



# Firm heterogeneity, trade, and wage inequality

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## ABSTRACT

This paper considers a world of symmetric countries with two factors of production 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.

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## 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.<sup>1</sup> 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.<sup>2</sup> However, this explanation is discounted by many 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

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<sup>1</sup> See, for example, *Katz and Murphy (1992)* and *Krusell et al. (2000)*. *Acemoglu (2002a)* provides a comprehensive review of this literature.

<sup>2</sup> See *Wood (1994, 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*).

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 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 15% of the increase in the US skill premium over the last 40 years.

The intuition behind these results can be summarized as follows. Since access to foreign markets is costly, trade provides new profit opportunities only to the more productive firms in each sector. Such profit opportunities also induce entry of more new firms into each sector. The increased demand for labor by the more productive firms and the new entrants increase real wages, which in turn forces the least productive firms to exit the market. However, since the skill-intensive sector is relatively more productive and open, the potential returns from export markets in this sector are higher. Consequently, the productivity gain due to the exit of the least productive firms is greater in this sector. This in turn reduces the relative price of the output of this sector, because more productive firms charge lower prices. Given that the output of the two sectors are gross substitutes, a fall in the relative price of the output of the skill-intensive sector increases the relative market share of this sector. This then raises the skill-premium, since the revenues are distributed back to the workers and the skill-intensive sector uses more skilled labor (see Section 2.3 for more details).

This paper contributes 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, Dinopoulos 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, a particularly related study is 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.<sup>3</sup> 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, under the same parameter restrictions, the quantitative analysis of this paper delivers a lower impact of trade on the skill premium than Epifani and Gancia's analysis.

This paper is also related to Bernard et al. (2007) who study how trade liberalization affects reallocations of resources both within and across industries and countries, when firms are heterogeneous, countries differ in relative factor abundance, and industries vary in factor intensity. This paper differs from theirs in two important aspects. First, their model is an extension of the standard Heckscher–Ohlin (HO) model, and hence, it explores effects of trade liberalization in a North–South framework, in contrast to the North–North framework used in this paper. Like the HO model, their model predicts that trade liberalization reduces the skill-premium in the skill-scarce foreign country (South), which contradicts several empirical studies (e.g., Behrman et al., 2000). Second, they assume that firms in both sectors draw their productivity parameters from the same distribution function; and thus, they do not investigate the implications of the asymmetric distributions of productivity across sectors as this paper does.

The plan of this paper is as follows. Section 2 introduces the model and identifies 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

<sup>3</sup> 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.

with  $L_s$  units of skilled labor and  $L_u$  units of unskilled labor. The skilled and unskilled labors 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:

$$U = [Y_s^{(\varepsilon-1)/\varepsilon} + Y_u^{(\varepsilon-1)/\varepsilon}]^{\varepsilon/(\varepsilon-1)}, \tag{1}$$

where  $Y_s$  and  $Y_u$  represent the consumption of final goods produced by the skill-intensive and the less skill-intensive sectors, respectively; and  $\varepsilon$  is the elasticity of substitution between the two goods. As in Acemoglu (2002b), it is assumed that the output of these two sectors are gross substitutes, i.e.,  $\varepsilon > 1$ .

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

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

where  $P_s$  and  $P_u$  denote the prices of the output of the skill-intensive and the less skill-intensive sectors, respectively.

2.2. Production

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

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

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,  $\sigma_i$ , 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

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

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:

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

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.<sup>4</sup> 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  $\delta$  in each period. Since there is also no uncertainty in the export market, each firm is indifferent between paying a 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  $w_i f_i$ .

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

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

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

<sup>4</sup> 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 A).

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  $\pi_x(\varphi)$ .

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

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

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  $\varphi$  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  $\delta$  in each period, the market value of a typical firm is given by

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

A firm with productivity  $\varphi$  produces only if  $\pi_d(\varphi) \geq 0$ . Since  $\pi_d(\varphi)$  is an increasing and continuous function of  $\varphi$ , there is a sufficiently small  $\varphi$  where  $\pi_d(\varphi) < 0$ . Then there exists a productivity cutoff level  $\varphi_d$  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  $\varphi$ ; hence, by the same logic, there exists a productivity cutoff level  $\varphi_x$  such that  $\pi_x(\varphi_x) = 0$ .

