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Firm Heterogeneity, Trade, and Wage Inequality

Bulent Unel
Louisiana State University

Working Paper 2008-02
Revised May 2009
http://bus.lsu.edu/McMillin/Working_Papers/pap08_02.pdf

Department of Economics
Louisiana State University
Baton Rouge, LA 70803-6306
http://www.bus.lsu.edu/economics/

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Bulent Unel*

This Version: May 2009

Abstract

This paper considers a world of two symmetric countries with two factors and two sectors. Outputs of the two sectors are imperfect substitutes and the sectors differ in relative factor intensity. Each sector contains a continuum of heterogeneous firms that produce differentiated goods within their sector. Trade is costly and there are both variable and fixed costs of exporting. The paper shows that under some plausible conditions supported by the data, trade between similar countries can increase the demand for skilled labor, which in turn increases the wage inequality between skilled and unskilled labor. The quantitative analysis suggests that such trade effects have played an important role in the increase in the US skill premium.

JEL Classification: F12, F13, and L1
Keywords: Firm Heterogeneity, Trade, and Skill Premium

*Department of Economics; Louisiana State University; Baton Rouge, LA 70803, USA. Tel: (225)578-3792 and Fax: (225)578-3708. E-mail: bunel@lsu.edu.

1 Introduction

A large literature documents dramatic changes in the US labor market over the post-war period: despite a rapid increase in the relative supply of skills, the skill premium has not declined.[1] Indeed, the skill premium has generally risen, and it has risen more significantly since the late 1970s. During the same period, trade with less developed countries (LDC) has also increased substantially. These patterns lead some economists to argue that the skill premium has increased because trade with LDCs raised the demand for skilled labor in the developed countries.[2] However, this explanation is discounted by most economists. For example, Krugman (1995) argues that although trade with LDCs has increased, volumes of trade with LDCs are still too small to explain the large increases in the skill premium that have taken place. Furthermore, several empirical studies (e.g., Behrman et al., 2000) find that many of the LDCs have also experienced rising inequality after opening to trade, which contradicts the conventional trade story.

This paper studies the effects of trade on the skill premium by focusing on the trade between symmetric countries (North-North trade). It develops a theoretical model, which is a blend of the models presented by Acemoglu (2002b) and Melitz (2003), to show that trade, even between similar countries, can increase the skill premium. The model has two sectors (skill intensive and less skill intensive) and two factors of production (skilled and unskilled labor). Outputs of the two sectors are imperfect substitutes as in Acemoglu (2002b), and each sector is populated by a continuum of firms each producing a different product. As in Melitz (2003), firms in each sector are heterogeneous in their productivity levels and higher productivity is modeled as producing a variety at lower marginal cost. Firms wishing to export face both fixed foreign-market entry costs and per unit trade costs.

There are three main findings. First, only the most productive firms engage in export

[1] See, for example, Katz and Murphy (1992) and Krusell et al. (2000). Aceomglu (2002a) provides a comprehensive review of this literature.

[2] See Wood (1994) and (1998). Another explanation is that new technologies have been skill biased and there has been an acceleration in skill-biased technical change (see, e.g., Acemoglu, 1998).

activities, and exposure to trade contributes to productivity gains in each sector. These results mirror the findings reported in Melitz (2003). Second, the positive effect of trade on the skill premium depends on both the dispersion of firm productivity levels and the degree of openness in each sector. In particular, it shows that when the productivity distribution of firms in the skill intensive sector (stochastically) dominate those in the labor intensive sector, and the firms in the skill intensive sector are more exposed to trade than those in the labor intensive sector, then such exposure to trade increases the skill premium. Finally, the quantitative analysis suggests that increases in trade can explain about 16 percent of the increase in the US skill premium over the last 40 years.

The intuition behind these results is as follows. Since entry into foreign markets is costly, exposure to trade provides new profit opportunities only to the more productive firms in each sector. Such profit opportunities also induce entry of more new firms in each sector, which further increases demand for both skilled and unskilled labor. The increased demand for inputs by the more productive firms and the new entrants increases real wages, which in turn forces the least productive firms to exit the market. However, since firms in the skill intensive sector are relatively more productive, use skilled labor more intensively, and are relatively more open, the potential returns from export markets are higher. As a result, the demand for skilled labor is higher than that for unskilled labor, which in turn raises the skill premium.

This paper is related to an emerging literature that proposes alternative mechanisms through which trade, even between similar countries, has a positive impact on the skill premium. For example, Dinopolous et al. (2001) present a monopolistic competition model that highlights the role of quasi-homothetic preferences, non-homothetic production, and output-skill complementarities on the skill premium. Moving from autarky to free inter-industry trade causes an expansion of firm size, and hence, an increase in the skill premium. Neary (2002), on the other hand, proposes an oligopolistic model in which a reduction in import barriers induces incumbent firms to invest more strategically. This strategic investment increases the demand for skilled labor, and hence, the skill premium. In an interesting article, Matsuyama (2007), using a Ricardian model of trade, argues that international trade inherently requires a more intensive use of skilled labor; as a result, exposure to trade increases the demand for skilled labor, and hence, the skill premium.

In this literature, this paper is more closely related to Epifani and Gancia (2008) who also consider a similarly structured two-sector model. They show that if the elasticity of substitution between output of two sectors is greater than one and the skill intensive sector has stronger returns to scale, then an exposure to trade will be skill-biased. Furthermore, their quantitative analysis suggests that the effects of trade on wage inequality can be substantial. The main differences between this paper and Epifani and Gancia (2008) are that my model incorporates firm heterogeneity and fixed costs of exporting.[3] These differences have important consequences. For example, the condition that the skill intensive sector has stronger returns to scale is *neither necessary nor sufficient* for trade to have a positive effect on the skill premium. As emphasized above, sufficiency conditions depend on both the dispersion of firm productivity levels and the degree of openness in each sector. Furthermore, my quantitative analysis delivers a lower impact of trade on the skill premium than Epifani and Ganica's analysis.

