Trade, Skills and Quality-Upgrading: A Theory with Evidence from Colombia

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ABSTRACT

We introduce vertical differentiation to a model of international trade and heterogeneous firms. More productive firms endogenously choose higher quality, become larger, sell their output and buy their inputs at higher prices, and they are more likely to export their output and import their inputs. We estimate the model structurally to data on manufacturing plants in Colombia before the trade liberalization, simulate a counterfactual liberalization and compare the results to post-liberalization data. As with other unilateral trade liberalizations in developing countries, the skill premium and the skill intensity in manufacturing increased and the size of firms decreased. In the model, a decrease in trade barriers induces quality upgrading among exporters. These upgrades increase the domestic demand and supply of high-quality inputs. Despite decreases in sales, other firms react by upgrading the quality of their own products, thereby amplifying these effects on domestic inputs. The relative demand for skilled labor from a wide range of firms then increase. Less productive firms downgrade and become less skill intensive.

Keywords: trade liberalization, skill, quality, intermediate inputs, amplification effect.

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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 broad changes in their manufacturing sectors: Measured productivity, investment, skill premium, skill intensity, the quality of inputs and of outputs all increased while firm size decreased or remained unchanged.¹

These changes are puzzling for two reasons. First, bilateral trade data suggest that developing countries have a comparative advantage in producing unskill-intensive low-quality goods. Rich and poor countries typically export goods in the same product categories, but rich countries systematically sell goods at higher unit prices.² A standard factor-proportions (Heckscher-Ohlin) model then predicts that a trade liberalization in a developing country should shift its production toward low-quality goods thereby increasing the relative demand and wages of unskilled workers. In contrast, trade liberalizations were typically followed by abrupt rises in the skill premium in the order of 10% to 20%. Second within countries and sectors, firm size, skill intensity and the unit price of output are all positively correlated, suggesting that the production of high-quality goods is not only skill-intensive but also exhibits increasing returns to scale. Import penetration and decreasing sales should then give further incentives for firms to shift toward their comparative advantage, low-quality goods. In contrast, trade liberalizations were followed by increases in skill intensity and in product quality (where observable).

We develop a quantitative model that reconciles these cross-sectional correlations to the changes after a trade liberalization. The model introduces vertical differentiation and factor intensities to Melitz (2003). The production of higher quality exhibits economies of scale, and it is intensive in skilled labor and in high-quality inputs. More productive firms then endogenously choose higher quality, become larger and more skill intensive. The price of their inputs and output is also higher. As in previous models, firms pay a fixed cost to import their inputs

¹These changes are unlikely to come only from other reforms because they are typically larger in sectors with larger tariff decreases. For productivity changes, see Eslava et al. (2011), Khandelwal and Topalova (2004), Pavcnik (2002), Treffer (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—China was not yet trading extensively.

²See Schott (2004). Similar patterns hold for capital. Prices are used here as a proxy for quality but the results are robust to controlling for quantity (Khandelwal (2010)).
or to export their output. If the relative demand and supply of high-quality goods are higher in the foreign country, as implied by the parameter estimates, larger and more skill-intensive (higher-quality) firms are more likely to engage in international trade.

The model thus combines elements of previous models in a unified quantitative framework that captures the positive correlation between firm size, skill intensity, wages, input and output prices, and import and export participation and intensities. We illustrate the advantage of this unified set up by estimating the model structurally to a cross-section of Colombian manufacturing plants in the chemical sector in 1988, before the trade liberalization in 1991. The joint distribution of firm characteristics allows for the identification of parameters governing firms’ demand for skilled labor, including parameters related to economies of scale and imported inputs. We then simulate a counterfactual trade liberalization and compare the results to the data in 1994, after the trade liberalization.\(^3\) In line with the data, the model predicts a decrease in firm size of 13% on average coupled with an increase in the share of skilled workers of 5 percentage points from 58% to 63%.

Even though exports relative to the size of the Colombian market expanded only from 7% to 10%, exporters precipitate a broad transformation in the domestic market. The share of exports in these firms’ sales increase during the trade liberalization because the domestic market shrinks with import competition. Exporters then upgrade their products to cater to foreign consumers. And by upgrading, they decrease the *domestic relative cost* of producing high-quality goods because they produce inputs for the domestic market, and they increase the *domestic relative demand* for high-quality goods because they demand inputs from the domestic market. As other firms respond by upgrading their own product quality, they magnify these cost and demand effects leading to even more quality upgrading and an even higher demand for skilled workers. Despite decreases in the sales of nearly all firms, 99%, the skill intensity increases in 50% of firms. In sum, the direct effects of trade in a small subset of firms catalyze large and widespread increases in the relative demand for skilled labor.\(^4\)

\(^3\)In the counterfactual, we allow for only two parameters to change—one controlling trade deficits and the other controlling non-tariff barriers—to exactly match changes in aggregate imports and exports. Non-tariff barriers are not observable and our static model does not speak to trade deficits.

\(^4\)This mechanism is akin to the multiplier effect of inputs in Jones (2011) and to the forward and backward linkages in Markusen and Venables (1999). Both of these models need the size of the market
The existing literature on heterogeneous firms presents several mechanisms through which trade directly affects firms’ demand for skilled workers. In Bustos (2011a) and Helpman et al. (2012), an increase in the scale of production of exporters increases these firms’ demand for skilled workers because production at larger scale is more efficiently done with skilled workers. In Burstein et al. (2012), Burstein and Vogel (2012) and Kugler and Verhoogen (2012), imported equipment and high-quality inputs complement skilled labor.\textsuperscript{5} Our theoretical model includes both these previously studied mechanisms and evaluate their quantitative importance to explain broad increase in skill intensity during Colombian trade liberalization.\textsuperscript{6} More importantly, we introduce quality complementarity of varieties in intermediate input production. We show that this additional channel is more important to reconcile the joint changes of plant size and skill intensity pre and post trade liberalization. The empirical richness of our model allow us to use pre-liberalization micro data to govern the potential effects of economies of scale and imported inputs on the demand for skill, and we find the direct effect of these mechanisms to be small. The scale of production generally decreases\textsuperscript{7}, and the effect of foreign inputs in the model is smaller than the effect of domestic inputs.\textsuperscript{8} Overall, Colombian plants medium run profits decrease, thus explaining the strong opposition of industry associations to trade liberalizations (Edwards (2003)).

Section 1 presents the model and section 2 presents a background on the Colombian reforms and the data. We estimate the model in section 3 and simulate the trade liberalization in section 4. Section 5 presents alternative counterfactual simulations and 6 concludes.

\textsuperscript{5}A potential third mechanism is offshoring documented by Feenstra and Hanson (1997) and Faber (2013). It is widespread in some developing countries such as Mexico, Hong Kong and China, although not so much in Colombia.

\textsuperscript{6}In Burstein, Cravino and Vogel (2012) capital complements skilled labor and play a role similar to material inputs here. Differences in wages here reflect exclusively differences in skill.

\textsuperscript{7}Most papers on the hypothesis of economies of scale and export expansion use export dummies. We use sales, a more direct measure of firm size. In India and most South American countries where trade liberalizations were unilateral, exports did not expand much until about ten years after the trade liberalization. Increases in skill premium and skill intensity in manufacturing typically occur within the five years of the liberalization.

\textsuperscript{8}Burstein et al. (2012) use country-level data, while we observe each firm’s imports of materials.
1 The model

Preferences are in section 1.1, technologies in section 1.2, and equilibrium in section 1.3. The model is static. There are two countries, Home and Foreign. Foreign variables are denoted with an asterisk. With our empirical application to a small country—Colombia—in mind, we take all Foreign variables as exogenous and focus on Home. Consumers are endowed with and supply skilled and unskilled labor. There is a continuum of goods indexed by \( \omega \). The set of goods is \( \Omega \) in Home and \( \Omega^* \) in Foreign, with \( |\Omega| = |\Omega^*| = 1 \).

