International Trade, Skill Premium and Endogenous Labor Division: The Case of Mexico

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Abstract

Why trade liberalizations increase the skill premium? To explain this empirical evidence that is in contrast with the conventional theory of Heckscher-Ohlin, I build up a general equilibrium micro-founded heterogeneous-firm model of international trade where firms make decisions on their division of labor, and firms' skill-intensities are endogenously determined. I show why the exporters are generally more productive and skill intensive and how trade cost reductions induce more productive firms to choose a higher degree of labor specialization, become more skill intensive and start to export. I further demonstrate how such internal horizontal organizational changes, after a trade cost reduction, can directly increase aggregate skill intensity and the relative demand for skilled workers, resulting in higher skill premium in a general equilibrium setting. Lastly, I calibrate this model to the Mexican data to quantify the rise in the skill premium in the period its trade liberalization 1985~1993. (JEL: F12, L22, J3)

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1 Introduction

In the last two decades of the 20th century, many countries implemented trade liberalization policies which opened them up to the international markets. Such policies were most notable in Latin American countries as well as in India. Conventional theories of international trade such as Stopler-Samuelson's theorem have stressed that free trade would lead to a greater degree of equality in a developing country, as low-skilled labor would be given the opportunity to attain a higher level of welfare as it is exposed to larger market in which its comparative advantage can be realized. However, as evidence shows, the skill premium, which is defined as the relative wage of the high skilled and low skilled workers has risen in the past decades following the trade liberalizations in those countries which implemented such policies. As is shown in Table 1, developing countries have experienced increases in skill premiums after their openings to trade. Recent literature has tried to identify various mechanisms to explain this phenomenon, ranging aspects from the role of intermediate goods, skill-biased technological change, capital flows, and immigration.

In this paper, by extending the model in Madanizadeh (2017) and Chaney and Ossa (2013), I develop and quantify a micro-founded model of international trade with endogenous skill intensities at the firm level, and show how opening to trade can raise skill premium in an economy through endogenous decisions on specialization at the firm level, and within-industry reallocations of labor. In this new framework, consistent with the empirical findings[1], I show how international trade induces firms to increase the level of worker specialization[2] and become more skill intensive; and how it increases the relative labor demand of high skilled workers vs. low skilled ones, since there is more gain in specializing the high skilled workers. Taking the supply of workers fixed in the economy, the relative wage of high vs low skilled workers may increase as the relative demand has increased.

[1] See Goldberg and Pavcnik (2007) and Pavnick (2007) as a survey on the literature about international trade and inequality.

[2] See Monte (2011) and Caliendo et al. (2015) for the effect of international trade on the organization of firms.

In this framework, a firm decides about the structure of its division of labor. Basically, the firm chooses how many divisions of specialization it needs, how many tasks a worker should perform in a division, and how it can coordinate different divisions in order to produce the output. In particular, a firm designs its organization and assign its workers to different imperfect substitute groups, performing different tasks. More groups means more division of labor and specialization, thus more gains. Also the less substitute the groups are, the higher gain the firm enjoys from this specialization. Here, I assume that the skilled workers are generally less substitutable with each other giving an advantage towards their specialization. This means that the difference between high and low skilled workers is that the skilled workers' gain from specialization is more than low skilled ones'.

On the other hand, in order to coordinate and set up the groups, the firm should pay some "Fixed Specialization Costs" such as capital purchases and/or training, coordination or monitoring costs. These costs create a trade-off, as having more groups gives a productivity gain to the firm at the cost of paying the "Fixed Specialization Costs". This trade-off generates an economy of scale based on the firm's desire to meet its production demand. Consequently, two variables positively affect the optimal degree of specialization: 1.) the scale of a firm 2.) the productivity of a firm. As such, an increase in the production demand or in the firm's productivity would induce the firm to increase the number of its specialized groups, resulting in an increase in labor productivity and becoming more skill-intensive; thus, an increase in the output demand induces a firm to expand and demand relatively more skilled workers. I look at the reallocation of high and low-skilled workers within the industry as an outcome of a firm's optimal decision on its division of labor and horizontal organizational expansion.

As mentioned before, skilled workers have a higher productivity gain from their specialization; therefore, a firm benefits more from specializing them. This gap in the productivity gain generates a shift toward the specialization of higher skilled workers. Thus, an increase in a firm's production demand or an increase in its productivity leads to the firm's decision

Table 1: Changes in the skill premium in developing countries

Country	**Δ**Skill premium	**Period**	**Definition of Skill Premium**
Mexico	68%	87-93	University education to primary education
Colombia	15%	86-98	University education to primary education
Argentina	20%	92-98	University education no complete education
India	13%	87-99	University education to primary education
Brazil	10%	90's	University education no complete education/men

Note: Changes in the skill premium in developing countries in the periods of trade liberalization.
Source: Goldberg and Pavcnik (2007)

to specialize its skilled workers to a higher extent. This biased expansion consequently increases a firm's relative labor demand (the ratio the demand for high skilled vs low skilled workers).

International trade, through a reduction in trade costs, introduces a rise in demand. This new demand induces the more productive firms to export; thus, old and new exporters restructure to not only become more specialized, but also more skill intensive[3]. With reduction in trade costs, a larger number of productive firms and exporters endogenously decide to become more skill intensive, and demand a larger number of high-skilled workers relative to low-skilled ones. This horizontal organizational expansion, specially in the new exporters, increases the proportion of more skill intensive firms in the industry. Such organizational changes in the above mentioned firms result in a reallocation of high-skilled workers within the industry toward the exporters. I show how these changes can result in a rise in the aggregate relative demand of high-skilled, relative to low-skilled labor, and consequently a rise in their relative wages.

In contrast to the above mentioned mechanism, another mechanism is active in general equilibrium,too. As discussed above, the horizontal organizational expansion of an exporter actually reduces it marginal cost, and hence its price. This implies a reduction in the industry

[3]Using French data, Caliendo and Rossi-Hansberg (2012) show that exporting firms have higher layers of hierarchy in their organisations. Also Bustos (2011) uses Argentinian data and show after trade costs reductions, new firm adopt higher and more skill intensive technologies.

aggregate price. This drop in prices will push down the domestic aggregate demand; creating a force which decreases the aggregate relative labor demand. In general equilibrium, this new channel competes with the previous one which would have raised the aggregate relative labor demand.

Interestingly, I find that trade liberalization initially increases and then decreases the skill premium. In general equilibrium, I show that a full transition of trade liberalization from autarky to free trade initially induces a rise, followed by a fall in the skill premium. Starting from Autarky, a reduction in trade costs would make the first channel (the increase in the extensive margin of more skill intensive firms) dominate. Therefore, the industry aggregate skill intensity increases; and thus, it raises the skill premium. As the transition shifts toward free trade, the second force comes to gain momentum and eventually it comes to dominate the former at some point. The result of these forces is a drop in the industry aggregate relative labor demand which diminishes the skill premium. Thus, the skill premium starts to drop.

A by-product of the described model is the introduction of a new channel for the gains from international trade[4]. As previously described, trade integration increases the exporters' degree of specialization which raises their overall labor productivity; hence, leading to a rise in the aggregate productivity of the whole industry. The increase in aggregate productivity would translate to a reduction in aggregate prices and increases in real wages; thus making this mechanism a new source of gain from trade.

To show the model's results quantitatively, I calibrate the model to the data from Mexico as a developing country by matching some moments of the model with the Mexican data. I match the fraction of exporters, export share of sales, skill premium and the average number of employees per firm from data to the predictions of the model to calibrate the primitive parameters of the model. Then I analyze several counterfactual scenarios to find out how much of the increase in the skill premium in a trade liberalization period can be elucidate

[4]See Chaney and Ossa (2013) as a closely related work.

by my model. I find that 10% of the rise of the skill premium in Mexico from 1985-1993 can be explained by this model through changes in the bilateral iceberg trade costs. I also study the counterfactual policies of changing fixed exporting cost, foreign aggregate demand and relative supply of high-skilled labor.

Finally, I analyze some comparative statics of changes in fundamental parameters of the model: gains from specialization and fixed specialization costs. I show that an increase/decrease in the gain from specialization of high/low-skilled workers or a decrease in the fixed cost of specialization for the high-skilled workers can increase the skill premium; although they have different implications on the extensive and intensive margins of trade.

Related Literature: In contrast to conventional theories, skill premium has risen in the last decades following the worldwide trade liberalizations, even the developing countries. As an example, Goldberg and Pavcnik (2007) document this fact by surveying the literature on the trade liberalization effects on different measures of inequality. Haltiwanger et al. (2004) looks into Latin American countries to document the effects of trade liberalization on the skill premium. Revenga (1997), Hanson and Harrison (1999), and Feliciano (2001) study the Mexican economy in this regard. Attanasio et al. (2004) show this fact for Colombia; and also Currie and Harrison (1997) studies the Morocco's liberalization period while Topalova (2010) investigates the liberalization period in India. Wacziarg and Wallack (2004) study a cross-country analysis to show the same fact.

As surveyed in Acemoglu and Autor (2011), there is an attempt to find mechanisms on why the traditional Stolper-Samuelson effect is not observed. Feenstra and Hanson (1996) show that developed countries out-source intermediate production into developing countries with cheaper labor. These productions demand high-skilled workers in the developing countries. Thus demand for skill rises in the developing countries too, inducing a rise in the skill premium.

From a different point of view, Krusell et al. (2000), Stokey (1996), Parro (2013) and Burstein et al. (2013), Cragg and Epelbaum (1996) argues that capital has a higher complementarity with the skilled workers; thus the growth in capital flows towards developing countries imposes higher demand for the skilled workers. Therefore, we should observe a rise in the skill premium in these countries too.

Many researchers like Burstein and Vogel (2017) argue that the technology is skill-biased; thus, opening to trade, which reduces the barriers, increases the measured productivity and increases the demand especially for the exporters, increase the demand for the skilled workers inducing a large rise in their relative wages. Attanasio, Goldberg and Pavcnik (2007) findings show that in Mexico, even low-skill intensity industries have been skill biased in technological advancements. Also exporting is a skill-biased activity; therefore the rise in trade due to reduction in trade costs affects the relative skill demand. In this regard, Acemoglu (2003) introduces a model of endogenous technological change to explain the increase in the wage premium.

On the other hand, there is part of the literature about the higher skill intensity in exporters, like Bustos (2011). Wood (1995) and Thoenig and Verdier (2003) show that trade induces more R&D in exporters. Matsuyama (2007) argues that export sectors are inherently more skill intensive and the rise in trade would raise the demand for high skilled workers. Helpman et al. (2010) show the more productive firms and exporters are better in screening their workers which results in a bias for high skilled workers in exporters, inducing a reallocation of labor toward exporters after trade opening within an industry. The other view is the "quality upgrading" in the exporters of the developing countries as in Verhoogen (2008) and Frías et al. (2009). Demand for quality translates to higher demand for skilled workers, resulting in a higher skill premium.

This paper extends the model in Madanizadeh (2017), and develops a new mechanism complementary to the "skill-biased technology" mechanism for describing the skill premium through the lens of labor division and endogenous firm organization. First, my model is close to Bustos (2011) which shows that more productive firms and exporters upgrade their skill-biased technologies and become more skill intensive. In contrast, this paper constructs a micro-founded model for the endogenous skill intensity as an organizational decision of a firm, similar to Caliendo et al. (2015). My model is more particularly focused on the within-firm organizational decisions rather than a technology selection.

Second, my work is related to Harrigan and Reshef (2011), Burstein et al. (2013) and Burstein and Vogel (2017) which employ a skill-biased production technology with inherently correlated productivity and skill intensity at the firm level. Therefore, trade will result in the survival of more productive firms and thus the more skill-intensive ones. Thus, a direct consequence would be higher skill intensity in the industry, resulting in an increase in the skill premium due to the rise in the aggregate demand for skill. But, in my model, all the changes happen endogenously inside the firm due to a rise in the output demand or a rise in an unbiased firm's productivity. In other words, I make this skill-biased technology to be endogenous and firm dependent, in contrast to Burstein and Vogel (2017). In my paper, it is the firm that decides about the organization of the firm and the level of specialization towards skilled workers. Moreover, the level of bias depends on the firm productivity and also the firm's demand. Higher productive firms and firms with higher demand choose to have a firm which is more biased towards high-skilled workers, in contrast to Burstein and Vogel (2017) where it is only the firm's productivity that determines the level of bias exogenously. In that paper, the firm's demand which is very important when one talks about international trade, has no role in the organization of the firm and no role in the skill-bias effect.

On the other hand, starting from Adam Smith (1776), there is a large literature about the productivity gains from labor division. To show the distributional effects of international trade, this paper constructs a micro-founded model of labor division and it is related to Acemoglu and Autor (2011) and Costinot (2009), as they study the patterns of specialization and comparative advantage across tasks.

Finally, this paper is connected to Caliendo and Rossi-Hansberg (2012), Caliendo et al. (2015) where they study the role of organization and the number of layers in a firm and how international trade can affect it. They show that reducing trade costs and the increase in demand will induce firms, especially the exporters, to increase the number of organizational layers and expand. In my paper, I focus on the distributional effects of trade on firms's horizontal organization and its labor division. Caliendo and Rossi-Hansberg's model represents a vertical organization in a firm whereas my model is discussing a horizontal expansion of the firm. In other words, yet the firm may have the same number of layers, but in each layer there might be more or less division of labor. Also, the wage differences are coming from differences of high skilled versus low-skilled substitutability which is a result of the gain from specialization.

The rest of the paper is organized in the following order. In section 2, I present the Model and solve for the equilibrium allocation. In section 3, I show the quantitative analysis and discuss the results of the model. In section 4, I conclude.

2 Model

In this paper, I propose a hetereogenous firm model of international trade where imperfect substitute workers work in specialized groups to produce a good. There is a return in having workers in specialized divisions and a return in increasing the number of divisions. On the other hand, there is a cost in generating a new division; thus there is a trade-off in generating more labor divisions because. These costs could include training, coordination, or monitoring costs. The return from having more specialized workers in more divisions is realized in an increase in the firm's productivity. I use this production framework to investigate its aggregate implication for the the effect of trade liberalization on the rise in the skill premium in a general equilibrium setting. In this section, I describe my model's components and present its analytical solution for the equilibrium allocations.

2.1 Households

The general setup is similar to the Heckscher-Ohlin type model and to the Krugman's and Melitz's heterogeneous firms model with the monopolistic competition framework in a small open economy setting. The country has L and H number of low-skilled and high-skilled workers, respectively. The representative household in country $i \in \{h, f\}$ supplies both types of labor and has constant elasticity of substitution (CES) preferences (as in Spence-Dixit-Stiglitz) over the consumption $c_i(A_j)$ of differentiated varieties, which are produced by a continuum of producers with productivity A_j in country j, such that $U_i = \left(\sum_{j=h,f} \int_{A_j} c_i(A_j)^{\frac{\sigma-1}{\sigma}} M_{ij} dF(A_j)\right)^{\frac{\sigma}{\sigma-1}}$.

The total measure of active sellers/producers of country j selling in country i is M_{ij} and $F(A)$ is the cumulative distribution function of productivity which is similar in both countries. Parameter σ is the elasticity of substitution between the differentiated varieties. Trade is balanced; therefore, the representative household has the following budget constraint

$$\sum_{j=h,f} \int_{A_j} d_{ij} p_j(A_j) c_i(A_j) M_{ij} dF(A_j) = X_i = w_L L + w_H H + \Pi$$

with X_i and Π as the total expenditure and the total profit of the firms in the home country. Wages for the labor of type k $(= H$ or $L)$ are w_{ik}. Therefore, the demand for good A_j in country i is $c_i(A_j) = (d_{ij} p_{ij}(A_j))^{-\sigma} \left(P_i^{\sigma-1} X_i\right)$ where $p_{ij}(A_i)$ is the price of the variety produced by the a firm with productivity A_j in country j selling in i. Parameter d_{ij} is the variable iceberg trade cost of exporting goods from j to i (Obviously $d_{ii} = 1$). Lastly, $P_i = \left(\sum_{j=h,f} M_{ij} \int_{A_j} p_{ij}(A_j)^{1-\sigma} dF(A_j)\right)^{\frac{1}{1-\sigma}}$ is the aggregate price index.

2.2 Market Structure

For notational simplicity, I drop the country and firm subscripts. The Market structure is the same as in Krugman (1980) so that each firm sells its differentiated good monopolistically in the market. Because of SDS preferences, the demand elasticity is constant and equals σ.

Thus, for a producer at home with productivity A, its total production demand is

$$y(A) = Dp(A)^{-\sigma} \tag{1}$$

where D is a "demand indicator" for a producer at home, such that $D = P^{\sigma-1}X$ for a domestic producer and $D = P^{\sigma-1}X + d_f^{1-\sigma}D_f$ for an exporter, where D_f is the aggregate demand from abroad (since we are assuming home as a small open economy; thus, the aggregate demand is given). Since the firm sells its unique variety as a monopoly in the market, it sets its price a constant markup $m = \frac{\sigma}{\sigma-1}$over marginal cost. Therefore $p(A) = m * mc(A)$.

2.3 Production

As in a Melitz-type framework, firms are heterogenous in their productivity in this model. They pay a sunk entry cost to draw a random productivity A from cumulative distribution function $F(A)$. I assume that the firms enter the home market and produce with no fixed operational cost, after observing their own productivity level. To enter the international market they need to pay an extra fixed exporting cost and export.

A firm should hire both high skilled and low skilled workers ($k = H, L$). For each worker type k, the firm specializes its worker of type k in S_k number of groups. It forms them by paying a fixed cost for each group, named fixed specialization cost. Within type k, workers are imperfect substitutes with each other with the elasticity of substitution ρ_k. Also workers of type H, L are imperfect substitutes of each other with elasticity ρ. We assume that $1 < \rho < \rho_H < \rho_L$ meaning that low-skilled workers are more easily substituted with each other than the high skilled workers. It also means that we are assuming a higher workers substitutability within each type than across types. Basically, the specialization fixed cost represents any costs like training, coordinating or monitoring costs. Therefore the firm's problem is:

$$
\begin{aligned}
C(Y) &= \min_{S_k,\{N_{H,i}\}_{i=1\ldots S_H},\{N_{L,j}\}_{j=1\ldots S_L}} \sum_{i=1}^{S_H}(w_H N_{H,i}+f_H)+\sum_{j=1}^{S_L}(w_H N_{H,j}+f_L) \qquad (2)\\
\text{s.t. } Y &= A\left(\left(\sum_{i=1}^{S_H} N_{H,i}^{1-\frac{1}{\rho_H}}\right)^{\frac{\rho_H}{\rho_H-1}\cdot\frac{\rho-1}{\rho}}+\left(\sum_{j=1}^{S_L} N_{L,j}^{1-\frac{1}{\rho_L}}\right)^{\frac{\rho_L}{\rho_L-1}\cdot\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}
\end{aligned}
$$

where for $k\in\{H,K\}$, w_k is the wage for group k and $N_{H,i}$ is the number of high skilled workers in group i which contains some high-skilled tasks. $N_{L,j}$ is also defined accordingly. In Appendix C., I present a micro-foundation for this theory of labor specialization to explain the endogenous changes at the firm-level and also the aggregate skill-intensities. Finally, note that if $\rho_H=\rho_L=\infty$ and $f_H=f_L=0$, this problem becomes equivalent to a standard simple Heckscher-Ohlin type model with no optimization on the firm's organization.

Due to symmetry, the firm's organization setup problem simplifies to

$$
\begin{aligned}
C(Y) &= \min_{\{S_k,N_k\}_{k=H,L}} \sum_{k=H,L}(w_k N_k+f_k S_k) \qquad (3)\\
\text{s.t. } Y &= A\left(\left(S_H^{\frac{1}{\rho_H-1}}N_H\right)^{\frac{\rho-1}{\rho}}+\left(S_L^{\frac{1}{\rho_L-1}}N_L\right)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}
\end{aligned}
$$

I call this problem the firm's organizational problem. This means that a firm has a CES production function where the productivities of each type of labor is proportional to S_k, which would be determined endogenously. The firm faces a trade-off between paying a fixed cost and increasing the productivity of its workers through increasing the number of specialization groups.

Given $S_k's$, the first-order conditions of the firm's problem results that demand for type k labor is $N_k=\frac{Y}{A}S_k^{\frac{\rho-1}{\rho_k-1}}\left(\frac{w_k}{\bar{W}}\right)^{-\rho}$ where $\bar{W}=\left(\sum_{k=H,L}S_k^{\frac{\rho-1}{\rho_k-1}}w_k^{1-\rho}\right)^{\frac{1}{1-\rho}}$ is the wage index. Since $\rho_k>\rho>1$, then $\bar{W}$ is decreasing in S_k. Define $C_k=w_kN_k$ as the cost of labor of type k

and $\bar{C} = \sum_k C_k$ as the total labor cost. Therefore, the total labor cost equals $\bar{C} = \bar{W}\frac{Y}{A}$ and is decreasing in S_k.

2.3.1 Firm's Organizational Problem

Now I turn to solving the firm's organizational problem which is choosing the optimum S_k. The firm faces a trade-off between paying a fixed cost of specialization (f_k) and taking advantage of higher productivity and lower marginal labor cost through higher levels of specialization.

Assumption: For tractability and without loss of generality, I assume that S_k is a continuous variable, rather than a discrete one.