Notice that at  $\varphi_x$ ,  $\pi_d(\varphi_x) > 0 \Leftrightarrow r_d(\varphi_x) > \sigma wf$ . From the export cutoff condition  $r_x(\varphi_x) = \sigma wf_x$ . But then  $\tau^{1-\sigma} r_d(\varphi_x) = \sigma wf_x$ , 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

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

### 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  $\varphi$  from a common distribution  $g(\cdot)$  with positive support over  $(0, \infty)$  and with continuous cumulative distribution  $G(\cdot)$ .<sup>5</sup>

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  $\zeta_x$  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 is then given by  $N_{ix} = \zeta_{ix} N_i$ . With the above distribution function, the aggregate price index defined (5) becomes

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

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

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

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

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

<sup>5</sup> 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  $g_i(\cdot)$ .

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

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

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:

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

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

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

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

How does this domestic cutoff level differ from 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  $\varphi_{id}^a$  is determined by  $f_i H(\varphi_{id}^a) = \delta f_{ie}$ , which is strictly less than the open-economy cutoff quality level  $\varphi_{id}$ . 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).

To determine the equilibrium number of firms, I only consider the stationary equilibrium in which the mass of successful entrants must be equal to the mass of incumbents who are hit with the bad shock and exit:  $[1 - G_i(\varphi_{id})] N_{ie} = \delta N_i$ , 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

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

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<sup>6</sup>

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

To derive the skill premium, first consider Eq. (2). Multiplying both sides by  $P_s/P_u$  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 Eqs. (13), (17), and (19) in (20) yields

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

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  $\gamma$  is a constant.<sup>7</sup> With  $\varepsilon > 1$ , it follows that the skill premium is positively related to the relative cutoff levels.

If  $\sigma_u > \sigma_s$ , as Epifani and Gancia (2008) assume, then the skill premium increases with increases in the size of the economy ( $L$ ) and decreases in the relative supply of skills ( $\theta$ ). The net effect depends on the strength of these opposite forces. Another particularly interesting case is  $\sigma_s = \sigma_u = \sigma$ . In this case, the market size effect disappears, and the skill

<sup>6</sup> 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 Eq. (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  $r_x(\tilde{\varphi}_x) = (\tau^{-1} \tilde{\varphi}_x/\varphi_d)^{\sigma-1} r_d(\varphi_d) = \sigma f(\tau^{-1} \tilde{\varphi}_x/\varphi_d)^{\sigma-1}$ .

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

premium is given by

$$\omega = \gamma \left( \frac{\varphi_{sd}}{\varphi_{ud}} \right)^{(\varepsilon-1)/\varepsilon} \left( \frac{L_s}{L_u} \right)^{(\varepsilon-\sigma)/(\varepsilon(\sigma-1))}$$

With  $\varepsilon > \sigma > 1$ , the skill premium increases with  $L_s/L_u$ . This is essentially the main conclusion of Acemoglu (1998 and 2002b).

However, notice that whether  $\sigma_u > \sigma_s$  (as Epifani and Gancia assume) or  $\varepsilon$  is sufficiently high (as Acemoglu assumes) is not essential for trade to have a positive effect on the skill premium. To see this, note that (21) implies

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

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. Under what conditions is the increase in the zero-profit cutoff level in the skill-intensive sector greater than that in the less skill-intensive sector?

To answer this question, I parameterize the distribution function by assuming that productivity draws follow a Pareto distribution with positive support over  $[1, \infty)$ :

$$G_i(\varphi) = 1 - \varphi^{-k_i}, \quad i = s, u, \tag{23}$$

where  $k_i$  is the shape parameter. I further assume that  $k_i + 1 > \sigma_i$ , which ensures that the integrals in aggregate variables converge.<sup>8</sup> The shape parameter  $k_i$  represents an index of dispersion which characterizes heterogeneity: a sector with higher  $k$  represents lower productivity dispersion across firms, i.e., the sector becomes less heterogeneous as its shape parameter increases.

