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Bulent Unel
Louisiana State University

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

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Bulent Unel*

Comments are welcomed

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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 sectors differ in relative factor intensity. Each sector contains a continuum of heterogenous 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 analyses suggest that such trade effects can explain up to 12 percent of 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 relative supply of skills and the skill premium, defined as wage of skilled labor relative to that of unskilled labor, over the last 40 years. Although the relative supply of skills has increased substantially, there has not been a tendency for the skill premium to decline. Instead, the skill premium has generally risen, and it has risen more significantly since 1980 (see, for example, Bound and Johnson (2000), Katz and Murphy (1992), and Autor et al. (2007)). There have been two main explanations for this pattern and both imply that the demand for skill must have expended more substantially than supply. The first argues that new technologies have been skill biased (Bound and Johnson (2000), Katz and Murphy (1992), and Acemoglu (1998) and (2002)). The second explanation is related to globalization. It basically states that increased trade with less developed countries (LDC) raises the demand for skilled labor.

However, many economists object to the second explanation for several reasons. First, if trade were responsible for the increase in inequality in the skill abundant US, there should have been a converse effect in the LDCs that have traded with the US. However, many of the LDCs have also experienced rising inequality after opening to trade (see, for example, Duryea and Szekely (2000) and Behrman et al. (2000)). Second, the Heckscher, Ohlin, Vanek (HOV) trade model implies that trade with LDCs should increase the relative price of skill-intensive goods, which in turn should increase the demand for skills. However, many empirical studies find no evidence of an increase in the relative price of skill-intensive goods (Sachs and Shatz (1994) and Desjounqueres et al. (1999)). Finally, and most importantly, trade with LDCs has increased substantially, but US trade with LDCs has not changed enough to explain the large changes in the skill premium that have taken place (Krugman (1995) and Leamer (1994)).

This paper reconsiders the effects of trade on the skill premium by focusing on the trade between identical countries (North-North trade). It develops a theoretical model, which is a blend of the models presented by Acemoglu (2002) and Melitz (2003), to show that trade, even between similar countries, can increase the skill premium. The model has two sectors (skill and labor intensive) and two factors of production (skilled and unskilled labor). Outputs of the two sectors are imperfect substitutes as in Acemoglu (2002), and each sector is populated by a continuum of firms that produce a different product. We further assume that the returns to scale in the skill intensive sector are at least as strong as those in the labor intensive sector. As in Melitz (2003), differentiated varieties are produced by heterogeneous firms and production involves both fixed and variable costs. Trade is costly and there are both variable and fixed costs of exporting.

We find that when productivity levels of firms in the skill-intensive sector (stochastically) dominate[1] 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.[2] We then investigate the quantitative implications of the model. We show that moving from autarky to *maximum* integration can increase the skill premium by 12 percent. When we calibrate the model with the US data, we find that increases in trade can explain up to 12 percent of the increase in the US skill premium between 1965 and 2000.

The intuition behind this result 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 will further increase demand for both skilled and unskilled labor. The increased demand for inputs by the more productive firms and the new entrants will increase real wages. 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 will be higher. As a result, the demand for skilled labor will be higher than

[1]More precisely, we assume that productivity distribution in each sector follows a Pareto distribution, and the productivity distribution in the skill intensive sector first-order stochastically dominates that in the labor intensive sector (see the discussion in section 3).

[2]The underlying assumptions are consistent with a host of stylized facts about firms and trade. We discuss them in detail in section 4.

that for unskilled labor, which in turn raises the skill premium.

This is not the first paper that explores the effects of trade between similar countries on the skill premium. For example, Dinopolous et al. (2001) present a monopolistic competition model that highlights the role of intra-industry trade on wage inequality. Their model assumes quasi-homothetic preferences, non-homothetic production, and endogenous factor supplies for skilled and unskilled labor. Moving from autarky to free inter-industry trade causes an expansion of firm size, and hence, an increase in the skill premium. In our model, preferences and production are homothetic and we have two sectors as opposed to one. The key ingredient in our model is that firms are heterogenous and the skill intensive sector is relatively more productive than the labor intensive sector. Exposure to trade asymmetrically affects demand for each factor. Neary (2002), on the other hand, presents 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 our model, however, there are no strategic interactions, and firms compete monopolistically. Finally, Matsuyama (2007) 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 our model, however, production technologies of goods are the same regardless of whether the goods are produced for domestic or foreign markets.[3] The exception in this literature is Epifani and Gancia (2007), who also consider a two-sector model similar to ours. They mainly show that stronger returns to scale in the skill intensive sector imply that any increase in the volume of trade tends to be skill-biased.

The main difference between this paper and Epifani and Gancia (2007) is that our model incorporates firms heterogeneity and fixed sunk costs of entry into foreign markets.[4] But

[3]Moreover, the framework used in both papers are different. Matsuyama uses the Ricardian model of trade with a continuum of goods, while we consider a two-sector monopolistic competition model with both fixed and variable trade costs as in Melitz (2003).