With this assumption, from the firm's cost minimization problem, one gets that the condition for the optimum choice of the number of specialization groups is:

$$\underbrace{f_k}_{\substack{\text{marginal cost of} \\ \text{increasing } S_k}} = \underbrace{-\frac{\partial \bar{W}}{\partial S_k}\frac{Y}{A}}_{\substack{\text{marginal benefit of} \\ \text{increasing } S_k}}$$

To solve for $S_k's$, first one needs to solve for $\bar{W}^*$, the solution to the following fixed-point problem:

$$\bar{W}^* = \left(\sum_{k=H,L} g_k \left(\frac{Y\bar{W}^{*\rho}}{A}\right)^{\frac{\rho-1}{\rho_k-\rho}}\right)^{\frac{1}{1-\rho}} \tag{4}$$

where $g_k = \left(\left(\rho_k - 1\right) f_k w_k^{\rho_k-1}\right)^{-\frac{\rho-1}{\rho_k-\rho}}$. Then the optimum number of specialization groups are $S_k\left(Y\right) = \frac{g_k}{(\rho_k-1)f_k}\left(\frac{Y\bar{W}^{*\rho}}{A}\right)^{\frac{\rho_k-1}{\rho_k-\rho}}$ and the optimum labor demand is

$$N_k\left(Y\right) = \frac{1}{w_k} g_k \left(\frac{Y\bar{W}^{*\rho}}{A}\right)^{\frac{\rho_k-1}{\rho_k-\rho}} \tag{5}$$

Since $\rho_H < \rho_L$, therefore $\frac{\rho_H-1}{\rho_H-\rho} > \frac{\rho_L-1}{\rho_L-\rho}$, which means that the effect of production level Y has a greater effect on $S_H(Y)$ and $N_H(Y)$ than $S_L(Y)$ and $N_L(Y)$.Thus, relative specialization and relative labor demand if high vs low skilled workers would be increasing in Y. The following lemma summarizes the results of the firm's optimal decision on its division of labor.

Lemma 1 *For a given Y, the firm optimally chooses the optimal level of specialization and its labor demand such that*

(a) The optimum degree of specialization for labor of type k, $S_k(Y)$, is increasing in Y and decreasing in f_k.

(b) The relative specialization of high vs. low-skilled labor, $\frac{S_H(Y)}{S_L(Y)}$, is increasing in Y.

(c) The relative labor demand of high-skilled vs. low-skilled workers (skill intensity), $\frac{N_H(Y)}{N_L(Y)}$, is increasing in Y .

(d) The marginal cost of producing Y, $mc(Y)$, and aggregate wage index $\bar{W}^*$ are both decreasing in Y.

Proof. See Appendix B. ■

This lemma shows that a firm with higher production demand chooses to invest on its organizational expansion and increase its division of labor for each type, be more specialized in each type of labor, thus increasing its labor productivity, and decreasing its marginal cost. Moreover, a firm with higher production demand invests more in specialization of its high-skilled workers since there is more gain in their division of labor ($\rho_H < \rho_L$); it becomes relatively more specialized in favor of the high skilled workers; and becomes more skill intensive.

To better understand how the firm behaves, I look at the log-linearized form of the results. Details can be found in Appendix B. We find that

$$\Delta S_k(Y) = \frac{\rho_k - 1}{\rho_k - \rho}(1 - \zeta\rho)(\Delta Y - \Delta A)$$

and

$$\Delta mc\left(Y\right)=-\left(\zeta\Delta Y+\left(1-\zeta\right)\Delta A\right) \tag{6}$$

where $\Delta X = d\log X$ is the percentage change in X; thus $\frac{\Delta X}{\Delta Z} \equiv \frac{\partial \log X}{\partial \log Z}$ is the elasticity of X with respect to Z; $\zeta \equiv \left(\rho + \frac{1}{\sum_k \frac{\psi_k}{\rho_k - \rho}}\right)^{-1}$ such that $\psi_k = \frac{C_k}{C} = S_k^{\frac{\rho-1}{\rho_k-1}} \left(\frac{w_k}{W}\right)^{1-\rho}$ is the cost share of type k labor. Obviously $0 \leq \zeta \leq \frac{1}{\rho}$.

Equation (6) shows how total production positively affects S_k and negatively affects marginal cost through the specialization channel. It is evident from the definition of ζ that higher gains from specialization (lower ρ_k) lead to higher effects of total production on the marginal costs. For the relative labor demand and relative skill specialization, I get

$$\Delta\left(\frac{C_H}{C_L}\right)=\Delta\left(\frac{S_H}{S_L}\right)=\frac{\left(\rho_L-\rho_H\right)\left(\rho-1\right)}{\left(\rho_L-\rho\right)\left(\rho_H-\rho\right)}\left(1-\zeta\rho\right)\left(\Delta Y-\Delta A\right) \tag{7}$$

Since $\rho_L > \rho_H > \rho > 1$ and $\zeta < \frac{1}{\rho}$, I conclude that relative labor demand and relative specialization are also positively correlated with production demand, meaning that higher production level leads to more skill intensity.

Lastly, note that in the special case of $\rho_H = \rho_L = \infty$ and $f_h = f_L = 0$ ones get $\zeta = 0$ and the model converges to the standard model and total production has no effect on the marginal cost.

2.3.2 Profit Maximization

As in any Krugman type framework, a firm sells its good monopolistically in the market. Since the demand elasticity is constant, the firm prices its good with a constant markup $m = \frac{\sigma}{\sigma-1}$ over marginal costs[5]. To solve for the optimum level of production Y and price p, I use the firm demand equation (1) which in results in solving the following fixed-point problem:

$$Y=\left(\frac{\sigma}{\sigma-1}mc\left(Y\right)\right)^{-\sigma}D \tag{8}$$

[5] σ is the elasticity of substitution between different varieties.

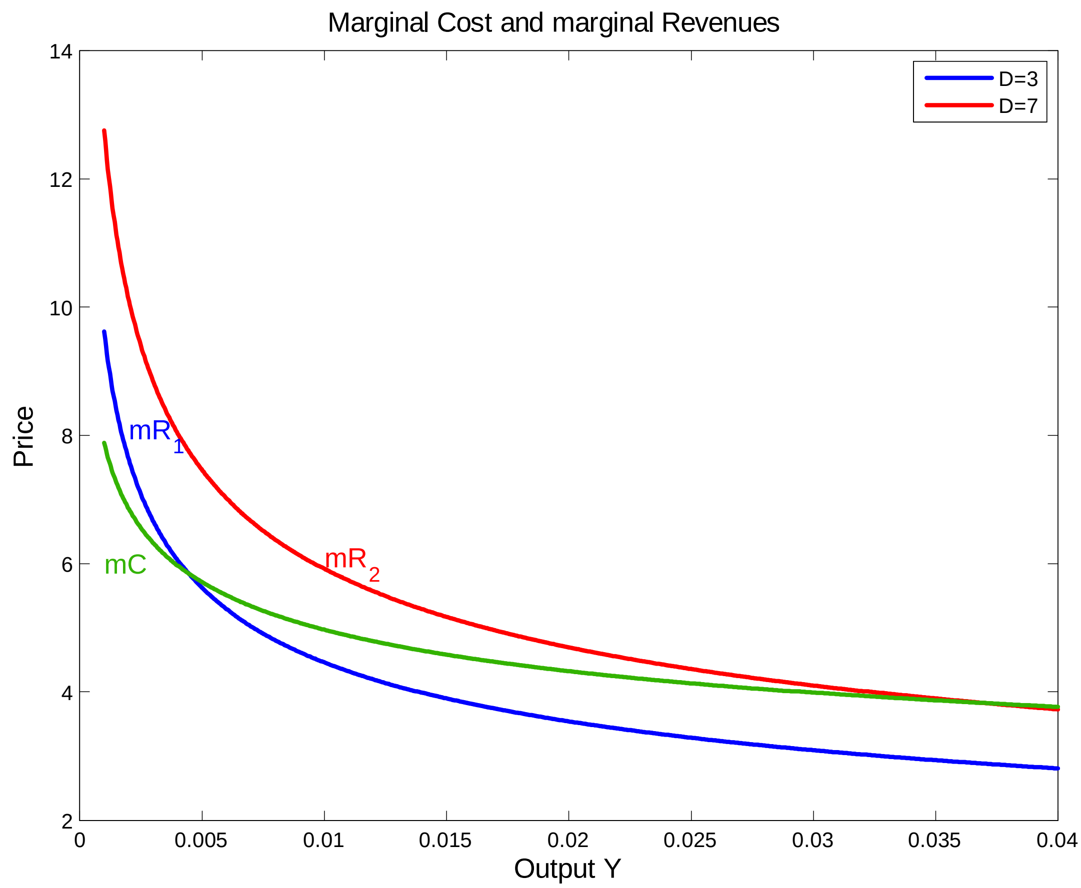

Figure 1: Effect of change in the Aggregate Demand on marginal revenue and marginal cost of a firm at different production level

Therefore, given the demand indicator D, a firm with productivity A chooses the optimum level of production and price $Y(A, D)$ and $p(A, D)$. It was shown in Lemma 1 that the marginal cost is decreasing in Y; thus, the firm's price is decreasing in Y, too. Figure 1 shows this feature. Any increase in the firm's production demand D shifts the marginal revenue curve to the right, inducing a reduction in the firm's price.

Lemma 2 *If $\rho_L > \rho_H > \rho > \sigma > 1$, then*

(a) The firm's optimum action exists and output and prices are positive and finite.

(b) The firm's total production Y is increasing in A and D, and it is decreasing in f_k.

(c) The firm's price p is decreasing in A and D, and it is increasing in f_k.

(d) The optimum degree of specialization (DoS) ,S_k, is increasing in A and D and decreasing in f_k.

(e) The optimum relative DoS $\left(\frac{S_H}{S_L}\right)$ *is increasing in* A *and* D*, decreasing in* f_H*, and increasing in* f_L*.*

(f) The relative demand of high vs. low skilled $\left(\frac{N_H}{N_L}\right)$ *is increasing in* A *and* D*, decreasing in* f_H*, and increasing in* f_L*.*

(g) The firm's optimum revenue $R(A, D)$*, is the solution to the following fixed-point problem:*

$$R = \frac{\sigma}{\sigma - 1} \sum_{k=H,L} C_k \tag{9}$$

where $C_k = g_k \left(m^\rho D^{\frac{1}{\sigma-1}} A R^{-\frac{\rho-\sigma}{\sigma-1}}\right)^{\frac{\rho_k - 1}{\rho_k - \rho}}$ *is the cost of labor of type* k*.*

Proof. See Appendix B. ■

As expected from Krugman-Melitz type models, more productive firms have lower prices (quality adjusted) and higher productions, revenues and profits. In contrast to these conventional models, what is new here is that between two firms with the same productivity A, the one with higher demand D has a lower price. This efficiency gain is the result of the economy of scale that exists in the firm's organizational expansion. Firms with higher demands are more horizontally expanded in their organization and have higher degrees of specialization for each type, decreasing their marginal costs, thus also their prices. Also it can easily be shown that the firm's revenue and output increases more than one to one with respect to production demand D which is again due to the productivity gain from specialization and horizontal expansion. This analysis shows another margin of gain from the economy of scale; I call it the "within-firm margin".

On the other hand, because the high-skilled workers gain more from specialization, a firm benefits by specializing them, relatively more than it does so by specializing the low-skilled workers. Thus, an increase in the firm's productivity has a biased effect in labor demand toward high-skilled workers. So if productivity increases, the relative demand for high-skilled workers vs. low-skilled workers increases. Such a biased effect is consistent with data where we observe that the skill intensity of a firm has positive correlation with the firm's

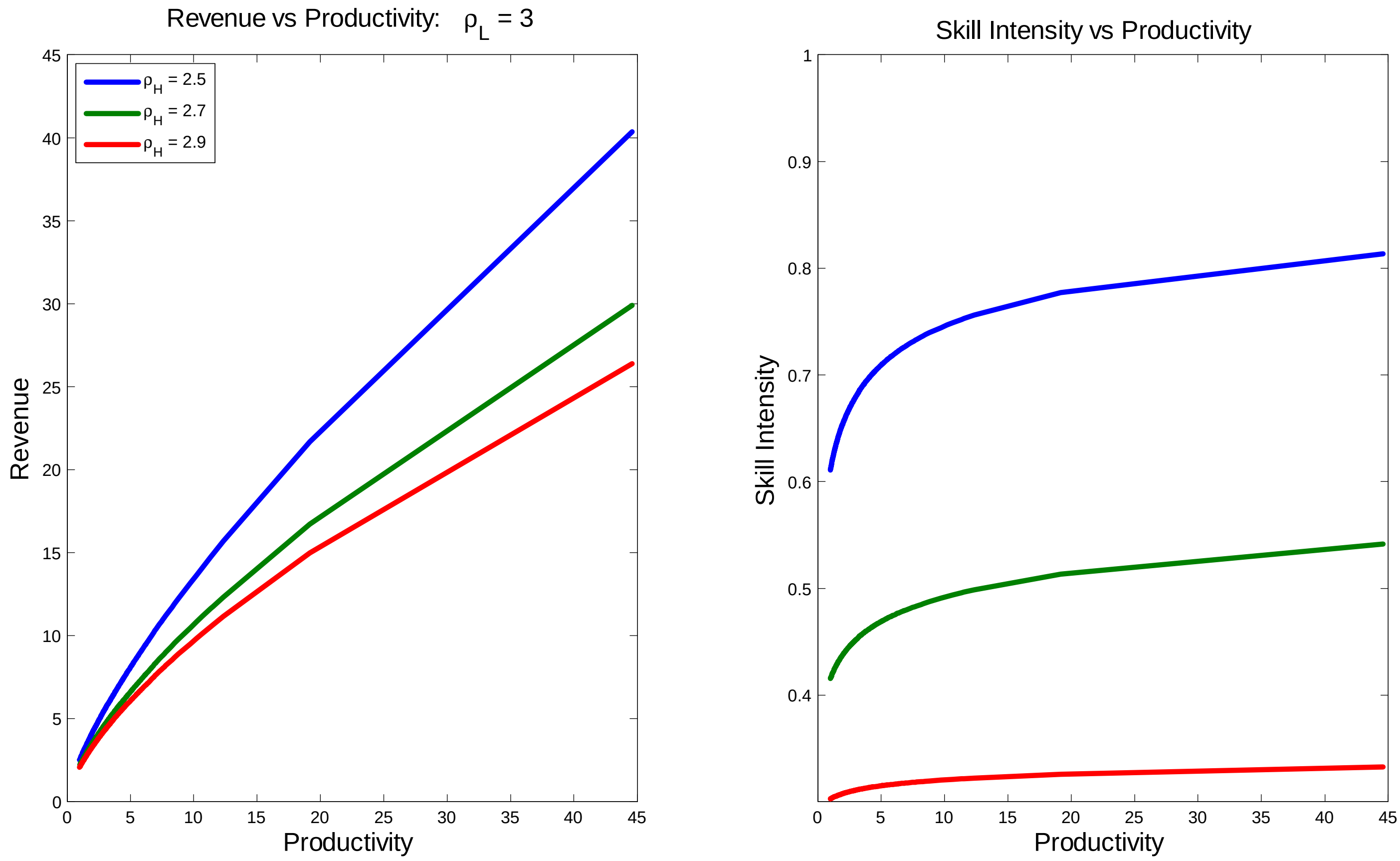

Figure 2: Revenue and Skill intensity ($\frac{C_H}{C_L}$) vs. Productivity

productivity as in Harrigan and Reshef (2011) and Bustos (2011). This feature does not exist in conventional models since there is no endogenous process of changes in the skill intensity. The biased effect arises from the notion that a firm can make a decision on its horizontal organizational expansion and its labor intensity. This choice gives a more-productive firm the opportunity to raise its skill intensity. Therefore, this model generates an endogenous process for biased technological change.

Figure 2 shows how firms' revenues and skill intensities are related to productivity for a given value of D. This figure clearly illustrates that both revenue and skill intensity are increasing in productivity as expected from the above proposition. Moreover, lower values of ρ_H, which is equivalent to higher specialization gains for high-skilled workers, generates greater effects on the level and growth rate for productivity and skill intensity.

Now, to have a better understanding of how different decision variables (R, Y, p, N_H, N_L, S_H, S_L) move with productivity and demand indicator parameters A and D, again I look at

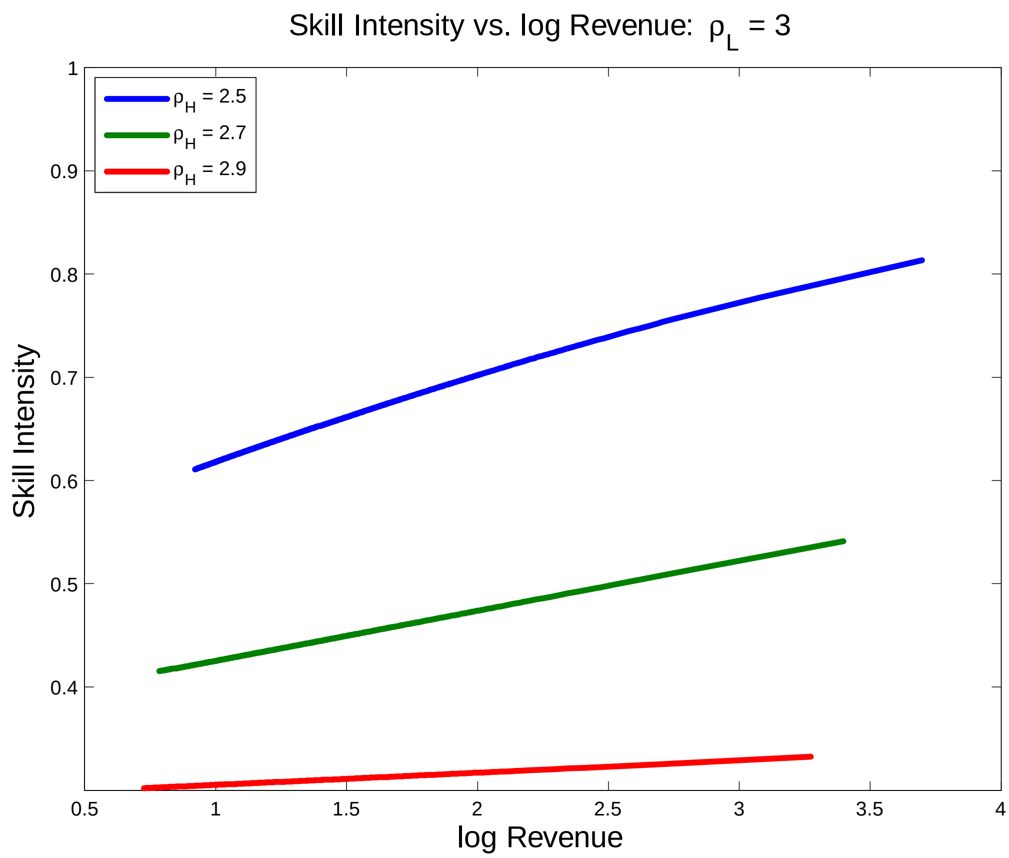

Figure 3: Skill Intensity ($\frac{C_H}{C_L}$) vs. Revenue for diferent values of ρ_H (elasticity of substitution within high skilled workers).

the log-linearized form of the model. As mentioned above, the monopoly faces the demand curve showing that its total production is a function of price, thus $\Delta Y = -\sigma \Delta p + \Delta D$. On the other hand, its optimum decision on price leads to a constant markup over the marginal costs, which depends also on the total production, thus $\Delta p = \Delta mc = -\left(\zeta \Delta Y + (1-\zeta)\Delta A\right)$, as was shown in 6. Therefore, there is another feedback loop here that has been shown in equation (8).

By solving this fixed-point problem, I find:

$$\Delta Y = \left(\sigma \frac{1-\zeta}{1-\sigma\zeta}\right)\Delta A + \left(\frac{1}{1-\sigma\zeta}\right)\Delta D \tag{10}$$

and

$$\Delta p = -\left(\frac{1-\zeta}{1-\sigma\zeta}\right)\Delta A - \left(\frac{\zeta}{1-\sigma\zeta}\right)\Delta D \tag{11}$$

Hence, the effect of productivity on price is greater than a linear relationship as in a typical Krugman-Melitz type model. The same analogy is true for the production. The effect of productivity on output is also greater than the one in the Krugman-Melitz-type model which is σ. The maximum absolute effects of productivity on output and price are $\sigma\frac{\rho-1}{\rho-\sigma}$ and $\frac{\rho-1}{\rho-\sigma}$, respectively[6]. On the other hand, equations (10) and (11) clearly show the negative effect of demand (ΔD) on prices and also a relationship of more than one-to-one for total production, since $\frac{1}{1-\sigma\zeta} \geq 1$. All of these greater effects, which are not in standard theories, are coming through the channel of within-firm margin of adjustment in the organizational expansion and gains from endogenous labor specialization

Lastly, using (7) results in

$$\Delta\left(\frac{C_H}{C_L}\right) = \Delta\left(\frac{S_H}{S_L}\right) = \underbrace{\frac{(\rho_L-\rho_H)(\rho-1)}{(\rho_L-\rho)(\rho_H-\rho)}}_{>0}\underbrace{(1-\zeta\rho)}_{>0}\left(\underbrace{\left(\frac{\sigma-1}{1-\sigma\zeta}\right)}_{>0}\Delta A + \underbrace{\left(\frac{1}{1-\sigma\zeta}\right)}_{>0}\Delta D\right)$$

which clearly show that increases in either productivity or demand would raise the relative labor demands and the relative specialization. The reason is that $\Delta\left(\frac{C_H}{C_L}\right) = \Delta\left(\frac{N_H}{N_L}\right) + \Delta\left(\frac{w_H}{w_L}\right)$ meaning that for a given variation in wages, the relative labor demand is equivalent to relative total costs of hiring.