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

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

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

Three points deserve further attention. First, note that  $\Omega_i$  increases as the number of trading partners ( $M$ ) goes up and trade costs ( $\tau_i$  and  $T_i$ ) go down. Thus,  $\Omega_i$  measures the degree of openness: a higher value of  $\Omega_i$  represents a more open economy. Second,  $\Omega_i$  decreases with increases in  $k_i$ . In other words, for any value of  $\tau$  and  $T$ , a sector becomes less open as it becomes less heterogeneous.<sup>9</sup> This makes sense: as the productivity dispersion across firms decreases, the probability of drawing a higher productivity level becomes smaller. This in turn reduces the number of more productive firms. Given that firms face foreign-market fixed entry costs, fewer firms will export. Finally, an inspection of (24) reveals that further exposure to trade increases the productivity cutoff level  $\varphi_{id}$ .

Eq. (22) then becomes

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

where  $\Omega_i$  is defined in (24). An inspection of (25) indicates that the condition  $\sigma_s < \sigma_u$  is neither necessary nor sufficient for trade to have a positive effect on the skill premium. To see this, first assume that  $\tau_s = \tau_u = \tau$ ,  $T_s = T_u = T$ ,  $k_s = k_u$ , and  $\varepsilon > 1$ . Then exposure to trade reduces the skill premium if  $T \geq 1$ ; and it increases the skill premium if  $T < 1$ . Thus, moving from autarky to trade has an ambiguous effect on the skill premium. A similar analysis shows that the effect of a further exposure to trade on the skill premium is also ambiguous. 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  $k_s \leq k_u$  and  $\Omega_s \geq \Omega_u$  (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 raises the skill premium.*
- (ii) *Let  $k_s \leq k_u$  and  $\Omega_s \geq \Omega_u$  (assuming that one of these holds with strict inequality). Suppose that after opening to trade, the economy is further exposed to trade and let  $\Omega'_i$  represents the new equilibrium value of  $\Omega_i$ . If  $\Omega'_s/\Omega_s \geq \Omega'_u/\Omega_u$ , then such further exposure to trade raises the skill premium.*

<sup>8</sup> In general, a Pareto distribution is given by  $G_i(\varphi) = 1 - (b_i/\varphi)^{k_i}$ , where  $b_i$  is a scale parameter that bounds the support  $[b_i, +\infty)$  from below. The parameter  $b_i$  is normalized to unity without loss of generality.

<sup>9</sup> Notice that  $\Omega_i$  can be written as  $\Omega_i = M T_i (\tau_i^{\sigma_i-1} T_i)^{-k_i/(\sigma_i-1)}$ . The condition  $\varphi_{ix} > \varphi_{id}$  implies that  $\tau_i^{\sigma_i-1} T_i > 1$  (see Eq. (11)).  $\Omega_i$  clearly decreases as  $k_i$  goes up.

To unveil the intuition behind these results, it is important to understand what  $k_s \leq k_u$  implies. Recall that the shape parameter  $k_i$  represents dispersion of productivity levels across firms: a sector with lower  $k$  has higher productivity dispersion. Indeed, in the present set-up, the productivity levels in the skill-intensive sector first-order stochastically dominates that in the less skill-intensive sector if and only if  $k_s \leq k_u$ .<sup>10</sup> Thus, the above proposition states that 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.

When firms in the skill-intensive sector are relatively more productive and more open, the potential returns from exports in this sector are higher than those in the less skill-intensive sector. The higher potential returns from exports also induce entry of more firms into this sector. Consequently, increased demand for labor by more productive firms and the new entrants bids up *real* wages in the skill-intensive sector more than that in the less skill-intensive sector, which in turn forces more firms with low productivity to exit the skill-intensive sector. As a result, exposure to trade contributes to a greater productivity gain in the skill-intensive sector (i.e.,  $\varphi_{sd}/\varphi_{sd}^a > \varphi_{ud}/\varphi_{ud}^a$ ).