We are interested in the medium-term effects of the trade liberalization, the five years in which most of the changes in the labor market occur. As typical with unilateral trade liberalizations, imports increased faster than exports in the medium term in Colombia. So, we allow for exogenous trade deficits. In addition, the average size of firms decreased and there was some exit. This is inconsistent with free entry and constant markups, where if the probability of surviving decreases, sales conditional on surviving have to increase. So, we take the set of potentially active firms \( \Omega \) as exogenous but firms may endogenously exit because there is a fixed cost of production. 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 led to an increase in exports and probably to an increase in firm size. To study the medium term, however, we rule out free entry and allow for unbalanced trade.

The key theoretical innovation is the production function. Profit maximization delivers a positive correlation between firm productivity, size, skill-intensity, input and output price in a quantitative set up. All other assumptions can be easily changed depending on the application.

1.1 Demand

Consumers take the price \( p(\omega) \) and quality \( \bar{q}(\omega) \) of each good \( \omega \in \Omega \cup \Omega^* \) as given, and choose quantities to maximize a demand function with constant elasticity of substitution (CES):

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

(1)
where $\sigma > 1$ is the elasticity of substitution. For convenience, we change the quality scale to the cumulative distribution function of a logistic random variable:

$$\tilde{q} = \Phi(q, Q)$$

where

$$\Phi(q, Q) = \frac{\exp(q - Q)}{1 + \exp(q - Q)}$$

(2)

and $Q = 0$ is the mode. A smooth distribution function, we show below, neatly summarizes the relative demand for high-quality goods in Home and Foreign with a single parameter. The boundness of $\Phi$ does not matter—we can always change the scale back to the identity function $\tilde{q}$. We henceforth refer to a firm’s quality level as $q(\omega)$, where $\tilde{q}(\omega) = \Phi(q(\omega), Q)$, and to $Q = 0$ as the consumer’s reference quality.

The CES price index is

$$\overline{P}(Q) = \left[ P(Q)^{1-\sigma} + P^*(Q)^{1-\sigma} \right]^{1/(1-\sigma)}$$

where

$$P(Q) = \left[ \int_{\Omega} p(\omega)^{1-\sigma} \Phi(q(\omega), Q)d\omega \right]^{1/(1-\sigma)}$$

and

$$P^*(Q) = \left[ \int_{\Omega^*} p(\omega)^{1-\sigma} \Phi(q(\omega), Q)d\omega \right]^{1/(1-\sigma)}$$

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

$$r_c(q, p) = \left( \frac{p}{\overline{P}(Q)} \right)^{1-\sigma} \Phi(q, Q)I.$$  

(4)

### 1.2 Production

Each good $\omega \in \Omega$ is potentially produced by a monopolistically competitive firm. Firms use skilled and unskilled labor, and inputs for production. To produce quality $q$, firm $\omega$ pays a fixed cost of $f(q)$ units of a composite of labor, and to import Foreign varieties in $\Omega^*$, it pays $f_M(\omega)$ units of labor.\footnote{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 need to pay an additional markup for the distribution costs. Firms can alternatively pay a fixed cost to forgo these distribution costs. This assumption does not change the empirical results, it only adds a parameter.} We assume for simplicity that the composite of labor for all fixed costs contains one unit of skilled and one of unskilled labor. The fixed cost of importing varies across

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firms because import participation in the data varies across firms with similar characteristics. After incurring these fixed costs, the output of firm \( \omega \) when producing quality \( q \) with import status \( 1_M \in \{0, 1\} \) is

\[
\tilde{a} z(q, \omega) L(q)^{\alpha} X(q)^{1-\alpha}
\]

where

\[
L(q) = \left[ \sum_{i \in \{s,u\}} l_i^{(\sigma_L - 1)/\sigma_L} \Phi_L(i, q)^{1/\sigma_L} \right]^{\sigma_L/(\sigma_L - 1)},
\]

\[
X(q) = \left[ \int_{\Omega_\ast(0)} \int_{\Omega_\ast(1)} x(\omega')^{(\sigma-1)/\sigma} \Phi(q(\omega'), q)^{1/\sigma} d\omega' \right]^{\sigma/(\sigma-1)},
\]

\( \tilde{a} = \alpha^{-a} (1 - \alpha)^{-(1-a)} \) 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 \( \omega' \) and \( q(\omega') \) is its quality, and \( \Phi_L : (\{s,u\} \times \mathbb{R}_+) \to \mathbb{R}_+ \) is a productivity shifter. The set \( \Omega_\ast(0) = \emptyset \) and \( \Omega_\ast(1) = \Omega_\ast \).

Production is a Cobb-Douglas 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

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

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 \( q \). In the empirical analysis below, we estimate the ratio \( \frac{\Phi_L(s, q)}{\Phi_L(u, q)} \) as a function of \( q \).

The CES aggregate \( X(q) \) is the same as in the utility function (1) but the consumer’s reference quality \( Q \) is replaced with the firm’s output quality \( q \). In the utility function, \( \Phi(q, Q) \) is the demand shifter of a final good of quality \( q \), and in the production function, \( \Phi(q', q) \) is the productivity shifter associated with an input of quality \( q' \) when the firm’s output quality is \( q \). By equation (2), firms are particularly sensitive to changes in the quality of inputs whose quality is close to its output. Figure 1 illustrates the productivity shifter \( \Phi(q, q_i) \) as a function of input quality \( q \) for two firms \( i \in \{1, 2\} \) with output qualities \( q_1 < q_2 \). If prices increase slowly with quality, firm 1 concentrates her purchases in region 1 and firm 2 in region 2: The high-quality firm 2 demands on average inputs of higher quality than firm 1.
Figure 1: Input productivity shifters for two firms with different output qualities

Figure 2: Demand shifter for Home and Foreign consumers
Firm $\omega$ pays a fixed cost $f_X(\omega)$ units of labor to access the Foreign market with demand

$$r^*(q, p) = p^{1-r} \Phi(q, Q^*) I^*.$$  

Demand in Foreign may arise from consumers or firms. Parameter $I^*$ captures the size of the Foreign market—it includes Foreign price index, total spending, trade costs and tariffs. Parameter $Q^*$ captures the relative demand of high- to low-quality goods in Foreign with respect to Home. Analogous to figure 1, figure 2 shows the demand shifters of Foreign $\Phi(q, Q^*)$ and of Home consumers $\Phi(q, Q)$ as a function of product quality $q$. If $Q^* > Q$, the relative demand for high-quality goods is higher in Foreign, and firms with higher-output quality are more likely to export. As in Melitz (2003), the fixed cost implies that larger, more productive firms are also more likely to export.

**1.2.1 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

$$C(q, 1_M) = w(q)^\alpha P_1(q, 1_M)^{1-\alpha},$$

where $w(q) = [\sum_{i=s,u} w_i^{(1-\sigma)} \Phi_L(i, q)]^{1/(1-\sigma)}$ is the CES price of labor, and $P_1(q, 1) = P(q)$ and $P_1(q, 0) = P(q)$ in equation (3) are the CES prices of materials. Importing decreases input costs. Since this benefit is proportional to size and the cost $f_M(\omega)$ is not, large firms are more likely to import. And if the quality of Foreign goods is high, high-quality firms gain more from importing.

