International Trade, Skill Premium and Endogenous Firm Organization

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Abstract

This paper shows theoretically and quantitatively that differences in the specialization of skilled and unskilled workers can explain the increase in the skill premium following trade liberalizations, independent of a country to be in South or in North. Production in the model requires combining perfectly substitutable low-skilled workers with imperfectly substitutable skilled workers who work in different divisions of the firm. More specialized divisions make the high-skill workers more productive but at the same time setting up a new division requires paying a fixed cost by the firm. I then show that in a general equilibrium setting with heterogeneous firms, trade cost reduction induces more productive firms to take advantage of this economy of scale and become more specialized. This increase in specialization increases both exporters' productivity and their demand for high-skilled labor endogenously, resulting in a rise

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in the skill premium. Moreover, as a result of endogenous choice of the level of specialization the aggregate productivity of the economy increases beyond Melitz-type models in which increase in productivity comes merely from reallocation of resources to more productive firms. Finally, I calibrate the model to the US data and show that a 20% decline in trade costs increases the skill-premium by 6%.

Keywords: International Trade, Skill Premium, Labor Specialization, Endogenous Skill Intensity, Firm Organization

JEL: F12, L22, J3

1 Introduction

The rise in income inequality following trade integration in the past three decades is a striking and robust empirical fact. Both developed and developing countries have experienced increases in skill premia[1] after their liberalization periods. This is in contrast to the predictions of standard trade models, such as Heckscher-Ohlin, which anticipate the skill premium to decline in developing countries after a reduction in trade costs.

Empirical researches show trade openness induces reallocations in the labor market between firms in an industry, especially by guiding high-skilled workers toward more productive and export-oriented entities, while increasing the skill intensity and organizational complexity of these firms. In view of these facts, one natural question here could be whether there exists any firm-level decision that may lead to the rise in skill premia in the process of trade liberalization.

To address this question, this paper proposes and quantifies a tractable model of international trade with endogenous firm organization and labor specialization. In this new framework, consistent with these empirical findings[2], I show how international trade openness, whether in a North or a South country, induces firms to take advantage of the imperfect

[1] Skill premiums refer to the relative wages of high skilled to low skilled workers.

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

substitutability of high-skilled workers and increase their own skill intensity endogenously[3]. I show how firms' decisions on their division of labor and horizontal organizational expansion result in a rise in the skill premium after trade liberalization.

In this model, a firm hires perfectly substitutable low-skilled workers and imperfectly substitutable high-skilled workers to produce the output. High-skilled workers operate in several imperfectly substitutable groups or divisions; each group has specific specialties and is assigned tasks that can hardly be assigned to others, making them imperfect substitutes.

For example, it is not easy to substitute a surgeon with a nurse, or an MBA graduate with an engineer. A firm needs to assign tasks requiring specialties to groups of high-skilled workers that are not perfectly substitutable with each other. Therefore, a firm benefits more from the specialization of high-skilled workers due to their imperfect substitutability.

Moreover, a firm enjoys higher gains from assigning special tasks to more divisions of high-skilled workers by paying a fixed cost to set up each division. These fixed costs could be in the form of training, capital purchases, coordination or monitoring costs. The firm can take advantage of these specialization groups and its additional labor divisions among high-skilled workers, and increase the firm's labor productivity.

The trade-off between paying these costs and the gains resulting from the specialization of high-skilled workers determines the optimal number of divisions in this framework, which I call "horizontal expansion" of the firm, and it endogenously determines the firm's skill intensity. This trade-off generates an economy of scale: a firm's higher production demand or higher productivity results in more specialization groups, making the firm more skill intensive. Thus, an increase in a firm's production demand or an increase in its productivity can lead to its decision for expanding its organization horizontally. This biased expansion consequently increases a firm's relative labor demand for high-skilled workers.

The market structure in this model is similar to the Melitz (2003) model of trade. There are potential heterogeneous firms to enter: they pay a sunk cost and their productivity shock

[3] See Rossi-Hansberg, Caliendo and Monte (2011 & 2012) for the effect of international trade on the organization of firms.

is then realized from a cumulative distribution function. If production is profitable, the firm pays a fixed cost of production, organizes itself as explained above and then produces its goods to sell in a monopolistic market. The monopolistic rent should pay for all the fixed cost and this would endogenously determine the threshold for the entry.

Free entry determines the size of the market. If the economy is open to trade, a firm should pay a fixed cost of export. This would entail that only more productive firms can export. Again, the rent from exporting determines the productivity threshold for exportation.

International trade introduces a higher demand for the industry, inducing more productive firms to reorganize and increase their division of high-skilled workers, be more specialized and become more skill intensive and more productive before exporting[4]. Therefore, the model predicts that exporters become more productive, attain a higher level of specialization and get more skill intensive. The prediction is consistent with the findings in the data, like the one in Bustos (2011a).

I show that more openness in trade induces a rise in the industry's aggregate skill intensity; it results in higher demand for high-skilled workers relative to low-skilled ones, generating a reallocation of high-skilled labor toward exporting firms. Starting from Autarky, a reduction in trade costs would increase aggregate relative labor demand toward high-skilled workers.

In general equilibrium with two symmetric open countries, I show analytically that a bilateral reduction in trade costs results in higher aggregate specialization, higher aggregate productivity, and higher aggregate skill intensity.

Furthermore, trade openness raises relative labor demand for high-skilled workers, but as the relative supply of high-skilled workers is fixed, trade openness would inevitably result in a rise in the skill premium, whether in a South or a North country. This fact is consistent with decades of observations from developed and developing countries, as surveyed in Pavcnik

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

and Goldberg (2007).

A byproduct of the described model is the introduction of a new channel for gains from international trade, too[5]. As previously described, trade integration endogenously increases the old and the new exporters' degree of specialization, raising their overall productivity and consequently aggregate productivity. The increase in aggregate productivity would translate into a reduction in aggregate prices and increases in real wages, making this mechanism a new source for trade gains.

Finally, to show how the model behaves quantitatively, I calibrate the model to US data by matching the identifying moments from the model to the ones in the US data. I match the model's prediction for the skill premium, fraction of exporters and the firms' death rate with the US data to calibrate the specialization fixed costs, exportation fixed costs and the entry sunk costs. I calibrate other parameters from other related literature before analyzing counterfactual scenarios to find out how much of the changes in trade costs or the specialization cost affects the skill premium. I find that with a 20% rise in US trade costs, the skill premium decreases by 6% and the aggregate welfare drops by 5%.

Related Literature: The goal of the paper is to propose a framework consistent with salient features of data and show how trade liberalization can raise the global skill premium through firm-level decisions. Empirical findings show that the skill premium has been increased in the developed and developing countries, post trade liberalizations[6].

Also, it has been shown that most of the resource reallocations due to trade cost reduction have occurred within industries and there is an increase in demand for skilled workers in sectors with larger tariff cuts[7]. In addition, the data show more skill-intensive and produc-

[5] See Chaney and Ossa (2012) asa closely related work.

[6] For the evidence on the rise in skill premium, see: For Latin Americans Countries: Schady and Paramo-Sanchez (2003), Gasparini (2003), Robbins (1996), Argentina: Gasparini (2003); Brazil: Dickerson, Green, Dickerson, Arbache (2001), Gasparini (2003); Chile: Ferreira and Litchfield (1999), Robbins (1995), Beyer et al. (1999), Pavcnik (2003); Mexico: Robertson (2004), Hanson (2004), Cragg and Eplebaum (1996); India: Kijima (2006), Topalova (2004a), Deaton and Dreze (2002); Colombia: Attanasio et al (2004); India: Kijima (2006), Topalova (2004a), Deaton and Dreze (2002); Hong-Kong: Hsieh and Woo (2005); China: Xubei Luo and Nong Zhu (2008); Europian Union: Acemoglu and Autor (2010)

[7] Pavnick (2007), Wacziarg and Wallack (2004)

tive firms are involved in export activities[8] and have a higher complexity of organization[9]. Followed by this literature, in this paper, my goal is to propose a new theoretical framework explaining and connecting these facts through firms' endogenous decisions (See also He (2012) and Limao et al. (2013))..

The impact of international trade on inequality is a classical question in economics. Traditional theories like Stolper-Samuelson Theorem predict a decline in the skill premium in unskilled labor-abundant countries through an inter-industry reallocation of labor. These predictions are in sharp contrast to the recent empirical researches surveyed in Goldberg and Pavcnik (2007)[10].

To explain this puzzle, as surveyed in Goldberg and Pavcnik (2007) and Acemoglu and Autor (2011), recent new theories have examined the problem through different channels. However, the current paper proposes a new channel that complements the literature showing that the rise in skill premium after liberalization is because of the larger market size, be it in a North or a South country.

Feenstra and Hanson (1996, 1997, 1999, 2003) show that following trade openness, developed countries outsource intermediate production into countries with less expensive labor. The production of these intermediate goods raises demand for high-skilled workers from developing countries and thus raises their skill premium.

Burstein and Vogel (2010), Parro (2010), Krusell et al. (2000), Stokey (1996) and Cragg and Epelbaum (1996) use the complementarity of capital with skilled labor and the growth in global capital flows to explain the rise in skill premium after trade openness.