To see how a greater productivity gain in the skill-intensive sector raises the skill premium, first notice that more productive firms charge lower prices (see Eq. (6)). Thus, for any given nominal wage rates, the relative price of the output of the skill-intensive sector ( $P_s/P_u$ ) declines when the skill-intensive sector is exposed to more trade. Furthermore, given that the outputs of two sectors are gross substitutes (i.e.,  $\varepsilon > 1$ ), the relative demand for the output of the skill-intensive sector rises as the relative price  $P_s/P_u$  falls (see Eq. (2)). This in turn increases the relative market share of the skill-intensive sector (i.e.,  $R_s/R_u = (P_s/P_u)^{1-\varepsilon} \uparrow$ ). Since revenues are distributed back to the labor worked in these sectors ( $R_i = w_i L_i$ ), an increase in the relative market share of the skill-intensive sector raises the skill premium.<sup>11</sup>

### 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  $\varepsilon$ , which also measures the elasticity of substitution between skilled and unskilled labor.<sup>12</sup> 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, extending the Katz–Murphy framework to a two-sector model and applying simulated method of moments, Reshef (2007) finds that the elasticity is about 3.2. 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  $\Omega_i/(1 + \Omega_i)$ .<sup>13</sup> Using the OECD (2007) bilateral trade database, 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.<sup>14</sup> For example, in 2000, the total trade share of the skill-intensive industries in the US (i.e., (export+import)/output) is more than 50%, while it is about 14% in the less skill-intensive industries.

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

Second, 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

<sup>10</sup> To see this, first recall that  $G_s$  first-order stochastically dominates  $G_u(\cdot)$  if and only if  $1 - G_s(\varphi) \geq 1 - G_u(\varphi)$  for each  $\varphi$ . Note that  $1 - G_s(\varphi) \geq 1 - G_u(\varphi) \Rightarrow \varphi^{k_s - k_u} \leq 1$  for all  $\varphi$ . If  $k_s > k_u$ , then for any values of  $\varphi > 1$ , the left-hand side will be greater. Thus,  $k_s \leq k_u$ .

<sup>11</sup> An alternative intuition for why exposure to trade increases the skill-premium can be obtained by considering  $R_s/R_u = (P_s/P_u)^{1-\varepsilon}$ . This equilibrium condition can be rewritten as  $(R_s/R_u)(w_s/w_u)^{\varepsilon-1} = [(w_s/P_s)/(w_u/P_u)]^{\varepsilon-1}$ . Since the real wage in the skill-intensive sector increases more than that in the less skill-intensive sector, the right-hand-side of the last equation will also increase. Given that  $R_i = w_i L_i$ , the equilibrium will be restored only if the skill-premium ( $w_s/w_u$ ) increases.

<sup>12</sup> 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  $Y = [(A_s L_s)^{(\varepsilon-1)/\varepsilon} + (A_u L_u)^{(\varepsilon-1)/\varepsilon}]^{\varepsilon/(\varepsilon-1)}$ .

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

<sup>14</sup> To be consistent with the theoretical exploration, here I only consider the trade between US and the OECD countries. In calculating trade share, I also correct the total output by subtracting the total trade to the non-OECD countries.

<sup>15</sup> Using the OECD (1998a) business R&D database, I find that the average R&D intensity (R&D expenditure divided by the value-added) of skill-intensive industries (such as chemical products, electric and electronic machinery, and non-electrical machinery) are several times higher than those of the less skill-intensive sectors (such as food, textile and apparel, wood and 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.

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

**Table 1**  
Effects of trade on skill premium (%).

$\Omega_s$	$\varepsilon = 2.0$		$\varepsilon = 1.5$	
	$k_s = 3$	$k_s = 5$	$k_s = 3$	$k_s = 5$
0.3	4.5	2.7	2.5	1.8
0.5	7.0	4.1	4.6	2.7
1.0	12.2	7.2	8.0	4.7
2.0	20.1	11.6	13.0	7.6

Notes: Calculations are based on Eq. (25) with  $\Omega_u = 0$ .