[4]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, Bernard et al. (2007) for a review of this literature.

this extension has three important consequences. First, their models yield that exposure to trade always increases the skill premium, whereas we show that theoretically it is possible that exposure to trade can reduce the skill premium, even if both sectors are exposed to the trade to the same degree. This basically stems from the existence of sunk costs of entry into foreign markets. Second, their results crucially hinge on the assumption that returns to scale in the skill intensive sector are stronger than that in the labor intensive sector. This implies that the elasticity of substitution between products of the skill-intensive sector is *smaller* than that of the labor intensive sector. In our model, however, we show that even if these elasticities are the same, trade can still have a positive impact on the skill premium (provided that other conditions are also satisfied). Finally, when firms are heterogeneous and trade has fixed costs, only more productive firms will be able to enter export markets, and, hence, the volume of trade would be lower when compared to that in Epifani and Gancia (2007). As a result, the effect of trade on the skill premium will be lower. Indeed, our quantitative analysis yields a considerably lower impact than theirs.

The plan of this paper is as follows: section 2 introduces a closed economy model; section 3 opens the economy to trade and investigates the implications of exposure to trade on the skill premium; section 4 investigates the quantitative implications of the model; and section 5 concludes the paper.

2 The Closed Economy Model

We begin with a description of consumer behavior. We assume that there is a representative agent whose utility is given by $U = Q$, where Q is a homogenous final good which is assembled from the output of two sectors, denoted by j, according to the following production function:

$$Q = \left[Q_s^{\frac{\varepsilon-1}{\varepsilon}} + Q_u^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2.1}$$

where Q_j represents the aggregate good of sector j and ε is the elasticity of substitution between output of the two sectors. We assume that $\varepsilon > 1$. We further assume that Q_s and

Q_u are competitively produced by the CES form:

$$Q_j = \left[\int_0^{N_j} q_j(i)^{\rho_j} di \right]^{\frac{1}{\rho_j}}, \tag{2.2}$$

where we assume that $0 < \rho_j < 1$ so that the elasticity of substitution between any two brands of each sector is given by $\sigma_j = 1/(1-\rho_j) > 1$. We further assume that $\sigma_u \geqslant \sigma_s > \varepsilon > 1$ (see section 4 for justification of this assumption).[5] This is a weaker assumption than that in Epifani and Gancia (2007) who assume that $\sigma_u > \sigma_s > \varepsilon > 1$.

Let P_s and P_u denote the prices of aggregate goods Q_s and Q_u. Since Q_s and Q_u are competitively produced, the first-order conditions imply the following relationship between these aggregates

$$\frac{Q_s}{Q_u} = \left(\frac{P_s}{P_u} \right)^{-\varepsilon}. \tag{2.3}$$

Given P_j and Q_j, it is easy to show that the optimal quantity and expenditure levels for individual brands are given by

$$q_j(i) = Q_j \left[\frac{p_j(i)}{P_j} \right]^{-\sigma_j} \quad \text{and} \quad r_j(i) = R_j \left[\frac{p_j(i)}{P_j} \right]^{1-\sigma_j}, \tag{2.4}$$

where $p_j(i)$ is the price of that brand i and $R_j = P_j Q_j = \int r_j(i) di$ is the aggregate expenditure on differentiated goods. Moreover, competition in the supply of goods $q_j(i)$ ensures the equilibrium price P_j (of the aggregate output Q_j) equals the unit manufacturing cost:

$$P_j = \left[\int_0^{N_j} p_j(i)^{1-\sigma_j} di \right]^{\frac{1}{1-\sigma_j}}. \tag{2.5}$$

Differentiated goods are produced by a continuum of monopolists, each choosing to produce a different variety. We assume that skilled and unskilled labor are the only factors of production and to simplify the exposition, we further assume that firms in the skill (labor) intensive sector use only skilled (unskilled) labor, which is inelastically supplied at

[5] The scale elasticity in this context is measured by $\sigma_j/(\sigma_j - 1)$. Thus, this assumption implies that the returns to scale in the skill intensive industry are at least as strong as those in the labor intensive industry.

its aggregate level L_s (L_u).[6] Production has both fixed and variable costs in each period: to produce q_j units of output in sector j, $f_j + q_j/\varphi$ units of type j-labor must be used, where f_j is a fixed overhead cost. Thus, as in Melitz (2003), all firms in sector j share the same fixed cost $w_j f$ but have different productivity levels, which remain constant during their lifetime, indexed by $\varphi > 0$. Regardless of its productivity level, each firm faces a demand curve described in (2.4). Profit maximizing behavior yields the following price rule:

$$p_j(\varphi) = \frac{w_j}{\rho_j \varphi}. \tag{2.6}$$

where w_j is the wage of j-type worker.

