - (D)	-0.02	-0.07	0.07	0.03	**0.00**

Bustos (2011), Kugler and Verhoogen (2012) and Pavcnik (2002) provide evidence that ex-ante larger firms grow and invest in product and process innovation relative to other firms following a trade liberalization. Since larger firms are typically more skill intensive, these findings are consistent with shifts in employment on table B.2. But these shifts do not appear regularly in the various sectors (including chemicals and machinery) in our data, possibly because of large errors in our measure of skills and because we look at the raw data without controls and interactions with tariff cuts.

C Robustness

This appendix checks for robustness. Section C.1 presents the counterfactual with inelastic labor, and section C.2 changes the values of parameters fixed in the estimation.

C.1 Counterfactual with inelastic labor supply

We repeat the counterfactual of section 4 assuming that labor is perfectly inelastic and the labor supply (L_u, L_s) does not change. Since the counterfactual allows for Y^* and p^* to change, in principle, we can allow only for w_u or only w_s to change to clear the labor markets, but to make the results comparable to the case of elastic labor, we allow both w_u and w_s to change and, instead, impose no change in consumer spending $Y = 1$. Domestic absorption changes by less than 1% since it is approximately Y/α.

The results again link trade to higher demand for skilled workers. The skill premium increases by 3.5% in chemicals, from $\frac{w_s}{w_u} = 2.70$ to 2.80, and by 9% in machinery, from 2.2 to 2.4. Increases in skill intensity in the benchmark were larger in the chemical sector, while here, increases in the skill premium are larger in the machinery sector. Relative to the benchmark, the rise in skill premium discourages firms to upgrade toward more skill-intensive, high-quality goods, and thereby decrease the indirect effects of Home inputs. Since these indirect effects are larger in the chemical sector, a smaller increase in skill premium decreases quality-upgrading sufficiently to keep relative demand for skilled workers constant.

Table C.1 shows the shifts in the distribution of sales and skill intensity. As in the benchmark and in the data, sales and white-collar shares increase in the upper tail relative to the rest

Table C.1: Changes in the distribution of sales and measured skill intensity, **inelastic labor supply**

CHEMICAL SECTOR	percentiles 10%	25%	50%	75%	90%	**total†**
ln(normalized sales), $\Delta = 1994 - 1988^{*}$						
data	-0.42	-0.25	-0.26	-0.22	-0.15	**-0.14**
model	-0.22	-0.21	-0.19	-0.16	-0.14	**-0.15**
skill intensity, $\Delta = 1994 - 1988$ **in %**						
data, white-collar shares	0.0	3.2	7.5	12.1	11.7	**7.9**
model, white-collar shares	-4.5	-3.9	-1.9	-1.2	-0.8	**0.0**
model, skilled labor shares	-2.1	-3.8	-8.3	1.0	1.1	**0.0**

MACHINERY SECTOR	percentiles 10%	25%	50%	75%	90%	**total†**
ln(normalized sales), $\Delta = 1994 - 1988$						
data	-0.58	-0.62	-0.66	-0.46	-0.63	**-0.63**
model	-0.57	-0.56	-0.50	-0.45	-0.43	**-0.42**
skill intensity, $\Delta = 1994 - 1988$ **in %**						
data, white-collar shares	1.0	2.0	2.9	4.8	9.0	**2.4**
model, white-collar shares	-4.6	-4.9	-3.8	0.0	-0.1	**0.0**
model, skilled labor shares	-3.1	-3.9	-5.2	-7.3	9.0	**0.0**

*A firm's normalized sales are its total sales divided by the sales of domestic and foreign firms in the Home market. † Changes in total skill intensity are larger than shifts in percentiles because labor shifts from less to more skill-intensive firms. See appendix B.

of the distribution. Drops in sales are in line with the data, especially in chemicals. Total skill intensity does not change by construction, but the distribution of white-collar shares shifts to the left as employment moves to more skill intensive firms (see appendix B). Firms are classified by participation in international trade on table C.2. New importers, new exporters and continuing exporters significantly increase their skill intensity. In machinery, they increase by 8.7, 5.3, and 23, respectively. Since the stock of labor is held fixed, other firms decrease skill intensity. As in the benchmark, the largest decreases come from *ex ante* medium quality firms that compete directly with new importers and exporters. Skill intensity of continuing importers falls relative to domestically-oriented firms in both sectors.

With the rise in skill premium, only about one quarter of firms increase their skill intensity. But because these firms are generally large, the effects of Home inputs are qualitatively the same as before: Importers and exporters increase the supply and demand for high-quality inputs in Home, leading other firms to upgrade.