Firm $\omega$’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 (9) below. The firm’s demand for skilled and unskilled labor is then

$$w_i l_i(\omega) = \left(\frac{w_i}{w(q(\omega))}\right)^{1-\sigma_L} \Phi_L(i, q(\omega)) R_L(\omega) \quad \text{for } i = s, u \quad (7)$$
where $R_L(\omega) = (\alpha / \mu) r_T(\omega)$ is the firm’s total spending on labor. The firm’s spending on an input with quality $q$ and price $p$ is

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

where $R_I(\omega) = [(1 - \alpha) / \mu] r_T(\omega)$ is total spending on inputs. Aggregating over consumers and firms (equations (4) and (8)), spending on a variety with price $p$ and quality $q$ in Home is

$$r(q, p) = r_c(q, p) + \int r_I(q, p, \omega) d\omega = p^{1-\sigma} \chi(q)$$

where $\chi(q) = \Phi(q, Q) P(Q)^{\sigma-1} I + \int \Phi(q, q(\omega)) P_I(q(\omega), 1_M(\omega))^{\sigma-1} R_I(\omega) d\omega$.

Function $\chi(q)$ summarizes the country-wide demand for quality $q$: Each type of spending, consumers’ $I$ and firms’ $R_I(\omega)$, is weighted by its own relative demand for quality $q$ captured by function $\Phi$. If $\Phi$ 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 $q$.

The cost of the composite labor is $\bar{w} = w_s + w_u$ and the markup is $\mu = \frac{\sigma}{\sigma-1}$. Firm $\omega$ sets $p = \mu C(q, 1_M) / z(q, \omega)$ and chooses quality $q$, entry $1_E$, import status $1_M$ and export status $1_X$ to maximize profits:

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

A firm’s operating profit $\sigma^{-1} [r(q, p) + 1_X r^* (q, p)]$ is proportional to its productivity $z(q, \omega)$ and the cost of producing higher quality $\bar{w} f(q)$ is fixed. So, more productive firms endogenously choose higher quality. The decision to import and export cannot be disentangled—exporting increases the scale of production rendering imports more profitable, and importing decreases variable costs rendering exports more profitable. Similarly intertwined is the decision of output quality since importing and exporting yield higher profits from quality upgrading. Before closing the model, we illustrate a firm’s choice of quality.
1.2.2 Choice of quality and international trade: An example

Consider the problem of a firm in choosing its output quality. Assume that its productivity is 
\( z(q, \omega) = z \) for all \( q \) and, for now, that it is not engaged in international trade \( M = X = 0 \). The firm’s profit as a function of its output quality \( q \) is then

\[
 z^{\sigma - 1} \left\{ [\mu C(q, 0)]^{1-\sigma} \chi(q) / \sigma \right\} - w f(q)
\]

The first term is the firm’s operating profit and the second, its fixed cost. Figure 3(a) graphs the two terms, where \( [\mu C(q, 0)]^{1-\sigma} \chi(q) / \sigma \) and \( w f(q) \) are taken from the estimates in section 3 below. 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 \( q = 5.4 \) and then declines. The fixed cost is linear by parametric assumption.

Figure 3(b) shows the firm’s first order conditions, the derivative of equation (11) with respect to \( q \). The firm chooses quality \( q = 4.8 \), where marginal operating profit equals marginal cost. Its total profit is the area between the two curves minus \( w f(0) \). 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.

Figure 4 illustrates the firm’s choice of quality for different import and export statuses. The marginal operating cost of the domestically-oriented firm is the same as in figure 3(b). The parameter estimates below are such that Foreign has a higher relative demand and supply of high-quality goods than Home. Thus, 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 of firms’ quality choices, we exogenously increase all firms’
Figure 3: A firm’s choice of output quality

(a) components of profit

(b) first order conditions

Figure 4: Choice of output quality and trade
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 5(a) shows the changes in the problem of the firm in figure 3(b), which neither imports nor exports. The effects of cost $C(q,0)$ and demand $\chi(q)$ are separated. The decrease in relative cost of high-quality inputs shifts the original marginal operating profit rightward, especially for high-quality goods whose adequate inputs for production are initially not available in Home. Demand shifts the marginal operating profit down and to the right. The downward shift is a decrease in sales that occurs because, as importing firms upgrade their product quality, they substitute Home materials with higher-quality Foreign materials. The rightward shift can be seen because the dashed marginal profit curves intercept at quality 6.9. It 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 4.8 to 5.7, almost the 1 point exogenous increase in other firms’ quality.\footnote{The issue of multiplicity of equilibria, discussed in appendix ??.

}\footnote{We make the standard assumption that Foreign factors are used to transport Foreign goods.}

Figure 5(b) shows the effect of the experiment on a firm that imports and exports. The cost effect is much smaller because the firm 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 half of Home firms to upgrade their product quality, and so its Home market effects are akin to this experiment.

1.3 Tariffs, trade and equilibrium

The rest of the model is standard. The price $p(\omega)$ that agents at Home pay for $\omega \in \Omega^*$ includes an \textit{ad valorem} tariff $\tau$: $p(\omega) = (1 + \tau)p^*(\omega)$ where $p^*(\omega)$ is the unit price of a Foreign variety $\omega \in \Omega^*$ after trade costs.\footnote{We make the standard assumption that Foreign factors are used to transport Foreign goods.} Home’s imports from Foreign is $R_{HF} = R_{HF}^T/(1 + \tau)$ where $R_{HF}^T$ is the after-tariff spending on Foreign goods,

$$R_{HF}^T = \left[ \frac{P^*(Q)}{P(Q)} \right]^{1-\sigma} I + \int_{\Omega} 1_M(\omega) \left[ \frac{P^*(q(\omega))}{P(q(\omega))} \right]^{1-\sigma} R_M(\omega) d\omega.$$
Home’s exports to Foreign are

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

The Home government redistributes tariff revenues \( T = \tau R_{HF} \) to consumers through a lump sum transfer. Consumer spending is

\[ I = w_s L_s(w) + w_u L_u(w) + \int_{\Omega} \pi(\omega) d\omega + T + D_H. \]

where \( L_s(w) \) and \( L_u(w) \) are the supply of skilled and unskilled labor when wages are \( w = (w_s, w_u) \) and \( D_H \) is Home’s exogenous trade deficit—by Walras’ law, \( R_{HF} = R_{FH} + D_H \). The labor market clears if:

\[ L_i(w) = \int_{\Omega} [l_i(\omega) + f(q(\omega)) + 1_M(\omega) f_M(\omega) + 1_X(\omega) f_X(\omega)] d\omega \quad \text{for } i = s, u. \quad (12) \]

To summarize, an economy is defined by Home’s labor supply \( L_s(w) \) and \( L_u(w) \), set of firms \( \Omega \) each with its productivity \( z(q, \omega) \), its fixed cost of importing \( f_M(\omega) \) and exporting
$f_X(\omega)$, economy-wide fixed production costs $f(q)$, tariffs $\tau$ and deficit $D_H$, and by Foreign’s demand shifters $Q^*$ and $I^*$ and the set of firm prices and quality levels $\{p^*(\omega), q(\omega)\}_{\omega \in \Omega^*}$. An equilibrium is a set of wages $w_s$ and $w_u$ that clears the labor markets.

2 Background of the Colombian trade liberalization

Following international trends, Colombia significantly reduced trade barriers in a broad range of industries between 1985 and 1991 after a long period of import-substitution policies.\textsuperscript{12} Non-tariff barriers, which affected 99.6% of industries in 1984, were removed, and the average tariff decreased from 27% to 10%. Figure 6 shows the evolution of effective tariff rates between 1984 and 1996. The decreases concentrated in 1991 were arguably unexpected. 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.\textsuperscript{13} We

\textsuperscript{12}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).