The plan of this paper is as follows. Section 2 introduces the model and identify conditions for trade to have a positive effect on the skill premium. Section 3 investigates the quantitative implications of the model. Finally, section 4 concludes the paper.

2 The Model

Consider a global economy consisting of $M + 1$ structurally identical countries. Each economy has two sectors, each containing a large number of heterogeneous firms. Labor is the only factor of production and each country is endowed with L_s units of skilled labor and

[3]There is now a large empirical literature that documents substantial variation in productivity across firms, even narrowly defined industries, and substantial sunk costs of entry into foreign markets. See, for example, Tybout (2003) for a review of this literature.

L_u units of unskilled labor. The skilled and unskilled labor are inelastically supplied and they remain constant over time.

2.1 Consumer Preferences

Consumer preferences are identical across all countries and modeled by the following CES utility function

$$U = \left[Y_s^{\frac{\varepsilon-1}{\varepsilon}} + Y_u^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad (1)$$

where Y_s and Y_u represent the consumption of final goods s and u, and ε is the elasticity of substitution between the two goods. As in Acemoglu (2002b), it is assumed that $\varepsilon > 1$.

Maximizing (1) subject to the budget constraint yields the following relative demand for two goods

$$\frac{Y_s}{Y_u} = \left(\frac{P_s}{P_u} \right)^{-\varepsilon}. \quad (2)$$

where P_s and P_u denote the prices of good s and u, respectively.

2.2 Production

The final goods are produced by perfectly competitive firms according to the following production technology,

$$Y_i = \left[\int_{j \in \mathcal{J}_i} y_i(j)^{\rho_i} dj \right]^{\frac{1}{\rho_i}}, \quad (3)$$

where $\mathcal{J}_i$ represents the mass of available intermediate goods in sector i and $y_i(j)$ is the amount of intermediate good type j used in the production of good i. I assume that $0 < \rho_i < 1$ so that the elasticity of substitution between any two goods, σ_i, is greater than one, i.e., $\sigma_i = 1/(1 - \rho_i) > 1$. It is further assumed that $\sigma_s, \sigma_u > \varepsilon$.

Given P_i and Y_i, it is easy to show that the optimal quantity and expenditure levels for each intermediate good are given by

$$y_i(j) = Y_i \left[\frac{p_i(j)}{P_i} \right]^{-\sigma_i} \quad \text{and} \quad r_i(j) = R_i \left[\frac{p_i(j)}{P_i} \right]^{1-\sigma_i}, \quad (4)$$

where $p_i(j)$ is the price of that brand j and $R_i = P_i Y_i = \int r_i(i)di$ denotes the aggregate expenditure on differentiated intermediate goods in sector i. Moreover, competition in the supply of goods $q_i(j)$ ensures the equilibrium price P_i equals the unit manufacturing cost:

$$P_i = \left[\int_{j \in \mathcal{J}_i} p_i(j)^{1-\sigma_i} dj \right]^{\frac{1}{1-\sigma_i}}. \tag{5}$$

Intermediate goods are produced by a continuum of monopolists, each choosing to produce a different variety. The skilled and unskilled labor are the only factors of production, and firms in the skill (less-skill) intensive sector use only skilled (unskilled) labor.[4] Production has both fixed and variable costs in each period: to produce y_i units of output in sector i, $f_i + y_i/\varphi$ units of type i labor must be used, where $f_i > 0$ is a fixed overhead cost. Thus, as in Melitz (2003), all firms in sector i share the same fixed cost, but have different productivity levels (which remain constant during their lifetime).

Firms wishing to export, however, face both per-unit trade costs and fixed costs. Per-unit costs (such as transport and tariffs) are modeled in the standard iceberg formulation: in sector i, $\tau_i > 1$ units of a good must be shipped in order for one unit to arrive at its destination. In addition, exporting involves a fixed foreign-market-entry cost of $w_i F_{ix} > 0$, where w_i is the wage rate of type i labor. The foreign market entry cost covers the cost of modifying the product to meet the foreign market specifications and costs based on regulations imposed by governments to erect non-tariff barriers to trade. The investment decision abroad occurs after the firm's productivity is revealed.

Each incumbent firm faces a constant probability of death δ in each period. Since there is also no uncertainty in the export market, each firm is indifferent between paying one time investment cost $w_i F_{ix}$ and paying $w_i f_{ix}$ (with $f_{ix} = \delta F_{ix}$) in each period. Hereafter I assume that in each period exporters pay $w_i f_{ix}$ in addition to the overhead production cost $w_i f_i$.

[4]Ventura (1997) and Acemoglu (2002b) also make the same assumption about factor intensity (see also Epifani and Gancia, 2008). Theoretical results will remain qualitatively similar, even if both factors are used in production, as long as the skill intensive sector uses skilled labor more intensively than the labor intensive sector. However, the analysis becomes quite complicated (see Appendix).

Consider the optimal pricing decision of a firm with productivity φ. Each firm faces a demand curve described in (4), and profit maximizing behavior yields the following price rules in domestic and foreign markets:

$$p_d(\varphi) = \frac{w}{\rho\varphi}, \qquad p_x(\varphi) = \frac{w\tau}{\rho\varphi}, \tag{6}$$

where I omit the sector subscript to simplify the notation, and will do so when this causes no confusion.

Given this pricing rule, the per-period profits of exporting firms can be decomposed into two parts: profits earned from domestic sales $\pi_d(\varphi)$, and profits earned from sales in each of M export markets $\pi_x(\varphi)$.

$$\pi_d(\varphi) = r_d(\varphi) - wy/\varphi - wf = r_d(\varphi)/\sigma - wf, \tag{7}$$

$$\pi_x(\varphi) = r_x(\varphi) - w\tau y/\varphi - wf_x = r_x(\varphi)/\sigma - wf_x, \tag{8}$$

where r_d and r_x denote the revenues obtained from sales in domestic and each of export markets.