Given this pricing rule, then firm profit is

$$\pi_j(\varphi) = r_j(\varphi) - w_j q_j/\varphi - w_j f_j = r_j(\varphi)/\sigma_j - w_j f_j, \tag{2.7}$$

where $r_j(\varphi)$ is firm revenue. Using this pricing rule in (2.4) and (2.7):

$$\begin{aligned} q_j(\varphi) &= Q_j(P_j\rho_j\varphi)^{\sigma_j}, \\ r_j(\varphi) &= R_j(P_j\rho_j\varphi)^{\sigma_j-1}, \qquad \pi_j(\varphi) = \frac{R_j}{\sigma_j}(P_j\rho_j\varphi)^{\sigma_j-1} - w_j f_j. \end{aligned} \tag{2.8}$$

These equations further imply that

$$\frac{q_j(\varphi_1)}{q_j(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma_j}, \qquad \frac{r_j(\varphi_1)}{r_j(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma_j-1}. \tag{2.9}$$

Hence, a more productive firm will have a lower price, will produce more output, and will earn a higher profit than a less productive firm.

To produce in sector j, firms first must make an initial investment of $f_{je} > 0$ units of type j-labor, which is thereafter sunk. Firms then draw their initial productivity parameter φ from a common distribution $g_j(\cdot)$, which is assumed to be common for firms in sector j.

[6] Acemoglu (1998), (2002), and (2003) also makes the same assumption about factor intensity, when he analyzes changes in the skill-premium in the US. Results qualitatively will remain the same, 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. Analysis, however, will be more complicated (see Appendix A.1).

After entry, firms then face a constant probability δ in every period of a bad shock that would force them to exit. Each firm's value is then given by

$$\nu_j(\varphi) = max\left\{0, \sum_{t=0}^{\infty}(1-\delta)^t \pi_j(\varphi)\right\} = max\left\{0, \frac{1}{\delta}\pi_j(\varphi)\right\},$$

where the second equality follows from the fact that each firm's productivity level remains constant during its lifetime; hence, its optimal per period profit will also remain constant.

Later in our analysis, we make two further assumptions. First, we assume that productivity levels in the skill intensive sector stochastically dominate those in the labor intensive sector. Second, we use a specific parametrization for the distributions. Following Cabral and Mata (2003), Melitz and Ottaviano (2008), and many others, we assume that productivity draws follow a Pareto distribution. Many studies, e.g. Cabral and Mata (2003), find that the distribution of firm sizes in the US closely follow a Pareto distribution. However, since most of our analysis does not hinge on these assumptions, we postpone our discussion about them until the end of next section.

A firm having productivity φ produces in sector j, if $\pi_j(\varphi) \geq 0$. Since $\pi_j(\varphi)$ is an increasing and continuous function of φ, there is a sufficiently small φ where $\pi_j(\varphi) < 0$. Then there exists a unique cutoff level φ_j such that $\pi_j(\varphi_j) = 0$.

Notice that the ex-ante probability of having productivity level φ is $g_j(\varphi)d\varphi$ and the ex-ante probability of successful entry is $1-G_j(\varphi_j)$, where $G_j(\varphi)$ is the cumulative distribution function for $g_j(\varphi)$. These together imply that the ex-post distribution of firm productivity, $\mu_j(\varphi)$, is the conditional distribution of $g_j(\varphi)$ on $[\varphi_j, \infty)$:

$$\mu_j(\varphi) = \begin{cases} \frac{g_j(\varphi)}{1-G_j(\varphi_j)} & \text{if } \varphi > \varphi_j \\ 0 & \text{otherwise} \end{cases} \tag{2.10}$$

With this distribution function, the aggregate price index P_j $(j = s, u)$ is now given by

$$P_j = \left[\int_0^{\infty} p_j(\varphi)^{1-\sigma_j} N_j \mu_j(\varphi) d\varphi\right]^{\frac{1}{1-\sigma_j}}.$$

Using the pricing rule in (2.5), this can be written as

$$P_j = N_j^{\frac{1}{1-\sigma_j}} p_j(\tilde{\varphi}_j), \tag{2.11}$$

where

$$\tilde{\varphi}_j \equiv \tilde{\varphi}_j(\varphi_j) = \left[\frac{1}{1-G_j(\varphi_j)} \int_{\varphi_j}^{\infty} \varphi^{\sigma_j - 1} g_j(\varphi) d\varphi\right]^{\frac{1}{\sigma_j-1}}. \tag{2.12}$$

As argued by Melitz (2003), $\tilde{\varphi}_j$ also represents aggregate productivity because it completely summarizes the information in the distribution of productivity levels $\mu_j(\varphi)$ relevant for all aggregate variables. Furthermore, by using (2.9) in (2.3) and (2.6) it is straightforward to show that the other aggregate variables are given by

$$Q_j = N_j^{\frac{\sigma}{\sigma_j - 1}} q_j(\tilde{\varphi}_j), \qquad R_j = N_j r_j(\tilde{\varphi}_j), \qquad \text{and} \qquad \Pi_j = N_j \pi_j(\tilde{\varphi}_j), \tag{2.13}$$