\textsuperscript{13}Plants report whether they belong to a firm with multiple plants, but not the plant(s) to which they
use two sample years: 1988 as pre-liberalization and 1994 as post-liberalization. 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.\textsuperscript{14} Last, our measure of white-collar workers is not available after 1994 because the classification of employees changed in 1995.

3 Pre-liberalization cross-section

We estimate the model to the chemical sector, which includes intermediate and final goods such as pharmaceutics, cosmetics and household cleaning products.\textsuperscript{15} The chemical sector has the largest number of firms, 438, and its pre- and post-liberalization patterns are similar to other sectors’ as shown in appendix ???. This is consistent with recent papers that find large systematic variations within and not across sectors.\textsuperscript{16}

This section structurally estimates the model with the simulated method of moments. The model delivers well-documented correlations between firm size, wages, skill-intensity, output prices and import and export behavior, and our moments describe the joint distribution of these firm characteristics in 1988. So, when we compare a counterfactual trade liberalization to the post-liberalization data in section 4, all the mechanisms governing the relative demand for skilled labor in the model are quantitatively consistent with pre-liberalization data. There are 

\textsuperscript{14}The number of firms decreases slightly in 1991, but there is a long term trend in increasing number of firms as the economy grows, making it hard to quantify exit. Fernandes (2007) documents firm exit in Colombia after the trade liberalization.

\textsuperscript{15}Sectors in Colombian manufacturing are classified according to their raw materials. For example, “plastics” and “metal products” also contain goods of final and intermediate usage.

\textsuperscript{16}See Bernard et al. (2003) and Helpman et al. (2012) for example. The appendix is still missing.
15 parameters and 47 moments. We present the parametrization 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.

3.1 Estimation procedure

3.1.1 Parametrization

We fix parameters that are not identified. The elasticity of substitution across goods $\sigma = 5$ is from Broda and Weinstein (2006), and the elasticity of substitution across skilled and unskilled labor $\sigma_L = 1.6$ from Acemoglu and Autor (2010) is in line with Katz and Murphy (1992) and Lee and Wolpin (2006). Tariff $\tau = 0.2$ is the average tariff on chemicals in 1988 in Colombia, and the share of labor in production $\alpha = 0.7$. We assume all foreign firms have the same price and quality, and set $p^*(\omega) = 1$ for all $\omega \in \Omega^*$. Instead of estimating the labor supply $L_i(w)$ and calculating equilibrium wages for each parameter guess, we set wages and calculate the labor supply that clears the labor market for each parameter guess. The skill premium in Colombia $w_s/w_u = 2.61$ is from Attanasio et al. (2004) and $w_u = 1$. We also normalize $I = 1$. Appendix B experiments with alternative values for these fixed parameters and variables.

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

$$z(q, \omega) = \max\{0, z(0, \omega) + z_2(\omega)q\}$$  \hspace{2cm} (13)

where $z(0, \omega)$ are independently drawn from a log-normal with mean parameter $\mu_1$ and variance parameter $\sigma_1$, and $z_2(\omega)$ are drawn from a normal distribution with mean zero and variance $\sigma_2$. 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. Assume $f(q) = f_1q$ where $f_1$ is a parameter to be estimated. Firms’ fixed costs of importing $f_M(\omega)$ are independently drawn from a log-normal with mean parameter $\mu_M$ and variance parameter $\sigma_M$, and their fixed costs of exporting $f_X$ are drawn from a log-normal with
parameters $\mu_X$ and $\sigma_X$. Assume
\[
\frac{\Phi_L(q,s)}{\Phi_L(q,u)} = \exp(l_1 + l_2q)
\]
\[
\Phi_L(q,u) = \bar{\phi}_L(q)
\]
where $l_1$ and $l_2$ are parameters to be estimated and $\bar{\phi}_L(q)$ is judiciously adjusted for every guess of $l_1$ and $l_2$ so that the CES price of labor $w(q) = 1$ for all $q$. 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 $\pi_s(\omega)$ of firm $\omega$’s skilled workers are misclassified as blue-collars, and a share $\pi_u(\omega)$ of its unskilled workers are misclassified as white-collars. Shares $\pi_s(\omega)$ and $\pi_u(\omega)$ are independently drawn from a normal distribution with mean $\mu_\pi$ and variance $\sigma_\pi$. Other estimated parameters are $q^\ast$, $Q^\ast$ and $I^\ast$. Table 1 lists the 15 parameters to be estimated.

### 3.1.2 Simulation

We simulate the behavior of 5000 firms. Each firm has a fixed vector of six independent standard normal random variables. For each parameter guess, we transform these vector to get productivity vectors $z(q, \omega)$, fixed costs $f_X(\omega)$ and $f_M(\omega)$ and measurement errors in skill $\pi_s(\omega)$ and $\pi_u(\omega)$. 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.

\[17 \Phi_L(q, u) = \left[\frac{w_1^{-\sigma_L} + \exp(l_1 + l_2)w_s^{1-\sigma_L}}{w_1^{1-\sigma_L} + \exp(l_1 + l_2)w_s^{1-\sigma_L}}\right]^{-1}\]

\[18 \text{Since } \pi_s(\omega) \in [0, 1], \text{ we draw } \pi_s(\omega) \text{ from a normal and let } \pi_s(\omega) = \min\{1, \max\{0, \pi_s(\omega)\}\}. \text{ The same procedure applies to } \pi_u(\omega).\]
Table 1: List of parameters

<table>
<thead>
<tr>
<th>model variable</th>
<th>description</th>
<th>parameter</th>
<th>estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$z(0, \omega)$</td>
<td>productivity levels at $q = 0$</td>
<td>$\mu_1$</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma_1$</td>
<td>0.66</td>
</tr>
<tr>
<td>$z(q, \omega)$</td>
<td>rate of productivity changes with quality</td>
<td>$\sigma_2$</td>
<td>0.002</td>
</tr>
<tr>
<td>$f(q)$</td>
<td>fixed cost of production</td>
<td>$f_1$</td>
<td>2.3e-5</td>
</tr>
<tr>
<td>$\Phi_L(q, s)/\Phi_L(q, u)$</td>
<td>productivity of skilled to unskilled workers</td>
<td>$l_1$</td>
<td>-1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l_2$</td>
<td>0.52</td>
</tr>
<tr>
<td>$f_M(\omega)$</td>
<td>fixed cost of importing</td>
<td>$\mu_M$</td>
<td>-7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma_M$</td>
<td>1.4</td>
</tr>
<tr>
<td>$f_X(\omega)$</td>
<td>fixed cost of exporting</td>
<td>$\mu_X$</td>
<td>-5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma_X$</td>
<td>1.0</td>
</tr>
<tr>
<td>$q^*$</td>
<td>quality of Foreign firms</td>
<td>$q^*$</td>
<td>8.6</td>
</tr>
<tr>
<td>$Q^*$</td>
<td>reference quality of Foreign demand</td>
<td>$Q^*$</td>
<td>6.7</td>
</tr>
<tr>
<td>$I^*$</td>
<td>size of Foreign market</td>
<td>$I^*$</td>
<td>0.126</td>
</tr>
<tr>
<td>-</td>
<td>measurement error in skill intensity</td>
<td>$\mu_{\pi}$</td>
<td>-0.13</td>
</tr>
<tr>
<td>-</td>
<td></td>
<td>$\sigma_{\pi}$</td>
<td>0.51</td>
</tr>
</tbody>
</table>

**Fixed parameters:** $I = p^* = w_u = 1, w_s = 2.6, \sigma = 5, \sigma_L = 1.6, \alpha = 0.7, \tau = 0.2$

Given firms’ discrete choices, the vector of price indices $P(q)$ is a fixed point estimated iteratively for each quality level in the grid. These price indices are fixed points because they enter into firms’ prices through material inputs. Given the price indices, the demand function $\chi(q)$ in equation (9) is also iteratively estimated 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.\textsuperscript{19} Given $P$ and $\chi$, 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 price, wages, share of white-collar workers, imports, exports, and sales. The parameter estimates below minimize the squared distance between the moments from these generated data to the observed moments, weighted by the inverse of their variance.\textsuperscript{20} Implicitly, this procedure takes labor supply $L(w)$ to equal firms’ demand for labor and the trade deficit $D_H$ to equal the difference between estimated imports

\textsuperscript{19}In estimating $P$ and $\chi$, instead of aggregating over the 5000 firms, we use the results in Melitz (2003) to aggregate only over the representative firm in each of the 800 discrete choices. This significantly speeds up the computation, especially since less than one-quarter of the possible choices are picked in a typical iteration.