Using the pricing rules given by (6) in (4) implies that

$$\frac{y_d(\varphi_1)}{y_d(\varphi_2)} = \frac{y_x(\varphi_1)}{y_x(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma}, \quad \frac{r_d(\varphi_1)}{r_d(\varphi_2)} = \frac{r_x(\varphi_1)}{r_x(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}, \quad \frac{r_x(\varphi)}{r_d(\varphi)} = \tau^{1-\sigma}. \tag{9}$$

As shall be shown below, only a fraction of firms export. Thus, a firm with productivity φ earns a per-period profit $\pi(\varphi) = \pi_d(\varphi) + max\{0, M\pi_x(\varphi)\}$. Since each firm faces a constant probability of death δ in each period, the market value of a typical firm is given by

$$\nu(\varphi) = max\left\{0, \sum_{t=0}^{\infty}(1-\delta)^t\pi(\varphi)\right\} = max\left\{0, \frac{1}{\delta}\pi(\varphi)\right\}. \tag{10}$$

A firm with productivity φ produces only if $\pi_d(\varphi) \geq 0$. Since $\pi_d(\varphi)$ is an increasing and continuous function of φ, there is a sufficiently small φ where $\pi_d(\varphi) < 0$. Then there exists a productivity cutoff level φ_d such that $\pi_d(\varphi_d) = 0$. Similarly, the firm serves in foreign markets only if $\pi_x(\varphi) \geq 0$. The profit function $\pi_x(\varphi)$ is also an increasing function of φ; hence, by the same logic, there exits a productivity cutoff level φ_x such that $\pi_x(\varphi_x) = 0$.

Notice that at φ_x, $\pi_d(\varphi_x) > 0 \;\Leftrightarrow\; r_d(\varphi_x) > \sigma w f$. From the export cutoff condition $r_x(\varphi_x) = \sigma w f_x$. But then $\tau^{1-\sigma} r_d(\varphi_x) = \sigma w f_x$, which in turn implies that $\tau^{\sigma-1} f_x > f$. To ensure partitioning of firms, I assume that this condition holds. Furthermore, the zero cutoff profit conditions for domestic and export markets yields

$$\frac{r_x(\varphi_x)}{r_d(\varphi_d)} = \tau^{1-\sigma} \left(\frac{\varphi_x}{\varphi_d}\right)^{\sigma-1} = \frac{f_x}{f} \quad \Longleftrightarrow \quad \varphi_x = \varphi_d \tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}. \tag{11}$$

2.3 Entry Decision and Equilibrium Analysis

The determination of the production cutoff quality level depends on firms' entry decisions. There is a large number of prospective and ex-ante identical entrants. Firms face an initial investment of $f_e > 0$ units of labor, which is thereafter sunk. Firms then draw their productivity parameter φ from a common distribution $g(\cdot)$ with positive support over $(0, \infty)$ and with continuous cumulative distribution $G(\cdot)$.[5]

Notice that the ex-ante probability of successful entry is $1 - G(\varphi)$. Thus, the ex-post distribution of firm productivity, $\mu(\varphi)$, is the conditional distribution of $g(\varphi)$ on $[\varphi_d, \infty)$:

$$\mu(\varphi) = \begin{cases} \frac{g(\varphi)}{1-G(\varphi_d)} & \text{if } \varphi > \varphi_d \\ 0 & \text{otherwise} \end{cases} \tag{12}$$

The ex-ante probability that one of these successful firms will export is given by $\zeta_x = [1 - G(\varphi_x)]/[1 - G(\varphi_d)]$. In addition, the law of large numbers implies that ζ_x equals the ex-post fraction of incumbent firms that export. Let N_i denote the mass of firms operating in sector i in any country. The mass of exporting firms then is given by $N_{ix} = \zeta_{ix} N_i$. With the above distribution function, the aggregate price index defined (5) becomes

$$P_i = \frac{w_i}{\rho_i} \left[N_i \tilde{\varphi}_{id}^{\sigma_i - 1} + M N_{ix} (\tau^{-1} \tilde{\varphi}_{ix})^{\sigma_i - 1} \right]^{\frac{1}{1-\sigma_i}}, \tag{13}$$

[5]Both the fixed costs and the distribution functions are sector specific. More precisely, firms in sector i invest f_{ie} units of type i labor, and then draw their productivity parameter from a common distribution $g_i(\cdot)$.

where M is the number of trading partners, and $\varphi_z \quad (z = d, x)$ is given by

$$\tilde{\varphi}_z \equiv \tilde{\varphi}_z(\varphi_z) = \left[\frac{1}{1 - G(\varphi_z)} \int_{\varphi_z}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi\right]^{\frac{1}{\sigma-1}}. \tag{14}$$

Thus, $\tilde{\varphi}_d$ is the weighted harmonic mean of the productivity levels of all operating firms and can be interpreted as the average (expected) productivity level. Similarly, $\tilde{\varphi}_x$ is the weighted harmonic mean of the productivity levels of exporters and can be interpreted as the average productivity level of exporting firms.

With this average productivity, it is easy to show that the average profit in sector i is given by

$$\bar{\pi}_i = \pi_{id}(\tilde{\varphi}_{id}) + \zeta_{ix} M \pi_{ix}(\tilde{\varphi}_{ix}). \tag{15}$$

Using (9) in the zero cutoff profit conditions, on the other hand, implies

$$\pi_{id}(\tilde{\varphi}_{id}) = w_i f_i \left[\left(\frac{\tilde{\varphi}_{id}}{\varphi_{id}}\right)^{\sigma_i - 1} - 1\right], \qquad \pi_{ix}(\tilde{\varphi}_{ix}) = w_i f_{ix} \left[\left(\frac{\tilde{\varphi}_{ix}}{\varphi_{ix}}\right)^{\sigma_i - 1} - 1\right].$$