2.4 Market Entry, Aggregation and Partial Equilibrium

There is a measure M_e of potential firms that pay a sunk entry cost f_e to draw a productivity level A with cumulative distribution function $F(A) = \Pr\left(A \geq \bar{A}\right)$. Again, following Melitz (2003) and Chaney (2008), I assume a Pareto distribution with parameter θ and minimum productivity level $\bar{A}$ such that $F(A) = \left(\frac{A}{\bar{A}}\right)^{-\theta}$. To guarantee the convergence in the

[6] Since $0 \leq \zeta \leq \frac{1}{\rho}$, I get $1 \leq \frac{1-\zeta}{1-\sigma\zeta} \leq \frac{\rho-1}{\rho-\sigma}$.

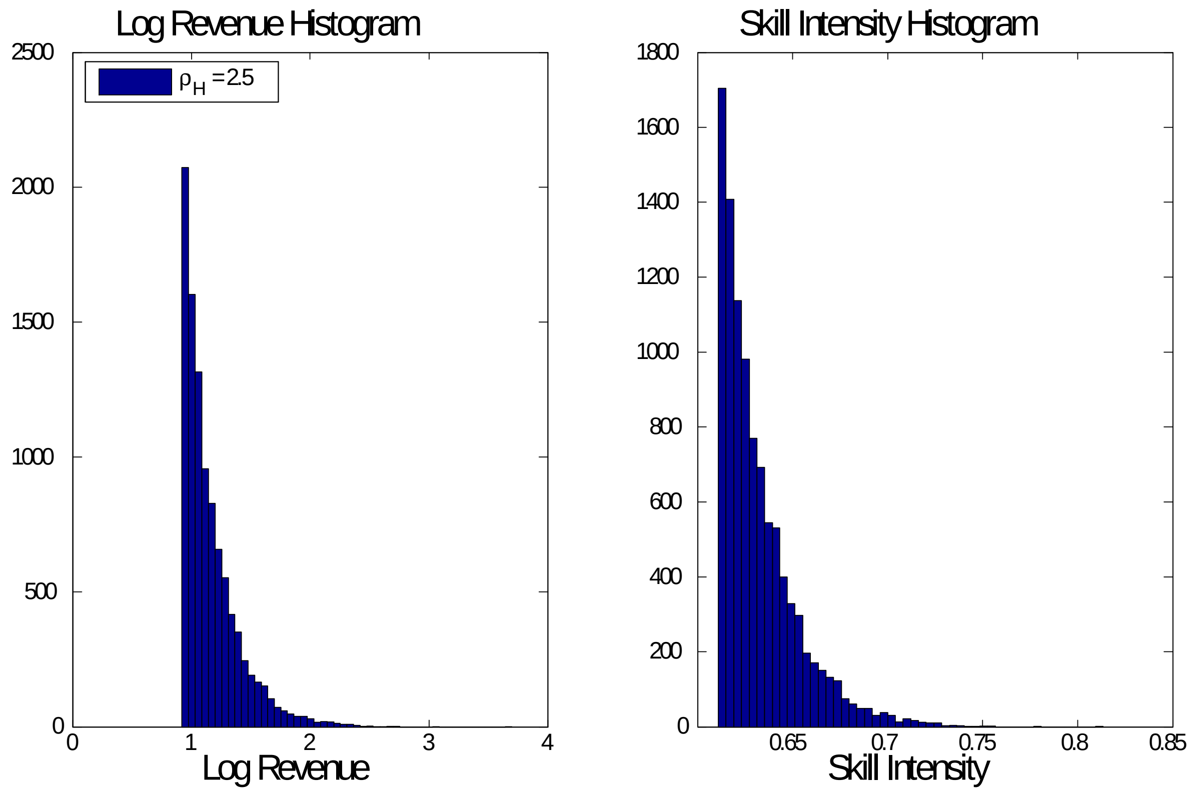

Figure 4: Distribution of revenues (Left) and skill intensities (Right) of firms with Pareto distribution productivity.

aggregation, the following condition should hold:

Assumption: $\theta > \eta = \frac{(\rho-1)(\sigma-1)}{\rho-\sigma}$.

Figure 4 shows how the distributions of revenues and skill intensities would look like, for a given level of demand indicator D.

Without loss of generality, we assume that after observing the productivity A, a firm does not need to pay an operational fixed cost to enter the domestic market, therefore, all the potential firms enter. Also the firm can pay a fixed exporting cost f_x to export, if it can earn more profit from exporting. This means that a firm exports if $\Pi(A, D + D_f) - \Pi(A, D) \geq f_x$, where D and D_f are the demand indicators for home and the foreign market. Since the countries are the same and there is an ice-berg trade cost d, then $D_f = d^{1-\sigma}D$.

The entry conditions result that more-productive firms can only enter the export market; defining export productivity thresholds $\bar{A}_x$, such that firms with productivity higher than $\bar{A}_x$ only enter the export market. It is easy to show that the negative effect of demand D

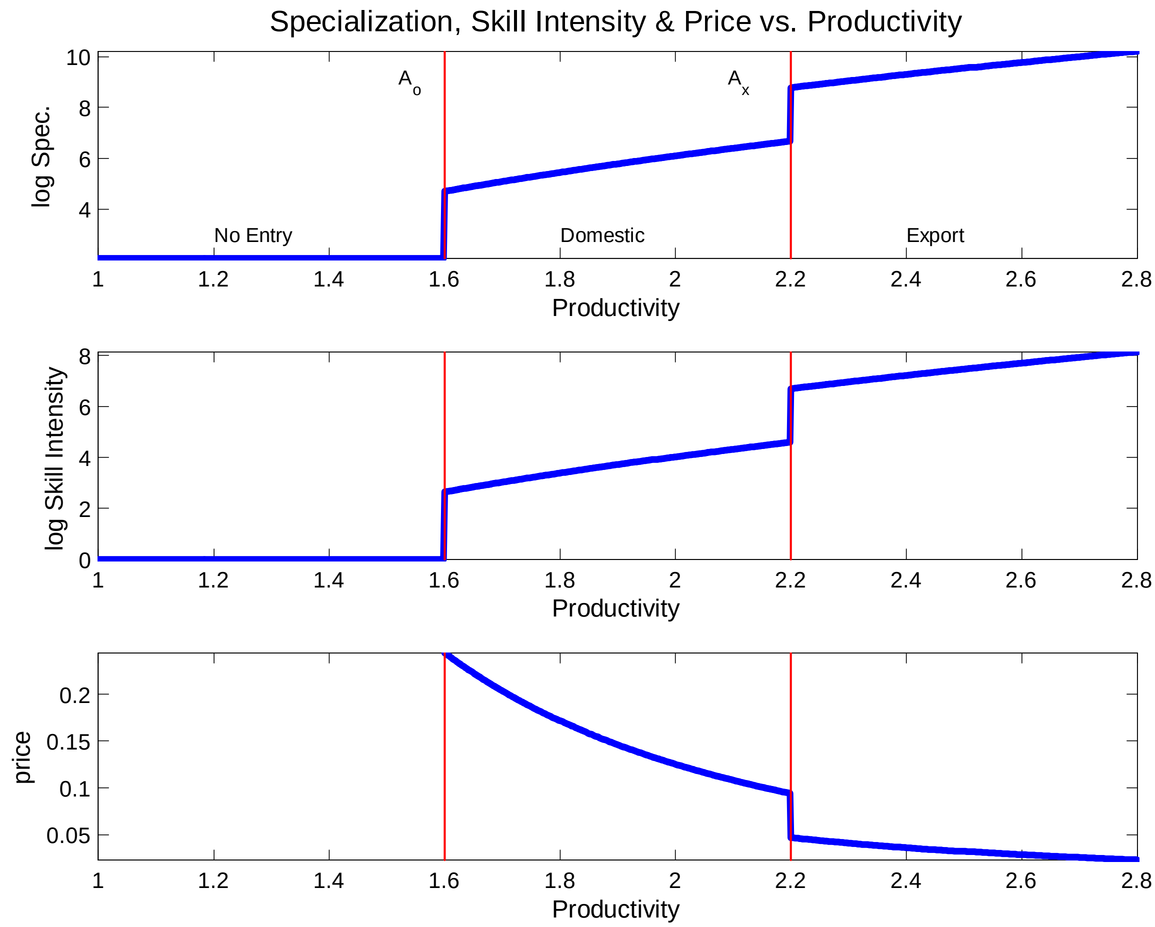

Figure 5: Relative Specialization, Skill intensity, and Prices of firms vs. their Productivity.

and the positive effects of trade barriers (d and f_x) on the entry and export thresholds. $\bar{A}_o$ and $\bar{A}_x$ are decreasing in D, since, profits are increasing in productivity A and production demand D; therefore, as in the Melitz model, an increase in demand induces more firms to pay fixed costs to operate or to export.

Figure 5 shows how firms with different productivities decide about their prices, outputs, skill intensities, entries, and export activities. As shown in the previous section, the relative labor demand is increasing in productivity A and demand indicator D. Thus more-productive firms choose to be more skill-intensive and demand more high-skilled workers relative to low-skilled ones. Also, because very productive firms decide to enter the foreign market and face a larger demand, they decide to be more specialized and also become more skill-intensive because of higher production demand. Therefore, they have more organizationally expanded firms, charge lower prices and choose to be much more skill-intensive than non-exporters.

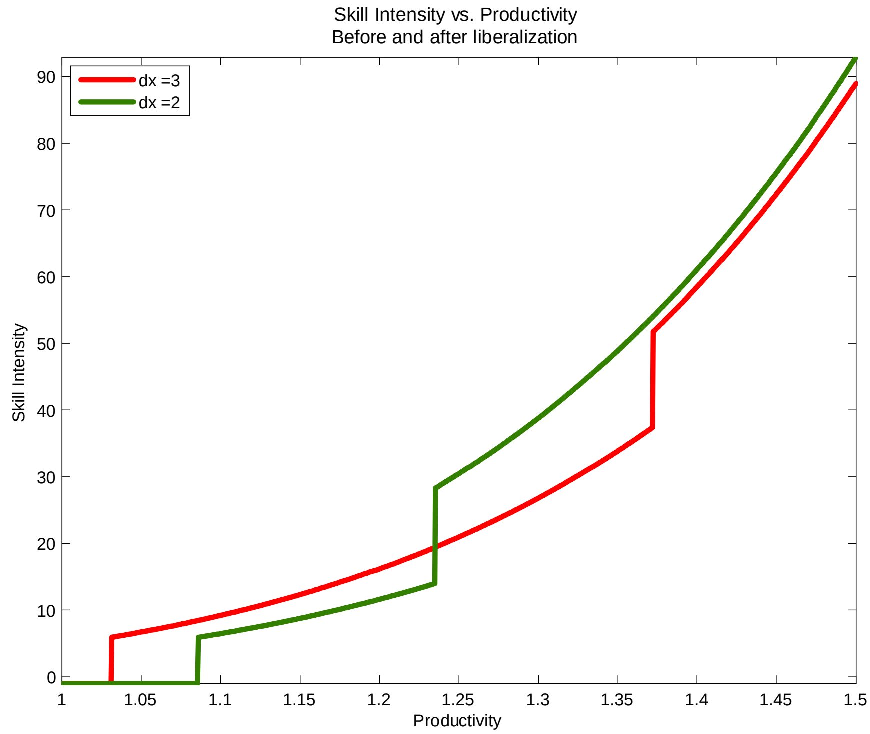

Figure 6: Effect of lowering trade barrier on the relative labor demand in a partial equilibrium setting.

Note that this new framework also shows a new source for the gain from international trade. Lowering trade costs induces the exporter to re-organize to a more specialized firm and become more productive. Therefore, a reduction in trade costs affects aggregate productivity through a new margin, other than the intensive and extensive margin of trade; I call it "within-firm margin".

As discussed above, this within-firm margin is a new source for generating an endogenous skilled bias technological change and a new source of gains in aggregate productivity and welfare. Also along with the intensive and extensive margins of trade, it is a new margin in the gravity equation where it allows firms to expand their organization and become more productive.

The predictions of the model regarding the reallocations of labor within industries are consistent also with the empirical work. Many empirical works have shown that more-productive firms and exporters are more skill-intensive and they have increased their skill-intensity after trade openness. Also, it is a robust feature of the data that the skill premium has increased after trade liberalizations[7].

3 Quantitative Analysis

In this section, I analyze the models aggregate implications by employing it to the study of the Mexican trade liberalization during the period of 1985-1993. The motivating empirical fact of this paper is the puzzle in the rise of the skill premium in developing countries after opening to trade; and these countries are mostly small economies. They face a large market when they begin to trade, and this increase in demand is the most relevant force in raising the skill intensity of the new exporters, through labor specialization, and driving up the relative demand for skilled workers, hence boosting the skill premium. Therefore I analyze the implications of the model in a small open-economy context to investigate the effects of trade liberalization on the skill premium changes.

To do so, I calibrate my model to the Mexican data in 1993 borrowed from the firm level data statistics provided by Verhoogen (2008) and Frías et al. (2009). I then analyze quantitatively the effect of some counterfactual trade policies on the skill premium and compare the results of the simulated model with the data. For robustness check, I present some comparative static analysis to show how the model's responses vary by changes in some of the model's fundamental parameters.

In Appendix D, I first present a background study about the trade liberalization in Mexico during the years 1985-1993. Then I present how to numerically solve for the equilibrium in a small open economy context given the parameters of the model. I then use the Simulated Method of Moments to calibrate the parameters to the Mexican data.

In what follows, I briefly state how to use the model in a small open economy framework and leave the details to Appendix D. Then, I simulate the model to solve for the equilibrium allocations. Finally, I impose different counterfactual policy reforms to the model and simulate it again to study how the economy responds to such policies in comparison to the

[7] See Goldberg and Pavnick (2007) for a survey on the literature.

actual data. More importantly, I look at the model's responses for the percentage changes in the skill premium, real wages, and aggregate welfare followed by these policies.

3.1 Setup

In a small open-economy context, the trading partners of a small open economy are large enough such that the home country cannot affect the prices and wages in the foreign economy. I take the foreign aggregate demand (D_f), the marginal cost of production of foreigners (p_f), and the measure of foreign exporters (M_{ef} normalized to 1) as given exogenously, so that any changes in the home country cannot affect them. As mentioned before, there is free entry with endogenous measure M_e of potential entrants at home. I also assume that the fixed costs are paid in terms of high- and low-skilled labor evenly[8]such that $f_e = \frac{w_H \bar{f}_e + w_L \bar{f}_e}{2}$ and $f_x = \frac{w_H \bar{f}_x + w_L \bar{f}_x}{2}$. For the fixed cost of specialization, I assume that the skill type $k \in \{H, L\}$ uses labor of the same type. Lastly, for simplicity and without loss of generality, I have assumed that there are no operational fixed costs $(f_o = 0)$[9]. Therefore all the potential firms would produce at least in the home market. A firm enters the export market, if $\Pi(A, D + D_f) - \Pi(A, D) \geq f_x$. This condition pins down the threshold $\bar{A}_x$ enabling firms with productivity $A \geq \bar{A}_x$ to export. It also solves for the fraction of exporters μ_x, given demand D and wages w_H and w_L. I continue with the assumption of Pareto distribution for the firms' productivities.

To solve for the equilibrium allocation, I first take all the parameters as given and show how to find the allocations and prices. Then, I calibrate some of the parameters using the existing literature. I then match some moments of the model to the actual available data and estimate the rest of the parameters. All the details are in Appendix D. Finally, I take the parameters and simulate the model under some actual and counterfactual changes in the parameters.

[8]The results are robust to changes in these assumptions.
[9]The results are robust to changes in these assumptions.

3.2 Counterfactual Policy Analysis

In appendix D, I have used Mexican data and calibrated the small open economy version of the model. In this section, I use the calibrated model and analyze some counterfactual policies to study responses of the model on the skill premium, welfare effects and some important endogenous variables. First of all, I look at the policy of changes in the bilateral trade costs to see how much the model can predict changes in the skill premium, compared to the actual data. I then study the effects of counterfactual policies of changing the fixed export costs, foreign aggregate demand and relative labor supply. In these policy experiments, I look at some variables of interest including the skill premium and aggregate welfare to show how much deviation from calibrated economy this model can generate. And lastly, in Appendix D, I run comparative statics on some critical parameters of interest such as ρ_H,ρ_L and f_h(fixed specialization cost of high-skilled) and show the qualitatively robustness of the model.

3.2.1 Bilateral Trade Costs

Changes in bilateral trade costs affect the trade patterns, wages, and the skill premium through different channels. First of all, it is typical in Melitz-type models that reducing these costs reduces the import prices, increasing the import competition and lowering the aggregate price index where home producers find lower demand as a result of higher competition from abroad.

On the other hand, reducing bilateral trade costs lowers the marginal cost of exporting, increasing the demand for some firms. Old exporters would export more because of the increase in their demands. More importantly, some non-exporters find it optimal to start exporting since the extra profit from exporting now dominates the export fixed costs. Thus both the old and new exporters face higher demand, inducing the to increase their level of labor specialization to become more productive and more skill-intensive. This change in the within-firm margin and in the extensive margin would lower the aggregate price index, because some firms are more productive and also there are more and cheaper varieties available for the consumers.

As explained in the previous sections, the former contraction for non-exporters and the latter expansion for exporters would induce firms to change their horizontal organizational expansions. Lower demand for domestic producers leads them to contract their organization, and according to the explained mechanisms in the model, they choose to become less skill-intensive. In contrast, exporters, and especially the new exporters, would expand their organization and become more skill-intensive, increasing their demand for high-skilled workers. In the aggregate, for higher levels of trade costs, the second effect is dominant, increasing the overall relative demand for high-skilled workers. Thus the skill premium would rise.

To analyze the effect of the Mexican liberalization period of 1985-1993, I calibrate the model to Mexican data in 1993, which is before NAFTA and the peso devaluation; thus these two events have no effect on the data for 1993. Then instead of analyzing the behavior of the model in a counterfactual policy of going to autarky, I run a policy experiment of increasing the bilateral trade costs to match the model with the level of trade in 1985. I show how much of the actual skill premium and other variables in the data of 1985 can be explained by the model.

As it is explained in the case study in Appendix D, tariffs were reduced to an average of 11%, from 23.5%, from 1985 to 1993. Also there were many other non-Tariff barriers, such as import licenses, which were largely removed during this period. This means that to study the effect of a bilateral trade liberalization, relying only on the tariff data in 1985 would be misleading. If I increase the bilateral trade costs by 12.5%, equivalent to actual change in the tariff rates from 1985 to 1993, the model's response should be far enough from what has actually happened.

Thus, in my policy experiment, I allow the bilateral iceberg trade costs to vary so that the fraction of exporters match with what the actual data are. The model would then be more comparable to the effects of the actual liberalization policy. In this method, I can also

Table 2: Simulation Results

Parameter	Benchmark	Counterfactual
Bilateral iceberg cost	1.11	2.04
Fraction of Exporters	.3	.1
Skill Premium	2.8	2.73
Aggregate welfare	.038	.037
Total expenditure	.012	.011
Aggregate price index	.305	.293
High-skilled real wage	.069	.066
Low-skilled real wage	.025	.024
Total export/Total production	.126	.045
Revenue of exporters/non-exporters	6.15	10.2
Emp. of high-skilled in exporters/non-exporters	2.4e+04	177
Emp. of low-skilled in exporters/non-exporters	2.17	1.86
H/L of marginal exporters/non-exporter	24.2	1.69
Average Emp. in exporters	421	735
Average Emp. in non-exporters	109	131

Note: Summary of the matched and simulated moments in the benchmark case (calibrated to data for the year 1993) and the counterfactual scenario where trade costs are larger such that the fraction of exporters matches with the actual data in year 1985.

compute the trade costs equivalent to non-tariff changes in barriers. Table 2 presents the outputs of the model in a benchmark (calibrated economy) case and in the case of changes in the bilateral trade costs so that the fraction of exporters changes to 10%, from 30.0%, to match the actual data in 1985. Table 2 shows that reducing the fraction of exporters to 10% can be achieved by increasing the bilateral iceberg trade costs to 2.04, which is equivalent to a 80.5 ($2.04 - 1.11 - .125 = 0.805$) percentage-point increase in the non-tariff barriers. This policy of raising the barriers decreases the skill premium from 2.80 to 2.73. The average skill premium in 1985 was around 2.0; thus the model can explain around 10% of the actual change.

The export share of sales for exporters reduces to 8.44%, from 17.4%, while the total export to total production declines from 12.6% to 4.5% which are comparable to the real data. Total sales was decreased by 7.7%.