\textsuperscript{20}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: Unconditional distribution of firm size and of skill intensity

<table>
<thead>
<tr>
<th></th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ln(normalized domestic sales)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>-10.0</td>
<td>-9.3</td>
<td>-8.1</td>
<td>-6.7</td>
<td>-5.6</td>
</tr>
<tr>
<td>model</td>
<td>-10.1</td>
<td>-9.0</td>
<td>-7.8</td>
<td>-6.6</td>
<td>-5.6</td>
</tr>
<tr>
<td><strong>white-collar workers/total number of workers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>0.18</td>
<td>0.29</td>
<td>0.46</td>
<td>0.61</td>
<td>0.73</td>
</tr>
<tr>
<td>model</td>
<td>0.18</td>
<td>0.31</td>
<td>0.46</td>
<td>0.59</td>
<td>0.72</td>
</tr>
</tbody>
</table>

and exports.

3.1.3 Moments

Most moments are displayed on tables 2 and 3, and in figure 7. On table 2 are 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. On table 3, 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 inputs divided by total spending on inputs and the export revenue divided by total revenue. In figure 7, we classify firms into quartiles of domestic sales and quartiles of average wages. This forms a grid of 16 potential bins classifying firms. We match the percentage of firms in each bin. The classification of firms by quartile of wage in the model reflects firms’ actual skill intensity without measurement error. Finally, we match the ratio of the average wage of white- to blue-collar workers. The 30 moments on tables 2 and 3, 16 moments in figure 7 plus the measured skill premium total 47 moments.

3.1.4 Identification

While the formal estimation procedure is above, we informally discuss parameter identification. The distribution of firm productivity \( z(q, \omega) \) captures primarily the unconditional distri-

\[21\] 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 in our manufacturing survey plus imports of chemicals minus exports of chemicals, where Colombian imports and exports are taken from Feenstra et al (2005).
Table 3: Joint distributions of firm size with other characteristics

<table>
<thead>
<tr>
<th></th>
<th>quartiles of domestic sales</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>average share of white-collar workers</strong></td>
<td>data</td>
</tr>
<tr>
<td></td>
<td>model</td>
</tr>
<tr>
<td><strong>share of importing plants</strong></td>
<td>data</td>
</tr>
<tr>
<td></td>
<td>model</td>
</tr>
<tr>
<td><strong>share of exporting plants</strong></td>
<td>data</td>
</tr>
<tr>
<td></td>
<td>model</td>
</tr>
<tr>
<td><strong>spending on imported inputs/total</strong></td>
<td>data</td>
</tr>
<tr>
<td></td>
<td>model</td>
</tr>
<tr>
<td><strong>export sales/total sales</strong></td>
<td>data</td>
</tr>
<tr>
<td></td>
<td>model</td>
</tr>
</tbody>
</table>

Figure 7: Distribution of firm domestic sales and wage
distribution of market shares. The overall level of market shares depends on import penetration. And since $p^* = 1$, parameter $\mu_1$ governs import penetration by increasing the productivity in Home relative to Foreign. Parameter $\sigma_1$ governs the variance of market shares. By allowing some firms to be relatively more productive at the skill-intensive high-quality goods, $\sigma_2$ governs the joint distribution of sales and wages in figure 7. We fix Home consumer spending $I = 1$ because our moments refer to market shares, not to sales in Colombian pesos or dollars. Given the size of the Home market, parameter $I^*$ governs export intensity.

Fixed trade costs $f_X(\omega)$ and $f_M(\omega)$ govern firms’ import and export status and their correlation with size. 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 $f(q)$ governs the dispersion of quality choices across firms. If quality choices are similar, firms’ import and export intensities do not depend on firm 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 firm size and skill intensity, and the shifter of Foreign demand $Q^*$ governs how export intensity varies with size and skill intensity. We assume $f(0) = 0$ because we cannot estimate it without observing exit.$^{22}$

Given quality choices, $l_1$ and $l_2$ capture the unconditional distribution of the shares of white-collar workers. The difference between the true skill premium $w_s/w_u = 2.6$ and the wages of white- to blue-collar workers, 1.9, helps identify the average measurement error in

$^{22}$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.
skill $\mu_\pi$, while the smaller dispersion in the distribution of sales and wages relative to sales and shares of white-collar workers help identify $\sigma_\pi$. The elasticity of substitution across skilled and unskilled labor $\sigma_L$ is not separately identified from $l_1$ since it enters the model only through the demand for labor in equation 7. Similarly, the elasticity of substitution across goods $\sigma$ is not separately identified from $z(q, \omega)$ since it enters only as an exponent of $z(q, \omega)$ in demand.

3.2 Results

The parameter estimates (standard errors not yet available) are on table 1 and the distribution of quality levels is in figure 8. The quality of Foreign goods $q^* = 8.6$ is above 7.3, the highest-quality chosen by Home firms, and the Foreign reference quality $Q^* = 6.7$ is well above the reference quality for Home consumer and most firms. Skill upgrading associated with international trade is very large. If we change the fixed costs of trading of a typical firm, its skill intensity increases by 10 percentage points if it switches from not trading to importing only, by 15 points if it switches to exporting only, and by 23 points if it switches to importing and exporting.

In 2000 US$, the average fixed cost of importing is 47,400 and of exporting is 47,300. Since firms with lower costs self-select into importing and exporting, the average cost paid is US$6,900 for importing and US$20,700 for exporting.\footnote{These costs are in line with Cherkashin et al. (2012) and Das et al. (2006). They are large because they reflect the expected profits from importing and exporting. We infer the fixed costs in US$ 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 are fixed through the normalization $I = 1$.} The estimated variance of fixed costs is higher for importing than for exporting because in the data small and large firms import, but only large firms export (see table 3). A firm’s decision to import is then largely governed by its idiosyncratic fixed cost, while its decision to export depends on market conditions and is more likely to change with the counterfactual trade liberalization.

The model matches well the unconditional distribution of firm size and measured skill intensity on table 2. On table 3, 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 a firm’s sales and wages in figure 7. Finally, the wages of white-
to blue-collar workers is 1.9 in the model and in the data.

3.2.1 Prices

It is an assumption of the model that firms’ skill intensity, wages, sales and participation in
international trade are all linked through firms’ choices of output quality. Neither prices nor
any direct measure of quality are used in the estimation. So, the positive correlation between
output prices and these firm characteristics in the data serves an outside validation of our
assumption. Although we do not yet have definite moments on prices from our data, we can
ex post match the joint distribution of prices and sales by redefining $\Phi(q, Q)$ and $z(q, \omega)$ as

$$
\Phi(q, Q) := \tilde{\phi}(q) \Phi(q, Q)
$$

$$
z(q, \omega) := \tilde{z}(q) z(q, \omega)
$$

where $\Phi(q, Q)$ and $z(q, \omega)$ are in equations (2) and (13) above and $z(q)$ is parameterized and estimated. Assuming $\tilde{\phi}(q) \tilde{z}(q)^{\tau - 1} = 1$ for all $q$, potential decreases in productivity $\tilde{z}(q)$ with quality $q$ are exactly offset with an increase in the demand shifter $\tilde{\phi}(q)$, so that firms’ choices remain unchanged because revenues remain unchanged. Thus nothing changes in the original estimates, but a firm’s unit price $C(q, 1, I(\omega)) \tilde{z}(q) z(q, \omega)$ increases with quality if $\tilde{z}(q)$ decreases fast enough.