Substituting these into the average profit function given by (15) yields

$$\bar{\pi}_i = w_i f_i \left[\left(\frac{\tilde{\varphi}_{id}}{\varphi_{id}}\right)^{\sigma_i - 1} - 1\right] + \zeta_{ix} M w_i f_{ix} \left[\left(\frac{\tilde{\varphi}_{ix}}{\varphi_{ix}}\right)^{\sigma_i - 1} - 1\right]. \tag{16}$$

Since the ex-ante probability of successful entry is $1 - G_i(\varphi_{id})$, in any equilibrium where entry is unrestricted, the net value of entry must be zero:

$$[1 - G_i(\varphi_{id})]\frac{\bar{\pi}_i}{\delta} = w f_{ie}. \tag{17}$$

Substituting (16) into the free entry condition (17) yields

$$f_i H_i(\varphi_{id}) + M f_{ix} H_i(\varphi_{ix}) = \delta f_{ie}, \tag{18}$$

where H is defined as

$$H(\varphi_z) \equiv [1 - G(\varphi_z)] \left[\left(\frac{\tilde{\varphi}_z}{\varphi_z}\right)^{\sigma - 1} - 1\right], \qquad z = d, x.$$

As originally shown by Melitz (2003), $H(\varphi_z)$ decreases in φ_z. Moreover, according to (11) φ_{ix} is an increasing function of φ_{id}. Thus, equations (11) and (19) yield a unique solution for $(\varphi_{id}, \varphi_{ix})$.

Before going further, it is interesting to compare the domestic cutoff level with that in autarky. The closed-economy steady-state equilibrium condition is obtained by setting the number of trading partners to zero (i.e., $M = 0$) in (18). Hence, the autarkic production cutoff level φ_{id}^a is determined by $f_i H(\varphi_{id}^a) = \delta f_{ie}$, which is strictly less than the open-economy cutoff quality level φ_{id}. As discussed in the introduction, exposure to trade provides new profit opportunities to the more productive firms, and hence, it induces more firms to enter the market. Increased demand for labor by the more productive firms and the new entrants bids up the real wages and forces the least productive firms to exit, as in Melitz (2003).

What will be the equilibrium number of products in each sector? Following Melitz (2003), I shall only consider stationary equilibrium. The mass of successful entrants must be equal to the mass of incumbents who are hit with the bad shock and exit, i.e., $[1 - G_i(\varphi_{id})]N_{ie} = \delta N_i$, where N_{ie} is the mass of new entrants. The total labor used by the new entrants is $L_{ie} = N_{ie} f_{ie} = \delta N_i f_{ie}/[1 - G_i(\varphi_{id})]$. Combining with the free-entry condition yields

$$L_{ie} = N_i \bar{\pi}_i / w_i \quad \Rightarrow \quad \Pi_i = w_i L_{ie} \quad \Rightarrow \quad R_i = \Pi_i + w_i L_{ip} = w_i L_i,$$

where L_{ip} denotes total amount of labor used in production in sector i. Thus, aggregate revenue must be equal to the total payments to labor used in sector i. Since $R_i = N_i \bar{r}_i$, the equilibrium mass of incumbent firms is[6]

$$N_i = \frac{w_i L_i}{\sigma_i(\bar{\pi}_i + w_i f_i + \zeta_{ix} M w_i f_{ix})}. \tag{19}$$

To derive the skill premium, first consider equation (2). Multiplying both sides by P_s/P_u

[6] To see this note that $\bar{r} = r_d(\tilde{\varphi}_d) + \zeta_x M r_x(\tilde{\varphi}_x) = \sigma f[\tilde{\varphi}_d^{\sigma-1} + \zeta_x M(\tau^{-1}\tilde{\varphi}_x)^{\sigma-1}]/\varphi_d^{\sigma-1}$, where the last equality follows from equation (9): $r_d(\tilde{\varphi}_d) = (\tilde{\varphi}_d/\varphi_d)^{\sigma-1} r_d(\varphi_d) = \sigma f(\tilde{\varphi}_d/\varphi_d)^{\sigma-1}$, and $r_x(\tilde{\varphi}_x) = (\tau^{-1}\tilde{\varphi}_x/\varphi_d)^{\sigma-1} r_d(\varphi_d) = \sigma f(\tau^{-1}\tilde{\varphi}_x/\varphi_d)^{\sigma-1}$.

and using $R_s/R_u = w_s L_s / w_u L_u$, we have

$$\left(\frac{P_s}{P_u}\right)^{1-\varepsilon} = \frac{w_s L_s}{w_u L_u}. \tag{20}$$

Using equations (13), (17), and (19) in (20) yields

$$\omega = \gamma \left(\frac{\varphi_{sd}}{\varphi_{ud}}\right)^{\frac{\varepsilon-1}{\varepsilon}} L^{\frac{(\varepsilon-1)(\sigma_u-\sigma_s)}{\varepsilon(\sigma_s-1)(\sigma_u-1)}} \left[\frac{\theta^{\frac{\varepsilon-\sigma_s}{\varepsilon(\sigma_s-1)}}}{(1-\theta)^{\frac{\varepsilon-\sigma_u}{\varepsilon(\sigma_u-1)}}}\right], \tag{21}$$

where $\omega = w_s/w_u$ represents the skill premium, $L = L_s + L_u$ is the total labor supply (or size of each country), $\theta = L_s/L$, and γ is a constant.[7] With $\varepsilon > 1$, it follows that the skill premium is positively related to the relative cutoff levels. If $\sigma_u > \sigma_s$, then the skill premium increases with increases in the size of the economy (i.e., total labor supply L) and decreases in the relative supply of skills. The net effect depends on the strength of these opposite forces.

It easily follows from (21) that

$$\omega = \left(\frac{\varphi_{sd}/\varphi_{sd}^a}{\varphi_{ud}/\varphi_{ud}^a}\right)^{\frac{\varepsilon-1}{\varepsilon}} \omega^a, \tag{22}$$

where superscript a stands for autarky. This equation indicates that if exposure to trade increases the domestic cutoff productivity level in the skill intensive sector more than that in the less skill intensive sector, then the skill premium will increase.