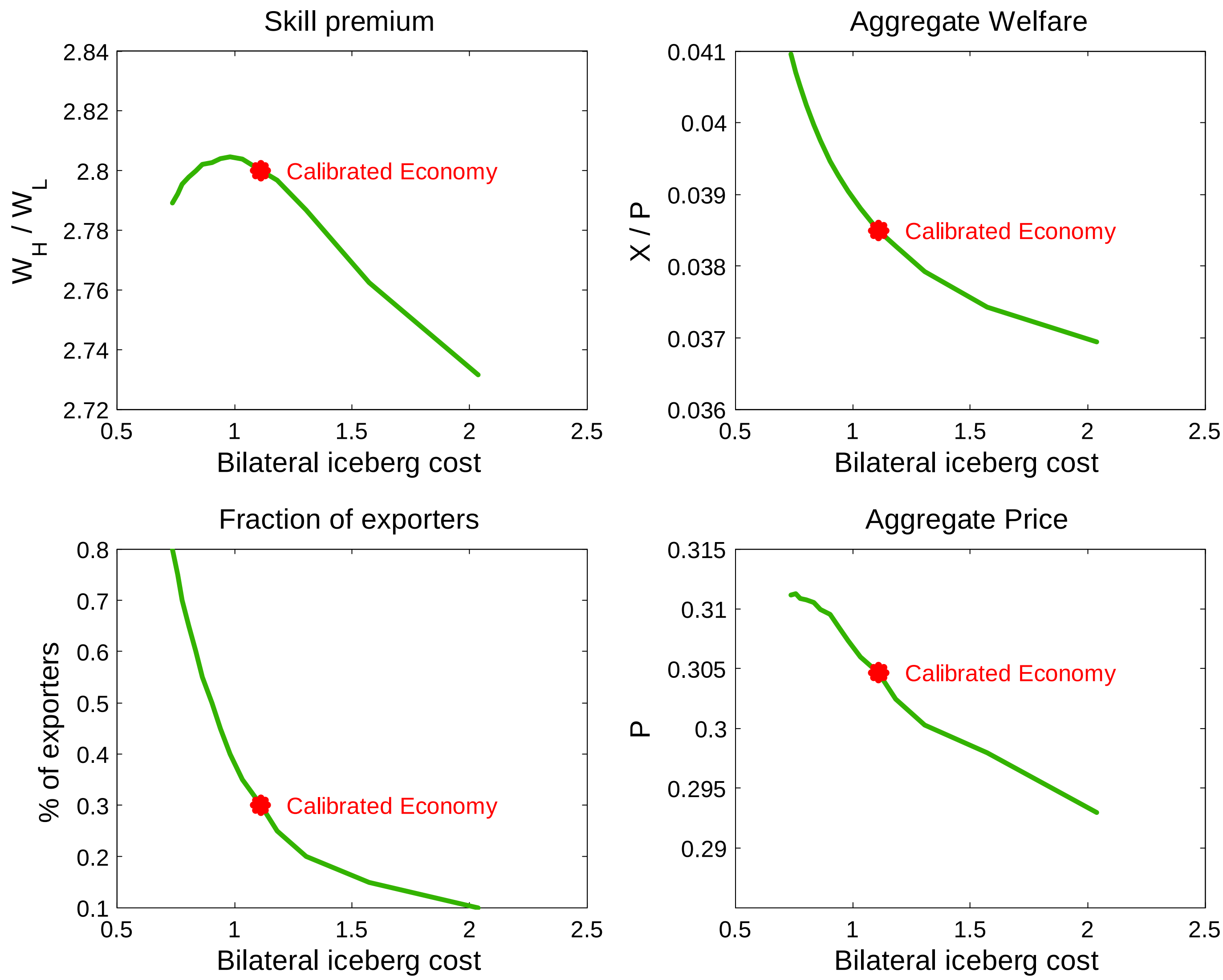

Figure 7: Effects of simulated changes in bilateral iceberg trade costs on the skill premium, aggregate welfare, fraction of exporters and aggregate prices

Also, as expected, the real wages of high- and low-skilled workers increase, although the increase is larger for the high-skilled workers. The other interesting result from this table is the relative skill intensity (H/L) of marginal exporters versus the marginal non-exporters. Increasing the trade costs has reduced this ratio. In other words, trade liberalization dramatically increases the skill intensity of exporters relative to non exporters.

Lastly, I study a continuum of counterfactual policies by changing the bilateral trade costs so that the fraction of exporters changes to 90%, from 10%. Figure 7 presents the behavior of the model for this analysis. Sweeping this trade cost to a high value from a low value shows that the skill premium initially increases; then it starts to drop with more trade openings. Another interesting observation is the huge rate of change in the extensive margin of firms' entries for low values of trade costs. It is evident from the lower panel that reducing trade costs below 1.1 increases the fraction of exporters by a large amount.

3.2.2 Fixed Export Costs

In this section, I study the counterfactual policy of changing the fixed exporting costs rather than the variable trade costs. Lowering fixed exporting costs makes exporting profitable for some non-exporting firms, creating incentives for them to export. Thus, the entry threshold for exporting goes down and new exporters enter the new market. Hence, these new exporters expand their organizations since they face the larger foreign markets, and they become more skill-intensive and more productive, allowing them to reduce their prices. Therefore in a partial equilibrium, it is expected that the aggregate price index declines and aggregate productivity goes up.

On the other hand, in general equilibrium, the increase in the aggregate productivity pushes up the demand for both types of workers, thus increasing their wages. This increase has an asymmetrical effect on the relative labor demand, since the effect of w_k on the demand for labor of type k depends on the parameter ρ_k. The lower this parameter the higher is the effect of change in w_k. Since the gains from specialization of high-skilled workers is higher than that of the low-skilled ones, thus $\rho_H < \rho_L$. Therefore the increase in the high-skilled workers' wage has a more significant negative effect on a firm's demand for high-skilled workers. Firms, except the non-exporters, find labor costs more expensive, especially for high-skilled workers. Therefore their marginal costs go up, and they charge higher prices than before. Because of this general equilibrium effect, the aggregate price index would go up. Also, as a result of the asymmetrical effect of wages on relative demand, aggregate relative labor demand goes down, reducing the skill premium.

Figure 8 shows the behavior of the skill intensity in response to changes in fixed export costs. Although the skill premium has declined, the aggregate productivity and aggregate

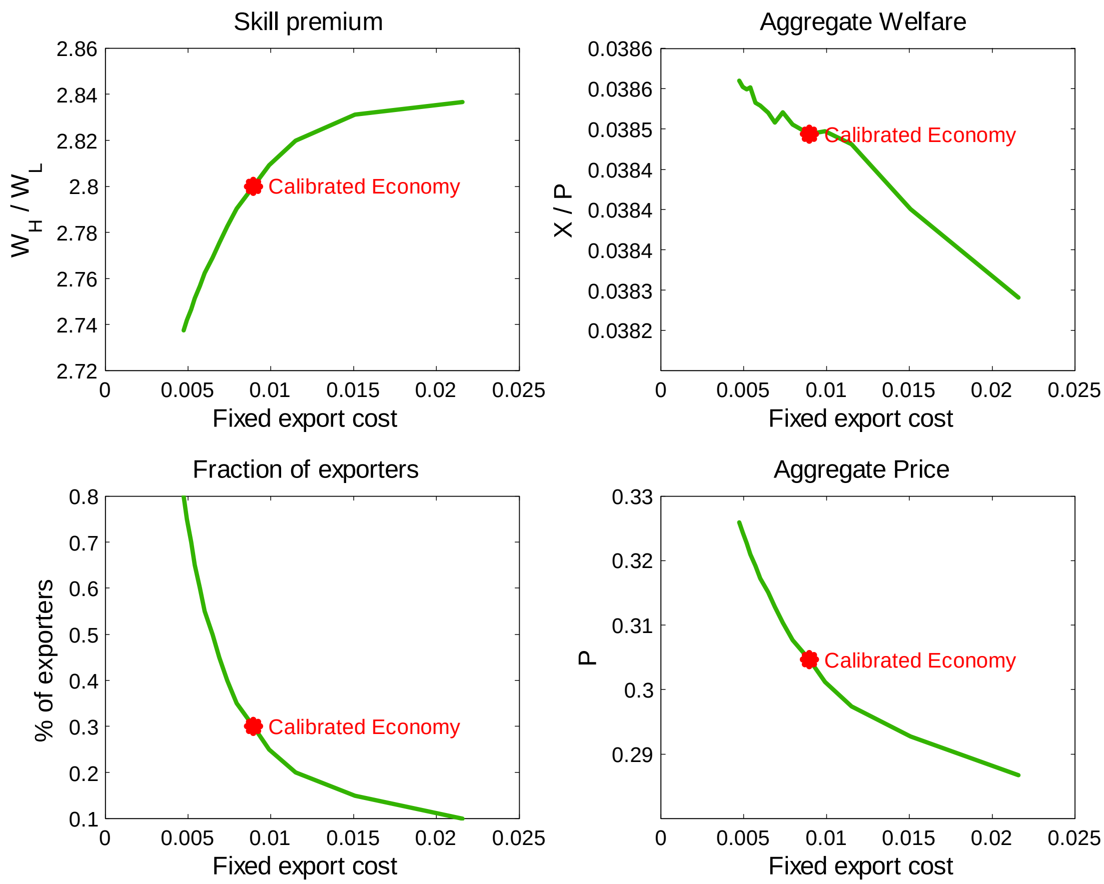

Figure 8: Effects of simulated changes in fixed export costs on the skill premium, aggregate welfare, fraction of exporters and aggregate prices

welfare increase because of the presence of the new more-productive exporters with lower prices. Therefore, such a policy can reduce income inequality while it increases aggregate productivity and welfare.

The decrease in the skill premium after lowering fixed export costs illustrates that different trade liberalization policies have different consequences in regard to inequality. As it was shown previously, lowering bilateral trade costs initiated more channels, resulting in a rise in the skill premium; but a decline in the fixed export costs initiates only a channel that results in the decline in the skill premium.

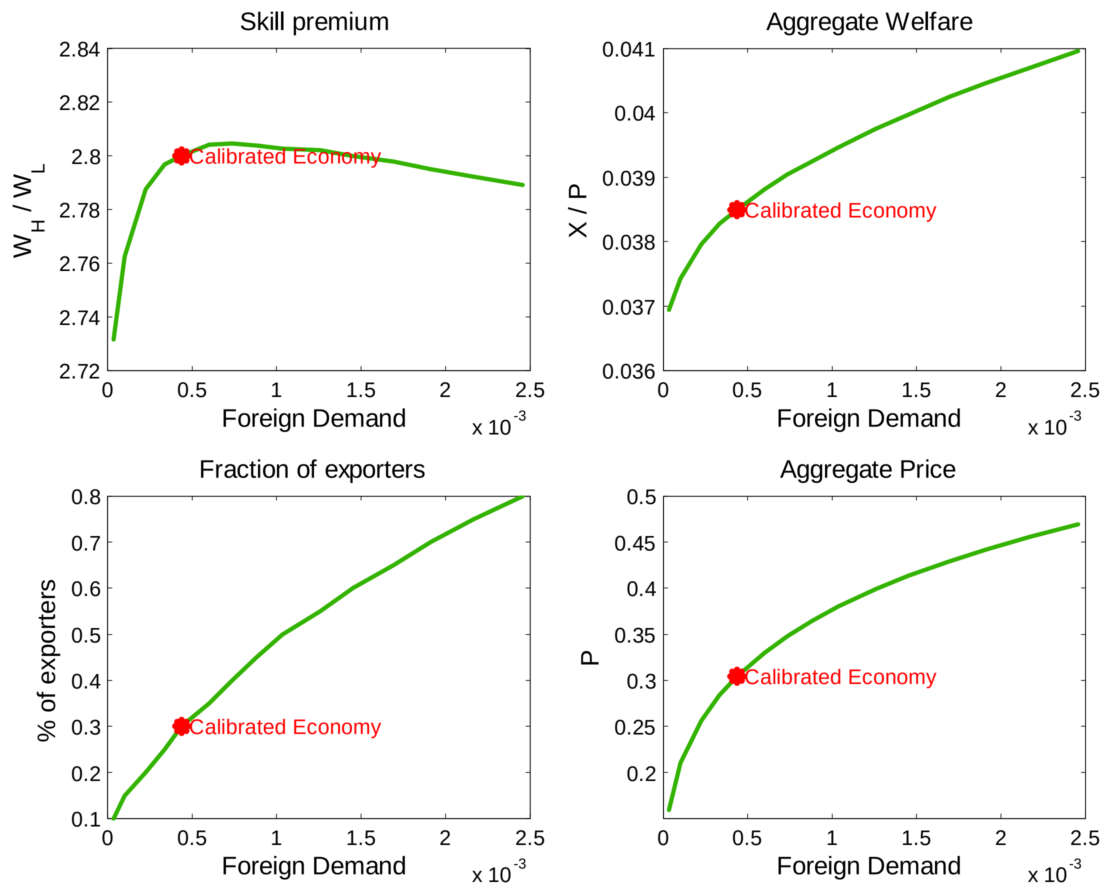

Figure 9: Effects of simulated changes in Foreign Demand Indicator on the skill premium, aggregate welfare, fraction of exporters and aggregate prices.

3.2.3 Foreign Aggregate Demand

In this section, I study the counterfactual experiment of changes in the total aggregate demand from foreign countries. This is equivalent to a unilateral trade-cost reduction by the trade partners. Figure 9 shows how the calibrated economy would change if aggregate foreign demand D_f changes. As it is expected, higher D_f would raise the revenue and variable profit of the exporters in addition to inducing more firms to start exporting through making it more profitable. The rise in the aggregate demand for the new exporters induces more expansion in exporters; raising their skill-intensity through the channels discussed in the theory section. Thus the aggregate skill-intensity can go up through this channel.

On the other hand, as explained in the previous subsection, the effect of wages on the relative labor demand is asymmetric. Higher values of real wages pushes the aggregate relative labor demand down, lowering the skill premium. Therefore as trade expands through exposition to a larger foreign market, the skill premium tends to go down through this channel. However, the former channel dominates the latter when the aggregate demand is low; hence the skill premium goes up, as shown in Figure 9. But after a threshold, the second channel dominates the first one, imposing the skill premium to go down. Thus opening up a country to a larger market generates gains in aggregate productivity and non-monotone consequences on income inequality.

Figure 10 shows these distributional changes. It presents the distribution of firms' skill intensity, prices, total revenue and labor productivity (Revenue/Total Employment) versus the firms' productivities. It shows how these distributions vary from the benchmark calibrated economy to the simulated counterfactual economy by increasing the foreign aggregate demand. It is evident in the figure that the skill-intensity of larger firms increases compared to those of smaller ones. The relative skill intensity of marginal exporters and marginal non-exporters changes dramatically because of huge change in the demand for exporters and its effect on their skill intensity and their horizontal organizational expansion.

3.2.4 Labor Supply

I conclude the analysis by studying changes in the relative supply of high-skilled workers versus low-skilled ones. As one expects, increases in the relative supply should push down the skill premium. On the other hand, as expected, aggregate productivity would be higher with higher relative supply, since relatively there are more productive workers in the economy. These results are reflected in Figure 11 which shows a unilateral reduction in the skill premium with the increase in the ratio of high-/low-skilled workers.

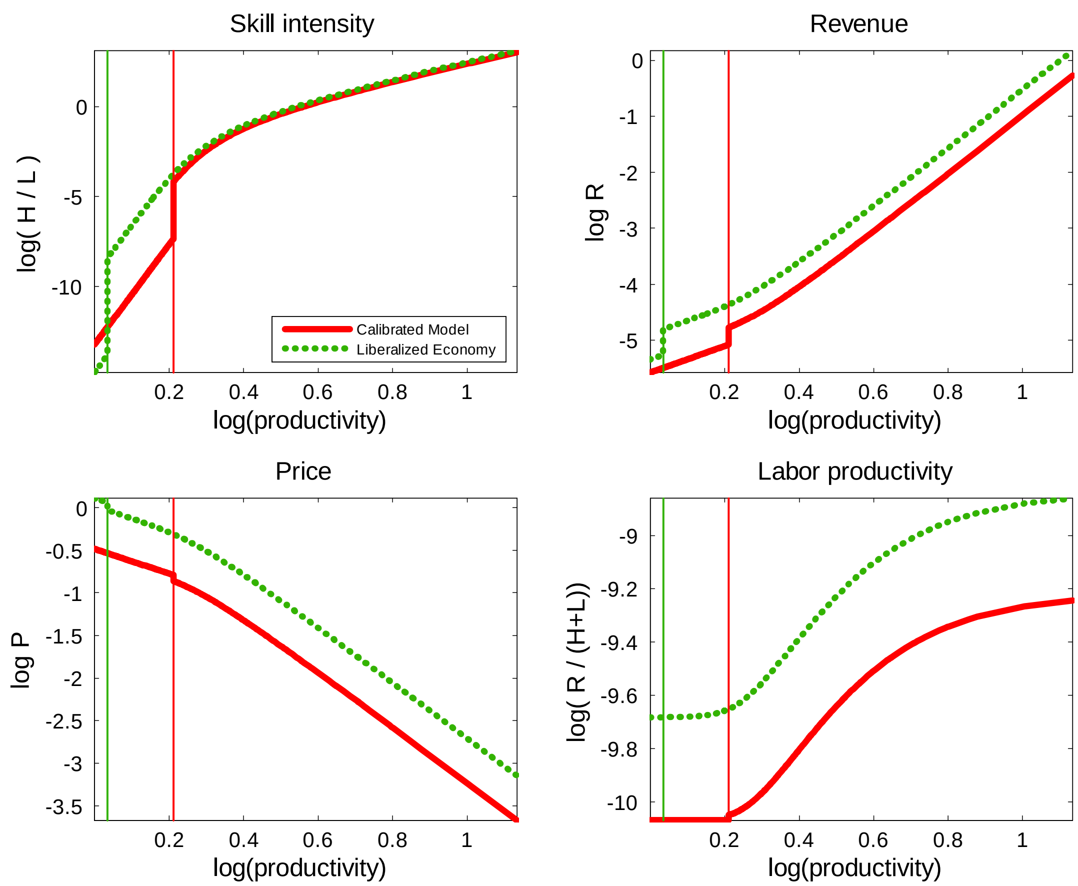

Figure 10: Relative skill intensities, prices, revenues and labor productivities of firms vs. their productivity in the benchmark economy and the counterfactual economy with higher foreign aggregate demand.

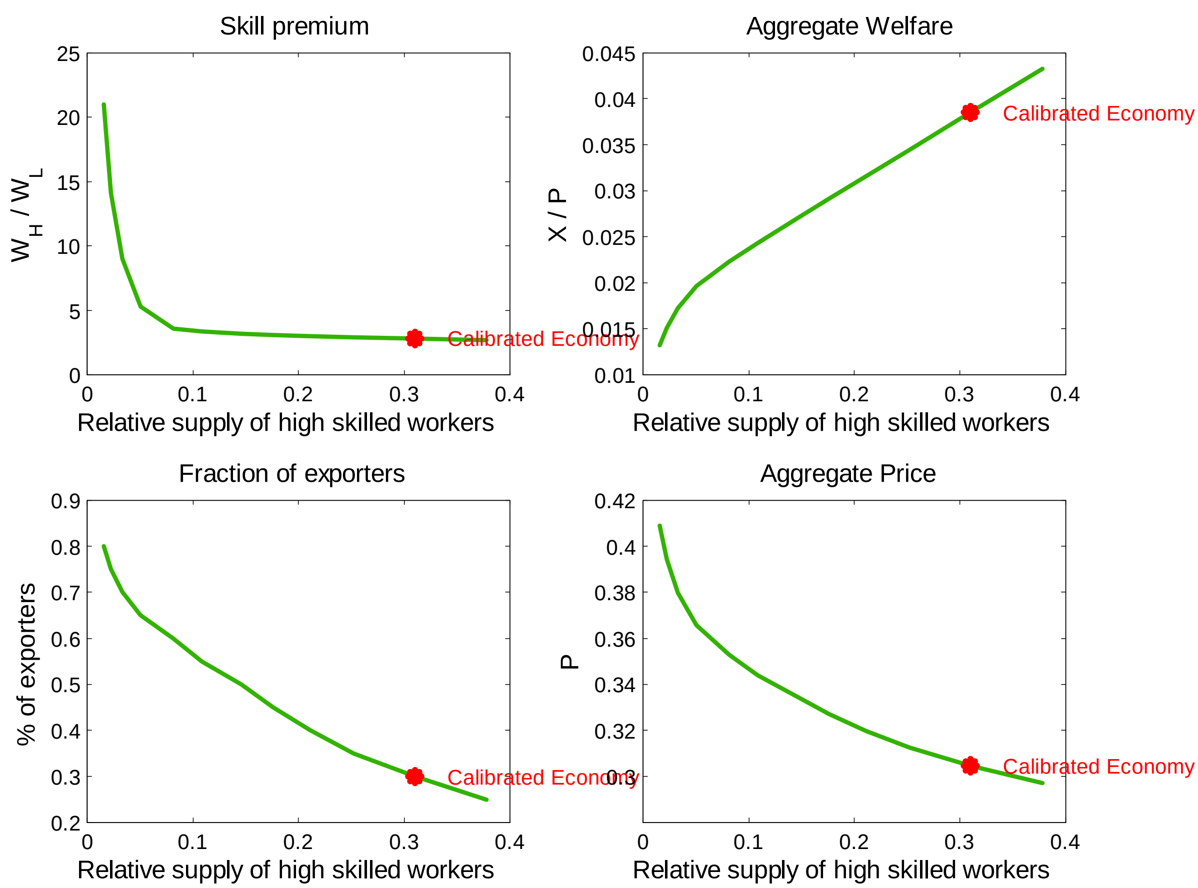

Figure 11: Effects of simulated changes in the relative supply of high skilled workers on the skill premium, aggregate welfare, fraction of exporters and aggregate prices.

4 Conclusion

In this paper, I have introduced a new model of skill specialization that can explain several stylized facts about the distributional effects and the labor market effects of international trade. The most important one is that it proposes a new mechanism for explaining the increase in the skill premium in developing countries after trade liberalization. By modeling the internal firm organization, I introduced a channel through which trade affects the skill premium through firms' re-organizational decisions about their labor divisions and degrees of specialization of their high- and low-skilled workers.

By introducing a model where a firm can specialize its workers into different divisions of labor and then optimize the degree of specialization, I found that the more-productive firms choose to specialize more and to demand relatively more skilled labor; becoming more skill intensive. Also, I show that for exporters, there's a jump in the degree of specialization, relative labor demand, and level of production and sales. An increase in the product demand will also result in more specialization and will induce a reduction in the marginal cost of production.