4 Pre- versus post-trade liberalization

A trade liberalization in Home is a decrease in its tariff and non-tariff barriers. In a general equi-librium model with balanced trade, wages in Home would decrease relative to Foreign so that the increase in imports would be exactly matched by an increase in exports—i.e., Home should experience a real depreciation of its currency. But in the period of interest, the Colombian trade deficit increased, and our static model has no way of forecasting deficits. Also, tariffs in the Colombian chemical sector decreased from 20% to 5%, but we do not observe non-tariff barriers. So, in simulating the trade liberalization, we exogenously decrease tariffs from $\tau = 0.20$
to 0.05 and allow for Foreign prices \( p^* \) and for Foreign income \( I^* \) to change to exactly match the aggregate change in imports and exports. To be specific, between 1988 and 1994, imports expanded from 21.5% to 35.2% of total absorption of chemicals in Colombia, and exports expanded from 7.1% to 9.7%, and we match this 13.7% expansion of imports and 2.6% expansion of exports. We keep the skill premium constant at its 1988 level for clarity—price and quantity effects are not commingled in the demand for skill and a firm’s skill intensity increases if and only if its output quality increases.

The post-liberalization estimates \( I^* = 0.13 \) and \( p^* = 0.98 \) imply a real depreciation of Colombian pesos and a decrease in non-tariff barriers—both \( I^*/I \) and \( p^*/I^* \) increase. On average, firm size decreases by 13%, the share of white-collar workers increases from 55% to 59% and the share of skilled workers increase from 58% to 63%, all sizable changes. Table 4, lines “benchmark”, compares the changes in the unconditional distribution of firm sales and share of white-collar workers to data. In the data and in the model, larger firms experience smaller decreases in sales and larger increases in skill intensity. The model captures well the magnitude of changes in sales but underestimates the increase in relative demand for skilled labor especially since the counterfactual disregards increases in the skill premium.\(^{24}\)

Changes in skill intensity of continuing importers and domestically-oriented firms are similar—only the highest quality firms increase their skill intensity. The increase in skill-intensity of new importers, new exporters and continuing exporters is large—13, 16 and 5 percentage points respectively. But new importers are only 2% of firms and thus have a small impact on the broader market.\(^{25}\) The larger impact comes from exporters even though total exports expand only by 2.6% of absorption.

To see this, table 5 decomposes firms’ changes in skill intensity into various effects. The procedure of the decomposition is in appendix A. As exporters upgrade the quality of their

\(^{24}\)Attanasio et al (2004) report an increase in skill premium of 11.5% in Colombia between 1988 and 1994. If we exogenously increase \( w_h \) by 11.5%, then the counterfactual trade liberalization predicts a decrease in skill intensity of 1.1 percentage points.

\(^{25}\)The finding that exporters, especially new exporters, disproportionately increase their skill-intensity and innovation is in Bustos (2011) and Lileeva and Trefler (2010). Larger firms disproportionately increase their skill intensity in Kugler and Verhoogen (2012). In the model, new importers have potentially the same effects as new exporters on the domestic market, but the large estimated variance of the fixed cost of importing implies that new importers are few. See section 3.2.
Table 4: Changes in the distribution of firm size and measured skill intensity

<table>
<thead>
<tr>
<th></th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ln(normalized sales)</strong>, $\Delta = 1994 - 1988^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>-0.42</td>
<td>-0.25</td>
<td>-0.26</td>
<td>-0.22</td>
<td>-0.15</td>
</tr>
<tr>
<td>model benchmark</td>
<td>-0.24</td>
<td>-0.21</td>
<td>-0.19</td>
<td>-0.16</td>
<td>-0.14</td>
</tr>
<tr>
<td>model alternative 1</td>
<td>-0.22</td>
<td>-0.20</td>
<td>-0.18</td>
<td>-0.14</td>
<td>-0.14</td>
</tr>
<tr>
<td>model alternative 2</td>
<td>-0.24</td>
<td>-0.21</td>
<td>-0.18</td>
<td>-0.11</td>
<td>-0.10</td>
</tr>
<tr>
<td>model alternative 3</td>
<td>-0.27</td>
<td>-0.23</td>
<td>-0.20</td>
<td>-0.17</td>
<td>-0.12</td>
</tr>
<tr>
<td><strong>share of white-collar workers</strong>, $\Delta = 1994 - 1988$ in %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>0.0</td>
<td>3.2</td>
<td>7.5</td>
<td>12.1</td>
<td>11.7</td>
</tr>
<tr>
<td>model benchmark</td>
<td>-1.7</td>
<td>-3.0</td>
<td>1.1</td>
<td>4.9</td>
<td>1.5</td>
</tr>
<tr>
<td>model alternative 1</td>
<td>0.0</td>
<td>-0.6</td>
<td>3.3</td>
<td>5.4</td>
<td>2.2</td>
</tr>
<tr>
<td>model alternative 2</td>
<td>-1.2</td>
<td>-1.7</td>
<td>4.9</td>
<td>7.2</td>
<td>3.2</td>
</tr>
<tr>
<td>model alternative 3</td>
<td>-2.8</td>
<td>-2.8</td>
<td>2.3</td>
<td>5.4</td>
<td>2.1</td>
</tr>
</tbody>
</table>

*A firm’s normalized sales are its total sales divided by the sales of domestic and foreign firms in the Home market.

products, they increase the Home supply of high-quality inputs. The ensuing change in cost induces a 10% increase in skill-intensity of domestically-oriented firms, and its overall effect on skill-intensity is larger than the decrease in the cost of Foreign inputs. As new importers and exporters upgrade the quality of their products they shift demand from low- to high-quality materials. The 40% higher-quality firms then upgrade and total skill intensity increases by 1.1 percentage points.

The fall in domestic demand decreases skill intensity by 1.4 percentage points on average, perhaps a smaller impact than one would expect from the decreases in sales on the last line of table 5. The cross-sectional correlation between firm size and wage in figure 7(a) is only 0.35, and so firms’ output quality is largely determined not by scale effects but by their productivity at low- relative to high-quality goods, implied by parameter $z_2(\omega)$. Also, the large continuing exporters experience two offsetting forces. On the one hand, the decreases in scale leads to quality downgrading, but on the other hand, the Foreign share in their sales increases and Foreign has a higher relative demand for high-quality goods. The two effects of Home demand are particularly detrimental to the quality of ex ante medium-quality firms that do not engage in international trade, firms which compete in the same segment of the intermediate-goods market as new importers and exporters. Last, the export market increases skill intensity by
Table 5: Decomposition of changes in skill intensity (in %) by participation in international markets