I now turn to the parametrization of the distribution function by assuming that productivity draws follow a Pareto distribution:

$$G_i(\varphi) = 1 - \left(\frac{b_i}{\varphi}\right)^{k_i}, \qquad i = s, u, \tag{23}$$

where k_i is the shape parameter and b_i is the scale parameter that bounds the support $[b_i, +\infty)$ from below. I further assume that $k_i + 1 > \sigma_i$, which ensures that the integrals in aggregate variables converge.

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[7] $\gamma = \left[\frac{\rho_s(\sigma_u f_u)^{\frac{1}{\sigma_u-1}}}{\rho_u(\sigma_s f_s)^{\frac{1}{\sigma_s-1}}}\right]^{\frac{\varepsilon-1}{\varepsilon}}$.

Pareto distribution has been widely used in recent trade literature and it makes the analysis analytically more tractable. Furthermore, many studies (e.g., Helpman et al. (2004)) find that the distribution of firm sizes in the US closely follow a Pareto distribution.

Using this specific distribution form in (11) and (17) yields

$$\varphi_{id} = (1+\Omega_i)^{\frac{1}{k_i}} \varphi_{id}^a \qquad \text{with} \qquad \Omega_i = M\tau_i^{-k_i} T_i^{1-\frac{k_i}{\sigma_i - 1}}, \qquad T_i = \frac{f_{ix}}{f_i}. \tag{24}$$

Note that Ω_i increases with increases in the number of trading partners (M) and decreases in trade costs (τ_i and T_i). Thus, Ω_i measures the degree of openness: a higher value of Ω_i corresponds to a more open economy. Furthermore, an inspection of (24) reveals that further exposure to trade increases the productivity cutoff level φ_{id}.[8]

Equation (22) then becomes

$$\omega = \left[\frac{(1+\Omega_s)^{\frac{1}{k_s}}}{(1+\Omega_u)^{\frac{1}{k_u}}} \right]^{\frac{\varepsilon-1}{\varepsilon}} \omega^a. \tag{25}$$

With no firm heterogeneity and foreign market fixed entry costs, the skill premium in the open economy is given by

$$\omega = \left[\frac{(1+M\tau_s^{1-\sigma_s})^{\frac{1}{\sigma_s - 1}}}{(1+M\tau_u^{1-\sigma_u})^{\frac{1}{\sigma_u - 1}}} \right]^{\frac{\varepsilon-1}{\varepsilon}} \omega^a. \tag{26}$$

Notice that equation (26) is the same as (25) with $k_i = \sigma_i - 1$.

To make a comparison between the two cases easier, assume that $\tau_s = \tau_u = \tau$, $T_s = T_u = T$, and $\varepsilon > 1$. Clearly, with $\sigma_s < \sigma_u$, exposure and further exposure to trade raises the skill premium in (26): Epifani and Gancia's (2008) main conclusion. An inspection of (25), on the other hand, indicates that the condition $\sigma_s < \sigma_u$ is *neither necessary nor sufficient* for trade to have positive effect on the skill premium: for example, under $k_s = k_u$, exposure to trade reduces the skill premium, if $T \geqslant 1$; and it increases the skill premium, if $T < 1$. Thus, moving from autarky to trade has an ambiguous effect on the skill premium.

[8] By using conditions described by (11) and (18), it is easy to show that this conclusion holds under any distribution function.

Similarly, the effect of a further exposure to trade is also ambiguous. Clearly, the shape parameter (k_i), which governs the size of dispersion of productivity, and the ratio of fixed costs (T) all play key roles in determining the effects of trade on the skill premium.[9]

When does trade have positive effects on the skill premium? The following proposition summarizes *sufficiency* conditions that make exposure and further exposure to trade have positive effects on the skill premium.

Proposition. *Suppose that the elasticity of substitution between output of two sectors is greater than one (i.e., $\varepsilon > 1$) and productivity draws follow the Pareto distribution described in (23).*

i. *If $k_s \leqslant k_u$ and $\Omega_s \geqslant \Omega_u$ (assuming that one of these holds with strict inequality), then the skill premium in the open economy is greater than that in the autarky, i.e. exposure to trade rises the skill premium.*

ii. *Let $k_s \leqslant k_u$ and $\Omega_s \geqslant \Omega_u$ (assuming that one of these holds with strict inequality). Suppose that after opening to trade, the economy is further exposed to trade and let Ω'_i represent the new equilibrium value of Ω_i. If $\Omega'_s/\Omega_s \geqslant \Omega'_u/\Omega_u$, then such further exposure to trade rises the skill premium.*

Before discussing quantitative implications of the model, it is important to evaluate what $k_s \leqslant k_u$ means. The shape parameter k_i represents dispersion levels of firm productivity: a sector with lower k has higher productivity dispersion levels. Indeed, the productivity levels in the skill intensive sector first-order stochastically dominates that in the less skill intensive sector if and only if $b_s \geqslant b_u$ and $k_s \leqslant k_u$.[10] Thus, $k_s \leqslant k_u$, in addition to $b_s \geqslant b_u$,

[9] It should be emphasized that the condition $\sigma_u > \sigma_s$ is still necessary for the market size effect to be positive, i.e., $d\omega/dL > 0$.

[10] To see this, first recall that G_s first-order stochastically dominates $G_u(\cdot)$ if and only if $1 - G_s(\varphi) \geqslant 1 - G_u(\varphi)$ for each φ. Suppose that $b_u > b_s$. Then for $\varphi = b_u, 1 - G_s(b_u) \geqslant 1 - G_u(b_u) \;\Rightarrow\; (b_s/b_u)^{k_s} \geqslant 1 \;\Rightarrow b_s \geqslant b_u$, a contradiction with our supposition. Thus, $b_s \geqslant b_u$. To show that $k_s \leqslant k_u$, note that $1 - G_s(\varphi) \geqslant 1 - G_u(\varphi) \;\Rightarrow\; b_s^{k_s}/b_u^{k_u} \geqslant \varphi^{k_s - k_u}$, for all φ. Since b_j and k_j are constants, the left-hand side

implies that productivity levels in the skill intensive sector are stochastically better than that in the less skill intensive sector. Then the above proposition can (roughly) be stated as follows: when the skill intensive sector is more productive (in a stochastic sense) and more open than the less skill intensive sector, trade has a positive effect on the skill premium.