[8] Bernard (1997) shows that the increases in employment at exporting plants contribute heavily to the observed increase in relative demand for skilled labor in manufacturing. Also, as notes in Verhoogen 2008, 2009, Bustos 2011, Harrigan 2012, Helpman, Elhanan, Itskhoki, and Redding 2010, exporters account for almost all of the increase in the wage gap between high- and low-skilled workers. See also Pupato (2017) and Zeira (2007)

[9] Rossi-Hansberg & Caliendo (2012)

[10] For the evidence on intra-industry reallocation, see: Mexico: Revenga (1997), Hanson and Harrison (1999), and Feliciano (2001) ; Colombia: Attanasio, Goldberg, and Pavcnik (2004); Morocco: Currie and Harrison (1997); India: Topalova (2004a); cross-country: Wacziarg and Seddon (2004); Latin American: Haltiwanger, Kugler, Kugler, Micco and Pages (2004)

Verhoogen (2008 and 2009), in his influential work, shows that quality upgrading of exporters in developing countries increases demand for better skilled workers and addresses the same question. This paper introduces another mechanism alongside these theories to explain the same fact, using the notion of imperfect substitutability of high-skilled workers.

Many empirical findings have shown that due to "skill-biased technology", in both developing and developed countries, there is a quantifiable increase in the share of skilled workers and their relative wages within a narrowly defined category of industries.

Attanasio, Goldberg, and Pavcnik's (2004) findings show that in Mexico, even low-skill intensity industries have been skill biased in technological advancements. Trade openness and skill-biased technologies affect the relative skill demand, thus increasing the skill premium. Burstein, Cravino and Vogel (2012) have used this notion in a novel work, while Wood (1995) and Thoenig and Verdier (2003) show that trade induces more R&D in exporters.

Acemoglu (2003) introduces a model of endogenous technological change to explain the increase in wage premium. Matsuyama (2007) argues that export sectors are inherently more skill intensive and the rise in trade would raise demand for high-skilled workers. Helpman and Itskhoki (2010) show the more productive firms and exporters are better in screening their workers, which results in a bias for high-skilled workers in export firms, inducing a reallocation of labor toward exporters after trade opening within an industry.

Other examples are Bustos (2011a) and Harrigan (2011) who use the notion that exportation is a skill-biased activity and explain the higher skill intensity of exporters and the rise in the skill premium. This paper is very close to these ones, making this bias an endogenous decision of the firms, aggregating to a macro phenomenon in the general equilibrium.

Bustos (2011a) shows that more productive firms and exporters are inclined toward upgrading their skill-biased technologies and hence endogenously evolve to become more skill intensive. In contrast, this paper constructs a micro-founded model that links the increase in skill intensity to the firms' organizational decisions and their workers' specialization levels.

Conversely, Burstein, Cravino and Vogel (2012) and Harrigan (2011) employ a skill-biased production technology where productivity is inherently correlated with skill intensity. They make the case that an increase in trade will ensure that only more productive firms, which are supposedly more skill intensive, will survive. Therefore, the overall skill demand within the industry picks up, resulting in an increase in the skill premium. In contrast, my model has a micro-foundation for this correlation with a firm-level decision.

Burstein, Cravino and Vogel (2012) elegantly implement a general equilibrium quantitative analysis to discover the extent to which their model can explain the rise in skill premium across countries. Since they define firms to be inherently more skill intensive through being more productive, they show that any policy in favor of more productivity will induce higher skill intensity.

In contrast to this paper, in their framework, a firm's skill intensity does not respond to changes in the scale and any demand shock has no impact on the firm's structure and skill intensity. As such, new exporters choose to be more skill intensive by changing their organizations, as empirically shown in Caliendo, Monte and Rossi-Hansberg (2012) and Bustos (2011b).

A large number of papers in economics are concerned with showing the productivity gains of labor specialization and assigning the narrow measure of tasks to workers. Based on the classical concepts in the works of Adam Smith (1776), Hayek (1945), Rosen (1983), Becker and Murphy (1992)[11], this paper examines the distributional effects of international trade, through the lens of labor division. In this model, it is the size of the market (the aggregate domestic and foreign demand) that induces a firm to choose the level of its labor specialization, making it more productive and more skill-intensive. These decisions in equilibrium lead to higher inequality between low- and high-skilled workers.

The imperfect substitutability of high-skilled workers is similar to the ideas in Card and Lemieux (2001) where different age groups within an educational group are imperfect substitutes. Card and Lemieux model the imperfectly substitutability hypothesis in a nested,

[11] For related literature see Krishna et al (2009), Bombardini et al (2012) and Noblet (2010)

two-level CES model. Versions of the multi-level CES are applied in a number of researches like Krusell (2000), Borjas (2003) and Acemoglu, Autor and Lyle (2004).

Similarly, Card (2009) and Peri and Ottaviano (2011) consider a model where skilled immigrants and natives are imperfect substitutes. Jäger (2016) shows that coworkers in the same occupation are substitutes, while high-skilled workers and managers appear to complement coworkers in other occupations.

These findings support a key assumption of models that skilled workers raise the productivity of other workers at the same firm (see, e.g., Lucas (1978); Murphy, Shleifer, and Vishny (1991)).

From another aspect, this paper shares close affinity with the literature on firms' organizations: Caliendo and Rossi-Hansberg (2011), Caliendo, Monte and Rossi-Hansberg (2012) employ the concept of organization in firms' heterogeneity frameworks and their responses to trade integration. They show, both theoretically and empirically, that increasing trade openness induces firms to augment the number of layers in their hierarchy and become more productive.

They also show that exporters have more vertically layered organizations. In contrast to trade impact on productivity gains and real wages as their main focus, my paper analyzes the distributional effects of trade through the lens of a firm's organization. Moreover, organizational expansions in this paper are horizontal, in contrast to vertical expansions in their work.

Finally, starting from Bernard (1997) and following huge empirical and theoretical works, most importantly by Bernard, Eaton, Jensen and Kortum (2003) and Melitz (2003), show that a firm's heterogeneity plays a crucial role in explaining international trade patterns and the reallocation of resources after trade liberalization. This paper builds upon these studies and connects the literature on division of labor and firms' organization to find the distributional effects of international trade.

2 Model

The model is a static two-symmetric countries model of international trade with two types of labor: High skilled and low-skilled workers. As in a Melitz model, production of varieties of goods takes place in a continuum of heterogenous firms which now should decide on their optimal horizontal organizational expansion. The general setup is similar to the Krugman-Melitz type models with heterogeneous firms and monopolistic competition framework. There are two symmetric countries, $j = h, f$ (home and foreign) with L low-skilled and H high-skilled workers.

2.1 Preferences

In country j, the representative household supplies both types of labor and has constant elasticity of substitution (CES) preferences (as in Spence-Dixit-Stiglitz) over the consumption $c_{ij}(A_i)$ of differentiated varieties, which are produced by a measure M_{ij} continuum of producers in i, selling in j; Its producer has productivity A_i which is randomly drawn from a cumulative distribution function $F(A)$, such that $U_j = \left(\sum_{i=h,f} \int_{A_i} c_{ij}(A_i)^{\frac{\sigma-1}{\sigma}} M_{ij} dF(A_i)\right)^{\frac{\sigma}{\sigma-1}}$. Parameter σ is the elasticity of substitution between the differentiated varieties. Trade is balanced; therefore the representative household has the following budget constraint

$$\sum_{i=h,f} \int_{A_i} d_{ij} p_i(A_i) c_{ij}(A_i) M_{ij} dF(A_i) = X_j = w_{Lj} L_j + w_{Hj} H_j + \Pi_j$$

where X_j is the total expenditure of country j, Π_j is the total profit of the firms in country j, and w_{kj} is the wage for labor of type k ($= H$ or L) in country j.

Therefore, the demand for variety A is $c_{ij}(A) = (d_{ij} p_i(A))^{-\sigma} \left(P_j^{\sigma-1} X_j\right)$ where $p_i(A)$ is the price of the variety produced by the a firm with productivity A in country i. Parameter d_{ij} is the variable iceberg trade cost of exporting goods from i to j. Lastly, $P_j = \left(M_{ij} \int_A p_i(A)^{1-\sigma} dF(A)\right)^{\frac{1}{1-\sigma}}$ is the aggregate price index.

2.2 Market Structure

The Market structure is the same as Krugman (1980) so that each firm sells its differentiated good monopolistically in the market. Because of SDS preferences, the demand elasticity is constant σ. Thus for a producer in country i with productivity A, its total production demand is

$$y_i(A) = p_i^{-\sigma}(A) D_i \tag{1}$$

where D_i is a "demand indicator" for a producer in i, such that $D_i = D_{ii}$ for a domestic producer and $D_i = \sum_j D_{ij}$ for an exporter, where $D_{ij} = d_{ij}^{1-\sigma} P_j^{\sigma-1} X_j$ with $d_{ii} = 1$.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.

2.3 Production

As in a Melitz-type framework, firms are heterogenous in productivity in this model. They pay a sunk entry cost to draw a random productivity A from cumulative distribution function $F(A)$, and after observing the productivity level, decide to pay a fixed entry cost to enter a market if it is profitable. To enter an international market they need to pay an extra fixed exporting cost. For notational simplicity, I drop the country and firm subscripts.

A firm hires l numbers of low-skilled and h numbers of high-skilled workers. Low skilled workers are perfect substitute with other while high-skilled workers are imperfect substitutes. The firm produces output Y such that:

$$Y = A\left(l^{\frac{\rho-1}{\rho}} + \int_0^S h_s^{\frac{\rho-1}{\rho}} ds\right)^{\frac{\rho}{\rho-1}} \tag{2}$$

where h_s is the number of high skilled workers in group s from a measure S of groups and

$$h = \int_0^S h_s ds \tag{3}$$

is the total number of employed high-skilled workers[12]. The elasticity of substitution between high skilled workers is $\rho > 1$ which is equal to the elasticity of substitution between the low-skilled and high-skilled group[13].