**Table 2**  
Effects of trade on skill premium (%) with  $\sigma_s = \sigma_u$ .

$\Omega_s \neq \Omega_u$			$\Omega_s = \Omega_u$		
$(\Omega_s, \Omega_u)$	$k_u = 4$	$k_u = 8$	$(\Omega_s, \Omega_u)$	$k_u = 4$	$k_u = 8$
(0.3,0.1)	3.2	3.8	(0.3,0.3)	1.1	2.8
(0.5,0.2)	4.6	5.8	(0.5,0.5)	1.7	4.3
(1.0,0.3)	8.6	10.4	(1.0,1.0)	2.9	7.5
(2.0,0.6)	13.2	16.6	(2.0,2.0)	4.7	12.1

Notes: Calculations are based on Eq. (25) with  $\varepsilon = 2, k_s = 3$ , and  $\sigma_s = \sigma_u = 3.5$ .

the skill-intensive sectors is usually lower than that in the less skill-intensive sectors, i.e.,  $k_s - (\sigma_s - 1) < k_u - (\sigma_u - 1)$ .<sup>17</sup> 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  $k_s < k_u$ .

I now turn to quantitative analysis. As discussed above, for  $\varepsilon, I$  shall consider two possibilities:  $\varepsilon = 1.5$  and 2. I assume that  $\sigma_s = 3.5$  (consistent with Morrison and Siegel, 1999); and  $\sigma_u = \infty$  (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, and it makes results more comparable to those in Epifani and Gancia (2008). However, later in this section, I will also present results when  $\sigma_s = \sigma_u$ . For the shape parameter  $k_s$ , I will consider  $k_s = 3$  and 5 (with  $\sigma_s = 3.5$ ,  $k_s = 3$  is closer to estimates in Helpman et al., 2004).

Table 1 reports the effects of trade liberalization on the skill premium based on Eq. (25). The parameter  $\Omega_s$  represents the degree of openness of the skill-intensive sector, and  $\Omega_s / (1 + \Omega_s)$  represents the share of exports in this sector. For example,  $\Omega_s = 0.3$  means that the share of exports in total output is about 23%. Thus, instead of calibrating the parameters  $M_s, \tau_s$ , and  $T_s$ , I directly calibrate the openness parameter  $\Omega_s$ , which makes the analysis more straightforward. Consistent with the discussion in Section 2.3, Table 1 demonstrates that the lower the dispersion of productivity across firms (i.e., as  $k_s$  increases), the smaller is the impact of trade on the skill premium.

How do the results change if there were no firm heterogeneity and no foreign-market fixed entry costs? Given that the impact of trade on the skill premium decreases as the dispersion index  $k_s$  goes up, one may tend to conclude that the impact of trade on the skill premium will be much smaller when there is no firm heterogeneity and no foreign-market fixed entry costs. However, this conclusion is not correct. Because when all firms have the same productivity and face no foreign-market fixed entry costs, they all will export. As a result, for any value of  $M$  and  $\tau$ , the degree of openness in this case will be greater than that obtained from my model (with firm heterogeneity and foreign-market fixed entry costs).<sup>18</sup> This further implies that the impact of trade on the skill-premium is higher when there is no firm heterogeneity and no foreign-market fixed entry costs (assuming no trade in the less skill-intensive sector).<sup>19</sup>

<sup>17</sup> Helpman et al. (2004) use the Melitz model as the basis for their estimates and in that framework they cannot separately estimate  $k$  and  $\sigma$ . 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  $k_u \approx \sigma_u - 0.1$ . See also Fig. 3 in Helpman et al. (2004).

<sup>18</sup> Thus, there is discontinuity in the degree of openness when the shape parameter becomes infinity and there is no foreign-market fixed entry costs.