which imply that $r_j(\tilde{\varphi}_j) \equiv \bar{r}_j$ and $\pi_j(\tilde{\varphi}_j) \equiv \bar{\pi}_j$ are, respectively, average revenue and average profit levels in sector j. With this average productivity $\tilde{\varphi}_j$, the average profit can further be written as:

$$\bar{r}_j = \left[\frac{\tilde{\varphi}_j}{\varphi_j}\right]^{\sigma_j - 1} r_j(\varphi_j), \quad \text{and} \quad \bar{\pi}_j = \left[\frac{\tilde{\varphi}_j}{\varphi_j}\right]^{\sigma_j - 1} \frac{r_j(\varphi_j)}{\sigma_j} - w_j f_j,$$

where the first equation simply follows from (2.9). Since at the cutoff level the profit is zero, which implies that $r_j(\varphi_j) = \sigma_j w_j f_j$, average profit $\bar{\pi}_j$ will be:

$$\bar{\pi}_j = w_j f_j \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma_j - 1} - 1\right]. \tag{2.14}$$

Since the ex-ante probability of successful entry is $1 - G_j(\varphi_j)$, in any equilibrium where entry is unrestricted, the net value of entry must be zero:

$$\frac{1 - G_j(\varphi_j)}{\delta} \bar{\pi}_j = w_j f_{je}. \tag{2.15}$$

Combining this free-entry condition with (2.14) yields:

$$H_j(\varphi_j) \equiv [1 - G_j(\varphi_j)] \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma_j - 1} - 1\right] = \delta \frac{f_{je}}{f_j}. \tag{2.16}$$

It is easy to see that $H_j(\varphi)$ is strictly decreasing in φ.[7] Thus, it has a unique solution.

What will be the equilibrium number of products in each sector? As in Melitz (2003), we shall only consider stationary equilibrium, which implies that the aggregate variables remain constant over the time. Thus, if N_{je} is the number of entrants, then the number of successful entrants should be equal to the number of incumbents who are hit with the bad shock and exit, i.e. $[1-G_j(\varphi_j)]N_{je} = \delta N_j$. The total labor used by the new entrants is $L_{je} = N_{je} f_{je} = \delta N_j f_{je}/[1-G_j(\varphi_j)]$. Combining with the free-entry condition:

$$L_{je} = N_j \bar{\pi}_j / w_j \quad \Rightarrow \quad \Pi_j = w_j L_{je} \quad \Rightarrow \quad R_j = \Pi_j + w_j L_{jp} = w_j L_j,$$

where L_{jp} denotes total amount of labor used in production in sector j. Since $R_j = N_j \bar{r}_j$ and $\bar{r}_j = (\tilde{\varphi}_j/\varphi_j)^{\sigma_j - 1} \sigma w_j f_j$, we have

$$N_j = \frac{L_j}{\sigma_j f_j \left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma_j - 1}}, \quad for \quad j = s, u. \tag{2.17}$$

To derive the skill premium, we first consider equation (2.3). Multiplying both sides by P_s/P_u and using $R_s/R_u = w_s L_s / w_u L_u$, we have

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

Using equations (2.11) and (2.17) in this equation and rearranging terms yields

$$\frac{w_s}{w_u} = \gamma \left(\frac{\varphi_s}{\varphi_u}\right)^{\frac{\varepsilon-1}{\varepsilon}} \frac{L_s^{\frac{\varepsilon-\sigma_s}{\varepsilon(\sigma_s-1)}}}{L_u^{\frac{\varepsilon-\sigma_u}{\varepsilon(\sigma_u-1)}}}, \qquad \text{where} \qquad \gamma = \left[\frac{\rho_s (\sigma_u f_u)^{\frac{1}{\sigma_u - 1}}}{\rho_u (\sigma_s f_s)^{\frac{1}{\sigma_u - 1}}}\right]^{\frac{\varepsilon-1}{\varepsilon}}. \tag{2.18}$$

As in Epifani and Gancia (2007), let us define $L = L_s + L_u$ and $L_s = \theta L$. Then from the above equation, we have the following:

Proposition 1. *The skill premium, ω, in autarky is given by*

$$\omega = \gamma \left(\frac{\varphi_s}{\varphi_u}\right)^{\frac{\varepsilon-1}{\varepsilon}} L^{\frac{(\varepsilon-1)(\sigma_u-\sigma_s)}{\varepsilon(\sigma_s-1)(\sigma_u-1)}} \left[\frac{\theta^{\frac{\varepsilon-\sigma_s}{\varepsilon(\sigma_s-1)}}}{(1-\theta)^{\frac{\varepsilon-\sigma_u}{\varepsilon(\sigma_u-1)}}}\right], \tag{2.19}$$

where γ is the constant defined in equation (2.18).

[7] $dH_j(\varphi)/d\varphi = (1-\sigma_j)[H_j(\varphi) + 1 - G_j(\varphi)]/\varphi < 0$, since $\sigma_j > 1$.