For a given S, a firm decides how to allocate its high skilled workers in different groups which are not perfect substitutes. A firm can pay a fixed cost of specialization $w_h \bar{f} S$ and generate measure S groups. These costs can be interpreted as coordination, training or monitoring costs. Here, the firm faces a trade-off between paying more fixed costs and having more groups of high skilled workers to enjoy the benefit of more specialization and higher productivity.

Therefore, a firm's cost minimization problem is

$$\begin{aligned} &\min_{S,l,h,\{h_s\}_0^S} w_l l + w_h h + w_h \bar{f} S \\ &\text{s.t. } (2) \ \& \ (3) \end{aligned}$$

for a given Y where w_l and w_h are wages for lows-skilled high skilled-workers respectively.

Due to symmetry, the firm chooses all the h_s's equal. Therefore the firm's production function is simplified to $Y = A\left(l^{\frac{\rho-1}{\rho}} + S^{\frac{1}{\rho}} h^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}$. Thus for a given S, optimal relative labor demand is $\frac{h}{l} = S\Omega^{-\rho}$ (with $\Omega = \frac{w_h}{w_l}$) which is increasing in the degree of specialization; leaving us with $C(S;Y) = w_l l + w_h h = \frac{Y}{A}\left(w_l^{1-\rho} + S w_h^{1-\rho}\right)^{\frac{1}{1-\rho}}$ as the total labor cost. As it is clear, this total cost is decreasing in S, the degree of of specialization(DoS); meaning that the firm can lower its costs by increasing the number of specialized groups and becoming more skill intensive.

[12] We can use discrete S number of groups as well, but for more trctability we take it as continous.s

[13] The more general case with $\rho_H > \rho$ is also true without loss of generality, where ρ_H is the elasticity of substitution between the high skilled workers.

2.3.1 Firm's Organizational Problem

As it was shown, a firm should pay fixed cost of specialization and choose S groups of specialization for its high skilled workers. Choosing S optimally can be interpreted as choosing the optimal horizontal degree of expansion in the firm organization; i.e. how a firm decides to increase the number of groups of high skilled workers and enjoy the gains from specializing them and having lower cost of production $C(S)$.

Solving the firm's organizational problem means setting $w_h \bar{f} = -\frac{\partial C(S;Y)}{\partial S}$, giving us the optimal degree of specialization as

$$S^*(Y) = \left(\frac{Y/A}{(\rho-1)\bar{f}}\right)^{\frac{\rho-1}{\rho}} - \Omega^{\rho-1} \quad (4)$$

and the conditional marginal cost as

$$mC(Y) = \left(\frac{(\rho-1)\bar{f}}{YA^{\rho-1}}\right)^{\frac{1}{\rho}} w_h$$

which are both functions of total production; the former is an increasing one, while the later is a decreasing one.

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

Lemma 1 *(a) The optimum degree of specialization $S^*(Y)$ is increasing in Y and decreasing in $\bar{f}$.*

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

(c) The marginal cost of producing Y, $mc(Y)$, is decreasing in Y.

Proof. See Appendix. ■

As the lemma states, the conditional firm organizational problem results in a decreasing marginal cost function with respect to total production; meaning that the firm can enjoy an increasing returns due to this endogenous specialization of its workers. Basically, a firm with higher production demand has more incentive to invest on its organizational expansion, increase its division of labor and be more specialized in its high skilled workers, thud increasing its labor productivity and decreasing its marginal cost[14].

2.3.2 Profit Maximization

As in Krugman type framework, a firm pays a fixed production cost and sells its production in a monopolistic market. Since the demand elasticity is constant, the firm has a constant markup $m = \frac{\sigma}{\sigma-1}$ over marginal costs[15], which is itself a function of Y. To solve for the optimum level of production Y and price p, I use the firm demand equation (1) which results in solving the following fixed-point problem:

$$Y = \left(\frac{\sigma}{\sigma - 1} mc\left(Y\right)\right)^{-\sigma} D \tag{5}$$

Therefore, given the demand indicator D, a firm with productivity A chooses the optimum level of production $Y\left(A, D\right)$ and price $p\left(A, D\right)$. Because marginal cost is decreasing in Y (as shown in the previous lemma), the firm's price is also decreasing in Y. Figure 1 shows this feature. Any increase in the firm's production demand shifts the marginal revenue curve to the right, inducing a reduction in the firm's price. Next lemma describes the optimal firm's decision about its output and price.

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

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

(b) The firm's optimum level of production $Y^*\left(A, D\right)$ is increasing in A and D, and decreasing in $\bar{f}$.

[14]In a more general case it has been shown that without loss of generality, we can have specialization of workers for both types of workers. But since high skilled workers' substitutability is less than the low skilled workers, for sake of tractibility, I use this extreme limit of perfect substitutability for low skilled workers and imperfect substitutability for high skilled ones.

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

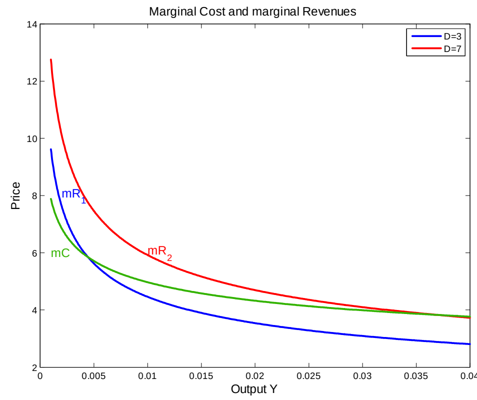

Figure 1: Marginal costs and marginal revenues: Effect of change in the Aggregate Demand

(c) The firm's price $p^*(A,D)$ *is decreasing in* A *and* D*, and increasing in* $\bar{f}$*.*

(d) The optimum degree of specialization (DoS) $,S^*(A,D)$ *, is increasing in* A *and* D *and decreasing in* $\bar{f}$*.*

(e) The relative labor demand $\left(\frac{N_H^*(A,D)}{N_L^*(A,D)}\right)$ *is increasing in* A *and* D*, decreasing in* $\bar{f}$*.*

(f) The firm's optimum revenue $R(A,D)$ *is*

$$R(A,D) = \bar{g} D^{\frac{\rho-1}{\rho-\sigma}} A^{\frac{\rho-1}{\rho-\sigma}(\sigma-1)} \tag{6}$$

(g) The cost of hiring high and low skilled workers are:

$$\begin{aligned} C_H(A,D) &= w_H N_H = \frac{\sigma-1}{\sigma} R(A,D) - (\rho-1)\bar{f}\Omega^{\rho-1} && (7) \\ C_L(A,D) &= w_L N_L = (\rho-1)\bar{f}\Omega^{\rho-1} && (8) \end{aligned}$$

where $\Omega = \frac{w_h}{w_l}$ *is the skill premium and* $\bar{g} = \left(\left(\frac{\sigma}{\sigma-1}\right)^{\rho}(\rho-1)\bar{f} w_h^{\rho-1}\right)^{-\frac{\sigma-1}{\rho-\sigma}}$*.*

Proof. See Appendix. ■

Note that output $Y(A,D)$ and $p(A,D)$ can be easily calculated accordingly. Variable profit function $\Pi(A,D)$ can be calculated as $\Pi(A,D) = \frac{\rho-\sigma}{\sigma(\rho-1)} R(A,D) + \bar{f}\Omega^{\rho-1}$. Also, specialization of high-skilled workers would be $S(A,D) = \frac{C_H(A,D)}{(\rho-1)\bar{f}}$ which is increasing and convex in A and D.

As expected from a Krugman-Melitz type model, more productive firms have lower prices (quality adjusted) and higher productions, revenues and profits and the relationship of productivity and price is one to one. In contrast, what is new here is that 1) the relationship of productivity and prices are more than one to one; i.e. one percent higher productivity results in more than one percent lower prices, 2) between two firms with the same productivity A, the one with higher demand D has a lower price; it shows a scale effect which it lacks in conventional trade models. 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 skilled workers, decreasing their marginal costs; thus their prices. This analysis shows another margin of gain from economy of scale; I call it the "within-firm margin".

Also it can easily be shown that the firm's revenue and output increases more than one to one with respect to demand D which is again due to the productivity gain from specialization and horizontal expansion; i.e. since $\frac{\rho-1}{\rho-\sigma} = 1 + \frac{\sigma-1}{\rho-\sigma} > 1$, showing larger effects of D on these variables in comparison to the conventional models.

Also, the elasticity of revenue with respect to productivity is $\eta = \left(1 + \frac{\sigma-1}{\rho-\sigma}\right)(\sigma-1) > \sigma-1$. This inequality shows that this model generates a more significant effect of productivity and aggregate demand compared to the typical Krugman-Melitz type models.

The most important result is that the high-skilled labor demand is increasing with productivity A and production demand D and the labor demand for low-skilled workers is constant with respect to these two variables. Therefore, the relative labor demand increases with productivity and production demand, making skill intensity positively correlated with these two variables. In other words, since specialization of the high-skilled workers brings gains for the firm, an increase in the firm's productivity has a biased effect in labor demand toward high-skilled workers, too. Thus, the skill intensity of the firm is endogenously determined by the firm's decisions; this feature does not exist in conventional models . This biased effect productivity is consistent with data where we observe that the skill intensity of a firm has positive correlation with the firm's productivity as in Harrigan (2012) or Bustus (2011a).

This 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.

2.4 Market Entry, Aggregation and Partial Equilibrium

2.4.1 Entry

The countries are similar, so they have the same allocation and prices; thus I do not use any country specific subscripts. 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 aggregation, the following condition should hold:

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

After observing the productivity A, a firm pays an operational fixed cost f_o to enter the domestic market, if it's profitable. 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 operates domestically if $\Pi(A, D) \geq f_o$ and it 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, where $D_f = d^{1-\sigma}D$.