3 Quantitative Analysis

How likely are the conditions in the above proposition satisfied in practice? If they hold in practice, what will be the impact of the trade on the skill premium? I start with the parameter ε, which also measures the elasticity of substitution between skilled and unskilled labor.[11] Using the CPS data over the period 1963-1987, Katz and Murphy (1992) find that it is about 1.4. Using a capital-skill complementary model, Krusell et al. (2000) estimate the elasticity as 1.67. However, recent studies using longer series and new estimation techniques find much higher estimates. For example, Reshef (2007), extending the Katz-Murphy framework to a two-sector model and applying simulated method of moments, find that the elasticity is about 3.2.[12] In my quantitative analysis, I will consider $\varepsilon = 1.5$ and 2.

An easy way to evaluate the claim that $\Omega_s > \Omega_u$ is to compare the total trade shares of the sectors, since the ratio of export (or import) to the sectoral output is given by $\Omega_i/(1+\Omega_i)$.[13] Using the OECD bilateral trade database (2007), I find that the total trade shares of the skill intensive industries are substantially higher than that of the less skill intensive industries in all available years.[14] For example, in 2000, the average trade share of

of this inequality is constant. If $k_s > k_u$, then for sufficiently large values of φ, the right-hand side will be greater. Thus, $k_s \leqslant k_u$.

[11] To see this, note that $w_i L_i = R_i = P_i Y_i$ implies that $Y_i = A_i L_i$, where $A_i = \rho_i \tilde{\varphi}_i N_i^{1/(\sigma_i - 1)}$ represents the index of technology in sector i. The production of the homogenous goods is then given by

$$Y = \left[(A_s L_s)^{\frac{\varepsilon-1}{\varepsilon}} + (A_u L_u)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

[12] Using longer series and different data, Polgreen and Silos (2008) re-estimate the Krusell et al. model. Their estimates vary between 2 and 9!

[13] Export (or import) to the sectoral output ratio is given by $R_{ix}/R_i = M\zeta_{ix} r_{ix}(\tilde{\varphi}_{ix})/[r_{id}(\tilde{\varphi}_{id}) + r_{ix}(\tilde{\varphi}_{ix})]$. Using (9) together with zero-profit cutoff conditions, one can easily show the above claim.

[14] To be consistent with the theoretical exploration, here I only consider the trade between US and the

the skill intensive industries in the US is more than 40 percent, while it is about 10 percent in the less skill intensive industries.

Consider now the condition $k_s \leqslant k_u$. There are two ways to evaluate this condition. First, recall that this condition holds when productivity draws in the skill intensive sector stochastically dominate that in the less skill intensive sector. Given that the skill intensive sectors often have more R&D investment for process innovation,[15] it is reasonable to expect that productivity levels in the skill intensive sector stochastically dominate those in the less skill intensive sectors. Indeed, using the OECD STAN (1998b) database, I find that the average total factor productivity (TFP) of high-skill intensive industries (such as non-electrical machinery, electrical machinery, and transport equipments) is about 40–90 percent higher than that of the low-skill intensive industries (such as food, textile & apparel, wood & furniture) in G5 countries over the period 1985-2000.[16]

Second, using using sales data of the US and the Western European firms, Helpman et al. (2004) estimate the measure of dispersion $k-(\sigma-1)$ at three-digit industrial level. According to their estimates, on average, the measure of dispersion in the skill intensive sectors are usually lower than that in the less skill intensive sectors, i.e., $k_s-(\sigma_s-1) < k_u-(\sigma_u-1)$.[17] This implies that $k_u - k_s > \sigma_u - \sigma_s$. Based on the previous empirical studies, Epifani and Gancia (2008) provide substantial evidence that $\sigma_u > \sigma_s$. More importantly, most studies find that the scale elasticity of the less skill intensive sectors do not significantly depart from constant returns to scale (see, e.g., Antweiler and Trefler, 2002). It then follows that

OECD countries. In calculating trade share, I also correct the total output by subtracting the total trade to the non-OECD countries.

[15]Using the OECD Business R&D database (1998a), I find that the average R&D intensity (R&D expenditure divided by the value-added) of skill intensive industries (such as food, textile & apparel, wood & furniture) are several times higher than that of low-skill intensive sectors (such as food, textile & apparel, wood & furniture). Some of the R&D investment may be related to quality improvement. However, as noted by Melitz (2003), higher productivity levels in this model may also be thought of as producing a higher quality variety at equal marginal cost.

[16]TFP is calculated as $Y/L^{\alpha}K^{1-\alpha}$, where K represents capital stock and $\alpha = 1/3$ is the capital share.

[17]See Figure 3 in Helpman et al. (2004). Table A.1 in the earlier version of their paper reports the estimated coefficients on $1/[k-(\sigma-1)]$ for 52 industries in the US, Western Europe, and France. According to this table, the simple average of the dispersions in the skill intensive sectors is around 0.75, while it is about 0.9 in the less skill intensive sectors, implying that $k_s \approx \sigma_s - 0.25$ and $k_u \approx \sigma_u - 0.1$.

$k_s < k_u$.[18]

I now turn to quantitative analysis. As discussed above, for ε, I shall consider two possibilities: $\varepsilon = 1.5$ and 2. I assume that $\sigma_s = 3.5$ (consistent with Morrison and Siegel, 1999 and Bernard et al., 2003); and following Epifani and Gancia (2008), I set $\sigma_u = \infty$ (consistent with Antweiler and Trefler, 2002). Setting $\sigma_u = \infty$ provides a benchmark case in which there will be *no* trade in the less skill intensive sector.[19] For the shape parameter k_s, I will consider $k_s = 3$ and 4 ($k_s = 3$ is closer to estimates in Helpman et al. (2004)).