This expression states that changes in the skill premium can be decomposed into three components: change in the relative cutoff levels (the second term on the right hand side), change in the scale of economy (the third term), and change in the composition of relative supply of skills (the last term). Two points should be emphasized. First, note that when $\sigma_u > \sigma_s > \varepsilon > 1$, it is easy to see that the skill premium is positively related to the relative cutoff levels, φ_s/φ_u, and the size of the economy (i.e., total labor supply L). On the other hand, the skill premium is negatively related to the relative supply of skills, i.e. $d\omega/d\theta < 0$. Thus, if there is an increase in the relative cutoff levels or in the size of the economy, the skill premium will rise. If, on the hand, the relative supply of skills rises, then it will fall. The final effect depends on the strength of these opposite effects. Second, if we assume that $\sigma_s = \sigma_u$, then the relative cutoff effect still works and the market size effect disappears unlike Epigani and Gancia (2007).

3 The Open Economy Model

We now consider the impact of trade in intermediate goods in a world that is composed of two countries of the kind just analyzed. The basic set-up remains the same as in the closed economy case. However, firms wishing to export must pay per-unit and fixed costs of trade as in Melitz (2003). Per-unit costs (such as transport and tariffs) do not depend on firm productivity, and they are modelled in the standard iceberg formulation: in sector j, $\tau_j > 1$ units of a good must be shipped in order for one unit to arrive at its destination.

In addition to the iceberg transportation cost, firms in each sector face a fixed investment cost of $w_j F_{jx} > 0$ that does not depend on the firm's characteristics, such as the productivity level. Existence of such sunk market entry costs have been well documented by econometric studies (see, for example, Roberts and Tybout (1997) and Bernard and Jensen (2004)). The foreign market entry cost covers the cost of modifying the product to meet the foreign market specifications and, more importantly, covers the regulation costs imposed by governments to erect non-tariff barriers to trade. The investment decision abroad occurs after the firm's productivity is revealed. Since firms face a constant probability of death in each period and there is no uncertainty in the export market, then the one time investment cost $w_j F_{jx}$ will equal paying $w_j \delta F_{jx}$ in every period. Hereafter we assume that as if firms pay $w_j f_{jx}$ in each period with $f_{jx} = \delta F_{jx}$. This adaptation makes the following analysis more tractable and notationally simple (Melitz (2003)), without affecting any results. Regardless of export status, a firm still incurs the same overhead production cost f_j. Because countries are symmetric, they have the same prices for aggregate goods and the same number of firms in each sector.

Each firm's price in its domestic market is still given by $p_{jd}(\varphi) = w_j/\rho_j\varphi$. Firms who export, however, will charge higher prices in the foreign markets: $p_{jx}(\varphi) = \tau_j w_j/\rho_j\varphi = \tau_j p_{jd}(\varphi)$. This basically reflects the increased marginal cost τ_j of serving the foreign market. Revenues earned from domestic sales and export sales are, respectively, $r_{jd}(\varphi)$ and $r_{jx}(\varphi) = \tau_j^{1-\sigma} r_{jd}(\varphi)$. The combined revenue of a firm, $r_j(\varphi)$, is then given by:

$$r_j(\varphi) = \begin{cases} r_{jd}(\varphi) & \text{if the firm does not export} \\ r_{jd}(\varphi) + r_{jx}(\varphi) & \text{if the firm exports} \end{cases} \tag{3.1}$$

The profit of firms who export now can be separated into two parts: profits earned from the domestic sales, $\pi_{jd}(\varphi)$, and export sales per country, $\pi_{jx}(\varphi)$:

$$\pi_{jd}(\varphi) = \frac{r_{jd}(\varphi)}{\sigma} - w_j f_j, \qquad \pi_{jx}(\varphi) = \frac{r_{jx}(\varphi)}{\sigma} - w_j f_{jx}. \tag{3.2}$$

Each firm's combined per-period profit can be written as $\pi_j(\varphi) = \pi_{jd}(\varphi) + max\{0, \pi_{jx}(\varphi)\}$. Similar to the closed economy case, firm value is given by $\nu_j(\varphi) = max\{0, \pi_j(\varphi)/\delta\}$. Now there are two cutoff productivity levels, φ_{jd} for successful entry into domestic market and φ_{jx} for successful entry into export market: $\pi_{jd}(\varphi_{jd}) = 0$ and $\pi_{jx}(\varphi_{jx}) = 0$. Note that at φ_{jx}, $\pi_{jd}(\varphi_{jx}) > 0 \;\Leftrightarrow\; r_{jd}(\varphi_{jx}) > \sigma_j w_j f_j$. From the export cutoff condition $r_{jx}(\varphi_{jx}) = \sigma_j w_j f_{jx}$. But then $\tau_j^{1-\sigma_j} r_{jd}(\varphi_{jx}) = \sigma_j w_j f_{jx}$, which, in turn, implies that $\tau_j^{\sigma_j - 1} f_{jx} > f_j$. To ensure partitioning of firms, we assume that this condition holds.