Assumption: "Home market" is softer than "foreign market." It means that exporting fixed costs are high enough so that if a firm operates in the foreign market, it would surely operate also in the domestic market.

These entry conditions result that more-productive firms can only enter and most productive ones enter the export market, too, defining entry and export productivity thresholds $\bar{A}_o$ and $\bar{A}_x$:

$$\bar{A}_o = Z_1 D^{\frac{-1}{\sigma-1}} \tag{9}$$

$$\bar{A}_x = Z_1 D^{\frac{-1}{\sigma-1}} \underbrace{\left(\frac{f_x}{f_a}\right)^{\frac{1}{\eta}} \left(\tilde{d}^{-\eta} - 1\right)^{-\frac{1}{\eta}}}_{\text{trade barrier}} \tag{10}$$

where $\tilde{d} = (1 + d^{1-\sigma})^{\frac{1}{1-\sigma}}$, $Z_1 = m^m \eta^{\frac{1}{\eta}} (\rho-1)^{\frac{1}{\rho-1}} w_H \bar{f}^{\frac{1}{\rho-1}} f_a^{\frac{1}{\eta}}$, $f_a = f_o - \bar{f}\Omega^{\rho-1}$ is an adjusted fixed cost variable.

Equations (9) and (10) show the negative effect of demand D 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; thus it lowers these thresholds.

Figure 2 schematically shows how firms with different productivities decide about their prices, outputs, skill intensities, entry 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. And since 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, charging lower prices and choosing to be much more skill-intensive than non-exporters.

2.4.2 Partial Equilibrium, Aggregate Price and Aggregate Production Demand

In partial equilibrium, wages w_H and w_L, aggregate expenditure X and the measure of entrants M_e are given. Using the polynomial form of the revenue function, Pareto distribution assumption for the productivities, and the entry conditions, I can solve and simplify the

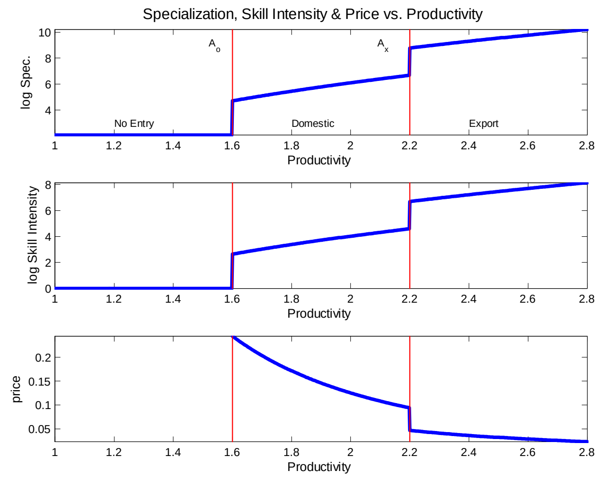

Figure 2: Specialization, Skill intensity, and Price vs. Productivity

aggregate revenue as

$$\tilde{R}(D) = (\rho - 1)\, m\zeta M_e \left(\mu_o f_a + \mu_x f_x\right)^{16} \tag{11}$$

where $\zeta = \frac{\theta(\sigma-1)}{(\theta-\eta)(\rho-\sigma)}$, $\mu_o = \left(\frac{\bar{A}_o}{\bar{A}}\right)^{-\theta}$ and $\mu_x = \left(\frac{\bar{A}_x}{\bar{A}}\right)^{-\theta}$ are the fractions of producers and exporters. Thus aggregate revenue $\tilde{R}(D)$ is a function of aggregate demand $D = P^{\sigma-1}X$ because the thresholds $\bar{A}_o$ and $\bar{A}_x$ depend on D as in (9) and (10).

Market clearing and trade balance imply that the aggregate revenue is equal to the aggregate expenditure. Hence $X = \tilde{R}\left(P^{\sigma-1}X\right)$. This fixed-point problem can pin down the equilibrium aggregate price index P as a function of aggregate expenditure X :

$$P = \frac{Z_2}{X^{\frac{1}{\sigma-1}-\frac{1}{\theta}}\left(1+O\right)^{1/\theta}} \tag{12}$$

where $Z_2 = \frac{Z_1}{\bar{A}((\rho-1)m\zeta f_a M_e)^{1/\theta}}$ and

$$O = \left(\frac{f_x}{f_a}\right)^{1-\frac{\theta}{\eta}} \left(\tilde{d}^{-\eta} - 1\right)^{\frac{\theta}{\eta}} \tag{13}$$

is an openness parameter which is decreasing in the trade costs.

Equation (12) shows that trade openness reduces aggregate prices through three sources. First is the typical Krugman type channel which is the availability of cheaper foreign varieties.

This is inherited in the $\tilde{d} = (1 + d^{1-\sigma})^{\frac{1}{1-\sigma}}$ term inside the openness parameter. As trade costs d goes down, foreign producers face lower marginal costs; thus they lower their prices. This would push down the aggregate price. The second source is the extensive margin-of-trade channel as in the Melitz (2003) and Chaney (2008), where the number of foreign exporters change and home country's households have access to increasingly more varieties of foreign goods. This mechanism shows up with the terms f_x and θ, in the price equation. The third source, which is the newly introduced source in this paper is the within-firm margin of adjustment where the old and new exporters re-organize to a more horizontally expanded and more specialized firm. This reorganization increases their labor productivity, reducing marginal costs, hence reducing their prices, resulting in declines in the aggregate price index. This notion shows up through the parameter $\eta = \left(1 + \frac{\sigma-1}{\rho-\sigma}\right)(\sigma - 1) > \sigma - 1$ in the openness parameter and the fixed specialization cost $\bar{f}$ inside the variable Z_2. Lowering $\bar{f}$ would lower the specialization costs, inducing more incentive for labor specialization and having increasingly more productive firms which will reduce the aggregate price index.

In contrast to this model, in the conventional model, where there is no within-firm margin of adjustment, the extensive margin of trade appears with $\frac{\theta}{\sigma-1}$ instead of $\frac{\theta}{\eta}$, as noted in Chaney (2008). Also, the intensive margin effect shows up with $d^{-\theta}$ instead of $d^{-\eta}$.[17]

Also, having P solved analytically and using the definition of D $(=P^{\sigma-1}X)$, the fraction of exporters and non-exporters can be solved as:

$$\mu_0 = \left(\frac{1}{(\rho-1)\, m\zeta}\right) \frac{X}{M_e} \frac{1}{(1+O)\, f_a} \tag{14}$$

$$\mu_x = \left(\frac{1}{(\rho-1)\, m\zeta}\right) \frac{X}{M_e} \frac{O}{(1+O)\, f_x} \tag{15}$$

As expected from the Melitz-type model, the fraction of exporters increases with openness O but the fraction of domestic producers decreases with it; making the market less crowded. This analysis shows that reducing trade costs increases foreign production demand, inducing

[17] Details are explained in the seminal work of Chaney (2008) which elaborates on the Melitz type model and distinguishes between different mechanisms affecting the prices.

more firms to become exporters. The production demands of older exporters also change, inducing them to re-organize, too.

To see how old and new exporters re-organize, I should look into the demand that they face. There are two sources that affect the exporters' demands. Since $D_f = (P^\sigma)\left(\frac{X}{P}\left(1+d^{1-\sigma}\right)\right)$, one source is the aggregate industry demand that shows up as $\frac{X}{P}\left(1+d^{1-\sigma}\right)$. In other words, when aggregate real expenditure on the industry goes up or trade costs goes down, total production demand for the industry goes up, increasing the production demand for each firm, specifically for the exporters; let's call it the Direct Channel. The second source is substitutability of the firms within the industry. A decrease in industry's aggregate price index, P, reduces a firm's production demand because of the substitution effect; since the competitors' prices are lower and consumers substitute away from this firm. This mechanism shows up with the term P^σ in the demand indicator D_f; let's call this second channel the Indirect Channel. As it was shown above, reducing d reduces P; thus reduces the aggregate demand. Therefore, reducing d would increase D_f through the Direct Channel and decrease it through the Indirect Channel. To find out which force dominates, I calculate D_f explicitly and I get

$$D_f(d) \propto \left(\tilde{d}^\theta + \left(\frac{f_x}{f_a}\right)^{1-\frac{\theta}{\eta}}\left(1-\tilde{d}^\eta\right)^{\frac{\theta}{\eta}}\right)^{-\frac{\sigma-1}{\theta}} \tag{16}$$

where $\tilde{d} = \left(1+d^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \in \left(\frac{1}{2^{\sigma-1}}, 1\right)$. Function $D_f(d)$ has been illustrated in Figure 3. It is easy to show that reducing trade cost d would initially raise foreign demand D_f initially through the Direct Channel, but bring it down later because of the drop in the aggregate price[18] through the Indirect Channel. Thus reducing variable trade cost may raise or drop the demand for old exporters in the equilibrium. Therefore, old exporters may increase or decrease their level of labor specialization depending on D_f.

New exporters are different. With a marginal change in d, some old non-exporters become

[18] This maximum occurs when $\tilde{d} = \left(1+\frac{f_x}{f_a}\right)^{-1/\eta}$ and hence, maximum D_x is $\left(\frac{Z_1}{A}\right)^{\sigma-1}\left(\frac{X}{M_e}\right)^{\frac{\sigma-1}{\theta}}\left(1+\frac{f_x}{f_a}\right)^{\left(\frac{\theta}{\eta}-1\right)\frac{\sigma-1}{\theta}}$.