Table C.2: Final - initial skill intensity in %, **inelastic labor supply**

	domestic	continuing importers	continuing exporters*	new importers†	new exporters*	**all firms**
chemicals	-4.2	-8.2	0.5	8.6	8.7	**0.0**
machinery	-4.6	-7.8	8.7	5.3	23	**0.0**

† includes firms that initially export only and start importing after the liberalization
* includes firms that import and export

Table C.3: Parameter estimates for the machinery sector

	benchmark, $\alpha = 0.7$		A3, $\alpha = 0.5$	
parameter	estimate	std. error	estimate	std. error
μ_1	-0.08	0.01	-0.11	0.01
σ_1	0.66	0.01	0.65	0.004
σ_2	0.004	0.001	0.009	0.001
f_1	9.9e-6	6.5e-6	1.7e-5	9.4e-6
l_1	-4.5	0.6	-4.8	0.6
l_2	0.89	0.15	1.21	0.19
μ_M	-5.8	0.1	-4.9	0.1
σ_M	1.1	0.1	1.2	0.04
μ_X	-2.9	0.3	-4.8	0.3
σ_X	2.0	0.1	1.6	0.06
w_s/w_u	2.17	0.11	1.95	0.12
q^*	6.9	0.2	6.5	0.2
Q^*	6.2	0.2	5.3	0.2
Y^*	0.20	0.03	0.22	0.03
σ_π	0.16	0.01	0.13	0.01

C.2 Robustness: Fixed parameters

This appendix checks the robustness of the model with respect to fixed parameters. Section C.2.1 checks the benchmark counterfactual, but some parameters matter only when labor is inelastic as in appendix C.1 above. These checks are in section C.2.2. Cross-sectional moments are not presented because they were almost unchanged for all experiments. Table C.3 presents the parameter estimates for the machinery sector when $\alpha = 0.5$ used to perform counterfactual A3 in section 5. All other results in this appendix are refer to the chemical sector.

C.2.1 Fixed parameters & elastic labor supply

Table C.4 presents the parameter estimates for alternative values of α and σ. The counterfactual with $\alpha = 0.5$ is specification A3 in section 5. In the benchmark, the elasticity of substitution is

Table C.4: Parameter estimates (est) and standard errors (se)

parameter	benchmark*		$\alpha = 0.5$		$\sigma = 2$		$\sigma = 7$	
	est	se	est	se	est	se	est	se
μ_1	-0.22	0.01	-0.17	0.02	-0.28	0.06	-0.21	0.01
σ_1	0.66	0.01	0.66	0.01	1.34	0.01	0.54	0.005
σ_2	0.002	0.001	0.002	0.0001	0.004	0.002	0.001	0.0003
f_1	2.3e-5	6.7e-6	2.9e-5	9.9e-6	2.7e-5	1.3e-5	1.4e-5	4.5e-6
l_1	-3.4	0.6	-5.3	1.2	-1.9	0.32	-5.3	0.63
l_2	0.66	0.10	1.0	0.21	0.38	0.06	0.88	0.11
μ_M	-7.1	0.16	-6.6	0.07	-6.6	0.20	-7.5	0.19
σ_M	1.4	0.06	1.4	0.04	1.5	0.07	1.4	0.06
μ_X	-5.7	0.19	-5.9	0.06	-5.2	0.14	-6.3	0.24
σ_X	1.0	0.06	1.1	0.06	1.1	0.08	1.1	0.09
w_s/w_u	2.70	0.13	2.69	0.06	2.75	0.14	2.69	0.13
q^*	9.0	0.32	10.0	0.40	15.1	0.49	9.1	0.44
Q^*	5.5	0.26	6.0	0.13	7.1	0.26	6.5	0.77
Y^*	0.19	0.01	0.23	0.01	0.08	0.003	0.31	0.04
σ_π	0.29	0.02	0.29	0.01	0.30	0.02	0.28	0.02

* benchmark $\alpha = 0.7$ and $\sigma = 5.0$.

$\sigma = 5.0$, around the mean of elasticities in Broda and Weinstein (2004) for three-digit product categories. We experiment here with $\sigma = 2.0$ corresponding to the median elasticity in Broda and Weinstein and $\sigma = 10$. The only significant change in the cross-section is in the fixed costs of importing and exporting. These costs reflect the expected operating profits from importing and exporting. Since a lower elasticity of substitution implies that gross profits are a higher share of sales, the estimated fixed costs nearly double when $\sigma = 2.0$ relative to the benchmark and they are halved when $\sigma = 10$. In the counterfactual, a low-elasticity of substitution induces a much larger increase in the demand for skilled workers. A low elasticity of substitution implies that firms quality choices depends more on the quality of its inputs. So, firms' choices are more intertwined, the indirect effects of inputs are magnified, and the counterfactual trade liberalization increases the share of skilled workers by 8.6 percentage points, compared with 7.4 points in the benchmark. For different reasons when $\sigma = 7.0$, increases in skill intensity are also larger than the benchmark, 9.8 percentage points. Here, estimates of the direct shifts in skill intensity associated with international trade are larger than in the benchmark. Shifts in the distributions of sales and white-collar workers are on table C.5. Note that the largest increases in the left tail of the white-collar distributions occur when $\sigma = 2$ and the domestic spillovers