The equilibrium distribution of productivity levels for incumbent firms is still given by $\mu_j(\varphi) = g_j(\varphi)/[1 - G_j(\varphi_{jd})]$ for $\forall\varphi \geq \varphi_{jd}$. The ex-ante probability of successful entry into export market will be given by $\zeta_{jx} = [1 - G_j(\varphi_{jx})]/[1 - G_j(\varphi_{jd})]$. Let N_j denote the equilibrium mass of incumbent firms in sector j of any country. $N_{jx} = \zeta_{jx} N_j$ then represents the mass of exporting firms.

Total revenue and total profit in sector j are now given by

$$R_j = N_j[r_{jd}(\tilde{\varphi}_{jd}) + \zeta_{jx} r_{jx}(\tilde{\varphi}_{jx})] \quad \text{and} \quad \Pi_j = N_j[\pi_{jd}(\tilde{\varphi}_{jd}) + \zeta_{jx}\pi_{jx}(\tilde{\varphi}_{jx})],$$

where $\tilde{\varphi}_{jd} = \tilde{\varphi}_j(\varphi_{jd})$ and $\tilde{\varphi}_{jx} = \tilde{\varphi}_j(\varphi_{jx})$ denote the average productivity levels of all firms and exporting firms only, respectively (see equation (2.12)). These equations ensure that the average revenue $\bar{r}_j = R_j/N_j$ and the average profit $\bar{\pi}_j = \Pi_j/N_j$ are now given by

$$\bar{r}_j = r_{jd}(\tilde{\varphi}_{jd}) + \zeta_{jx} r_{jx}(\tilde{\varphi}_{jx}) \quad \text{and} \quad \bar{\pi}_j = \pi_{jd}(\tilde{\varphi}_{jd}) + \zeta_{jx}\pi_{jx}(\tilde{\varphi}_{jx}). \tag{3.3}$$

To determine the cutoff levels φ_{jd} and φ_{jx}, we need two equations. First, the zero cutoff profit conditions ensures that $r_{jd}(\varphi_{jd}) = \sigma_j w_j f_j$ and $r_{jx}(\varphi_{jx}) = \sigma_j w_j f_{jx}$, which further imply that

$$\frac{r_{jx}(\varphi_{jx})}{r_{jd}(\varphi_{jd})} = \tau_j^{1-\sigma_j}\left(\frac{\varphi_{jx}}{\varphi_{jd}}\right)^{\sigma_j - 1} = \frac{f_{jx}}{f_j} \quad \Longleftrightarrow \quad \varphi_{jx} = \varphi_{jd}\tau_j\left(\frac{f_{jx}}{f_j}\right)^{\frac{1}{\sigma_j - 1}}. \tag{3.4}$$

Second, notice that (2.10) and (3.2) together with the zero cutoff profit conditions yield that:

$$\pi_{jd}(\tilde{\varphi}_{jd}) = w_j f_j\left[\left(\frac{\tilde{\varphi}_{jd}}{\varphi_{jd}}\right)^{\sigma_j - 1} - 1\right] \quad \text{and} \quad \pi_{jx}(\tilde{\varphi}_{jx}) = w_j f_{jx}\left[\left(\frac{\tilde{\varphi}_{jx}}{\varphi_{jx}}\right)^{\sigma_j - 1} - 1\right].$$

Now using (3.4), the average profit can be expressed as a function of the cutoff levels φ_{jd} and φ_{jx} :

$$\bar{\pi}_j = w_j f_j\left[\left(\frac{\tilde{\varphi}_{jd}}{\varphi_{jd}}\right)^{\sigma_j - 1} - 1\right] + w_j f_{jx}\zeta_{jx}\left[\left(\frac{\tilde{\varphi}_{jx}}{\varphi_{jx}}\right)^{\sigma_j - 1} - 1\right]. \tag{3.5}$$

As in the closed economy, $\bar{\pi}_j/\delta$ is the present value of the average profit flows and $(1 - G_j(\varphi_{jd}))\bar{\pi}_j/\delta - w_j f_{je}$ is the net value of entry. The free entry condition ensures that

$$\bar{\pi}_j = \frac{\delta w_j f_{je}}{1 - G_j(\varphi_{jd})}. \tag{3.6}$$

Combining this with (3.4) yields

$$H_j(\varphi_{jd}) + \frac{f_{jx}}{f_j} H_j(\varphi_{jx}) = \frac{\delta f_{je}}{f_j}, \tag{3.7}$$

where H_j is defined in (2.16). Equations (3.4) and (3.7) constitute a system of two equations with two unknowns φ_{jd} and φ_{jx}. We have already shown that $H_j(\varphi)$ is a monotone-decreasing function. Moreover, since according to (3.4) φ_{jx} is an increasing function of φ_{jd}, equation (3.7) together with (3.4) yields a unique solution for $(\varphi_{jd}, \varphi_{jx})$. Furthermore, notice that the right hand sides of (2.16) and (3.7) are identical. For each φ, the left hand side of (3.7), however, is greater than that of (2.16), which implies that $\varphi_{jd} > \varphi_j$.