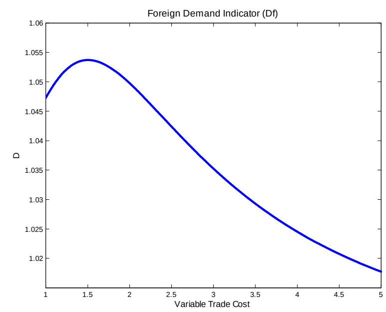

Figure 3: D_f vs trade costs

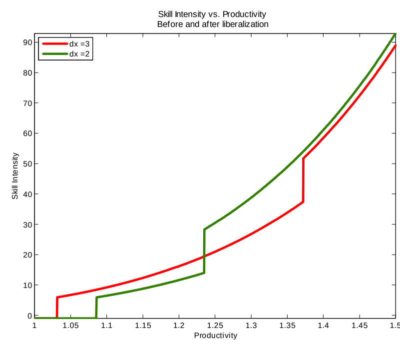

Figure 4: Effect of lowering trade barrier on the relative labor demand in a partial equilibrium setting

new exporters. The demand they were facing has been multiplied by $1 + d^{1-\sigma} > 1$, which is a large increase compared to a marginal change through the Indirect Channel. Consequently, new exporters always expand their specialization level. Figure 4 shows the skill intensity of the firms with respect to their productivities before and after a change in variable trade costs.

On the other hand, it is clear from (16) that reducing the fixed export costs f_x can only reduce D_f for the old exporters, because it can only reduce the price index from the Indirect Channel and has no positive Direct Channel. This means that reducing fixed export costs results in a contraction in old exporters. New exporters with the same reason as above will face expansion of labor division.

2.4.3 Aggregate Relative Labor Demand

Due to the polynomial form, the aggregate labor demand for both types of workers can be solved analytically. According to (8), labor demand of the low-skilled workers is independent of productivity A and demand D; hence $\tilde{C}_L$, the total cost of low-skilled workers of all the firms is $\tilde{C}_L = M_e \mu_o (\rho - 1) \bar{f} \Omega^{\rho-1}$. On the other hand, from (8) and (7), total labor demand $C_H + C_L$ equals $\frac{R}{m}$ for each firm. Therefore, from (11), the aggregate cost of labor is $\tilde{C}_L + \tilde{C}_H = (\rho - 1) \zeta M_e (\mu_o f_a + \mu_x f_x)$[19]. Proposition 3 presents the aggregate relative labor demand equation.

Proposition 3 *If* $\Omega < \left(\frac{\sigma-1}{\rho-1}\frac{f_o}{\bar{f}}\right)^{\frac{1}{\rho-1}}$ *, the aggregate relative labor demand equals*

$$\frac{\tilde{N}_H}{\tilde{N}_L} = \Omega^{-1}\left(\zeta\left(\frac{f_o}{\bar{f}}\Omega^{1-\rho} - 1\right)(1 + O) - 1\right) \tag{17}$$

where $\zeta = \frac{\theta(\sigma-1)}{(\theta-\eta)(\rho-\sigma)}$, $\tilde{N}_k$ *is the aggregate total labor demand of type* $k = H, L$ *for all firms in the industry,* $\Omega = \frac{w_H}{w_L}$ *is the skill premium and* O *is the openness parameter in (13) and in terms of the exogenous variables* w_H, w_L, X *and* M_e, *the aggregate relative labor demand is only a function of the skill premium* $\Omega = \frac{w_H}{w_L}$.

Proof. See Appendix. ■

With higher trade barriers, the openness parameter decreases and therefore aggregate relative labor demand decreases. In the extreme case where trade barriers are infinity, openness becomes zero ($O = 0$); hence equation (17) presents the model under autarky (closed economy)[20]. Increase in the aggregate relative labor demand following a reduction in trade barriers is the result of labor reallocation in three types of firms: New exporters, old exporters and non-exporters. First of all, new exporters are those highly productive previous non-exporters who found it optimal to expand their organization and hire more skilled workers due to the large international demand; thus they become more skill intensive. Second, old exporting firms,, depending on d, may face more or less demand because of

[19] $\tilde{C}_H$ and $\tilde{C}_L$ are the aggregate cost of high skilled and low workers, respectively.

[20] Note that (17) is the analytical equation for relative labor demand in the Upper Boundary Case, and it is valid when $\Omega < \left(\frac{f_o}{f_H}\right)^{\frac{1}{\rho-1}}$. This condition ensures that the specialization costs should be low enough relative to the entry costs f_o so that all the firms have incentive to hire high-skilled workers. As long as this condition holds, lowering trade barriers would increase the aggregate relative labor demand.

Table 1: Effect of trade cost reduction in partial equilibrium

	Production Demand	Relative Labor Demand
Domestic producers	Less	Less
New exporters	More	More
Old exporters (high trade costs)	More	More
Old exporters (low trade costs)	Less	Less

the drop in the aggregate price, as discussed earlier; therefore, they will restructure and become more or less skill-intensive; increasing or decreasing their demands for high-skilled workers. Third, less productive non-exporters, who do not find it optimal to export, face lower demand (D) because of the presence of much more productive firms in the industry; thus, relative labor demand for these firms would decline since they shrink their organization and become less skill intensive. Table 1 summarizes the above discussion.

These organizational changes result in a reallocation of high-skilled workers from domestic producers toward new and old exporters in an environment with high trade costs. In a low trade cost environment, the reallocation of high-skilled workers is from domestic producers and old exporters toward new exporters. Nevertheless, from (17) it turns out that the reallocation towards the new exporters dominates and the aggregate relative demand increases with lowering trade costs.

Finally, note that this framework is a new source of gain from international trade. Lowering trade costs induces an exporter to re-organize to a more specialized one 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".

2.5 General Equilibrium Results

In general equilibrium, all the goods and labor markets clear. Trade is balanced between the two countries; hence, aggregate income equals aggregate expenditure. Entry is free; therefore aggregate profit equals zero. Thus, the measure of potential firms M_e, aggregate expenditure X and wages become endogenous.

Without loss of generality, I assume that all the fixed specialization costs, operational costs, and export and entry costs are paid in terms of high-skilled labor; therefore $f_e = w_h \bar{f}_e$, $f_o = w_h \bar{f}_o$ and $f_x = w_h \bar{f}_x$. Relaxing these assumptions does not change the results qualitatively, as is shown in the Appendix. I take low-skilled labor to be the numéraire; hence $w_L = 1$.

Assumption: Specialization costs are low enough so that $\frac{\rho-1}{\sigma-1}\bar{f}\Omega^{\rho-1} \leq \bar{f}_o$.

If the above assumption holds, the equilibrium conditions can be simplified as:

$$\frac{H}{L} = \Omega^{-1}\left(m\zeta\left(\frac{\bar{f}_o}{\bar{f}}\Omega^{1-\rho} - 1\right)(1+O) - 1\right) \quad \text{(relative labor demand and trade balance)} \tag{18}$$

$$\bar{f}_e M_e = \frac{L\Omega^{-1} + H}{m\theta} \quad \text{(aggregate zero profit)} \tag{19}$$

$$L = (\rho - 1)\, M_e \mu_o \bar{f}_H \Omega^{\rho} \quad \text{(low-skilled labor demand market clearing)} \tag{20}$$

The skill premium Ω can be solved by using the only equation (18). Measure of entrants would be solved from (19). Fraction of active producers (μ_o) can be solved from (20)[21] and therefore aggregate expenditure would be easily calculated from (11). Proposition 4 presents conditions for the unique equilibrium and its results.

Proposition 4 *If* $\frac{H}{L} > v^*$, *then*

[21] Fraction of exprters can also be solved as $\mu_x = \mu_o O \frac{f_a}{f_x}$.

(a) There is a unique equilibrium.

(b) The skill premium increases as trade costs (fixed or variable) decreases.

(c) Openness O increases as trade costs (fixed or variable) decreases.

The parameter ν^* is defined as: $\nu^* = \frac{\sigma\theta\left(\tilde{d}^{-\eta}-1\right)^{\frac{\theta}{\eta}}\left(\frac{\rho-\sigma}{\rho-1}\frac{\bar{f}_o}{\bar{f}_x}\right)^{\frac{\theta}{\eta}-1}+\theta+(\sigma-1)\eta}{(\sigma-1)(\theta-\eta)\left(\frac{\sigma-1}{\rho-1}\frac{\bar{f}_o}{\bar{f}}\right)^{\frac{1}{\rho-1}}}$.

Proof. (a) The skill premium Ω can be determined using equation (18). The right-hand side of this equation is decreasing in trade costs since the openness parameter$O$ is decreasing in both of the variable and fixed trade costs. This ensures that reducing trade costs shifts the relative labor demand curve up resulting in an increase in the skill premium. Finally, the condition above insures that $\frac{\rho-1}{\sigma-1}\bar{f}\Omega^{\rho-1} \leq \bar{f}_o$.

(b) The right-hand side of (18) is decreasing in the trade costs. Therefore reducing these costs shifts up the demand curve; increasing the skill premium.

(c) Multiplying both sides of (18) by Ω and rewriting Ω in terms of O leads to a downward sloping function of O on the left-hand side and an increasing function in terms of O and trade costs on the right-hand side. Therefore reducing trade costs, decreases the right-hand side shifting down the upward sloping function of the right-hand side, and O increases. This completes the proof. ■

Reductions in variable or fixed exporting costs would increase the aggregate relative labor demand; but since the relative labor supply is fixed, the skill premium rises, as illustrated in figure 5. It is important to note that the argument above is true when the condition in the proposition holds. This condition is violated when trade costs are very low.