After a productivity or demand shock, more skilled workers reallocate to more productive firms. Therefore opening up to trade will initially induce more productive firms to enter the foreign markets and expand their degrees of specializations and their demands for high-skilled labor. This would generate an increase in the relative demand for high-skilled workers, which will result in an increase in the skill premium.

I could also find that an unbiased change in a firm's productivity results in change in the average degree of specialization, and therefore a biased change in relative demand for skilled workers and consequently a biased labor productivity change. This skill-biased technological change will induce also an increase in the skill premium.

I calibrate the model to Mexican data, to quantitatively measure the effects of this new mechanism by analyzing the Mexican liberalization period of 1985-1993. I run counterfactual policy experiments of changes in the bilateral trade costs to find how much of the actual skill premium and other variables in the data can be explained by the model. I find that this model can explain 10% of the rise in the skill premium in this period in Mexico. I also run other policy scenarios to investigate the effects on the skill premium and aggregate productivity through the new mechanism developed in this paper.

In summary, this paper has linked the within-firm organizational decisions to the aggregate-skill premium changes in the economy. This new within-firm margin motivates more firm-level empirical work in the future, studying the effects of trade openness on firms' horizontal expansions in their organizations. It also motivates studying the links that connect these expansions with a reallocation of high-skilled workers to the exporters and more-productive firms . Furthermore, a small multi-country general equilibrium quantitative analysis would be another venue to quantify the extent of the model in explaining the changes in the skill premium. This can be well performed after having sophisticated estimations of the primitive parameters of the model, which itself is an agenda for future work.

References

Acemoglu, D. (2003). Patterns of skill premia. *The Review of Economic Studies 70*(2), 199–230.

Acemoglu, D. and D. Autor (2011). Skills, tasks and technologies: Implications for employment and earnings. In *Handbook of labor economics*, Volume 4, pp. 1043–1171. Elsevier.

Attanasio, O., P. K. Goldberg, and N. Pavcnik (2004). Trade reforms and wage inequality in colombia. *Journal of development Economics 74*(2), 331–366.

Behar, A. (2010). The elasticity of substitution between skilled and unskilled labor in developing countries is about 2. *International Monetary Fund. Selected works*.

Bernard, A. B., J. Eaton, J. B. Jensen, and S. Kortum (2003). Plants and productivity in international trade. *American economic review 93*(4), 1268–1290.

Blankenau, W. F. and S. P. Cassou (2011). Industry estimates of the elasticity of substitution and the rate of biased technological change between skilled and unskilled labour. *Applied Economics 43*(23), 3129–3142.

Burstein, A., J. Cravino, and J. Vogel (2013). Importing skill-biased technology. *American Economic Journal: Macroeconomics 5*(2), 32–71.

Burstein, A. and J. Vogel (2017). International trade, technology, and the skill premium. *Journal of Political Economy 125*(5), 1356–1412.

Bustos, P. (2011). Trade liberalization, exports, and technology upgrading: Evidence on the impact of mercosur on argentinian firms. *American economic review 101*(1), 304–40.

Caliendo, L., F. Monte, and E. Rossi-Hansberg (2015). The anatomy of french production hierarchies. *Journal of Political Economy 123*(4), 809–852.

Caliendo, L. and E. Rossi-Hansberg (2012). The impact of trade on organization and productivity. *The quarterly journal of economics 127*(3), 1393–1467.

Chaney, T. (2008). Distorted gravity: the intensive and extensive margins of international trade. *American Economic Review 98*(4), 1707–21.

Chaney, T. and R. Ossa (2013). Market size, division of labor, and firm productivity. *Journal of International Economics 90*(1), 177–180.

Ciccone, A. and G. Peri (2005). Long-run substitutability between more and less educated workers: evidence from us states, 1950–1990. *Review of Economics and statistics 87*(4), 652–663.

Costinot, A. (2009). On the origins of comparative advantage. *Journal of International Economics 77*(2), 255–264.

Cragg, M. I. and M. Epelbaum (1996). Why has wage dispersion grown in mexico? is it the incidence of reforms or the growing demand for skills? *Journal of development Economics 51*(1), 99–116.

Currie, J. and A. Harrison (1997). Trade reform and labor market adjustment in morocco. *Journal of Labor economics 15*(3), S44–71.

Feenstra, R. C. and G. H. Hanson (1996). Globalization, outsourcing, and wage inequality. Technical report, National Bureau of Economic Research.

Feliciano, Z. M. (2001). Workers and trade liberalization: the impact of trade reforms in mexico on wages and employment. *ilr Review 55*(1), 95–115.

Frías, J. A., D. S. Kaplan, and E. A. Verhoogen (2009). Exports and wage premia: Evidence from mexican employer-employee data. Technical report, Columbia University mimeo.

Goldberg, P. K. and N. Pavcnik (2007). Distributional effects of globalization in developing countries. *Journal of economic Literature 45*(1), 39–82.

Haltiwanger, J., A. Kugler, M. Kugler, A. Micco, and C. Pages (2004). Effects of tariffs and real exchange rates on job reallocation: evidence from latin america. *The Journal of Policy Reform 7*(4), 191–208.

Hanson, G. H. and A. Harrison (1999). Trade liberalization and wage inequality in mexico. *ILR Review 52*(2), 271–288.

Harrigan, J. and A. Reshef (2011). Skill biased heterogeneous firms, trade liberalization, and the skill premium. Technical report, National Bureau of Economic Research.

Helpman, E., O. Itskhoki, and S. Redding (2010). Inequality and unemployment in a global economy. *Econometrica 78*(4), 1239–1283.

Katz, L. F. and K. M. Murphy (1992). Changes in relative wages, 1963–1987: supply and demand factors. *The quarterly journal of economics 107*(1), 35–78.

Krugman, P. (1980). Scale economies, product differentiation, and the pattern of trade. *The American Economic Review 70*(5), 950–959.

Krusell, P., L. E. Ohanian, J.-V. Ríos-Rull, and G. L. Violante (2000). Capital-skill complementarity and inequality: A macroeconomic analysis. *Econometrica 68*(5), 1029–1053.

Madanizadeh, S. A. (2017). Trade, skill premium and endogenous firm organization. *Available at SSRN 3022301*.

Matsuyama, K. (2007). Beyond icebergs: Towards a theory of biased globalization. *The Review of Economic Studies 74*(1), 237–253.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *econometrica 71*(6), 1695–1725.

Mollick, A. V. (2011). The world elasticity of labor substitution across education levels. *Empirical Economics 41*(3), 769–785.

Monte, F. (2011). Skill bias, trade, and wage dispersion. *Journal of international Economics 83*(2), 202–218.

Parro, F. (2013). Capital-skill complementarity and the skill premium in a quantitative model of trade. *American Economic Journal: Macroeconomics 5*(2), 72–117.

Psacharopoulos, G. and K. Hinchliffe (1972). Further evidence on the elasticity of substitution among different types of educated labor. *Journal of Political Economy 80*(4), 786–792.

Revenga, A. (1997). Employment and wage effects of trade liberalization: the case of mexican manufacturing. *Journal of labor Economics 15*(S3), S20–S43.

Robertson, R. (2000). Trade liberalisation and wage inequality: lessons from the mexican experience. *World Economy 23*(6), 827–849.

Stock, J. H., J. H. Wright, and M. Yogo (2002). A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business & Economic Statistics 20*(4), 518–529.

Stokey, N. L. (1996). Free trade, factor returns, and factor accumulation. *Journal of Economic Growth 1*(4), 421–447.

Thoenig, M. and T. Verdier (2003). A theory of defensive skill-biased innovation and globalization. *American Economic Review 93*(3), 709–728.

Topalova, P. (2010). Factor immobility and regional impacts of trade liberalization: Evidence on poverty from india. *American Economic Journal: Applied Economics 2*(4), 1–41.

Verhoogen, E. (2004). *Trade, quality upgrading and wage inequality in the Mexican manufacturing sector: theory and evidence from an exchange rate shock*. Number 67. Center for Labor Economics, University of California.

Verhoogen, E. A. (2008). Trade, quality upgrading, and wage inequality in the mexican manufacturing sector. *The Quarterly Journal of Economics 123*(2), 489–530.

Wacziarg, R. and J. S. Wallack (2004). Trade liberalization and intersectoral labor movements. *Journal of international Economics 64*(2), 411–439.

Wood, A. (1995). How trade hurt unskilled workers. *Journal of Economic perspectives 9*(3), 57–80.

A Microfoundation for the firm's production

Each firm produces a good which constitutes performing a measure-one continuum of complementary tasks $t \in [0, 1]$. The total performed task t is $y(t)$, and Y, the total output of the good is a CES aggregate of the performed tasks; such that

$$Y = A\left(\int_0^1 y\left(t\right)^{\frac{\varepsilon-1}{\varepsilon}}\,dt\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{12}$$

where $\varepsilon \leq 1$ is the elasticity of substitution between the tasks and A is the total factor productivity of the firm. In an extreme case, tasks are perfect complements ($\varepsilon = 0$) and we have a Leontief production function over the tasks. Task t is performed only by labor so that $n\left(t\right)$ amount of labor with productivity $\alpha\left(t\right)$ will perform $\alpha\left(t\right)n\left(t\right)$ of task t. There are two types of workers with different productivities to perform the tasks: High-skilled (H) and low-skilled (L) workers with wages w_H and w_L, respectively. Workers are identical within the type, and they can perform any tasks in the set $(0, 1)$. For each type of worker, $k = H$ or L, the firm defines S_k number of specialization groups, assigns a set of tasks $\tau_{k,s} \subseteq [0, 1]$ (for $s \in \{1, ...S_k\}$) and $N_{k,s}$ number of workers to each group and pays a fixed specialization cost f_k for every group.

A worker's productivity depends on the measure of tasks assigned to him. His productivity is higher if fewer tasks are assigned to him, since the worker can concentrate and specialize more on performing each task. Therefore productivity $\alpha_{k,s}\left(t\right)$ of a worker of type k $(= H$ or $L)$ in specialization group $s \in \{1, ...S_k\}$ is a decreasing function of the measure of the tasks assigned to the worker; i.e., it depends on the size $T_{k,s} = |\tau_{k,s}|$ of the subset $\tau_{k,s}$ that t belongs to. Therefore, the aggregate productivity of each type of worker increases with the number of groups since there are fewer tasks per group; this productivity gain thus induces a firm to increase the number of specialization groups with narrow measures of tasks assigned to each group. So the trade-off in this horizontal expansion of the firm is between the gain from specialization and the fixed costs of forming each group. Figure 12 illustrates this framework.

For simplicity, I take $\alpha_{k,s}\left(t\right) = \alpha_{k,s} = T_k^{-\frac{1}{\rho-1}+r_k}{T_{k,s}}^{-r_k}$, where $T_{k,s} = |\tau_{k,s}|$ is the measure of tasks in group s, $t \in \tau_{k,s}$ and $T_k = \sum_{s=1}^{S_k} T_{k,s}$ is the total measure of tasks assigned to workers of type k (Obviously, $T_H + T_L = 1$). In this productivity function, $r_k \geq 0$ is a parameter that shows the gain that workers get from focusing on narrower tasks; i.e. one percent decrease in the measure of assigned tasks to type k, increases their productivity by r_k percent. The term $T_k^{-\frac{1}{\rho-1}+r_k}$ shows the productivity loss regarding the coordination costs in assigning the tasks to workers of type k.

The main difference between a high-skilled and a low-skilled worker is the difference in their gains from specialization. Basically, I assume

$$r_H \geq r_L \tag{13}$$

meaning that the specialization of a high-skilled worker generates more gain than that of a low-skilled worker. Intuitively, high-skilled workers gain more if they are assigned to perform fewer tasks, concentrating more on each task and enjoying the benefits of their increasing returns of human capital.

Note that in this model, in contrast to Acemoglu and Autor (2011) and Costinot (2009), I am adopting no comparative advantage that workers of different types may have in performing the tasks. Basically, I am assuming that in performing each task, workers of each type are different only in their productivity and their gains from concentration, and it does not matter which task they perform. In a more general model, the comparative advantage can be included by introducing a profile of productivity over tasks for each type as in Acemoglu and Autor (2011). However, I do not use this notion to keep the model simple so that it can deliver the concept of labor specialization .

Summarizing the above discussions, the firm's problem for producing Y amount of output is to minimize costs by optimally choosing the number of specialization groups for each type, assigning tasks to each group, and employing workers for that group. Therefore the firm's conditional cost function is as follows:

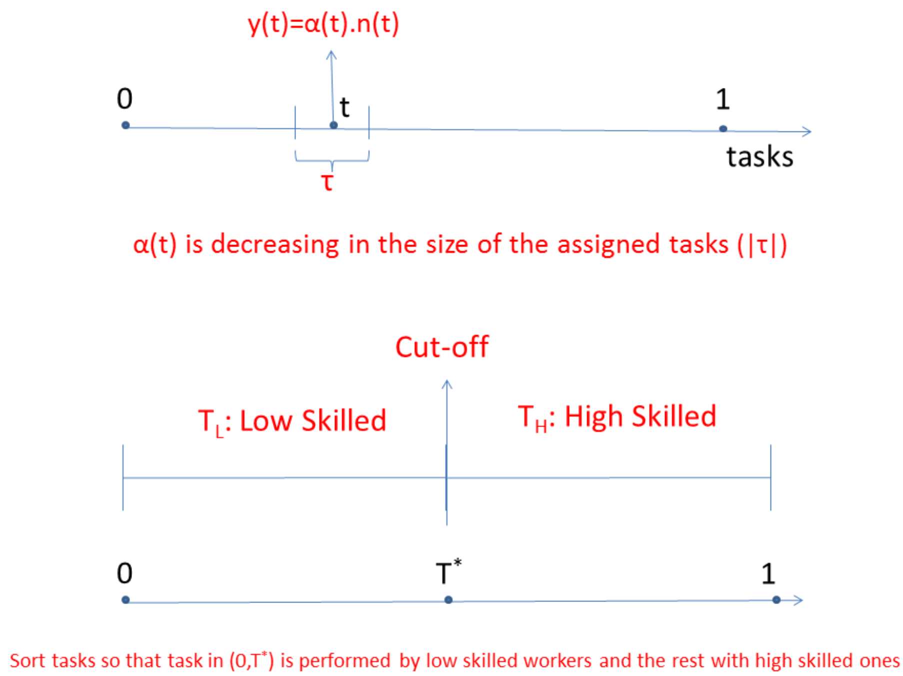

Figure 12: Illustration of the Task based model. (Top) Labor productivity of the assigned tasks. (Bottom) Assignment of tasks to low and high skilled workers.

$$
\begin{aligned}
C(Y) &= \min_{S_k, n_{k,s}(t), \tau_{k,s}} \sum_{k=H,L} \left(w_k N_k + f_k S_k\right) \qquad (14)\\
\text{s.t. } Y &= \left(\int_0^1 y(t)^{\frac{\varepsilon-1}{\varepsilon}} dt\right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{where } \left. y(t)\right|_{t\in\tau_{k,s}} = \sum_{k=H,L} \alpha_{k,s} n_{k,s}(t)\\
N_k &= \sum_{s=1}^{S_k} N_{k,s} \quad \text{for } k = H, L \text{ where } N_{k,s} = \int_{t\in\tau_{k,s}} n_{k,s}(t)\, dt
\end{aligned}
$$

Lemma 3 *(a) Measure zero of tasks is performed with more than one type of labor; also measure zero of tasks is assigned to more than one specialization group.*

(b) For each type of worker, specialization groups have the same sizes ($T_{ks} = T_{ks'} = \frac{T_k}{S_k}$ for any s,$s' \in \{1...S_k\}$); the number of workers in each group are the same ($N_{ks} = N_{ks'} = \frac{N_k}{S_k}$ for each $s\&s' \in \{1...S_k\}$); and firm assigns the same amount of labor to each task ($n_{ks}(t) = n_{ks}(t') = \frac{N_{ks}}{T_{ks}} = \frac{N_k}{T_k}$ for any t,$t' \in \tau_{ks}$).

(c) High-skilled and low-skilled workers are imperfect substitutes with elasticity of substi-

tution greater than one.

Proof. See Appendix B. ■

Basically the lemma shows that in the firm's optimal decision, it would not assign a positive measure of tasks to more than one group or to more than one type of worker[10]. Also, within each type of worker, the same amount of labor are assigned to each task and specialization groups have the same sizes and number of workers.

Since T_H and T_L are determined endogenously by the firm, the high-skilled and low-skilled workers turn out to be imperfect substitutes with each other[11]. The idea is that if the measure of assigned tasks T_H and T_L are fixed, the elasticity of substitution between high- and low-skilled workers is $\varepsilon \leq 1$. But since the firm optimizes over T_H and T_L, an increase in the skill premium (relative wage of high vs. low skilled) would decrease the measure of assigned tasks to the high-skilled workers (T_H) and increase that of low-skilled ones (T_L), implying less demand for the high-skilled vs. low-skilled workers. Also, because of this change in the measure of assigned tasks, the average productivity of high-skilled workers would increase relative to that of low-skilled workers, implying more reduction in the demand for high-skilled workers. This is true because of the complementarity between the tasks. These two forces together are enough to imply a large effect on the relative demand for high- vs. low-skilled workers, resulting in a more than one to one change for the relative demand, and making high- and low-skilled workers imperfect substitutes with elasticity of substitution greater than one. More interestingly, it has been shown that the parameter ε

[10]Note that tasks at the boundaries of the groups and types can be performed twice, but they have a measure zero and will not change any of the results that follow.

[11]Relative demand of high- vs. low-skilled workers is $\frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-\varepsilon}\left(\frac{A_H T_H^{-r_H} S_H^{r_H}}{A_L T_L^{-r_L} S_L^{r_L}}\right)^{\varepsilon-1}\frac{T_H}{T_L}$ where $A_k T_k^{-r_k} S_k^{r_k}$ is the productivity per task of type k worker and $\frac{T_H}{T_L}$ is the relative assigned tasks which is an endogenous variable. Given S_k, a firm optimally chooses the boundary task $T_H^*\&T_L^{*s}$ so that the relative productivities per task are equalized with the relative wages; i.e. $\frac{A_H T_H^{-r_H} S_H^{r_H}}{A_L T_L^{-r_L} S_L^{r_L}} = \frac{w_H}{w_L}$.This implies $\frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-1}\frac{1-T_L^*}{T_L^*}$ with $\frac{1-T_L^*}{T_L^*}$ an increasing function of $\frac{w_H}{w_L}$. Therefore the elasticity of substitution between the high and low skilled is greater than 1.

disappears in this elasticity of substitution; because the substitution effect cancels out the productivity effect, resulting in the elimination of ε.

Proposition 4 *The firm's cost minimization problem in the above micro founded model, with the specific productivity function* $\alpha_{k,s}(t) = \alpha_{k,s} = \left(\frac{T_{k,s}}{T_k}\right)^{-r_k} T_k^{-\frac{1}{\rho-1}}$ *(for* $k = H, L$*), is equivalent to the following problem:*

$$
\begin{aligned}
C(Y) &= \min_{\{S_k,N_k\}_{k=H,L}} \sum_{k=H,L} (w_k N_k + f_k S_k) \\
s.t.\ Y &= A\left(\left((S_H)^{r_H} N_H\right)^{\frac{\rho-1}{\rho}} + \left((S_L)^{r_L} N_L\right)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}
\end{aligned}
\tag{15}
$$

if $\rho_k = 1 + \frac{1}{r_k} \geq \rho > 1$*, where* ρ *is the elasticity of substitution between high and low-skilled workers.*

Proof. See Appendix B. ■

This proposition simplifies the above micro-founded problem into a simple firm cost minimization problem with CES production function with endogenous productivity of type k labor. It shows that a firm achieves a higher productivity if it increases the number of specialization groups (S_k) by paying a fixed cost for each group (f_k); generating a new margin for the firm. Resulting from the trade-off between the gain in productivity from increasing the degree of specialization and paying the fixed cost of specialization, the firm would choose a unique optimum degree of specialization for each type of workers.

On the other hand, since the gain from focusing on narrower tasks is higher for the high-skilled workers ($r_H \geq r_L$), the productivity gain from specialization is higher for the high-skilled workers; thus $\rho_H \leq \rho_L$. This difference is crucial in determining the difference between high- and low-skilled workers. As I show in the next section, the difference in the gain from specialization is the key driving force for the difference in relative labor demand.

Finally, note that taking $r_H = r_L = 0$ and $f_H = f_L = 0$ shuts down the gain from specialization and the problem becomes equivalent to a simple Heckscher-Ohlin-Krugman-Melitz type model with no optimization on the firm's organization.

B Proofs for the Micro-Foundation of the Production Process

Proof of Lemma 3 :

(a) This lemma means that in the optimal allocation of tasks and labor, the firm assigns each task to only one specialization group and to only one type of workers[12]. If a positive measure of tasks τ is performed with two types of labor or two different specialization groups, say s_1 and s_2, then the firm can remove these tasks τ from s_1 and assign them to only to s_2. Reducing the measure of tasks to s_1 would increase the productivity of this group (since they get higher productivities) and increase the overall productivity; therefore, it reduces the total costs.

(b,c) Using part (a) of the lemma, we can sort the tasks by the types of workers and the assigned specialization groups. I sort it such that the tasks in $[0, T^*)$ are performed with the low-skill workers L and task in $[T^*, 1)$ are performed with high-skilled workers H. Thus, $T_L = T^*$ and $T_H = 1 - T^*$. Also, the tasks within each type is sorted according to the index of their specialization groups $s = 1, ..S_L$ or $s = 1...S_H$. After such a sorting, we can easily realize that the solution regarding the size of the groups and employment levels are all unique. Here, I break the firm's decision into four steps:

1. For each worker of type k, given the boundary task T^*, the total number of specialization groups S_k and the task assignments $\{\tau_{k,s}\}$, the firm optimally chooses the number of workers for each specialization group; i.e. the firm solves for $n_{k,s}(t)$ for each group s in type k given $\{\tau_{k,s}\}\,\&S_k, T^*$.