Table C.5: Changes in the distribution of sales and measured skill intensity, chemicals

	percentiles					total
	10%	25%	50%	75%	90%	
ln(normalized sales), $\Delta = 1994 - 1988^{*}$						
data	**-0.42**	**-0.25**	**-0.26**	**-0.22**	**-0.15**	**-0.14**
model benchmark $\sigma = 5$	-0.24	-0.22	-0.20	-0.17	-0.15	-0.15
model $\sigma = 2$	-0.22	-0.20	-0.18	-0.16	-0.13	-0.14
model $\sigma = 7$	-0.23	-0.21	-0.19	-0.16	-0.14	-0.14
share of white-collar workers, $\Delta = 1994 - 1988$ **in %**						
data	**0.0**	**3.2**	**7.5**	**12.1**	**11.7**	**7.9**
benchmark $\sigma = 5$	0.1	2.7	3.8	2.7	1.9	5.1
model $\sigma = 2$	2.3	3.6	5.0	3.3	2.1	5.7
model $\sigma = 7$	-0.8	2.6	5.3	3.8	1.9	6.6

are largest. Our choice of $\sigma = 5$ is conservative in the sense of predicting the smallest changes in skill intensity, but the difference between $\sigma = 2$ or $\sigma = 7$ is not large and the results remain qualitatively unchanged.

C.2.2 Fixed parameters & inelastic labor supply

The assumption that fixed costs use some perfectly elastic factor implies that these costs do not change with the counterfactual or with changes in wages. This assumption is innocuous if labor is elastic because wages do not change anyway. But in the counterfactual with inelastic labor, average wages decreased by 10%. Allowing all fixed costs to decrease with wages, makes it cheaper for firms to upgrade their product quality, but the increase in the skill premium during the liberalization increases only from 3.52% to 3.54%. The elasticity of labor supply σ_L again has no effects on the results if labor is elastic, but if labor is inelastic, the higher the elasticity, the smaller the change in skill premium needed to clear the labor market after the liberalization. Values for σ_L in the literature are $\sigma_L = 1.1$ in Lee and Wolpin (2006), $\sigma_L \in [1.6, 1.8]$ in Acemoglu and Autor (2010) and $\sigma_L = 1.4$ in Katz and Murphy (1992). The predicted change in the skill premium in the counterfactual trade liberalization is 3.8 if $\sigma_L = 1.1$, 3.5 if $\sigma_L = 1.6$ (benchmark), and 3.4 if $\sigma_L = 1.8$. So, again, the results barely change with σ_L.

D Multiple equilibria and Monte Carlo simulations

There is a coordination element to the model: As some firms increase their output quality, they increase other firms' incentives to increase quality. We cannot rule out multiplicity of equilibria, but it is unlikely that they exist at least for the parameter estimates. As described in section 3.1.2, for each set of parameters, we iterate over firms' choices of quality and participation in international trade until no firm wants to change its choices. To check for multiple equilibria given the parameter estimates, we randomize over firms initial choices 1,000 times and see if their choices converge to the same point. In all 1,000 experiments the choices of all 5,000 remained the exactly same.

In estimating the model, we simulate the behavior of 5,000 firms. For each parameter guess, we transform a *fixed* vector of random variables to get each firm's productivity $z(q, \omega)$ and costs $f_M(\omega)$ and $f_X(\omega)$. The number of firms was chosen due to computational constraints, but to assess whether the number is large we change the vector of random variables forty times and re-run the optimization algorithm. If 5,000 is sufficiently large, the results should not change much. About 60% of the parameter estimates are within 99% confidence interval of the original estimates. The parameters that are worse identified are Q^*, q^* and μ_M. When the random draws change, the distribution of quality choices change and q^* and Q^* need to change accordingly. Our parameter estimates also imply a large variance in firms fixed importing costs. So, it is also natural that the mean cost is not well identified. The counterfactual results change the increase in skill intensity varies by about one percentage point, but there is no qualitative change. The results do not change at all if we double the number of quality choices $q \in [0, 10]$ from 200 to 400 or if we expand the choice set beyond the upper bound of $q = 10$.

We also conduct Monte Carlo simulations. We generate data with random parameters drawn from a uniform distribution with support of four standard deviations from the original parameter estimates. For each generated data set, we run our simulation algorithm to recover the original parameters. We repeat this exercise 100 times, and find that the parameter estimates are within two deviations of the original estimates 80% of the time and that the median deviation is just 0.67 times standard errors, showing that the parameters are reasonably well identified.[49]

[49] To get our parameter estimates, we ran two algorithms, a simulated annealing and a simplex algorithm, but for these Monte Carlo experiments, we only run the simulated annealing. Identification would probably be even better if we had automated the process and ran also the simplex algorithm.