Equation (19) will pin down the measure of a potential firm such that $M_e = \frac{L\Omega^{-1}+H}{m\theta\bar{f}_e}$. Because a reduction in trade costs will raise Ω, M_e declines. Moreover, equation (20) will pin down the measure of actual producers as $M_e\mu_o = \frac{L\Omega^{-\rho}}{(\rho-1)\bar{f}_h}$ which will also reduce along with a reduction in trade costs, as expected to happen as a result of any Melitz-type model, stating that the market becomes less crowded following the trade liberalization. Moreover, equation (15) reduces to $\mu_x = \frac{O}{1+O}\frac{m\theta\bar{f}_e}{\bar{f}_x}$. Since openness O increases with a reduction in trade costs in the equilibrium, the fraction of exporters would increase. Finally, export intensity can be

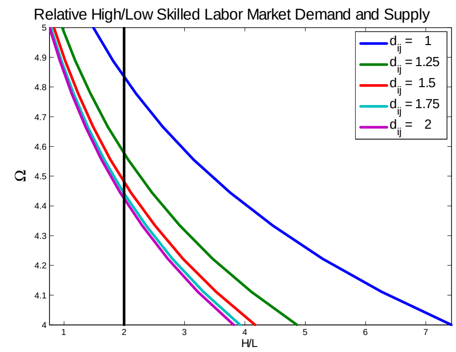

Figure 5: Relative labor demand: Supply and demand meet.

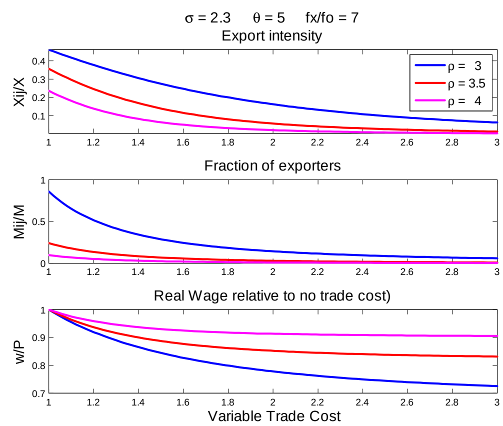

Figure 6: Export intensity, fraction of exporters and real wages

calculated as $\frac{X_{ij}}{X} = \frac{1-\tilde{d}^{\eta}}{1-\tilde{d}^{\sigma-1}} \frac{O}{O+1}$ which can be easily shown to be decreasing in trade costs, as expected.

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. In figure 6, responses of the model to trade costs for different values of ρ have been shown. What this model predicts is that the parameter ρ, which is a notion of gains from labor specialization (lower ρ, higher gain from specialization) also affects the trade elasticity as θ and σ do. Therefore, this parameter also becomes a crucial determinant of gains from trade, just like θ and σ.

The predictions of the model regarding the reallocations of labor within industries are also consistent with the empirical works. Many empirical works cited above 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[22]. In the next section, I quantify the model by calibrating the model to the US data and show that the model can generate a large increase in the skill premium with small reductions in trade costs.

3 Quantitative Analysis: Calibration to U.S. Economy

In this section, I show numerically how the model behaves in the general equilibrium by calibrating the model to US economy. I run some comparative statics and counterfactual analysis to show how the economy would change in different scenarios.

To calibrate the model, first I normalize the productivity parameter $\bar{A}$ and the fixed cost cost of operation $\bar{f}_o$ to one. These two variables can only change the definition of number of produced goods and the measure of firms which could be normalized to anything. Then I calibrate the other parameters using the existing related literature. I use Acemoglu (2010) and set $\frac{H}{L}$ to 1.28 from the 2003 data. In our analysis, only the ratio of high skilled to low skilled labor matters and thus I use the ratio $\frac{H}{L}$. I use Chaney 2005 and set $\sigma = 3.9$ which is close to 3.79 as in BEJK (2003). I also take the relative skill intensity equal to 1 which is in the range that Burstein & Vogel (2011) have shown. Then, I calibrate $d_{ij} = 1.3$ as in Ghironi & Melitz (2006). Chaney (2005) estimates the distribution of firms' sales which is Pareto by parameter $\sigma - 1$ and show that $\widehat{\frac{\theta}{\sigma-1}} = 1.89$. In our model, distribution of firms' sales is Pareto with parameter η and therefore we use his estimate to take $\widehat{\frac{\theta}{\eta}} = 1.89$. I take $\rho = 5.5$ which results in $\theta = 4.69$ very close to that of most of heterogenous firm models of trade estimations.

For the remaining parameters $\bar{f}_x, \bar{f}, \bar{f}_e$ I need to match the parameters with the model. I take $\Omega = 1.91$ from Acemoglu (2010) for the year 2003. Also I take the fraction of exporters

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

Table 2: Calibration to US data summary

Parameter		Value	Source
Minimum productivity	$\bar{A}$	1	Normalized
Fixed Operational Cost	$\bar{f}_x$	1	Normalized
College/High school	$\frac{H}{L}$	1.28	In 2003 from Acemoglu 2010
Variable Trade cost	d_x	1.3	Ghironi & Melitz 2005
Ex-post Firm Sale Het.	$\frac{\theta}{\eta}$	1.89	Chaney 2005 (EKK = 2.46)
Goods Subs. Elasticity	σ	3.9	Chaney 2005 (BEJK= 3.79)
Skill Intensity	β_h	0.5	Burstein Vogel 2010 (0.1 to 0.6)
Labor Subs. Elasticity	ρ	5.5	$\Rightarrow \theta = 4.69$
Skill Premium	Ω	1.91	In 2003 from Acemoglu 2010
Fraction of Exporters	$\frac{M_x}{M_o}$	21%	BEJK 2003
Firms Death rate	$1-\frac{M}{M_e}$	10%	Ghironi Melitz 2005

Table 3: Results of matching model moments to US data

Parameter		Matched Value
Fixed Exporting Cost	$\bar{f}_x$	1.0659
Fixed Specialization Cost	$\bar{f}$	0.0435
Fixed Entry Cost	$\bar{f}_e$	0.4945

Estimated Parameters from matching moments to US data

$\frac{M_x}{M} = 21\%$ as in BEJK (2003). Finally I take the firms' death rate $\delta = 10\%$. Then I match these three variables using the model as below:

$$
\begin{aligned}
1 + \Omega H/L &= \frac{\sigma}{\rho - \sigma} \frac{\theta}{\theta - \eta} \frac{\bar{f}_a}{\bar{f}_o - \bar{f}_a} \left(1 + \left(\tilde{d}^{-\eta} - 1 \right)^{\frac{\theta}{\eta}} \left(\frac{\bar{f}_a}{\bar{f}_x} \right)^{\frac{\theta}{\eta} - 1} \right) \\
\frac{M_x}{M} &= \left(\tilde{d}^{-\eta} - 1 \right)^{\frac{\theta}{\eta}} \left(\frac{\bar{f}_a}{\bar{f}_x} \right)^{\frac{\theta}{\eta}} \\
\delta &= 1 - \frac{M_o}{M_e} = 1 - \frac{\theta - \eta}{\eta} \frac{\bar{f}_e}{\bar{f}_a + \frac{M_x}{M} \bar{f}_x}
\end{aligned}
$$

Table 2 shows the summary of the calibration and estimations from matching the parameters:

Table 4: Implied Values from Estimation

Parameter	**Value**
Domestic Entry cutoff	1.007
High-skill Employer Entry cutoff	1.085
Foreign Entry cutoff	1.114
High-skilled Real Wages	1.096
Low-skilled Real Wages	0.574
Fraction of only Low-skilled Firms	0.682

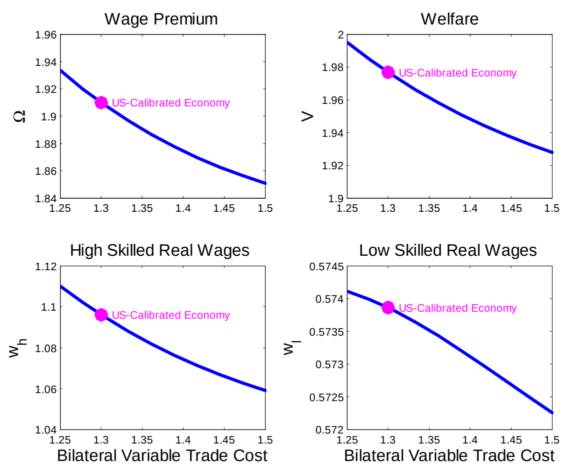

Figure 7: Impact of reduction in trade cost in US on the skill premium, real wages and welfare

3.1 Bilateral Variable Trade Cost Reduction

In this sub-section, I quantify the model under the upper boundary case with two symmetric economies, by using the calibrated model and measure the effects of changes in important variables of interests. I vary the variable trade cost and show that how much the reduction in trade costs can decrease the skill premium. I find that by reducing the variable trade costs, both type of workers' real wages increases but this change is so meaningful for the high-skilled workers. Also, as it is shown in Figure 7, by 20% rise in trade cost, the skill premium decreases by 6% and the aggregate welfare drops by %5.

Figure 8 illustrates the equilibrium distribution of high-skilled workers in the industry and degree of specialization of firms from 10% reduction in trade costs from $d = 1.4$ to $d = 1.3$. As it was expected, reducing trade costs shrinks the measure of entrants and increases the entry threshold. Also, the new exporter would expand their organization and increase their

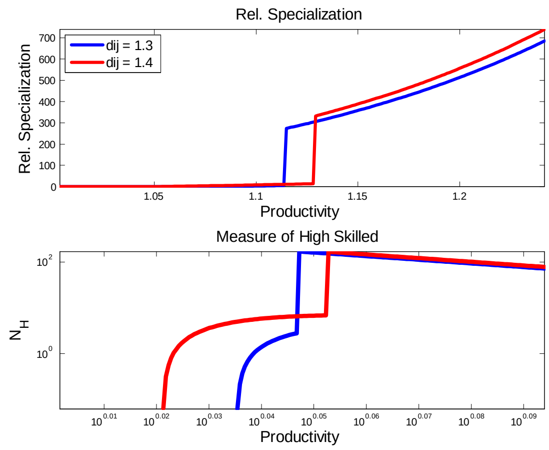

Figure 8: Impact of reduction in trade cost in US on the distribution of specialization and allocation of high skilled workers

degree of specialization. Finally, aggregate demand will also decline since aggregate prices drop in the equilibrium. Therefore, reduction in trade costs results in lower demand for domestic producers which is also called import competition. Finally, due to the drop in the demand, old exporters also lower their specialization a little bit since now they have more competitors and less demand. The conclusion is that the reduction in trade costs induces a reallocation of labor from domestic producers and old exporters toward the new exporters which are now highly specialized.