<sup>19</sup> The skill premium in the model with no firm-heterogeneity and no fixed exporting costs is given by  $\omega = [(1 + \Omega_s^n)^{(\varepsilon-1)/(\alpha(\sigma_s-1))} / (1 + \Omega_u^n)^{(\varepsilon-1)/(\alpha(\sigma_u-1))}] \omega^{\alpha}$ , where  $\Omega_i^n = M \tau_i^{1-\sigma_i}$  represents the degree of openness. In my model,  $\varphi_{ix} > \varphi_{id}$  implies that  $\tau_i^{\sigma_i-1} T_i > 1$  (see Eq. (11)). Using this condition together with  $k_i > \sigma_i - 1$  implies that  $\Omega_i < \Omega_i^n$ , where  $\Omega_i$  is defined in (24). Since  $k_s > \sigma_s - 1$  and there is no trade in the less skill-intensive sector ( $\Omega_u = \Omega_u^n = 0$ ), it easily follows that  $(1 + \Omega_s)^{1/k_s} < (1 + \Omega_s^n)^{1/(\sigma_s-1)}$  for any  $M, \tau_s$ , and  $T_s$ . For example, with  $\varepsilon = 2$  and  $k_s = 3$ , moving from autarky to a partial integration with  $M_s = 5, \tau_s = 1.91$ , and  $T_s = 2$  (yielding  $\Omega_s^n = 1$  and  $\Omega_s = 0.62$ ) raises the skill premium by 15% in the model with no firm heterogeneity and no foreign-market entry costs; while it increases the skill premium by 11.7% in my model. Consequently, compared to Epifani and Gancia (2008), my model delivers a lower positive impact of trade on the skill-premium.

I now investigate the implications of this exercise when the scale effect is removed (i.e.,  $\sigma_s = \sigma_u$ ). Table 2 presents the results based on Eq. (25) with  $\varepsilon = 2$ ,  $k_s = 3$ , and  $\sigma_s = \sigma_u = 3.5$ .<sup>20</sup> For  $k_u$ , I consider two different values:  $k_u = 4$  and 8. As the proposition in the previous section stated, the impact of trade on the skill-premium is higher when the skill-intensive sector is more open ( $\Omega_s > \Omega_u$ ) and the less skill-intensive sector is less productive (i.e.,  $k_u$  is higher). It is also interesting to note that exposure to trade has a positive effect on the skill-premium when both sectors have the same degree of openness.<sup>21</sup>

It will be also interesting to investigate the implications of this exercise for the increase in the US skill premium. In 1970, the total trade (export plus import) shares in the skill-intensive and the less skill-intensive sectors<sup>22</sup> output were about 12% and 5%, respectively; which imply that  $\Omega_s = 0.06$  and  $\Omega_u = 0.02$ . In 2005, however, the total trade shares of these sectors are about 60% and 13%, which imply that  $\Omega_s \approx 0.43$  and  $\Omega_u = 0.07$ . For  $\varepsilon = 2$ ,  $k_s = 3$ , and  $k_u = 8$ , these measures imply about a 4.8% increase in the skill premium, whereas they imply about 3% increase in the skill premium under  $\varepsilon = 1.5$  and  $k_u = 4$ . Given that there has been about a 27% increase in the wage gap between skilled and unskilled labor,<sup>23</sup> these further imply that the trade between US and OECD countries (according to the above model) can account for about a 15% 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 about 15% of increases in the skill premium.

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.<sup>24</sup> 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  $\sigma_s = \sigma_u$ .

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#### Appendix A. When each sector uses both factors

Assume that the cost function takes the following form:

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

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

$$p_{id}(\varphi) = \frac{c_i(w_s, w_u)}{\rho\varphi}, \quad p_{ix}(\varphi) = \frac{\tau C(w_s, w_u)}{\rho\varphi}. \tag{26}$$

Firms first must make an initial investment of  $c_{if_{ie}} > 0$ , which is thereafter sunk. Firms then draw their initial productivity parameter  $\varphi$  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  $\delta$  in every period of a bad shock that would force them to exit. Furthermore, firms wishing to export must spend  $c_{if_{ix}}$  in each period. All of the analysis in Section 2 remains the same except  $w_i$  will be

<sup>20</sup> The analysis based on the alternative values of these parameters yield similar conclusions, and are available upon request. Note that  $\sigma_s$  and  $\sigma_u$  are not used in the calculations of Table 2. The value of  $\sigma_i$  only affects the lower bound of  $k_i$ , since  $k_i > \sigma_i - 1$ .