<table>
<thead>
<tr>
<th>% of firms</th>
<th>domestic</th>
<th>continuing importers</th>
<th>continuing exporters*</th>
<th>new importers†</th>
<th>new exporters*</th>
<th>all firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial skill intensity</td>
<td>37</td>
<td>50</td>
<td>60</td>
<td>47</td>
<td>49</td>
<td>58</td>
</tr>
<tr>
<td>+ cost of Home inputs</td>
<td>9.9</td>
<td>5.2</td>
<td>1.9</td>
<td>6.8</td>
<td>5.6</td>
<td>2.6</td>
</tr>
<tr>
<td>+ cost of Foreign inputs</td>
<td>-</td>
<td>3.0</td>
<td>1.8</td>
<td>7.3</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>+ Home market size</td>
<td>-8.8</td>
<td>-6.4</td>
<td>-0.6</td>
<td>-2.7</td>
<td>-6.0</td>
<td>-1.4</td>
</tr>
<tr>
<td>+ Home demand shift</td>
<td>-3.6</td>
<td>-0.6</td>
<td>1.3</td>
<td>0.8</td>
<td>-0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>+ export market</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>0.2</td>
<td>13.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Σ = final skill intensity</td>
<td>35</td>
<td>51</td>
<td>65</td>
<td>59</td>
<td>65</td>
<td>63</td>
</tr>
<tr>
<td>Δ = final - initial</td>
<td>-2.5</td>
<td>1.2</td>
<td>4.8</td>
<td>12.6</td>
<td>15.7</td>
<td>5.0</td>
</tr>
<tr>
<td>log change in sales</td>
<td>-0.24</td>
<td>-0.19</td>
<td>-0.13</td>
<td>-0.03</td>
<td>-0.04</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

All figures are weighted averages. For example, initially 58% of all workers are skilled.
† includes firms that initially export only and start importing after the liberalization
* includes firms that import and export

0.3% for continuing exporters and 14% for new exporters.

Overall, despite the large decreases in sales, 50% of firms increase skill-intensity. The sales of continuing exporters, for example, decrease by 13% and their skill intensity increases from 60% to 65%. The indirect cost and demand effects in Home account for an increase in sectoral skill-intensity of 3.7 (=2.6 + 1.1) percentage points, while the direct effects of economies of scale, Foreign sales and Foreign inputs exploited in previous papers together account for 1.3 (=2.0 - 1.4 + 0.7) percentage points.

5 Scale, exports, and other explanations

We conduct three alternative counterfactual trade liberalizations for robustness and didactic purposes. The first two further emphasize the role of exports vis-à-vis economies of scale. First, the evidence on changes in firm size is not as clear cut as the decreases in normalized sales on table 4 suggest. Real absorption of chemicals in Colombia increased by 33% between 1988 and 1994, and the number of employees per firm increased by 24%.

Similar changes occur in other sectors. Part of the increase in personnel may attributed to product and process innovation interpreted as the fixed cost in the model. Corroborating with the hypothesis of decreases in firm size, the World Bank reports that the share of manufacturing value added GDP
Table 6: Changes in skill intensity by participation in international markets

<table>
<thead>
<tr>
<th></th>
<th>final - initial skill intensity (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>domestic</td>
</tr>
<tr>
<td>benchmark</td>
<td>-2.5</td>
</tr>
<tr>
<td>alternative 1</td>
<td>-1.5</td>
</tr>
<tr>
<td>alternative 2</td>
<td>1.0</td>
</tr>
<tr>
<td>alternative 3</td>
<td>-2.0</td>
</tr>
</tbody>
</table>

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

the increase in absorption in a model without growth, we repeat the counterfactual but allow Home consumer spending \( I \) to exogenously increase to match the 33% increase in absorption. As before, \( I^* \) and \( p^* \) change to exactly match an import expansion of 13.7% of total absorption and an export expansion of 2.6%. The results are labeled as “alternative 1” on tables 4 and 6. The notable change is an increase in the share of white-collar workers in the lower tail.

Second, imports expand faster than exports between 1988 and 1994 but exports expand faster thereafter. If firms invest in product innovation in anticipation of these exports, our benchmark counterfactual will underestimate the increases in skill intensity. As a crude exercise, we simulate a counterfactual with an export expansion of 5.1%, instead of 2.6% of domestic absorption in chemicals, where 5.1% is the increase in exports between 1988 and 1995. As in the benchmark, imports expand by 13.7% of absorption and absorption is kept constant. The results, in table 4 line “alternative 2”, show a sizable increase in the share of white-collar workers among the ex ante high-quality firms. Table 6 shows the changes in skill intensity by participation in international trade. All firm types increase their skill intensity relative to the benchmark and to alternative 1, including domestically-oriented firms which increase their skill intensity by 1.0 percentage point. Sectoral skill intensity increases by 7.2 percentage points, well above 5.0 points in the benchmark and the 5.2 points in alternative 1. In sum, the amplification effects of exports is so strong that an increase in exports of just 2.5% (=5.1 - 2.6) of domestic absorption has a greater effect on skill intensity than a 33% increase in absorption.

Third, throughout the paper, we take non-labor inputs to be materials but these inputs may decreased from 38% to 31% between 1988 and 1994.
be more broadly interpreted to include capital inputs. Following this interpretation, we increase the labor share in the benchmark estimation from \( \alpha = 0.7 \) to 0.5. The new parameter estimates are in appendix B and the cross-sectional moments practically do not change. The results of the counterfactual are labeled as “alternative 3” on tables 4 and 6. Skill intensity increases by 6.9 percentage points, and Colombian pesos appreciate by 16% to match the export expansion in the data. Quality upgrading due to Foreign inputs and the magnifying effects of supply and demand for intermediates in Home are so large that Home goods become well suited for the export market. Without the real appreciation of the currency, export would expand beyond the observed 2.6% of absorption. Following the trade liberalization, Colombian pesos appreciated in real terms, and investment and capital flows are deemed as proximate causes for this appreciation. Even without dynamics, the model corroborates with this explanation.

Our amplification mechanism depends exclusively on the assumption that the production of higher-quality goods is more intensive in skilled labor and high-quality inputs—an assumption well supported by data. Although in the model all firms produce final and intermediate goods, the mechanism works whether exporters produce final or intermediate goods. Producers of intermediate inputs directly increase the availability of high-quality inputs as they upgrade the quality of their products to service foreign markets. Final goods producers, in turn, may increase the availability of high-quality inputs by imposing stricter quality standards on local input producers.

Quantitatively the model underestimates the effect of the trade liberalization on the demand for skilled workers, probably because other effects, including some suggested in the literature, occur in parallel. Whatever the additional explanations be, the data suggest that they should spill over to the domestic market. In several developing countries, exports are only a small share of a minority of plants, while increases in skill premium are large and increases in skill intensity are ubiquitous.27

27See Goldberg and Pavcnik (2004, 2007). Changes in imported inputs and capital are harder to observe and hence not well documented. Also, our data show a long-term upward trend in skill intensity, and so not all increases between 1988 and 1994 should be attributed to the trade liberalization.
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 to the domestic economy through changes in cost and demand, leading to widespread increases in quality upgrading and 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.\textsuperscript{28}

This multifaceted interaction between firms’ decision to adopt skill-biased technology arises in the model from the assumption that skill- and unskill-intensive firms produce different types of goods—an assumption from the classic factor-proportions model that explains cross-sectional correlations of firm characteristics. We focus on unilateral trade liberalizations in developing countries because, as explained in the introduction, their ensuing increase in the demand for skilled labor is particularly puzzling, but other potential applications are bilateral liberalizations, the successful export-promotion policies of East Asian countries, and trade in developed countries.\textsuperscript{29} And beyond international trade, are foreign direct investment, offshoring and the role of industrial policy in skill-biased technology changes within firms.\textsuperscript{30}

\textsuperscript{28} Amiti and Khandelwal (2012) 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).

\textsuperscript{29} Bernard and Jensen (1995,1997) document that US firms also increase productivity when engaging in international trade. The reason for quality upgrading may differ in developed countries. See Hummels and Skiba (2004) for example.