3.2 Specialization Fixed Cost Reduction

In this sub-section, I analyze numerically the effect of reducing the specialization costs of high-skilled workers using the calibrated model as before. Obviously, decreasing the fixed cost of specialization induces firms to specialize high-skilled workers more and therefore the demand for the high-skilled workers goes up. As we can see from the Figure 9, a 20% decrease in this cost can raises the wage premium by 5%.

Figure 9: Impact of reduction in specialization cost in US

4 Conclusion

In this paper, I introduce a new model of skill specialization that can explain several stylized facts about distributional effects and the labor market effects of international trade. The most important one is that it proposes a new mechanism in explaining the increase in the skill premium in developing and developed countries after trade liberalization. By modeling the internal firm organization, I introduce a channel through which trade affects the skill premium through firms' organizational decisions about their labor divisions and degrees of specialization of their 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. 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 changes in the average degree of specialization, and therefore biased changes in relative demand for skilled workers and consequently biased labor productivity changes. This skill-biased technological change will induce also an increase in the skill premium.

Finally, I calibrate the model to US data and numerically analyze the model's performance in explaining the changes in the skill premiums. I show that a 20% rise in the variable trade costs can reduce the skill premium by 6% and a 5% welfare losses in the US economy.

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A Appendix A - "For Online Publication" Canonical Model

Proof of lemma 2:

For revenue R:

$$\begin{aligned}
R(A,D) &= m^{-\frac{\rho(\sigma-1)}{\rho-\sigma}}\left(D^{\frac{1}{\sigma-1}}A\right)^{\eta}Q(A,D)^{\frac{1-\sigma}{\rho-\sigma}} \\
&\rightarrow m^{-\frac{\rho(\sigma-1)}{\rho-\sigma}}D^{\frac{\rho-1}{\rho-\sigma}}A^{\frac{\rho-1}{\rho-\sigma}(\sigma-1)}\left(\left((\rho-1)\bar{f}\right)w_H^{(\rho-1)}\right)^{\frac{1-\sigma}{\rho-\sigma}} \\
&= \bar{g}D^{\frac{\rho-1}{\rho-\sigma}}A^{\frac{\rho-1}{\rho-\sigma}(\sigma-1)}
\end{aligned}$$

The rest are also the same.

For the cost of low-skilled labor, we had $C_L(A,D) = (\rho-1)\bar{f}\Omega^{\rho-1}$ which is independent of A and D. For the high-skilled workers, I use the following simple relationship which can also be found from definition of Q as well:

$$R(A,D) = m\left(C_H(A,D) + C_L(A,D)\right)$$

thus

$$\begin{aligned}
C_H(A,D) &= \frac{R(A,D)}{m} - C_L(A,D) \\
&= \frac{\bar{g}}{m}D^{\frac{\rho-1}{\rho-\sigma}}A^{\frac{\rho-1}{\rho-\sigma}(\sigma-1)} - (\rho-1)f_H\Omega^{\rho-1}
\end{aligned}$$

also, as I showed in the previous lemma, we have $\bar{f}S = \frac{w_H N_H}{\rho-1}$. Hence

$$S(A,D) = \frac{\bar{g}}{m(\rho-1)\bar{f}}D^{\frac{\rho-1}{\rho-\sigma}}A^{\frac{\rho-1}{\rho-\sigma}(\sigma-1)} - \Omega^{\rho-1}$$

Finally

$$\begin{aligned}
\Pi(A,D) &= R(A,D) - \left(C_H(A,D) + C_L(A,D) + f_H S_H(A,D)\right) \\
&= \frac{R(A,D)}{\sigma} - f_H S_H(A,D) \\
&= \frac{R(A,D)}{\sigma} - \frac{C_H(A,D)}{\rho-1} \\
&= \frac{R(A,D)}{\sigma} - \frac{\frac{R(A,D)}{m} - C_L(A,D)}{\rho-1} \\
&= \frac{\rho-\sigma}{\rho-1}\frac{R(A)}{\sigma} + \bar{f}\Omega^{\rho-1}
\end{aligned}$$

This completes the proof. Note that this is the variable profit. The fixed operational fixed costs, fixed export costs and fixed sunk costs would be subtracted in the next steps.

Lemma 5 *(a) the firm in i produces domestically if:*

$$A \geq \bar{A}_o = Z_1 D^{-\frac{1}{\sigma-1}} \tag{21}$$

and the firm in i exports to j if

$$A_i \geq \bar{A}_x = Z_1 D^{-\frac{1}{\sigma-1}} \left(\frac{f_x}{f_a}\right)^{\frac{1}{\eta}} \left(\left(1+\frac{D_f}{D}\right)^{\frac{\rho-1}{\rho-\sigma}} - 1\right)^{-\frac{1}{\eta}}$$

where $f_a = f_{oi} - \frac{\beta_l}{\beta_h} w_{hi} \bar{f}_i \Omega_i^{\rho-1}$, $Z_1 = Z_1 = m^m \eta^{\frac{1}{\eta}} (\rho-1)^{\frac{1}{\rho-1}} w_H \bar{f}^{\frac{1}{\rho-1}} f_a^{\frac{1}{\eta}}$.

(b) In the two symmetric countries model, $\bar{A}_x$ *simplifies to*

$$A_i \geq \bar{A}_x = Z_1 D^{-\frac{1}{\sigma-1}} \left(\frac{\bar{f}_x}{\bar{f}_a}\right)^{\frac{1}{\eta}} \left(\tilde{d}^{-\eta} - 1\right)^{-\frac{1}{\eta}}$$

Proof. (a) A firm operates in the domestic market if $\frac{\rho-\sigma}{\rho-1}\frac{\bar{g}D^{\frac{\rho-1}{\rho-\sigma}}A^{\eta}}{\sigma}+w_H\bar{f}\Omega^{\rho-1}-f_o\geq 0$; thus

$$\begin{aligned} A &\geq \left(\frac{(\rho-1)\,\sigma}{\rho-\sigma}\frac{f_o-w_H\bar{f}\Omega^{\rho-1}}{\bar{g}D^{\frac{\rho-1}{\rho-\sigma}}}\right)^{\frac{1}{\eta}} \\ &= \left(\frac{(\rho-1)\,\sigma}{\rho-\sigma}\frac{f_a}{\bar{g}}\right)^{\frac{1}{\eta}}D^{-\frac{1}{\sigma-1}}=\bar{A}_o \end{aligned}$$

and a firm export if $\frac{\rho-\sigma}{\rho-1}\frac{\bar{g}\left(D+D_f\right)^{\frac{\rho-1}{\rho-\sigma}}A^{\eta}}{\sigma}+w_H\bar{f}\Omega^{\rho-1}-f_o-f_x\geq\frac{\rho-\sigma}{\rho-1}\frac{\bar{g}D^{\frac{\rho-1}{\rho-\sigma}}A^{\eta}}{\sigma}+w_H\bar{f}\Omega^{\rho-1}-f_o$; thus

$$\begin{aligned} A &\geq \left(\frac{(\rho-1)\,\sigma}{\rho-\sigma}\frac{f_x}{\bar{g}\left((D+D_f)^{\frac{\rho-1}{\rho-\sigma}}-D^{\frac{\rho-1}{\rho-\sigma}}\right)}\right)^{\frac{1}{\eta}} \\ &= \left(\frac{(\rho-1)\,\sigma}{\rho-\sigma}\frac{f_x}{\bar{g}}\right)^{\frac{1}{\eta}}D^{-\frac{1}{\sigma-1}}\left(\left(1+\frac{D_f}{D}\right)^{\frac{\rho-1}{\rho-\sigma}}-1\right)^{-\frac{1}{\eta}} \end{aligned}$$

(b) $\bar{A}_x=\left(\frac{(\rho-1)\sigma}{\rho-\sigma}\frac{f_x}{\bar{g}}\right)^{\frac{1}{\eta}}D^{-\frac{1}{\sigma-1}}\left(\left(1+\frac{D_f}{D}\right)^{\frac{\rho-1}{\rho-\sigma}}-1\right)^{-\frac{1}{\eta}}$

$$\begin{aligned} \left(\left(1+\frac{D_f}{D}\right)^{\frac{\rho-1}{\rho-\sigma}}-1\right)^{-\frac{1}{\eta}} &= \left(\left(1+d^{1-\sigma}\right)^{\frac{\rho-1}{\rho-\sigma}}-1\right)^{-\frac{1}{\eta}} \\ &= \left(\left(1+d^{1-\sigma}\right)^{-\frac{\eta}{\sigma-1}}-1\right)^{-\frac{1}{\eta}} \\ &= \left(\tilde{d}^{-\eta}-1\right)^{-\frac{1}{\eta}} \end{aligned}$$

This completes the prove. ■

Proof of Proposition 3:

In the Upper Boundary Case , the fraction of producers out of total potential producers is the fraction of firms which can pay the operational fixed cost and enter the domestic market. Also, productivities are Pareto distributed, thus $\mu_o=\left(\frac{\bar{A}_o}{\bar{A}}\right)^{-\theta}$ and the fraction of exporters are $\mu_x=\left(\frac{\bar{A}_x}{\bar{A}}\right)^{-\theta}$.