<sup>21</sup> This effect disappears in the model with no firm heterogeneity and no foreign-market fixed entry costs (see the equation in footnote 19 with  $\Omega_s^n = \Omega_u^n$  and  $\sigma_s = \sigma_u$ ).

<sup>22</sup> 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 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.

<sup>23</sup> 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.

<sup>24</sup> The detail analysis of this extension is available from the author upon request.

replaced by  $c_i$ . Following the same steps in Section 2, one can easily show that Eqs. (11) and (18) still determine the zero profit cutoff levels, i.e., the zero profit cutoff levels are identical with that in Section 2.

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

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

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

$$L_{isp} = N_i \alpha_i [\rho_i \bar{r}_i + c_i (f_i + M \zeta_{ix} f_{ix})] / w_s, \quad (27)$$

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

$$L_{ise} = f_{ie} N_{ie} \frac{\partial C_i}{\partial w_s} = N_i \frac{\alpha_i}{w_s} \frac{\delta c_i f_{ie}}{1 - G_i(\varphi_{id})} = \frac{N_i \alpha_i \bar{\pi}_i}{w_s}, \quad (28)$$

where  $\bar{\pi}_i = \bar{r}_i / \sigma_i - c_i (f_i + M \zeta_{ix} f_{ix})$  is the average profit. Combining (27) and (28) gives total amount of skilled labor used in sector  $i$ :

$$L_{is} = \alpha_i N_i \bar{r}_i / w_s = \alpha_i R_i / w_s. \quad (29)$$

Using this in the labor market clearing conditions implies

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

which in turn yield

$$R_s = \frac{(1 - \alpha_u) w_s L_s - \alpha_u w_u L_u}{\alpha_s - \alpha_u}, \quad R_u = \frac{\alpha_s w_u L_u - (1 - \alpha_s) w_s L_s}{\alpha_s - \alpha_u}. \quad (30)$$

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

$$R_i = N_i \bar{r}_i = \sigma_i c_i f_i [N_i \tilde{\varphi}_{id}^{\sigma_i - 1} + M N_{ix} (\tau^{-1} \tilde{\varphi}_{ix})^{\sigma_i - 1}] / \varphi_{id}^{\sigma_i - 1}. \quad (31)$$

The aggregate price index  $P_i$  is now given by

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

Combining this with (31) implies

$$P_i = \left( \frac{c_i}{\rho_i \varphi_{id}} \right) \left( \frac{\sigma_i c_i f_i}{R_i} \right)^{1/(\sigma_i - 1)}. \quad (32)$$

Finally, substituting (32) into  $(P_s/P_u)^{1-\varepsilon} = R_s/R_u$ , and then using (30) yields

$$\frac{\varphi_{sd}}{\varphi_{ud}} = \gamma \left\{ \frac{[(1 - \alpha_u) \omega L_s - \alpha_u L_u]^{\sigma_u - \varepsilon / (\sigma_u - 1)(\varepsilon - 1)}}{[\alpha_s L_u - (1 - \alpha_s) \omega L_s]^{\sigma_s - \varepsilon / (\sigma_s - 1)(\varepsilon - 1)}} \right\}^{\omega ((\alpha_s \sigma_s) / (\sigma_s - 1) - (\alpha_u \sigma_u) / (\sigma_u - 1))}, \quad (33)$$

where  $\gamma$  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  $\omega$  (assuming that  $\varepsilon > 1$ ). Furthermore, when  $\sigma_u \geq \sigma_s$ , the last term also increases in  $\omega$ .<sup>25</sup> Thus, the skill premium,  $\omega$ , is an increasing function of the relative cutoff levels,  $\varphi_s/\varphi_u$ . The sufficiency conditions described in the proposition in Section 2 still hold under this generalized case (assuming that  $\sigma_u \geq \sigma_s$ ).

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<sup>25</sup> 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  $\sigma_u \geq \sigma_s$ . Notice that  $\sigma_u \geq \sigma_s$  is a weaker condition than  $\sigma_u > \sigma_s$ .

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