Table 1 represents the results for different parameter values for ε, k_s, and Ω_s. The second column represents results when there is no firm heterogeneity and foreign-market fixed entry cost. As indicated before, Ω_s represents the degree of openness, and $\Omega_s/(1+\Omega_s)$ represents the share of exports in the total output of sector s. For example, $\Omega_s = 0.3$ means that the share of export in total output is about 23 percent. The table shows that moving from autarky to a partial integration with $\Omega_s = 1$ (i.e., to an export share of 67 percent) can raise the skill premium by 15 percent when there is no heterogeneity; while it increases the skill premium by *up* to 12 percent under heterogeneous firms. A comparison of the last three columns in Table 1 with column 2 shows that under the firm heterogeneity the impact of trade on the skill premium is considerably lower than that under the no heterogeneity case.

It will be interesting to investigate the implications of this exercise for the rises in the US skill premium. In 1970, the total trade (export plus import) share in the skill intensive industry output was about 10 percent, which implies that $\Omega_s = 0.05$.[20] In 2005, however,

[18] Helpman et al. (2004) use the Melitz model as the basis for their estimates and in that framework they can not separately estimate k and σ. Using firm-level data, Corcos et al. (2007) directly estimate k at two-digit industrial level, and according to their results $k_s \approx k_u$ (see Table 7 in their paper). However, their model doesn't have elasticity of substitution (σ_i) between different products because of the quasi-linear preference structure that they use. Furthermore, they don't consider fixed foreign market entry costs.

[19] Allowing for trade in the less skill intensive sector will not have any significant effect on the skill premium. There are two reasons for this. First, as discussed above, according to the OECD trade database Ω_s is substantially higher than Ω_u. Second, given that σ_u is very high, the condition $k_u > 1 + \sigma_u$ implies that k_u is also very high. Consequently, $(1 + \Omega_u)^{1/k_u}$ will be very small.

[20] I consider Chemical Products, Non-Electrical Machinery, Electrical Machinery, and Transport Equipments as the skill intensive sectors. To be consistent with the model, I only consider the trade between

Table 1: Increase in the Skill Premium (%)

Ω_s	$\varepsilon = 2.0$			$\varepsilon = 1.5$		
	No Heter.	$k_s = 3$	$k_s = 4$	No Heter.	$k_s = 3$	$k_s = 4$
0.3	5.4	4.5	3.3	3.0	2.5	1.9
0.5	8.4	7.0	5.2	5.6	4.6	3.4
1.0	14.9	12.2	9.1	9.7	8.0	5.9
2.0	24.6	20.1	14.7	15.8	13.0	9.6

Notes: No Heter. refers to no firm heterogeneity and no fixed foreign market entry costs.

the *total* trade share was about 65% (and export being about 30%), which implies that $\Omega_s \approx 0.50$. For $\varepsilon = 2$ and $k_s = 3$, these measures imply about a 6.2 percent increase in the skill premium, whereas they imply about about 11 percent increase in the skill premium under $\varepsilon = 1.5$ and $k_s = 4$. Given that there has been about a 27 percent increase in the wage gap between skilled and unskilled labor,[21] these further imply that the trade between US and OECD countries (according to the above model) can account for about a 16% increase in the US skill premium: a significant contribution to the overall wage inequality.

4 Concluding Remarks

This paper studies the effects of intra-industry trade between similar countries on the skill premium. It develops a two-sector model in which outputs of the two sectors are imperfect substitutes, and each sector contains a large number of heterogeneous firms specialized to produce differentiated goods. I show that under some plausible conditions supported by the data, trade between similar countries can increase the skill premium. When the model is calibrated with the US data, I find that increases in trade can explain up to 23 percent of rises in the skill premium.

the US and the OECD countries. In calculating trade share, I also corrected total output by subtracting the total trade to other countries. The data are taken from the various issues of the OECD STAN and the bilateral trade databases, which cover from 1970 to 2005.

[21] The skill premium is calculated using the CPS surveys that cover 1970-2005. Following Krusell et al. (2000), everyone who has at least 16 years of schooling (i.e., at least college degree) is considered skilled, and those who have fewer years of schooling are unskilled.

Although firms in the model are forward looking, there is no technical change, and hence, no growth. I also extended the model to a product innovation growth model to analyze the combined effects of skill-biased technical change and trade on the skill premium as in Acemoglu (2002b). In addition, I incorporated capital goods in the production process. However, these modifications require that $\sigma_s = \sigma_u$; otherwise, there would not be a balanced growth path.[22] Under this extension, the trade still has a positive effect on the skill premium, but the market size effect will disappear due to the restriction that $\sigma_s = \sigma_u$.

Appendix: When Each Sector Uses Both Factors

Assume that the cost function takes the following form

$$c_i(w_s, w_u)\left[f_i + \frac{y_i}{\varphi}\right] \qquad \text{with} \qquad c_i(w_s, w_u) = w_s^{\alpha_i} w_u^{1-\alpha_i}$$

where α_i is the labor share of skilled workers in sector i and we assume that $\alpha_s > \alpha_u$, i.e. sector s is more skilled intensive than sector u. With this cost function, the optimal pricing rule is now given by

$$p_{id}(\varphi) = \frac{c_i(w_s, w_u)}{\rho\varphi}, \qquad p_{ix}(\varphi) = \frac{\tau c(w_s, w_u)}{\rho\varphi}. \tag{27}$$

Firms first must make an initial investment of $c_i f_{ie} > 0$, which is thereafter sunk. Firms then draw their initial productivity parameter φ from a common distribution $g_i(\cdot)$, which is assumed to be common for firms in sector i. After entry, firms then face a constant probability δ in every period of a bad shock that would force them to exit. Furthermore, firms wishing to export must spend $c_i f_{ix}$ in each period. All of the analysis in section 2 remains the same except w_i will be replaced by c_i. Following the same steps in section 2, one can easily show that equations (11) and (18) still determine the zero profit cutoff levels, i.e., the zero profit cutoff levels are identical with that in section (2).