The intuition behind this result is simple. Since firms face a fixed (foreign market) entry cost, only more productive firms can afford to cover such cost. Therefore exposure to trade provides new profit opportunities only to the more productive firms. Furthermore, such profit opportunities also induce more new entry. The increased demand for inputs by the more productive firms and the new entrants bid up the real wages and force the least productive firms to exit (for more details, see Melitz (2003)).

Following the same steps as in the closed economy, we obtain the following result (see appendix A.2 for details).

Proposition 2. *The skill premium, ω, in the open economy is given by*

$$\omega = \gamma \left(\frac{\varphi_{sd}}{\varphi_{ud}}\right)^{\frac{\varepsilon-1}{\varepsilon}} L^{\frac{(\varepsilon-1)(\sigma_u-\sigma_s)}{\varepsilon(\sigma_s-1)(\sigma_u-1)}} \left[\frac{\theta^{\frac{\varepsilon-\sigma_s}{\varepsilon(\sigma_s-1)}}}{(1-\theta)^{\frac{\varepsilon-\sigma_u}{\varepsilon(\sigma_u-1)}}}\right], \tag{3.8}$$

where γ is the constant defined in equation (2.18).

Combining this with the skill premium expression described in equation (2.19) yields

$$\omega_o = \left(\frac{\varphi_{sd}/\varphi_s}{\varphi_{ud}/\varphi_u}\right)^{\frac{\varepsilon-1}{\varepsilon}} \omega_a, \tag{3.9}$$

where ω_o and ω_a stand for the skill premia in the open economy and the autarky. Thus, if the first term on the right hand side is greater than 1, then exposure to trade raises the skill premium.

We now turn to the parametrization of the distribution function. We assume that productivity draws follow a Pareto distribution:

$$G_j(\varphi) = 1 - \left(\frac{b_j}{\varphi}\right)^{k_j}, \qquad j = s, u, \tag{3.10}$$

where k_j is the shape parameter and b_j is the scale parameter that bounds the support $[b_j, +\infty)$ from below. This distribution has finite a variance if and only if $k_j > 2$. We assume that $k_j + 1 > \sigma_j$, which ensures that the integrals in aggregate variables converge. This specific distribution form together with (2.16), (3.4), and (3.7) ensures that

$$\varphi_{jd} = (1+\Omega_j)^{\frac{1}{k_i}} \varphi_j \qquad \text{with} \qquad \Omega_j = \tau_j^{-k_j} T_j^{1-\frac{k_j}{\sigma-1}} \quad \text{and} \quad T_j = \frac{f_{jx}}{f_j}. \tag{3.11}$$

Notice that $0 \leqslant \Omega_j \leqslant 1$[8] and when τ_j and/or T_j decrease, Ω_j increases. Thus, Ω measures the degree of openness: a higher value of Ω_j corresponds to a more open economy. Using the first equation in (3.11) in (3.9), the following results are easily follow.

Corollary 1. *Suppose that the productivity draws in sector j follow the Pareto distribution described in (3.10). Then we have*

i. The skill premium in the open economy is related to the skill premium in the autarky as follows

$$\omega_o = \left[\frac{(1+\Omega_s)^{\frac{1}{k_s}}}{(1+\Omega_u)^{\frac{1}{k_u}}}\right]^{\frac{\varepsilon-1}{\varepsilon}} \omega_a, \tag{3.12}$$

[8]There is a simple way to see this. It is easy to show that the share of total trade (export plus import) in output is given by $(EX_j + IM_j)/P_jQ_j = 2\Omega_j/(1+\Omega_j)$. Since this share must be less than or equal to one, we have $\Omega_j \leq 1$.

where ω_o *and* ω_a *represent the skill premia in the open economy and the autarky,* k_j *is the shape parameter of the Pareto distribution, and* Ω_j *is the measure of openness defined as in (3.11).*

ii. 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.*

iii. 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'_j *represent the new equilibrium value of* Ω_j*. If* $\Omega'_s/\Omega_s \geqslant \Omega'_u/\Omega_u$*, then such further exposure to trade rises the skill premium.*

Parts (ii) and (iii) of this corollary present *sufficient* conditions that make exposure and further exposure to trade have positive effects on the skill premium. If these conditions are not satisfied, then the effects of trade can be negative or ambiguous. For example, $k_s = k_u$ and $\sigma_u > \sigma_s$ imply that when both sectors are exposed to trade at the same degrees (i.e. $\tau_s = \tau_u$ and $T_s = T_u$), then such exposure will actually reduce the skill premium. If, on the other hand, $k_s \leqslant k_u$, $\tau_s = \tau_u$, and $T_s = T_u$, then effect of trade on the skill premium is ambiguous. These results are different than that in Epifani and Gancia (2007) who find that exposure to trade always increases the skill premium. The main reason stems from the firm heterogeneity and foreign market entry costs.

4 Quantitative Analysis

In the previous sections we developed a theoretical model and identified conditions under which exposure to trade raises the skill premium. In this section, we confront the model with data to investigate whether these conditions are satisfied in practice. Then we study their quantitative implications.