[12] Note that the tasks at the boundaries of the groups and types, can be performed twice, but they have a measure zero and doesn't change any results that follow.

To do so, the firm optimally chooses $n_{k,s}(t)$ such that it is the same for all the tasks within the specialization group; i.e. $n_{k,s}(t) = \frac{N_{k,s}}{T_{k,s}}$, since productivity of workers within the specialization group is the same for each task. Also, since the production function is CES on the output tasks, it's easy to show that the relative demand for each specialization group is inversely related to the measure of the tasks of that group, such that $\frac{N_{k,s}}{N_{k,s'}} = \left(\frac{T_{k,s}}{T_{k,s'}}\right)^{-\left(r_k+\frac{1}{1-\varepsilon}\right)}$, where $N_{k,s}$ is the total number of workers of type k assigned to group s and $T_{k,s}$ is the measure of tasks in specialization group $\tau_{k,s}$. Remember that we assumed a functional form for the productivity such that $\alpha_{k,s}(t) = T_k^{-r+r_k} T_{k,s}{}^{-r_k}$ where $r = \frac{1}{\rho-1} > 0$.

2. Given S_k and T^*, the firm optimally chooses the task assignments $\{\tau_{k,s}\}$.

   To do so, the firm optimally chooses the task assignments $\{\tau_{k,s}\}$ such that the measure of tasks of specialization groups are all the same within each type, due to the symmetric that exist in the productivity of workers across the specialization groups and within the skill type. Thus $T_{k,s} = T_{k,s'} = \frac{T_k}{S_k}$, where $T_L = T^*$ and $T_H = 1 - T^*$. This implies that: $N_{k,s} = \frac{N_k}{S_k}$, $n_{k,s}(t) = \frac{N_k}{T_k}$, $Y_k = T_k^{-\left(r+\frac{1}{1-\varepsilon}\right)} S_k^{r_k} N_k$. Also it turns out that the relative demand of high vs. low-skilled workers is:

$$\frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-\varepsilon} \left(\frac{T_H^{-r} S_H^{r_H}}{T_L^{-r} S_L^{r_L}}\right)^{\varepsilon-1} \frac{T_H}{T_L}$$

   where $T_k^{-r} S_k^{r_k}$ is the average productivity per task of type $k = H,L$ workers.

3. Given S_k, the firm optimally chooses the boundary task T^*. In other words, the firm decides what tasks to be performed by low-skilled workers (and the rest being performed by high-skilled workers).

   This happens when the relative productivities per tasks are equalized with the relative wages; i.e.

$$\frac{T_H^{-r} S_H^{r_H}}{T_L^{-r} S_L^{r_L}} = \frac{w_H}{w_L} \tag{16}$$

.This implies that

$$\frac{T_H}{T_L} = \left(\frac{S_H^{r_H}}{S_L^{r_L}}.\frac{w_L}{w_H}\right)^{\frac{1}{r}}$$

thus

$$\frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-\left(1+\frac{1}{r}\right)} \frac{S_H^{\frac{r_H}{r}}}{S_L^{\frac{r_L}{r}}} \tag{17}$$

Equation (16) implies that the elasticity of substitution between the high and low-skilled is $\rho = 1 + \frac{1}{r} > 1$. Also, note that the parameter ε disappears in this allocation. Finally, it is easy to show that similar results about the elasticity of substitution can be found ($\frac{\partial \frac{N_H}{N_L}}{\partial \frac{w_H}{w_L}} > 1$) if we assume a general productivity function.

4. The firm optimally chooses S_k for each type k.

Proof of Proposition 4:

As shown in the previous lemma, following relationships can be found:

$$\begin{aligned}
\alpha_k &= T_k^{-r} S_k^{r_k} \\
T_k &= \frac{\tilde{w}_k^{-\frac{1}{r}}}{\tilde{T}} \text{ where } \tilde{w} = \frac{w_k}{S_k^{r_k}}, \tilde{T} = \sum_{k'} \tilde{w}_{k'}^{-\frac{1}{r}} \\
Y &= \left(\sum_k Y_k^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \text{ where } Y_k = \alpha_k N_k T_k^{\frac{\varepsilon}{1-\varepsilon}} \\
\zeta &\equiv \frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-1} \left(\frac{\tilde{w}_H}{\tilde{w}_L}\right)^{-\frac{1}{r}}
\end{aligned}$$

therefore

$$\alpha_k = w_k \tilde{T}^r$$

Now let's define $\bar{C}_k = w_k N_k$ the cost of labor k, $\bar{C} = \sum_k \bar{C}_k$ total cost of labor, and $\psi_k = \frac{\bar{C}_k}{\bar{C}}$ the cost share of labor of type k. Therefore

$$\psi_k = \frac{\tilde{w}_k^{-\frac{1}{r}}}{\tilde{T}} = T_k$$

thus

$$\begin{aligned}
Y &= \left(\sum_k \left(w_k \tilde{T}^r N_k T_k^{\frac{\varepsilon}{1-\varepsilon}}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \\
&= \left(\sum_k \left(\bar{C}\psi_k \tilde{T}^r \psi_k^{\frac{\varepsilon}{1-\varepsilon}}\right)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \\
&= \bar{C}\tilde{T}^r \left(\sum_k T_k\right)^{\frac{1}{1-\varepsilon}} \\
&= \bar{C}\tilde{T}^r
\end{aligned}$$

since $\sum_k T_k = 1$. Hence

$$\bar{C} = Y\left(\sum \left(\frac{w_k}{S_k^{r_k}}\right)^{-\frac{1}{r}}\right)^{-r}$$

This means that after optimizing over the task assignments and optimum labor demand assignment, the micro-founded model simplifies to the following problem:

$$C(Y) = \min_{S_k} Y\left(\sum_{k=H,L}\left(\frac{w_k}{S_k^{r_k}}\right)^{-\frac{1}{r}}\right)^{-r} + \sum_{k=H,L} f_k S_k \tag{18}$$

On the other hand, the canonical model in (15) can be simplified by optimizing over N_k, first. First order conditions of this simplified problem with respect to $N_L$and N_H result in

$$\frac{N_H}{N_L} = \left(\frac{w_H}{w_L}\right)^{-\left(1+\frac{1}{r}\right)} \frac{S_H^{\frac{r_H}{r}}}{S_L^{\frac{r_L}{r}}}$$

which is exactly the same as (17). For a given set of $\{S_k\}$, we can solve for N_H and N_L and get $\bar{C} = \sum w_k N_k = Y\left(\sum_{k=H,L}\left(\frac{w_k}{S_k^{r_k}}\right)^{1-\rho}\right)^{\frac{1}{1-\rho}}$. This means that the canonical problem in (15) simplifies to

$$C(Y) = \min_{S_k} Y\left(\sum_{k=H,L}\left(\frac{w_k}{S_k^{r_k}}\right)^{1-\rho}\right)^{\frac{1}{1-\rho}} + \sum_{k=H,L} f_k S_k$$

which is equivalent to (18) if $\rho = 1 + \frac{1}{r} > 1$.

C Canonical Model

C.1 Proofs of lemmas, propositions and corollaries

Proof of Lemma 1:

For a given S_k, the first order conditions of the firm's conditional cost minimization problem with respect to N_H and N_L imply that the labor demand for type k is:

$$N_k = \frac{Y}{A} S_k^{\frac{\rho-1}{\rho_k-1}} \left(\frac{w_k}{\bar{W}}\right)^{-\rho} \tag{19}$$

where the aggregate wage index equals

$$\bar{W} = \left(\left(\frac{w_H}{S_H^{\frac{1}{\rho_H-1}}} \right)^{1-\rho} + \left(\frac{w_L}{S_L^{\frac{1}{\rho_L-1}}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{20}$$

thus:

$$\text{cost share of type } k \text{ labor} = \frac{w_k N_k}{\sum_{k'=H,L} w_{k'} N_{k'}} = \frac{S_k^{\frac{\rho-1}{\rho_k-1}} w_k^{1-\rho}}{\sum_{k'=H,L} S_{k'}^{\frac{\rho-1}{\rho_{k'}-1}} w_{k'}^{1-\rho}}$$

In the next step, I find the first order conditions with respect to S_k. I get:

$$S_k = \left(\frac{\bar{W}^{\rho} w_k^{1-\rho} Y}{(\rho_k - 1) f_k A} \right)^{\frac{\rho_k-1}{\rho_k-\rho}} \tag{21}$$

Note that from (20) we know that the wage index $\bar{W}$ is also a function of S_k. Therefore, we are facing a fixed-point problem. Using (21) for $k = H, L$ and combining them we find that the wage index $\bar{W}$ is the solution to the following problem:

$$\bar{W} = \left(\sum_{k=H,L} \left(\frac{\bar{W}^{\rho} Y}{g_k A} \right)^{\frac{\rho-1}{\rho_k-\rho}} \right)^{\frac{1}{1-\rho}} \tag{22}$$

where

$$g_k = (\rho_k - 1) f_k w_k^{\rho_k - 1} \tag{23}$$

RHS of (22) is decreasing in $\frac{Y}{A}$; thus, $\bar{W}$ is decreasing in $\frac{Y}{A}$.Moreover I define $Q = \frac{\bar{W}^{\rho} Y}{A}$. Therefore Q is the solution to the following equation:

$$Q = \frac{Y}{A} \left(\sum_{k=H,L} \left(\frac{Q}{g_k} \right)^{\frac{\rho-1}{\rho_k-\rho}} \right)^{\frac{\rho}{1-\rho}} \tag{24}$$

RHS of (24) is increasing in $\frac{Y}{A}$; thus, Q is increasing in $\frac{Y}{A}$. This definition of Q helps us to solve for the optimum degree of specialization S_k. We can rewrite (21) as:

$$\begin{aligned} S_k &= \left(\frac{w_k^{1-\rho}}{(\rho_k - 1) f_k} Q \right)^{\phi_k} \\ &= \frac{g_k^{1-\phi_k} Q^{\phi_k}}{(\rho_k - 1) f_k} \end{aligned}$$

where $\phi_k = \frac{\rho_k - 1}{\rho_k - \rho}$. Since Q is increasing in $\frac{Y}{A}$ and $\phi_k > 0$; thus S_k is increasing in $\frac{Y}{A}$. Moreover, since $r_H > r_L \Rightarrow \rho_H < \rho_L \Rightarrow \phi_H > \phi_L$. Therefore the relative specialization is also increasing in $\frac{Y}{A}$, since:

$$\frac{S_H}{S_L} = \frac{\left(\frac{r_H w_H^{1-\rho}}{f_H} \right)^{\phi_H}}{\left(\frac{r_k w_H^{1-\rho}}{f_k} \right)^{\phi_k}} Q^{\phi_H - \phi_L}$$

After finding S_k, I can now solve for the labor demand by plugging S_k back into (19). Then I get:

$$\begin{aligned} w_k N_k &= Q S_k^{\frac{\rho-1}{\rho_k-1}} w_k^{1-\rho} \\ &= Q \left(\frac{g_k^{1-\phi_k} Q^{\phi_k}}{(\rho_k - 1) f_k} \right)^{\frac{\rho-1}{\rho_k-1}} w_k^{1-\rho} \\ &= g_k^{1-\phi_k} Q^{\phi_k} \end{aligned}$$

thus $f_k S_k = \frac{w_k N_k}{\rho_k - 1}$ which means that the specialization cost of labor of type k is proportional to the cost of labor of type k with ratio of $\rho_k - 1$.

Similar to relative specialization, we get relative labor demand as

$$\frac{N_H}{N_L} = \frac{\left(\frac{w_H}{(\rho_H - 1) f_H}\right)^{\phi_H - 1} w_H^{-\rho\phi_H}}{\left(\frac{w_L}{(\rho_L - 1) f_L}\right)^{\phi_L - 1} w_L^{-\rho\phi_L}} Q^{\phi_H - \phi_L}$$

which is increasing in $\frac{Y}{A}$ since Q is.

Finally, the marginal cost is

$$\begin{aligned} mc\,(Y; A) &= \frac{\partial C(Y, \{S_k\})}{\partial Y} \\ &= \frac{\bar{W}}{A} \end{aligned}$$

which is decreasing in both Y and A since $\bar{W}$ is decreasing in Y and A.

Proof of lemma 2:

In the monopolistic market structure we have $Y = p^{-\sigma} D$ and the firm sets prices at $p = \frac{\sigma}{\sigma - 1} mc\,(y)$ .Therefore by using the definition of Q^* I get:

$$p = \left(\frac{D}{Y}\right)^{\frac{1}{\sigma}} = \frac{\sigma}{\sigma - 1} \frac{1}{A} \left(\frac{AQ^*}{Y}\right)^{\frac{1}{\rho}} \tag{25}$$

thus

$$Y = \left(\frac{\sigma - 1}{\sigma}\right)^{\frac{\rho\sigma}{\rho - \sigma}} D^{\frac{\rho}{\rho - \sigma}} A^{\frac{(\rho - 1)\sigma}{\rho - \sigma}} Q^{\frac{-\sigma}{\rho - \sigma}} \tag{26}$$

Since Q is also a function of Y, we have a fixed-point problem here, too. Manipulating the equations, it turns out that $Q\,(A, D)$ solves:

$$1 = \sum_k \underbrace{m^{\frac{\sigma(\rho - 1)}{\rho - \sigma}} g_k Q^{\phi_k + \frac{\sigma - 1}{\rho - \sigma}} \left(D^{\frac{1}{\sigma - 1}} A\right)^{-\eta}}_{s_k\text{:Cost share of type } k \text{ labor}} \tag{27}$$

where $g_k = ((\rho_k - 1)\, f_k)^{1 - \phi_k} w_k^{-(\rho - 1)\phi_k}$. Thus, $Q\,(A, D)$ is increasing in A and D. If the assumption $\rho_k > \rho > \sigma > 1$ holds, then second order conditions hold and hence, the solution exist.

Also by using the equation for p, it turns out that $p(A, D)$ is the solution to the following equation:

$$1 = \sum_k g_k m^{1-\rho\phi_k} D^{\phi_k - 1} A^{(\rho-1)\phi_k} p^{(\rho-\sigma)\phi_k+\sigma-1}$$

since $\phi_k - 1 > 0$,$(\rho - 1)\phi_k > 0$ and $(\rho - \sigma)\phi_k + \sigma - 1 > 0$, thus p is decreasing in D and A.

Next, by using (25) and (26) I can solve for the total revenue as well. Revenue R would also be a solution to an equation similar to above ones. But we can also represent it as:

$$R(A, D) = m^{-\frac{\rho(\sigma-1)}{\rho-\sigma}} \left(D^{\frac{1}{\sigma-1}} A\right)^{\eta} Q(A, D)^{\frac{1-\sigma}{\rho-\sigma}} \tag{28}$$

where $\eta = \frac{(\rho-1)(\sigma-1)}{\rho-\sigma}$. Using this representation and using the relationship of p, Y and R, it is easy to show that:

$$\begin{aligned} Y(A, D) &= m^{-\frac{\rho\sigma}{\rho-\sigma}} D^{\frac{\rho}{\rho-\sigma}} A^{\frac{(\rho-1)\sigma}{\rho-\sigma}} Q(A, D)^{\frac{-\sigma}{\rho-\sigma}} && (29) \\ p(A, D) &= m^{\frac{\rho}{\rho-\sigma}} D^{-\frac{1}{\rho-\sigma}} A^{-\frac{\rho-1}{\rho-\sigma}} Q(A, D)^{\frac{1}{\rho-\sigma}} && (30) \\ \Pi(A, D) &= \sum_k \frac{m^{\frac{\sigma(\rho-1)}{\rho-\sigma}} g_k Q(A, D)^{\phi_k}}{\eta_k} && (31) \end{aligned}$$

where

$$\begin{aligned} \eta_k &= \frac{(\rho_k - 1)(\sigma - 1)}{\rho_k - \sigma} \\ \eta &= \frac{(\rho - 1)(\sigma - 1)}{\rho - \sigma} > \sigma - 1 \end{aligned}$$

Moreover, using the labor demand equation in the last lemma, I can solve for the cost of labor of each type, as well. It turns out that:

$$C_k(A, D) = w_k N_k(A, D) = g_k Q(A, D)^{\phi_k} \tag{32}$$

thus the relative labor demand would be

$$\frac{N_H(A,D)}{N_L(A,D)} = \frac{w_L}{w_H}\frac{g_H}{g_L} Q(A,D)^{\phi_H - \phi_L}$$

which is increasing in A and D since $Q(A,D)$ is increasing in A and D and $\phi_H - \phi_L > 0$.

From the previous lemma it turns out that the specialization for each type of labor would be

$$S_k(A,D) = \frac{g_k Q(A,D)^{\phi_k}}{(\rho_k - 1) f_k} \tag{33}$$

Since Q is increasing in A and D, hence, the specialization level is increasing in A and D as well. Also, the relative specialization would be

$$\frac{S_H(A,D)}{S_L(A,D)} = \frac{\frac{g_H}{(\rho_H - 1) f_H}}{\frac{g_L}{(\rho_L - 1) f_L}} Q(A,D)^{\phi_H - \phi_L}$$

which is increasing in A and D since $\phi_H - \phi_L > 0$.

Finally Combining (28) and (27) results in (9).

Lemma 5 *(a) Elasticity of Q wrt D is $\zeta \equiv \frac{\Delta Q}{\Delta D} = \frac{1}{1 + \frac{\rho - \sigma}{\rho} \sum_k \frac{s_k}{\rho_k - \rho}}$ where s_k is the cost share of type k.*

(b) Elasticity of Q wrt A is $\frac{\Delta Q}{\Delta A} = (\sigma - 1)\zeta$.

(c) $0 \leq \zeta \leq 1$

Proof. (a) Using the definition of $Q(A,D)$, I take the elasticity from both sides of the equation (27) and I get:

$$1 = \sum_k \underbrace{m^{\frac{\sigma(\rho-1)}{\rho-\sigma}} g_k Q^{\phi_k + \frac{\sigma-1}{\rho-\sigma}} \left(D^{\frac{1}{\sigma-1}} A\right)^{-\eta}}_{s_k:\text{Cost share of type } k \text{ labor}}$$

$$0 = \sum_k s_k \left(\left(\phi_k + \frac{\sigma - 1}{\rho - \sigma} \right) \Delta Q - \frac{\eta}{\sigma - 1} \Delta D \right)$$

thus

$$
\begin{aligned}
\frac{\Delta Q}{\Delta D} &= \frac{\frac{\rho-1}{\rho-\sigma}}{\sum_k s_k\left(\phi_k+\frac{\sigma-1}{\rho-\sigma}\right)} \\
&= \frac{\rho-1}{\sigma-1+(\rho-\sigma)\sum_k s_k\phi_k} \\
&= \frac{1}{1+\frac{\rho-\sigma}{\rho}\sum_k\frac{s_k}{\rho_k-\rho}}
\end{aligned}
$$

(b) wrt A, we get

$$
0=\sum_k s_k\left(\left(\phi_k+\frac{\sigma-1}{\rho-\sigma}\right)\Delta Q-\eta\Delta D\right)
$$

thus

$$
\frac{\Delta Q}{\Delta A}=(\sigma-1)\,\zeta
$$

(c) since $\phi_k \geq 1$, hence $\sum_k s_k\phi_k \geq \sum_k s_k = 1$. Thus $\frac{\rho-1}{\sigma-1+(\rho-\sigma)\sum_k s_k\phi_k} \leq \frac{\rho-1}{\sigma-1+(\rho-\sigma)} = 1$. Finally since all the terms in $\frac{\rho-1}{\sigma-1+(\rho-\sigma)\sum_k s_k\phi_k}$ are positive, then $\zeta \geq 0$. ■

Lemma 6 *(a)Output, price and revenue have following elasticities with respect to demand indicator D:*

$$
\begin{aligned}
0 &\leq -\frac{\Delta p}{\Delta D}=\frac{1-\zeta}{\rho-\sigma}\leq\frac{1}{\rho-\sigma} \\
1 &\leq \frac{\Delta Y}{\Delta D}=1+\sigma\frac{1-\zeta}{\rho-\sigma}\leq 1+\frac{\sigma}{\rho-\sigma} \\
1 &\leq \frac{\Delta R}{\Delta D}=1+(\sigma-1)\,\frac{1-\zeta}{\rho-\sigma}\leq 1+\frac{\sigma-1}{\rho-\sigma}
\end{aligned}
$$

(b)Output, price and revenue have following elasticities with respect to productivity A:

$$
\begin{aligned}
1 &\leq -\frac{\Delta p}{\Delta A} = \left(1 + \frac{\sigma - 1}{\rho - \sigma}(1 - \zeta)\right) \leq 1 + \frac{\sigma - 1}{\rho - \sigma} \\
\sigma &\leq \frac{\Delta Y}{\Delta A} = \left(1 + \frac{\sigma - 1}{\rho - \sigma}(1 - \zeta)\right)\sigma \leq \left(1 + \frac{\sigma - 1}{\rho - \sigma}\right)\sigma \\
\sigma - 1 &\leq \frac{\Delta R}{\Delta A} = \left(1 + \frac{\sigma - 1}{\rho - \sigma}(1 - \zeta)\right)(\sigma - 1) \leq \left(1 + \frac{\sigma - 1}{\rho - \sigma}\right)(\sigma - 1)
\end{aligned}
$$

Proof. These results are straightforward using the previous lemma and equations (30),(29) and (28).