[22] The detail analysis of this extension is available from the author upon request.

For a firm with productivity φ, using Shephard's lemma, the total amount of skilled labor used in the production is given by

$$\left[f_i + \frac{y_{id}}{\varphi} + \chi\left(f_{ix} + \tau_i \frac{y_{ix}}{\varphi}\right)\right] \frac{\partial c_i}{\partial w_s} = \frac{\alpha_i}{w_s}\left[\rho_i r_{id}(\varphi) + c_i f_i + \chi\{\rho_i r_{ix}(\varphi) + c_i f_{ix}\}\right],$$

where $\chi = 1$, if the firm exports and zero otherwise. Similarly, the total amount of unskilled labor used in production is given by $(1-\alpha_i)[\rho_i r_{id}(\varphi) + c_i f_i + \chi\{\rho_i r_{ix}(\varphi) + c_i f_{ix}\}]/w_u$. It then follows that the total amount of skilled labor used in the production process of sector i is given by

$$L_{isp} = N_i \alpha_i [\rho_i \bar{r}_i + c_i(f_i + M\zeta_{ix} f_{ix})]/w_s, \tag{28}$$

where $\bar{r}_i$ represents the average revenue and M is the number of trading partners.

Total amount of skilled labor used in the entry process, on the other hand, is given by

$$L_{ise} = f_{ie} N_{ie} \frac{\partial c_i}{\partial w_s} = N_i \frac{\alpha_i}{w_s} \frac{\delta c_i f_{ie}}{1 - G_i(\varphi_{id})} = \frac{N_i \alpha_i \bar{\pi}_i}{w_s}, \tag{29}$$

where $\bar{\pi}_i = \bar{r}_i/\sigma_i - c_i(f_i + M\zeta_{ix} f_{ix})$ is the average profit. Combining (28) and (29) gives total amount of skilled labor used in sector i :

$$L_{is} = \alpha_i N_i \bar{r}_i / w_s = \alpha_i R_i / w_s. \tag{30}$$

Using this in the labor market clearing conditions implies

$$w_s L_s = \alpha_s R_s + \alpha_u R_u, \qquad w_u L_u = (1-\alpha_s) R_s + (1-\alpha_u) R_u,$$

which in turn yield

$$R_s = \frac{(1-\alpha_u) w_s L_s - \alpha_u w_u L_u}{\alpha_s - \alpha_u}, \quad R_u = \frac{\alpha_s w_u L_u - (1-\alpha_s) w_s L_s}{\alpha_s - \alpha_u}. \tag{31}$$

However, using the zero profit conditions together with (9) yields

$$R_i = N_i \bar{r}_i = \sigma_i c_i f_i \left[N_i \tilde{\varphi}_{id}^{\sigma_i - 1} + M N_{ix} (\tau^{-1} \tilde{\varphi}_{ix})^{\sigma_i - 1}\right] / \varphi_{id}^{\sigma_i - 1}. \tag{32}$$

The aggregate price index P_i is now given by

$$P_i = \frac{c_i}{\rho_i} \left[N_i \tilde{\varphi}_{id}^{\sigma_i - 1} + M N_{ix} (\tau^{-1} \tilde{\varphi}_{ix})^{\sigma_i - 1} \right]^{\frac{1}{1-\sigma_i}} .$$

Combining this with (32) implies

$$P_i = \left(\frac{c_i}{\rho_i \varphi_{id}} \right) \left(\frac{\sigma_i c_i f_i}{R_i} \right)^{\frac{1}{\sigma_i - 1}} . \tag{33}$$

Finally, substituting (33) into $(P_s/P_u)^{1-\varepsilon} = R_s/R_u$, and then using (31) yields

$$\frac{\varphi_{sd}}{\varphi_{ud}} = \gamma \left\{ \frac{[(1-\alpha_u)\omega L_s - \alpha_u L_u]^{\frac{\sigma_u - \varepsilon}{(\sigma_u - 1)(\varepsilon - 1)}}}{[\alpha_s L_u - (1-\alpha_s)\omega L_s]^{\frac{\sigma_s - \varepsilon}{(\sigma_s - 1)(\varepsilon - 1)}}} \right\} \omega^{\left(\frac{\alpha_s \sigma_s}{\sigma_s - 1} - \frac{\alpha_u \sigma_u}{\sigma_u - 1} \right)}, \tag{34}$$

where γ is a constant that depends on the parameters of the model, and $\omega = w_s/w_u$ represents the skill premium. Given that $\sigma_s > \varepsilon$ and $\sigma_u > \varepsilon$, it is easy to see that the expression in the curly bracket is an increasing function of ω (assuming that $\varepsilon > 1$). Furthermore, when $\sigma_u \geqslant \sigma_s$, the last term also increases in ω.[23] Thus, the skill premium, ω, is an increasing function of the relative cutoff levels, φ_s/φ_u. The sufficiency conditions described in the proposition in section 2 still hold under this generalized case (assuming that $\sigma_u \geqslant \sigma_s$).

[23] To see this, note that $\frac{\alpha_s \sigma_s}{\sigma_s - 1} - \frac{\alpha_u \sigma_u}{\sigma_u - 1} = \alpha_s \left[1 + \frac{1}{\sigma_s - 1} \right] - \alpha_u \left[1 + \frac{1}{\sigma_u - 1} \right] = (\alpha_s - \alpha_u) + \frac{\alpha_s}{\sigma_s - 1} - \frac{\alpha_u}{\sigma_u - 1} > 0$, where the inequality follows from our assumptions that $\alpha_s > \alpha_u$ and $\sigma_u \geqslant \sigma_s$. Notice that $\sigma_u \geqslant \sigma_s$ is a weaker condition than $\sigma_u > \sigma_s$.

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