References


A Decomposition of change in skill intensity

This appendix details the decomposition of firms’ changes in skill intensity on table 5. We gradually introduce changes to the economic environment and allow the firm to re-optimize its quality level given the new environment and its import and export status. Because wages are the same before and after the trade liberalization, each quality level is associated with a skill intensity through

\[
\frac{l_s}{l_s + l_u} = \left( \frac{w_s}{w(q)} \right)^{-\sigma_L} \Phi_L(s, q). \tag{A.1}
\]

Superscripts 0 and 1 refer to variables before and after the trade liberalization, respectively. To introduce changes in the cost of domestic inputs only, define the inputs cost

\[
C^{01}(q, 1_M) = w(q)^\alpha P^{01}_I(q, 1_M)^{1-\alpha},
\]

where

\[
P^{01}_I(q, 0) = P^1(q),
\]

\[
P^{01}_I(q, 1) = P^{01}_L(q),
\]

\[
P^{01}(q) = \left[ P^1(q)^{1-\sigma} + P^{00}(q)^{1-\sigma} \right]^{1/(1-\sigma)}.
\]

And after cost effects, to introduce the scale effect of domestic demand, we define the demand function \( \chi^{01}(q) \) as

\[
\chi^{01}(q) = \Phi(q, Q)P^1(Q)^{\sigma-1}I^1 + \int_\Omega \Phi(q, q^0(\omega))P^1_L(q^0(\omega), 1_M(\omega))^{\sigma-1}R^1_1(\omega)d\omega
\]

That is, prices \( P^1(Q) \), \( P^1_L(q^0(\omega)) \), and total spending \( I^1 \) and \( R^1_1(\omega) \) are at their post-liberalization levels, but firms allocate their spending in intermediate goods as if their quality choices were
still at their pre-liberalization levels $q^0(\omega)$. We then define quality levels

\begin{align*}
q^0(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^0(q, 1^0_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^0(q) + 1^0_X(\omega)\chi^{*0}(q) \right] - \overline{w} f(q) \quad \text{(initial)} \\
q^1(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^01(q, 1^1_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^0(q) + 1^0_X(\omega)\chi^{*0}(q) \right] - \overline{w} f(q) \quad \text{(Home inputs)} \\
q^2(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^1(q, 1^1_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^1(q) + 1^1_X(\omega)\chi^{*1}(q) \right] - \overline{w} f(q) \quad \text{(Foreign inputs)} \\
q^3(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^1(q, 1^1_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^{01}(q) + 1^1_X(\omega)\chi^{*0}(q) \right] - \overline{w} f(q) \quad \text{(Home market size)} \\
q^4(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^1(q, 1^1_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^1(q) + 1^0_X(\omega)\chi^{*1}(q) \right] - \overline{w} f(q) \quad \text{(Home demand shift)} \\
q^5(\omega) &= \arg \max_q \frac{1}{\sigma} \left[ \frac{C^1(q, 1^1_M(\omega))}{\mu z(q, \omega)} \right]^{1-\sigma} \left[ \chi^1(q) + 1^1_X(\omega)\chi^{*1}(q) \right] - \overline{w} f(q) \quad \text{(Foreign demand)}
\end{align*}

To construct table 5, for each firm $\omega$, we calculate quality levels $q^1(\omega) - q^5(\omega)$ and the corresponding demand for skilled and unskilled labor, as in the main body:

\[ w_i l_i(\omega) = \left( \frac{w_i}{\overline{w}(q(\omega))} \right)^{1-\sigma} \Phi_L(i, q(\omega)) R_L(\omega) \quad \text{for } i = s, u \]

where $R_L(\omega) = (\alpha / \mu) r_T(\omega)$. We then partition the firms according to their participation in international trade, and for each set of firms, the table presents the overall level of skill intensity, i.e.,

\[ \frac{\int l_s(\omega) d\omega}{\int l_s(\omega) + l_u(\omega) d\omega}. \]
Table 7: Parameter estimates

<table>
<thead>
<tr>
<th>parameter</th>
<th>benchmark</th>
<th>$\alpha = 0.5$</th>
<th>$\sigma = 10$</th>
<th>$\Phi$ normal</th>
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<tbody>
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<td>$\mu_1$</td>
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<td>-0.05</td>
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<td></td>
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<tr>
<td>$\sigma_1$</td>
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<tr>
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<td>4.6e-5</td>
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<tr>
<td>$l_1$</td>
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<td>-2.9</td>
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<td></td>
</tr>
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</tr>
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</tr>
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</tr>
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<td>$I^*$</td>
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<tr>
<td>$\sigma_\pi$</td>
<td>0.51</td>
<td>0.47</td>
<td></td>
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</tr>
</tbody>
</table>

B Robustness checks

Incomplete

This appendix tests the robustness of the model with respect to changes in the fixed parameters and functional form for $\Phi$ relative to the benchmark estimation and counterfactual. Table 7 presents the parameter estimates. For the case of $\alpha = 0.5$, alternative 3 in section 5, some parameter estimates change because the distribution of quality choices change, but the economically relevant cross-sectional results are very similar to the benchmark and thus omitted (available only upon request). Changes in the counterfactual are documented in the main text.

We do not present results for alternative values of the elasticity of substitution between skilled and unskilled labor $\sigma_L$ because it has no bearing on the results. Parameter $\sigma_L$ enters the model only through the demand for labor, and nothing changes in model if $l_1$ changes so that

$$
\left( \frac{w_s}{w_u} \right)^{-\sigma_L} \frac{\Phi_L(s,0)}{\Phi_L(u,0)} = \left( \frac{w_s}{w_u} \right)^{-\sigma_L} e^{l_1}
$$

is kept constant.

We experiment with elasticity of substitution across goods $\sigma = 10$, an upper bound on the estimates in Broda and Weinstein (2004). In the benchmark, $\sigma = 5$. The elasticity enters as
an exponent on prices, which involve both technologies $z(q, \omega)$ and input cost $C(q, 1_M)$. Since $w(q) = 1$ for all $q$, a judicious adjustment $z(q, \omega)$ in principle keeps the firms’ problems unchanged but in practice it changes the functional form and other parameters may change. The benchmark assumes $\Phi$ is the cumulative distribution function of a logistic random variable, and table 7 shows the estimates when $\Phi$ is the cdf of a normal distribution.

The skill premia documented in in Attanasio, Goldberg and Pavcnik (2004, table 4) are: $w_s/w_u = 2.6$ for university to elementary school, 1.9 for university to secondary and 1.4 for secondary to elementary school. Our estimation assumes that some skilled workers are misclassified as blue-collars and some unskilled workers are misclassified as white-collars. Under this assumption, the skill premium picked must be larger than the observed ratio of wages of white- to blue-collar workers in our manufacturing survey 1.9. We then pick $w_s/w_u = 2.6$, the only skill premium in Attanasio et al (2004) satisfying this criterion. One issue with this choice, however, is that the estimated average skill intensity of 58% is unreasonably high—58% of workers in chemicals in Colombia are not university graduates. So, another way to interpret the model is to assume that unskilled workers contain only elementary school graduates and skilled workers contain a bundle of university and secondary school graduates. Under this interpretation, the true skill premium, i.e., the wages of the skilled bundle relative to the unskilled bundle, is not 2.6. It is simply not observed. So for robustness, we then re-estimate the model taking $w_s/w_u = 2.2$ and $w_s/w_u = 3.0$.\footnote{Obviously, the cases where $w_s/w_u \in \{2.6, 3.0\}$ imply that the average skill premium in chemicals is larger than the Colombian average, possibly because its skilled workers are more skilled than the average. This is plausible given the high wages of white-collar workers relative to blue-collars.} The results are not yet available.