for example, from $p = m^{\frac{\rho}{\rho-\sigma}} D^{-\frac{1}{\rho-\sigma}} A^{-\frac{\rho-1}{\rho-\sigma}} Q(A, D)^{\frac{1}{\rho-\sigma}}$, we can get

$$
\begin{aligned}
\frac{\Delta p}{\Delta D} &= -\frac{1}{\rho - \sigma} + \frac{1}{\rho - \sigma}\frac{\Delta Q}{\Delta D} \\
&= \frac{\zeta - 1}{\rho - \sigma}
\end{aligned}
$$

Also since $0 \leq \zeta \leq 1$, then $0 \leq -\frac{\Delta p}{\Delta D} \leq \frac{1}{\rho-\sigma}$

The rest are proved the same. ■

Lemma 7 *If $\rho_H \to \rho$,$\rho_L \to \infty$ and $f_l \to 0$ then*

$$
Q \to ((\rho - 1) f_H) w_H^{(\rho-1)}
$$

Proof. In this limiting case $\phi_H \to \infty$ and $\phi_L \to 1$. Without loss of generality, I consider the convergence such that $(\rho_k - 1) f_k \to 1$. Therefore $g_L \to w_L^{-(\rho-1)}$. Thus, the equation that solves for Q would be simplified to

$$
1 = \left(((\rho - 1) f_H)\left(\frac{Q}{((\rho - 1) f_H) w_H^{(\rho-1)}}\right)^{\phi_H} + w_L^{-(\rho-1)}\right) m^{\frac{\sigma(\rho-1)}{\rho-\sigma}} Q^{\frac{\sigma-1}{\rho-\sigma}} \left(D^{\frac{1}{\sigma-1}} A\right)^{-\eta}
$$

if $\frac{Q}{((\rho-1)f_H)w_H^{(\rho-1)}}$ converges to any number other than 1, then RHS would explode or converges to zero. Hence

$$\frac{Q}{((\rho-1)\,f_H)\,w_H^{(\rho-1)}} \rightarrow 1$$

therefore

$$Q \rightarrow ((\rho-1)\,f_H)\,w_H^{(\rho-1)}$$

also

$$\left(\frac{Q}{((\rho-1)\,f_H)\,w_H^{(\rho-1)}}\right)^{\phi_H} \rightarrow \frac{m^{-\frac{\sigma(\rho-1)}{\rho-\sigma}}\left(((\rho-1)\,f_H)\,w_H^{(\rho-1)}\right)^{-\frac{\sigma-1}{\rho-\sigma}}\left(D^{\frac{1}{\sigma-1}}A\right)^{\eta} - w_L^{-(\rho-1)}}{(\rho-1)\,f_H}$$

■

C.2 Log Linearization

To better understand how the firm behaves, I look at the linearized form of the results. Let's define $\Delta X = \partial \log X$ as the percentage change in X and $\frac{\Delta X}{\Delta Z} \equiv \frac{\partial \log X}{\partial \log Z}$ to be the elasticity of X with respect to Z. For given $S_k' s$, log-linearizing the first order condition with respect to variations in Y and A results in

$$\Delta C_k = \Delta Y - \Delta A + \rho\Delta\bar{W} + \frac{\rho-1}{\rho_k-1}\Delta S_k \tag{34}$$

and

$$\Delta\bar{W} = -\sum_k \frac{\psi_k}{\rho_k-1}\Delta S_k \tag{35}$$

In the organizational problem of the firm, choosing optimum S_k results in $f_k S_k = \frac{C_k}{\rho_k-1}$; thus

$$\Delta S_k = \Delta C_k = \frac{\rho_k-1}{\rho_k-\rho}\left(\Delta Y - \Delta A + \rho\Delta\bar{W}\right) \tag{36}$$

So from (35) and (36), ΔS_k depends on $\Delta\bar{W}$ and vice versa, generating a feedback loop that is equivalent to the fixed-point problem (4). Solving the fixed-point problem results in

$$\Delta \bar{W}^{*} = -\zeta \left(\Delta Y - \Delta A \right)$$

and

$$\Delta S_k \left(Y \right) = \frac{\rho_k - 1}{\rho_k - \rho} \left(1 - \zeta \rho \right) \left(\Delta Y - \Delta A \right)$$

and

$$\Delta mc \left(Y \right) = -\left(\zeta \Delta Y + \left(1 - \zeta \right) \Delta A \right) \tag{37}$$

where $\zeta \equiv \frac{\sum_k \frac{\psi_k}{\rho_k - \rho}}{1 + \rho \sum_k \frac{\psi_k}{\rho_k - \rho}}$ and $0 \leq \zeta \leq \frac{1}{\rho}$.

Equation (37) shows how total production positively affects S_k and negatively affects marginal cost through the specialization channel which shows up in a single term ζ. It is evident from the definition of ζ that higher gains from specialization (lower ρ_k) lead to higher effects of total production on the marginal costs.

For the relative labor demand and relative skill specialization, I get

$$\Delta \left(\frac{C_H}{C_L} \right) = \Delta \left(\frac{S_H}{S_L} \right) = \frac{\left(\rho_L - \rho_H \right) \left(\rho - 1 \right)}{\left(\rho_L - \rho \right) \left(\rho_H - \rho \right)} \left(1 - \zeta \rho \right) \left(\Delta Y - \Delta A \right) \tag{38}$$

Since $\rho_L > \rho_H > \rho > 1$ and $\zeta < \frac{1}{\rho}$, I conclude that relative labor demand and relative specialization are positively correlated with production demand.

Lastly, note that in the Lower Boundary Case, where the gains from specialization are completely shut down by setting $\rho_H = \rho_L = \infty$, I get $\zeta = 0$. In this case, by shutting down the gains from labor specialization, the model converges to the standard Krugman-Melitz type model and total production has no effect on marginal cost. On the other hand, in the Upper Boundary Case where the relative gains from specialization is maximum by setting $\rho_H = \rho$ and $\rho_L = \infty$, I get $\zeta = \frac{1}{\rho}$ which is its maximum possible value. The effect of production on marginal cost is at the maximum level in this case.

D Details of Data and Quantitative Analysis

D.1 Background on Mexico's Trade Reform

From 1980 to 2000, Mexico faced several major economic and trade reforms. Over this period, the export and import rates increased to 31.4% and 33.25, from 10.7% and 13.0% , respectively. There were five major trade liberalization reforms in the 1980's: Maquiladoras liberalization (1983), Unilateral trade liberalization (WTO entry) and peso devaluation (50%) in 1985-87, FDI liberalization (1989), and Immigration reforms. Other than trade reforms, it also experienced Privatization, Labor Market, and Deregulation reforms as well. In the 1990's joining NAFTA and a large peso devaluations in 1994-1997 were two major changes to Mexican economic policies. NAFTA happened in the January of 1994, lowering many trade barriers among Mexico, the U.S. and Canada. In late 1994, the peso was devaluated about 80%; inducing a GDP free fall in constant prices by 6.5% as reported in Verhoogen 2008. Unemployment rose sharply to 6.9%, from 3.2%, (World Bank public data), and low-skilled workers' wages dropped over a year's duration to \$0.90 an hour, from \$1.50 an hour (Verhoogen 2008).

Over the period from 1985-1993 (pre-NAFTA), Mexico implemented large tariff and non-tariff barrier reductions. After four decades of import substitution industrialization, Mexico joined GATT/WTO in 1985. Maximum effective tariffs in manufacturing have been 80% prior to its joining the GATT. The average tariff was reduced to 11% in 1993, from 23.5% in 1985[13], and the share of manufacturing production subject to import licenses also dropped to 23.2%, from 92% (Harrison and Honson 1999).

Reforms in the years from 1985 to 1993 have affected workers disproportionately. Goldberg and Pavcnik (2007) report that from the 1980s until the mid-1990s, all measures of inequality, such as the skill premium, relative wages of white collar/blue collar employees, 90-10 log wage differentials, Gini of log wages. and Income Inequality (Gini), have increased.

[13] The maximum tariff before NAFTA was as low as 20% (Robertson 2004)

Table 3: Average real wages of Mexican workers

Education level	**1987**	**1993**	**Change**
Primary	0.56	0.60	0.08
Secondary	0.72	0.83	0.15
Postsecondary	1.11	1.86	0.68

Note: Average wages (1987 pesos) of Mexican workers with different levels of education in 1987 and 1993 (almost before and after the reforms)
Source: Cragg and Epelbaum (1996)

Cragg and Epelbaum (1996) document that the average wage of workers with postsecondary education relative to those with primary education have increased approximately 68%. According to Verhoogen (2004), the 90/10 percentile wage ratio of white-collar vs., blue-collar workers increased to 2.7 in 1993, from 2.0 in 1988 . Also. the average relative wage of white-collar/blue-collar workers increased to 2.54 in 1990, from 1.93 in 1984 (Hanson and Harrison (1999)). In the same period, white-collar real wages in pesos changed to 70.46 per hour, from 62.12, while the blue-collar real wages changed to 27.69. from 32.19.

Although total employment increased 7% in both groups, relative employment was rather stable at 0.43 during these years. Robertson (2000) reports that the relative wage of non-production workers has increased to 2.6 in 1994, from 2.3 in 1986, and then it declined to 1.7 in 1999. Also, their 90-10 log wage differential increased to 1.29, from 1.24, in 1994, and then dropped to 1.21 in 2000. Moreover, Hanson and Harrison (1999) find that the share of white-collar workers is higher in exporting firms than in non-exporting firms, which is another support for our theory. On the other hand, as Verhoogen (2004) documents, the total and within-industry variances of log real plant-level average hourly wages were rather stable from 1984 to 1993, showing that most changes in the skill premium attributes this to changes in the average payments across industries and plants. Figure 13 shows the wage inequalities during the reform years. Table 3 shows their average wages as they relate to different levels of education.

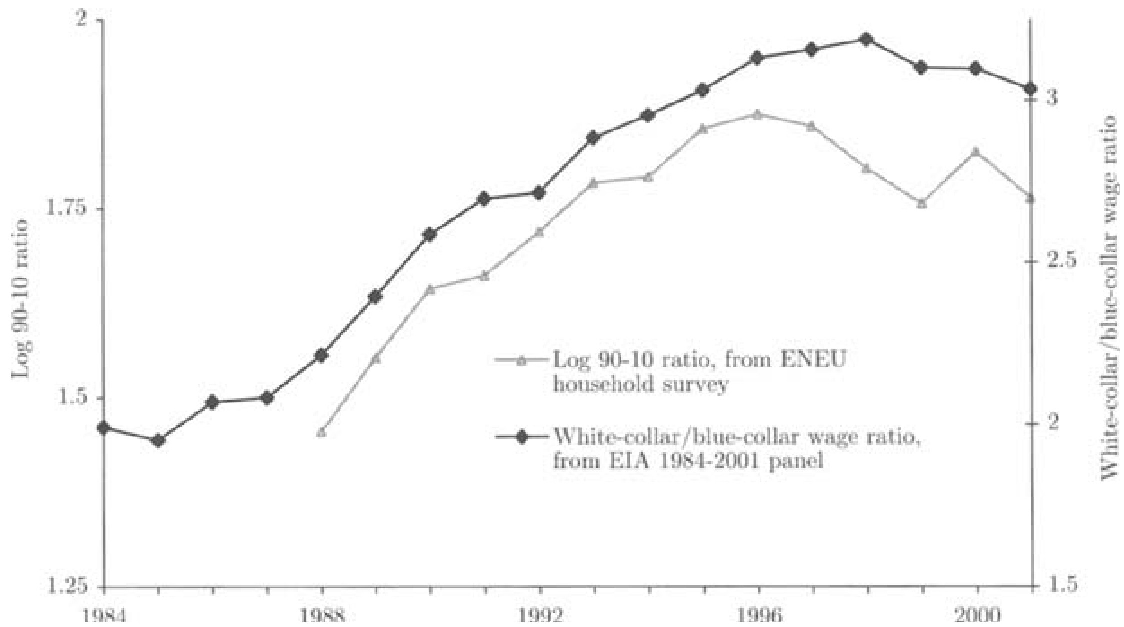

Figure 13: Wage inequality in Mexico during the reforms from 1984-2001. Source: Verhoogen (2008)

D.2 Calibration

The contribution of the paper is about the elasticities of substitution within a worker type; thus I first discuss about the calibration of these crucial parameters. In the literature, most of the works are concentrated on estimating the elasticity of substitution between skilled and unskilled labor such as Katz and Murphy (1992) whose estimate is 1.41. Krusell et al. (2000) estimate it to be 1.67. Ciccone and Peri (2005) estimate this elasticity of substitution to be 1.5. Blankenau and Cassou (2011) found 1.396 to be a good estimate. Stock et al. (2002) have a preferable number of 1.5 for the longrun elasticity of substitution. Last but the least, Behar (2010) has a very nice work which concludes an estimate of 2 for developing countries.

As the notion of elasticity of substitution within type is a rather a new concept in the literature, there is not quantitative measure in the literature for it and thus they should be identified using some micro data or using simulations. But fortunately there are some notions that support the idea of elasticity of substitution within types. Mollick (2011), in a very nice work shows that the elasticity of substitution between high and low skilled depends on how we define the skilled worker. This paper finds that for the "college educated" definition of skilled worker the estimates vary between 2.00 to 3.21; but for the "secondary-completed" definition the estimates vary from 3.53 to 4.07 and for the "primary-completed" definition the estimates are between 6.25 to 12.66. Similarly, Psacharopoulos and Hinchliffe (1972) has shown estimates of 2.2, 4.8 and 50 for different definitions sorted from higher threshold to lower thresholds as the definition of education. This analysis tell us that the substitution elasticity is lower with higher thresholds and the possibility of switching between the two types is less likely. In other words and in the context of my paper, their analysis supports the idea that substitution among higher levels of education is harder; in contrast, substitution among lower skilled workers is easier.

As they these two papers find higher values for lower thresholds, it means that the substitution of very low skilled and medium skilled workers are higher when we compare medium skilled worker with very high skilled workers. Basically, their estimates can give me some upper and lower bounds for the calibration process. Specifically, as the upper bound for the college educated definition is 3.21 in Mollick (2011), I set $\rho_H = 3.21$ as it should be a lower bound for the elasticity of substitution among high skilled since workers within a type are more substitutable than across type. Also as the number 6.25 is the lower estimate for the elasticity substitution for the lowest threshold, it can be a good lower bound for ρ_L as the low skilled workers are more substitutable among themselves relative to high skilled ones. So in order to be conservative in my analysis, I choose 3.21 and 6.25 for the two parameters of ρ_H and ρ_L respectively. For the elasticity of substitution between high skilled and low skilled workers, the literature shows different values as I discussed above and a conservative number for analysis can be $\rho = 2$. By the way, in my analysis, I simulate for different values of these parameters and show how robust the results are[14],[15].

To calibrate the rest of the model, I take some of the conventional parameters from the literature. For other variables, I match the related moments to the available data from micro level analysis in the literature. Table 4 shows the summary of the calibrated parameters to the data using the literature.

I take $\sigma = 2.5$ close to the average elasticity of substitution across goods. I calibrate $\theta = 5$ close to the preferred estimated value in the trade literature as Bernard et al. (2003). I use Verhoogen (2008) on Mexican data in 1993 for the white-collar employment share and set $\frac{N_H}{N_H+N_L} = 31\%$. For the variable trade costs d, I use Verhoogen (2008) to set the average tariff rates of Mexico on manufacturing in 1993 to 11%; so I set $d = 1.11$. With the purpose of price normalization, I set the foreign aggregate prices and measure of foreigner exporters to 1 $(p_f = 1, M_f = 1)$.

To calibrate the fixed specialization costs, I use the O*NET data from BLS on the average months of "on-the-job-training" for each occupation. Based on the average needed education, I categorize the occupations as high-skilled or low-skilled, based on the average required education for that occupation. If the average is greater than or equal to "college graduate" I call it a "high-skilled occupation" and the rest "low-skilled occupation," I then take the

[14] One could estimate these parameters if there were enough micro level data as well. According to (5), the labor demand for each type of workers in a firm depends on Y/A with an elasticity that depends on ρ and ρ_K for $K = H$ or L. Also (25) and (26) show that output Y and price p, both depend on A, the firm's productivity, and the demand indicator D, which is the same for all the domestic producers (in an industry). Therefore, by using the firm level data for Y, p, L_H, L_L One can use NLLS estimation and match these variables in the data with the model and identify ρ, ρ_H and ρ_L. Briefly, by assuming that Demand indicator D is the same for doemstic producers within an industry, matching data on Y and p would identify ρ and also it gives us an estimate of A_i for each domestic producer i; since the term D appears as a fixed constant term for domestic producers and it disappears when we take differences of $\log(Y)$ or $\log(p)$ for the firm i with that of a benchmark firm indexed by firm$_0$. Then, for each $K = H$ or L, the difference of the $\log(L_K)$ for firm i and firm$_0$, depends only on the log-difference of Y_i/A_i with a coefficient that depends on ρ and ρ_K. This means that matching $\log(N_{K,i}) - \log(N_{K,0})$ can identify ρ_K. In other words, equations (5), (25) and (26) can identify ρ_H, ρ_L and ρ.

[15] Another way to identify ρ_K is to use a calibrated value for ρ from the literature and the use equation (5) to identify ρ_H, ρ_L using the same procedure mentioned above. Basically, we use (26) to calculate A_i and use it in (5) to identify ρ_H, ρ_L by differencing the log values for two domestic producers. In other words, differencing between two domestic producers' labor demand helps us to get rid of fixed effect terms which depend on the industry level measures and thus the elasticities of substitutions can be identified.

Table 4: Calibration Results

Parameter	Calibrated Value	Description
ρ	3.2	Elasticity of substitution across H,L
ρ_H	3.3	Specialization gain parameter of high-skilled
ρ_L	6	Specialization gain parameter of low-skilled
σ	2.5	Goods elasticity of substitution
θ	5	Ex-post firm sale heterogeneity param.
p_f	1	Foreign aggregate price
N_H/N	0.31	white collar fraction of employment
N	1	Total employment
f_H/f_L	1.61	Relative fixed specialization costs
f_H	0.068	high-skilled fixed specialization costs

Note: Calibration of fundamental parameters and variables of the Model

average over the months of "on-the-job-training" for each high- or low-skilled occupation and set $\frac{f_h}{f_l}$ to be the ratio of these two averages. To calibrate f_H,I use Caliendo and Rossi-Hansberg (2012) finding that 11% of the industry is involved with the teaching activity. I use the rest of the variables in the matching-moment part.

Now to identify and calibrate four parameters, $\bar{f}_x$,D_f,$\bar{f}_e$ and β (relative productivity parameter of high-skilled vs. low-skilled workers.[16]), I match four moments of the model with the actual data. I use the statistics from Verhoogen (2004) which covers around 3000 Mexican manufacturing firms in 1993. First, I match the fraction of exporters to 30% to identify $\bar{f}_x$. Then I match export share of sales to 17.43% to identify D_f. Next, I match the skill premium (average relative wage of white collars vs. blue collars) to 2.80 to calibrate β and I match the average number of employees per firm $\frac{N}{M_e}$ with 240.8, to identify $\bar{f}_e$. Table 5 shows the results of this matching. Our matching is just identified and all the moments were fully fitted with their counterpart values. Having all the parameters calibrated and estimated, I use the algorithm of the previous section to solve for the equilibrium in the counterfactual economy to see how the model responds to different policies.

[16] In the theory section, I took this to be one. But here I allow it to be different than one and I calibrate it.

Table 5: Matching moments results: Mexico

Description	Parameter	Matched Value
Fixed export cost	$\bar{f}_x$	$9.0e-03$
Foreign demand indicator	D_f	$4.4e-04$
Relative skill intensity	β	3.84
Fixed sunk entry cost	$\bar{f}_e$	0.036

Note: Estimation results for the fundamental parameters of the Model by matching the simulated moments to the ones in the data for Mexico in 1993.

D.3 Equilibrium Allocations in the small open economy case

In this section, I concentrate on the general case of the model in a small open-economy setting. The reason is that the motivating empirical fact for this paper is the puzzle in the rise of the skill premium in developing countries after the opening of trade, and these countries are mostly small economies. They face a large market when they begin to trade, and this increase in demand is the most relevant force in raising the skill intensity of the new exporters, through labor specialization, and driving up the relative demand for skilled workers, hence boosting the skill premium.

In a small open-economy context, the trading country is large enough such that the home country cannot affect the prices and wages in the foreign country. I take the foreign aggregate demand $\left(D_f = P_f^{\sigma-1} X_f\right)$, the marginal cost of production of foreigners (p_f), and the measure of foreign exporters $(M_{ef} = 1)$ as given exogenously, so that any changes in the home country cannot affect them. As before, there is free entry with endogenous measure M_e of potential entrants at home. I also assume that the fixed costs are paid in terms of high- and low-skilled labor evenly[17]such that $f_e = \frac{w_H \bar{f}_e + w_L \bar{f}_e}{2}$ and $f_x = \frac{w_H \bar{f}_x + w_L \bar{f}_x}{2}$. For the fixed cost of specialization, I assume that skill type k uses labor of the same type. Lastly, for simplicity and without loss of generality, I assume that there are no operational fixed costs $(f_o = 0)$. Therefore all the potential firms would produce at least in the home market.

[17]The results are qualitatively robust to changes in these assumptions.