Revenue for a domestic producer is $R_d(A) = \bar{g} D^{\frac{\rho-1}{\rho-\sigma}} A^{\eta}$ and revenue for an exporter is

$$\begin{aligned} R_x(A) &= \bar{g}(D+D_f)^{\frac{\rho-1}{\rho-\sigma}} A^{\eta} \\ &= R_d(A) + \bar{g}\left((D+D_f)^{\frac{\rho-1}{\rho-\sigma}} - D^{\frac{\rho-1}{\rho-\sigma}}\right) A^{\eta} \end{aligned}$$

thus the aggregate revenue is

$$\begin{aligned} R &= M_e\left(\int_{\bar{A}_o}^{\bar{A}_x} R_d(A)\, dF(A) + \int_{\bar{A}_{ij}}^{\infty} R_x(A)\, dF(A)\right) \\ &= M_e\left(\int_{\bar{A}_o}^{\infty} R_d(A)\, dF(A) + \int_{\bar{A}_{ij}}^{\infty}\left(\bar{g}\left((D+D_f)^{\frac{\rho-1}{\rho-\sigma}} - D^{\frac{\rho-1}{\rho-\sigma}}\right) A^{\eta}\right) dF(A)\right) \\ &= \frac{m\theta\eta}{\theta-\eta}\left(\mu_o f_a + \mu_x f_x\right) M_e \end{aligned}$$

On the other hand since the low-skilled labor demand is independent of A and D and is equal to $\left((\rho-1)\, w_H \bar{f}\right) \Omega^{\rho-1}$, the aggregate Demand for labor of type L is

$$C_L = \left((\rho-1)\, w_H \bar{f}\right) \Omega^{\rho-1} \mu_o M_e$$

Therefore I can solve for the aggregate demand for the high-skilled using the notion that

$$C_H = \frac{R}{m} - C_L$$

So I find that

$$
\begin{aligned}
\frac{C_H}{C_L} &= \frac{R}{mC_L} - 1 \\
&= \frac{\frac{\theta\eta}{\theta-\eta}\left(\mu_o f_a + \mu_x f_x\right) M_e}{\left(\left(\rho-1\right) f_H\right)\Omega^{\rho-1}\mu_o M_e} - 1 \\
&= \frac{\theta\eta}{\left(\theta-\eta\right)\left(\rho-1\right)} \frac{f_a}{w_H \bar{f}\Omega^{\rho-1}} \left(1 + \frac{\mu_x f_x}{\mu_o f_a}\right) - 1 \\
&= \frac{\theta\eta}{\left(\theta-\eta\right)\left(\rho-1\right)} \frac{f_a}{f_o - f_a} \left(1 + \left(\frac{f_x}{f_a}\right)^{\frac{-\theta}{\eta}} \left(\tilde{d}^{-\eta} - 1\right)^{\frac{\theta}{\eta}} \frac{f_x}{f_a}\right) - 1 \\
&= \xi \frac{f_a}{f_o - f_a}\left(1 + O\right) - 1
\end{aligned}
$$

where $\xi = \frac{\theta\eta}{(\theta-\eta)(\rho-1)}$ and $O = \left(\frac{f_x}{f_a}\right)^{\frac{-\theta}{\eta}} \left(\tilde{d}^{-\eta} - 1\right)^{\frac{\theta}{\eta}}$. This completes the proof.

Proof of Proposition 4:

(a) In the general equilibrium with balanced trade, aggregate income equals aggregate demand. Also free entry ensures that aggregate profit is zero. Thus aggregate income equals $w_L L + w_H H$, and also aggregate revenue equals aggregate income. Thus,

$$
w_L L + w_H H = R = \frac{m\theta\eta}{\theta-\eta}\left(\mu_o f_a + \mu_x f_x\right) M_e \tag{22}
$$

In equilibrium all the markets clear. Since all the fixed costs are being paid in terms of high-skilled workers, aggregate low-skilled labor demand equals aggregate labor supply; thus,

$$
w_L L = C_L = \left(\left(\rho-1\right) w_H \bar{f}\right)\Omega^{\rho-1}\mu_o M_e \tag{23}
$$

Dividing (22) and (23) results in

$$
1 + \Omega\frac{H}{L} = m\xi\frac{f_a}{f_o - f_a}\left(1 + O\right) \tag{24}
$$

LHS is an increasing function of the skill premium Ω which changes from 1 to infinity.

RHS is a decreasing function of Ω since both f_a and O are decreasing in Ω. If the assumption in the proposition hold, then RHS goes from infinity to zero. Hence, there exists an equilibrium intersection which solves for Ω. In order to see how this assumption hold, we can rewrite the above equation in terms of f_a and thus RHS would be a function of f_a such that $f_a \in (0, f_o)$. LHS would be a decreasing function of f_a. In order that we have all the firms employing high-skilled workers we should have $C_H\left(\bar{A}_o\right) > 0$. By imposing this condition, then the inequality $\frac{1+\nu_2\left(\tilde{d}^{-\eta}-1\right)^{\frac{\theta}{\eta}}\left(\frac{\bar{f}_O}{\bar{f}_x}\right)^{\frac{\theta}{\eta}-1}}{1+\nu_1\frac{H}{L}\left(\frac{\bar{f}_O}{\bar{f}}\right)^{\frac{1}{\rho-1}}} < \frac{(\sigma-1)(\theta-\eta)}{\sigma\theta}$ ensures a solution to the equation.

(b) RHS of (24) is decreasing in both of the trade costs d and $\bar{f}_x$. Thus the equilibrium Ω is decreasing in the trade costs.

(c) Rewriting (24) in terms of O ensures that reducing trade costs results would results in an increase in the equilibrium O.

Proposition 6 *In general equilibrium, by reducing trade costs, the skill premium initially rises and then it falls.*

Proof. It has been shown numerically using the algorithm mentioned in the paper. ■

A.1 Relaxing Assumptions

Suppose the fixed costs are in terms of Final good: In this case we have: $f_i = P_i\bar{f}_i$, $f_{oii} = P_i\bar{f}_{oii}$, $f_{oij} = P_i\bar{f}_{ij}$ (or $P_j\bar{f}_{ij}$), $f_{ei} = P_i\bar{f}_{ei}$. Equilibrium condition for low-skilled labor doesn't change. For the revenue equation, we have

Total Revenue-Fixed costs = Total Household Income

Thus we have the following Equilibrium equations ($f_H = w_H\bar{f}$):

$$w_L L = M_o\left(\rho - 1\right) f_H \Omega^{\rho-1}$$

$$w_L L + w_H H = \frac{\theta\eta}{\theta - \eta}\left(M_o f_a + M_x f_x\right)$$

$$P = \left(\frac{(\rho-1)\,\sigma}{\rho-\sigma}\frac{\theta}{\theta-\eta}\right)^{\frac{1}{1-\sigma}}\left(\frac{M_o f_a}{D} + \frac{M_x f_{oij}}{D+D_x}\frac{1-(1-z_x)^{\frac{\sigma-1}{\rho-1}}}{z_x} + \frac{M_x d^{1-\sigma} f_x}{D+D_x}\frac{1}{z_x}\right)^{\frac{1}{1-\sigma}}$$

with definitions:

$$\begin{aligned}
f_H &= P\bar{f}_H, f_o = P\bar{f}_o, f_x = P\bar{f}_x \left(\text{or } P_j\bar{f}_x\right), f_e = P\bar{f}_e. \qquad (25)\\
X &= w_L L + w_H H + \Pi \\
& \begin{cases} \text{No Free Entry} & \begin{cases} M_e \text{ is given} \\ \Pi = \frac{w_L L + w_H H}{\theta} - M_e f_e \end{cases} \\ \text{Free Entry} & \begin{cases} Me = \frac{1}{\theta}\frac{X}{f_e} \\ \Pi = 0 \end{cases} \end{cases} \\
D_{ik} &= d_{ik}^{1-\sigma} P_k^{\sigma-1} X_k \\
M_o &= a^{\theta}\left(\frac{\rho-\sigma}{\sigma(\rho-1)}\frac{F^{\frac{1-\sigma}{\rho-\sigma}} D^{\frac{\rho-1}{\rho-\sigma}}}{f_o - f_H \Omega^{\rho-1}}\right)^{\frac{\theta}{\eta}} Me \\
M_x &= a^{\theta}\left(\frac{\rho-\sigma}{\sigma(\rho-1)}\frac{F^{\frac{1-\sigma}{\rho-\sigma}}\left((D+D_x)^{\frac{\rho-1}{\rho-\sigma}} - D_x^{\frac{\rho-1}{\rho-\sigma}}\right)}{f_x}\right)^{\frac{\theta}{\eta}} Me
\end{aligned}$$

Here the equations are of the same form as the original assumption except with a change in parameter in the revenue equation. Therefore by division of the first two, we get the following relative labor demand:

$$1 + \Omega H/L = \bar{r}\frac{\bar{f}_a}{\bar{f}_o - \bar{f}_a}\left(1 + \underbrace{O}_{\text{Openness Effect}}\right)$$

where

$$\begin{aligned} O &= \left(\frac{z_x}{1-z_x}\right)^{\frac{\theta}{\eta}}\left(\frac{\bar{f}_a}{\bar{f}_x}\right)^{\frac{\theta}{\eta}-1} \\ \bar{r} &= \frac{\theta\eta}{(\theta-\eta)(\rho-1)} \end{aligned}$$