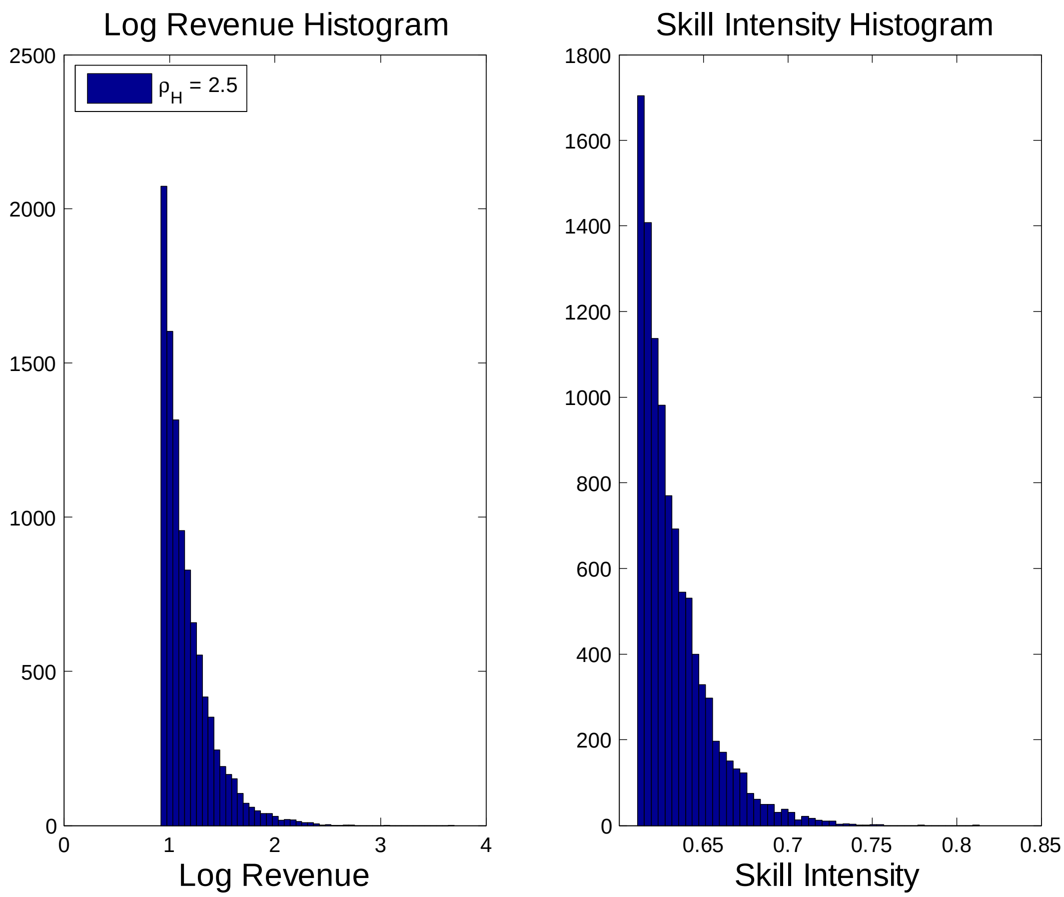

Figure 14: Distribution of revenues (Left) and skill intensities (Right) of firms with Pareto distribution productivity.

Because of the assumption of zero operational costs, every firm enters, and $\mu_o = 0$. A firm enters the export market, if $\Pi(A, D + D_f) - \Pi(A, D) \geq f_x$. This condition pins down the threshold $\bar{A}_x$ enabling firms with productivity $A \geq \bar{A}_x$ to export. It also solves for the fraction of exporters μ_x, given demand D and wages w_H and w_L.

In this section, I present the aggregate behavior of the economy and equilibrium allocations in general and I continue with the assumption of Pareto distribution for the firms' productivities. It turns out that revenue and skill intensity have a distribution similar to the one in Figure 14.

As mentioned in lemma 2, revenue $R(A, D)$ of a firm with productivity A is the solution to (9). Therefore the aggregate revenue equals $\bar{R}(D; D_f) = M_e\left((1-\mu_x)\bar{R}_d + \mu_x \bar{R}_x\right)$ where $\bar{R}_d(D) = g_k E\left[R(A, D) \mid A \leq \bar{A}_x\right]$ and $\bar{R}_x(D; D_f) = g_k E\left[R(A, D + D_f) \mid A > \bar{A}_x\right]$ are the average revenue of non-exporters and exporters respectively. Since for each firm, price p is such that $p = \left(\frac{R(A,D)}{D}\right)^{\frac{1}{1-\sigma}}$ which can be shown that it is a decreasing function in A and D. Therefore the aggregate price index is the solution to the fixed-point problem

$$P = \left(M_e \left((1 - \mu_x) \frac{\bar{R}_d (D)}{D} + \mu_x \frac{\bar{R}_x (D + d^{1-\sigma} D_f)}{D + d^{1-\sigma} D_f} \right) + (d_f p_f)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

where $D = P^{1-\sigma} X$. The left-hand side is linearly increasing in P. It can easily be shown that the right-hand side is decreasing in P. Therefore the price index has a unique solution . In partial equilibrium, where wages, aggregate expenditure, and measure of entrants is given, one can solve numerically for price index. It is easy to show that any comparative statics that increases the RHS would increase P.

Similar to the Upper Boundary Case, reducing trade costs affects the aggregate price index through different channels. Reducing d_f, the importing trade costs, reduces the price of the imported goods, reducing the aggregate price index. A decrease in exporting trade costs d increases the exporting firms' demands, increasing their degree of specialization, and therefore their labor productivity. So it decreases the exporters' prices, reducing the aggregate price index. Also, a reduction in d affects the aggregate price index tremendously through the extensive margin. Since a decrease in d increases the foreign demand, it motivates many non-exporters to specialize and to expand their organizations to become more productive and export. Therefore they also reduce their prices.

Note that the reduction in the aggregate price pushes the aggregate home demand down. Therefore, domestic producers would face lower aggregate demand after trade cost reductions. New exporters face a larger demand from the export market while old exporters' aggregate demand may increase or decrease. The reason for this is that from one side they face the Direct Channel of reduction in d, and at the same time they face the Indirect Channel of reduction in aggregate prices and hence reduction in aggregate demand. Similar to the Upper Boundary Case, it can be shown that a reduction in trade costs raises the aggregate demand initially, but decreases it after a certain threshold.

Also recall that the cost of labor of type k equals

$$C_k(A,D) = g_k \left(m^{\rho} D^{\frac{1}{\sigma-1}} AR(A,D)^{-\frac{\rho-\sigma}{\sigma-1}} \right)^{\frac{\rho_k-1}{\rho_k-\rho}}$$

Therefore the aggregate cost of type k labor for production (excluding those costs related to the fixed costs of specialization, entry or exporting) can be simplified to $\bar{C}_k = M_e\left((1-\mu_x)\bar{C}_{kd} + \mu_x \bar{C}_{kx}\right)$, where $\bar{C}_{kd}$ and $\bar{C}_{kx}$ are the average labor demands of domestic producers and exporters, respectively[18].

Non-monotonic behavior of aggregate demand, with respect to trade costs for the old exporters and the negative correlation of trade costs and aggregate demand for domestic producer have generated a non-monotonic behavior of aggregate relative labor demand in regard to trade costs in the whole industry. It is shown numerically that reducing trade costs from autarky toward free trade would increase aggregate relative labor demand initially but it may result in a decrease after a certain threshold.

For the general equilibrium analysis, three more conditions would determine all the allocations and prices endogenously and pin down wages w_H and w_L, measure M_e of potential firms and aggregate expenditure X: Labor markets clearing, balanced trade, and aggregate zero profit:

[18] $\bar{C}_{kd} = g_k E\left[C_k(A,D) \mid A \leq \bar{A}_x\right]$ and $\bar{C}_{kx} = g_k E\left[C_k(A,D+D_f) \mid A > \bar{A}_x\right]$

$$
\begin{aligned}
\text{(Low-skilled labor market) } w_L L &= \frac{\rho_k}{\rho_k - 1} M_e \left((1-\mu_x) \bar{C}_{Ld} + \mu_x \bar{C}_{Lx} \right) + \\
&\quad \left(M_e w_L \bar{f}_e + M_e \mu_x w_L \bar{f}_x \right) /2 \\
\text{(High-skilled labor market) } w_H H &= \frac{\rho_k}{\rho_k - 1} M_e \left((1-\mu_x) \bar{C}_{Hd} + \mu_x \bar{C}_{Hx} \right) + \\
&\quad \left(M_e w_H \bar{f}_e + M_e \mu_x w_H \bar{f}_x \right) /2 \\
\text{(Aggregate zero profit) } 0 &= \sum_k \left(\frac{\sigma}{\sigma - 1} - \frac{\rho_k}{\rho_k - 1} \right) \left((1-\mu_x) \bar{C}_{kd} + \mu_x \bar{C}_{kx} \right) \\
&\quad - \mu_x \left(w_H \bar{f}_x + w_L \bar{f}_x \right) /2 - \left(w_h \bar{f}_e + w_L \bar{f}_e \right) /2 \\
\text{(Balanced trade) } X &= w_H H + w_L L
\end{aligned}
$$

Note that since I have taken the foreign supply price as the numéraire and set it equal to 1, I need to solve for both wages and home aggregate price.

As discussed earlier, in partial equilibrium a reduction in trade costs reduces the aggregate price index. However, the aggregate demand initially increases, but then it decreases because of the Indirect Channel. Therefore the aggregate skill intensity may go up first and then come down.

In general equilibrium, beside the Direct and Indirect Channels, there is a third channel that affects the aggregate demand and aggregate skill intensity; name it Wage Channel. Basically, high-skilled and low-skilled wages have asymmetrical effects on the labor demand, since the gains from specialization of workers of different types are different ($\rho_H < \rho_L$). Therefore when high-skilled wages are large enough, firms find it more expensive to employ more high-skilled; therefore they tend to employ more low-skilled workers. Hence, a large reduction in trade costs affects wages such that it may lead firms to decrease their skill intensity as a result of this channel. Consequently, the skill premium may go down with trade liberalization. These three channels have been discussed in the numerical section of this paper in more detail. I conclude that in the general equilibrium, by reducing trade costs, the skill premium initially rises and then it falls.

D.4 Algorithm to Solve for the Equilibrium

To solve for the equilibrium allocation, I first take all the parameters as given and show how to find the allocations and prices. Then I calibrate some of the parameters using the existing literature. I then match some moments of the model to the actual available data and estimate the rest of the parameters. Finally, I take the parameters and simulate the model under some actual and counterfactual changes in the parameters.

The following algorithm solves for the equilibrium allocation numerically and by simulation:

1. Take all the parameters $\sigma, \theta, \rho_k, \rho, \beta, f_k, D_f = d^{1-\sigma} P_f^{\sigma-1} X_f, p_f, M_f = 1$ as given.

2. Take N random draws $u_i : i = 1...N$ from uniform distribution and construct random sample productivity variables A_u Given parameter θ by setting $A_u = u^{-1/\theta}$. Sort firms by their productivities so that Monte Carlo simulation in simulating their behavior can be faster. These variables will be fixed throughout the process.

3. Guess a value for μ_x (Fraction of exporters)

4. Mark fraction μ_x of the most productive firms (those with highest A_u) as exporters.

5. Solve the fixed-point problem $T(\phi^*) = \phi^*$ for $\varphi = (w_H, w_L, D, M_e)$. Define $T(\varphi)$ as

    (a) For random sample u, set $D_u = D + D_f$ if u is an exporter; otherwise set $D_u = D$.

    (b) For each random productivity A_u, solve for the sufficient variable

    $$Q_u 1 = \sum_k m^{\frac{\sigma(\rho-1)}{\rho-\sigma}} g_k v_u^{-\eta} Q_u^{\phi_k + \frac{\sigma-1}{\rho-\sigma}}$$

    where $v_u = D_u^{\frac{1}{\sigma-1}} A_u$

(c) Find the profit of the firm A_u by

$$\Pi\left(A_u\right) = \left\{ \begin{array}{cc} \sum_k \frac{C_{k,u}}{\eta_k} & \text{if non-exporter} \\ \sum_k \frac{C_{k,u}}{\eta_k} - w_h \bar{f}_x & \text{if exporter} \end{array} \right\} \tag{39}$$

where $C_{k,u} = g_k Q_u^{\phi_k}$

(d) Set

$$w_L^* = \frac{M_e m_L}{L_L} * \text{mean}(C_{L,u}) \tag{40}$$

$$w_H^* = \frac{M_e m_H}{L_H} * \text{mean}(C_{H,u}) + M_e w_H \bar{f}_e + M_e \mu_x w_H \bar{f}_x \tag{41}$$

$$K^* = P^{\sigma-1} X \tag{42}$$

where $X = \sum_k w_k^* L_k$ and
$P = \left((dp_x)^{1-\sigma} + M_e * \text{mean}\left(m^{\frac{-\rho(\sigma-1)}{\rho-\sigma}} D_u^{\frac{\sigma-1}{\rho-\sigma}} A_u^{\eta} Q_u^{\frac{1-\sigma}{\rho-\sigma}} \right) \right)^{\frac{1}{1-\sigma}}$.

(e) Set $T(\varphi) = (w_h^*, w_l^*, K^*)$

6. Set $d\Pi = \Pi_{ux} - \Pi_{ud}$ where Π_{ux} is the profit of the least productive exporter (lowest A_u among exporters) and Π_{ud} is the profit of the most productive non-exporter (highest A_u among non-exporters.).

7. Do a grid search on μ_x to find ϕ^* such that $d\Pi \geq 0$ and that it is the minimum possible amount.

Given the model parameters, the above algorithm can solve for the equilibrium allocation. To set the model parameters, I calibrate some parameters using the data in the literature and for others, I match some moments of the model to the actual data. Then, for the counterfactual analysis, I need to change the model parameters and solve for the equilibrium again.

To do so, I use a shortcut in the above algorithm. Since I have data on the fraction of exporters both in the calibration and the counterfactual world, I set μ_x to the value from data; but in step 7 I solve for the policy instrument or the other matching moments values. Thus steps 5, 6, and 7 simplify to

- Solve $\begin{bmatrix} T(\phi) - \phi \\ d\Pi \\ \text{moments} \end{bmatrix} = 0$

This means that I solve for the equilibrium, policy instrument and/or parameters of moments-matching, all at the same time. This algorithm speeds up the process of simulation and analysis dramatically.

D.5 Comparative Statics

In this section, I keep the policy variables unchanged, but deviate from the calibrated economy by changing some important parameters of the models. I show some comparative statics for changes in ρ_H,ρ_L, and f_H (fixed-specialization cost of high-skilled workers). I show how changes in these variables affect the calibrated economy and also the simulated economy in the counterfactual world. In my counterfactual analysis, I vary these parameters so that the extensive margin of trade becomes equal to 40%. Then I can compare the responsiveness of the model in regard to changes in these variables, especially the trade-related ones.

As it has been shown in the theoretical section, parameters ρ_H and ρ_L are inversely related to the gains from labor specialization. Also, it was shown that their distance from each other enhances the model's power in changing the skill intensity at the firm and industry levels. And I also showed that maximum gains are attained when ρ_L goes to infinity and ρ_H is close to ρ (the elasticity of substitution between high- and low-skilled workers). Table 6 shows how changes in ρ_H would change the skill premium, intensive and extensive margins of trade, and aggregate welfare . Higher ρ_H means that high-skilled workers gain less from concentration and focus on more tasks. Thus their productivity would be lower, inducing

Table 6: Comparative Statics

	Benchmark	**(1)**	**(2)**	**(3)**
ρ_H : High-skilled spec. param.	3.3	3.65		
ρ_L : Low-skilled spec. param.	6		3.82	
f_h : Fixed Specialization cost of High-skilled	.068			0.296
Skill premium	2.80	2.71	2.5	1.79
Fraction of exporters	.30	.40	.40	.40
Export share of total production	12.6%	12.8%	13.8%	14.0%
Change in Agg. Welfare		1.3%	.3%	22.6%

Note: This table demonstrates how changes in the calibrated values of ρ_H, ρ_L and f_H (the first three rows) affect the predicted moments (rows 4-6) with the data in 1993 and the changes in the predicted increase in the aggregate welfare before and after trade liberalization of 1985-1993 in Mexico (row 7).

firms to invest less in their specializations. The firm's level of labor specialization and of organizational expansion (in favor of high-skilled workers) decreases. This would lower a firm's skill intensity and its productivity. In the aggregate, since all firms are facing the same changes, total aggregate skill intensity and aggregate productivity would go down.

Comparative static results regarding changes in ρ_L have been reflected in the third column of Table 6. Lower ρ_L means that the gain from specialization of low-skilled workers is more. Therefore a firm invests more in their specialization, and thus its skill-intensity decreases. Overall skill intensity and relative skill demand decreases; thus the skill premium goes down. It is clear that the effect of changes in ρ_L on the extensive margin of trade is lower than ρ_H. It is needed to have a large change in ρ_L to increase the extensive margin of trade to 40% in contrast to a small change in ρ_H, which can generate the same results.

Then, I analyze the effect of changes in the fixed specialization costs of high-skilled workers f_H. When this cost rises, a firm invests less in the specialization of high-skilled workers, decreasing its skill intensity and labor productivity. Thus, it is expected to have lower skill premium and lower aggregate welfare. Column four of Table 6 reflects these results.

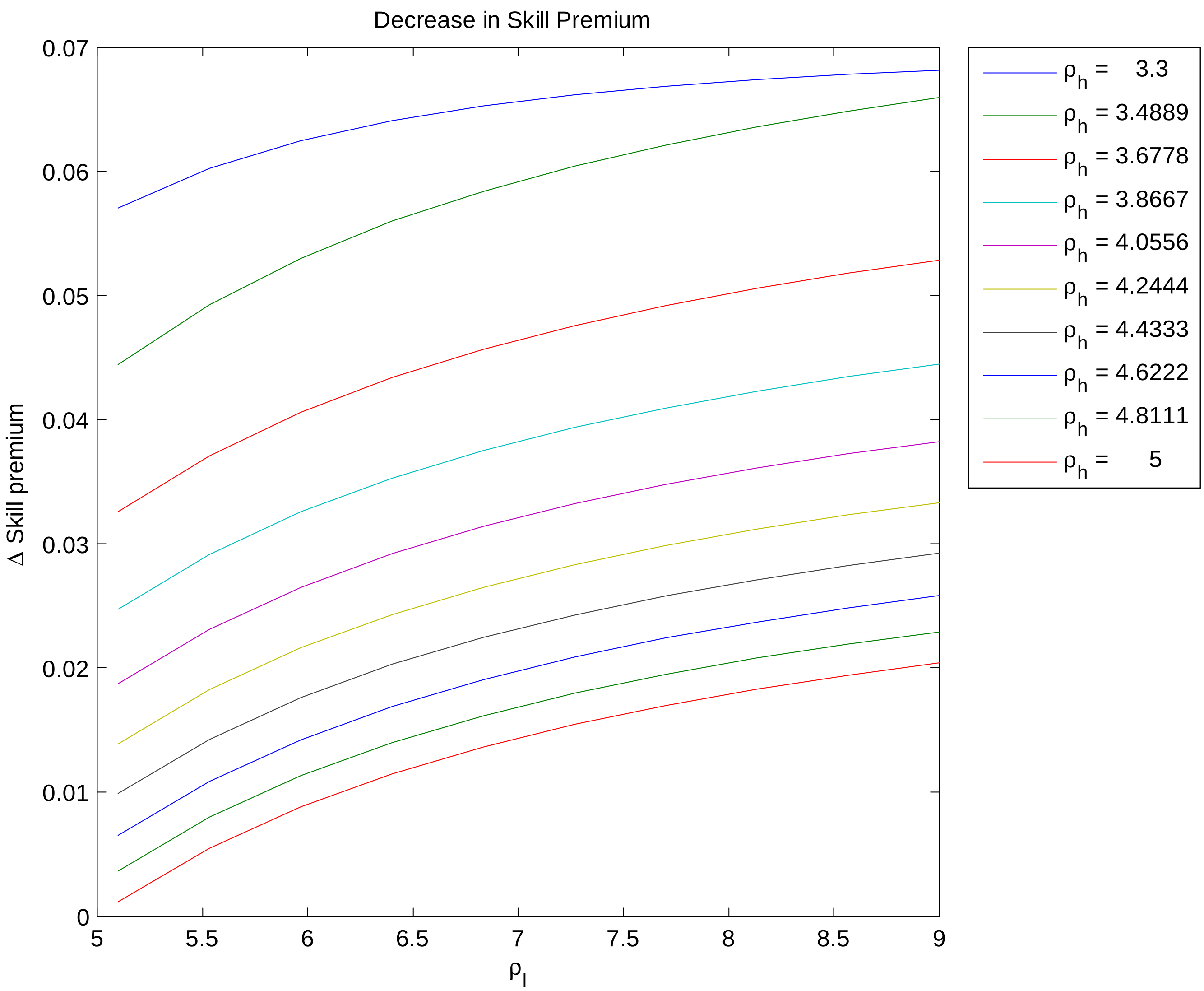

Figure 15: Simulated predicted changes (decrease) in skill premium before and after the trade liberalization period (1985-1993 in Mexico) with different values ρ_H and ρ_L.

In the next step, I vary both fundamental parameters ρ_H and ρ_L, calibrate and simulate the model repeatedly to investigate how much the counterfactual skill premium would change when one makes different choices for these two fundamental parameters. The reason is that these two parameters cannot be calibrated easily using standard and available micro data; thus this comparative statics would show robustness of the results and the extent of the model in predicting the changes in the skill premium. Figure 15 shows the amount of decreases in the skill premium if I reduce the fraction of exporters from 30% to 10% (counterfactual of going from 1993 to 1985) by changing the bilateral trade costs. As expected, the maximum reduction in the skill premium happens when ρ_H is at its minimum and ρ_L is at its maximum possible value. Also the effectiveness of the model in explaining the changes in the skill premium increases as the two parameters are further from each other; the effectiveness disappears if these two values are the same.