We first need to calibrate the parameters ε, σ_l, and σ_s. Note that ε also measures the elasticity of substitution between skilled and unskilled labor,[9] and there is a large labor-economics literature that focuses on its estimate. The most influential study is by Katz and Murphy (1992), whose estimate, based on the CPS data over the period 1963-1987, is about 1.4. Autor et al. (2007) extend the period to 2005, and they find that it is about 1.6. Using a state-level panel data, Ciccone and Peri (2005) find that the long-run elasticity of substitution between more and less educated workers to be around 1.5. Indeed, based on the various econometric estimates, Autor et al. (1998) conclude that this elasticity is very unlikely to be greater than 2. In our quantitative analysis, we consider two possibilities: $\varepsilon = 1.5$ and 2.

How about σ_s and σ_u? Based on the previous empirical studies,[10] Epifani and Gancia (2007) provide substantial evidence that $\sigma_u > \sigma_s$. For example, using international trade data for 71 countries, Antweiler and Trefler (2002) find that the average scale elasticity of the skill intensive sectors (e.g. Petroleum Refineries and Coal Products, Pharmaceuticals, Equipment and Machinery, and Electronic) is around 1.2, while that of the labor intensive sectors (e.g. Food, Apparel, and Leather) are characterized by constant returns.[11] In our empirical analysis, we consider $\sigma_s = 3.5$ (consistent with Bernard et al. (2003) and Morrison and Siegel (1999)) and $\sigma_s = 6.0$; and, as in Epifani and Gancia (2007), $\sigma_u = \infty$ (consistent with Antweiler and Trefler (2002)). Setting $\sigma_u = \infty$ provides a benchmark case in which there will be no trade in the labor intensive sector, and hence, the results related to each specification represent the maximum effect of trade on the skill premium.

We now turn to evaluate the sufficiency conditions in corollary 1. How reasonable to assume that $k_s \leq k_u$? Unfortunately, there are no industry-level empirical studies that

[9] To see this, note that $w_j L_j = R_j = P_j Q_j$ implies that $Q_j = A_j L_j$, where $A_j = \rho_j \tilde{\varphi}_j N_j^{1/(\sigma_j - 1)}$ represents the index of technology in sector j. The production of homogenous consumption good is then given by

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

Clearly ε represents the elasticity of substitution between skilled and unskilled labor.

[10] See, for example, Morrison and Siegel (1999), Diewert and Fox (2004), and Antweiler and Trefelr (2002).

[11] Since the scale elasticity is measured by $\sigma_j/(\sigma_j - 1)$, a scale elasticity of 1.2 implies that $\sigma_s = 6$, and a scale elasticity of 1 (constant returns) implies $\sigma_u = \infty$.

estimate k. However, there two good reasons to believe that $k_s \leqslant k_u$. First, as stated by Melitz (2003), higher productivity levels in this model may also be thought of as producing a higher quality variety at equal marginal cost. Given that the skill intensive sectors often have more R&D investment,[12] it is reasonable to expect that product qualities in the skill intensive sector are better than those in the labor intensive sectors. This further implies that productivity levels in the skill intensive sector are, on average, higher than those in the labor intensive sectors.[13] The relative productivity differences can be captured when the productivity distribution of the skill intensive sector first-order stochastically dominates that of the labor intensive sector. Since the productivity draws follow a Pareto distribution, then the first-order stochastic dominance implies that $b_s \geqslant b_u$ and $k_s \leqslant k_u$.[14]

Second, recall that our theoretical model requires that $k_j + 1 > \sigma_j$. Using US plant and macro data, Bernard et al. (2003) find that the elasticity of substitution between *any* two products is about 3.8. Combined with the standard deviation of log US plant domestic sales reported by Bernard et al. (2003), this elasticity implies that the corresponding shape parameter is about 3.4 (see, for example, Ghirno and Melitz (2005) and Demidova (2006)).[15]

[12]The data also confirms this. Using the OECD Business R&D database (1998a), we find that the average R&D intensity (R&D expenditure divided by the value-added) of skill-intensive industries (such as Chemical Products, Non-Electrical Machinery, Electrical Machinery, and Transport Equipments) are several times higher than that of low-skill intensive sectors (such as Food, Textile & Apparel, Wood & Furniture, and Paper). Of course, some of the R&D investment may be related to the new product development. However, there is a large growth literature that documents that substantial amount of R&D activities is about quality improvement.

[13]Alternatively, using OECD STAN (1998c) database, we also calculated the total factor productivity (TFP) levels at two- to three-digit ISIC, and found that the average 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, and Paper) in G5 countries between 1985 to 1996. TFP is calculated as $Y/L^{\alpha}K^{1-\alpha}$, where K represents capital stock. However, we should also stress that such differences in TFP levels of the two sectors may also reflect the differences in human capital and other factors which are not captured by the model.

[14]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 $\varphi = b_u,\ 1 - G_s(b_u) \geq 1 - G_u(b_u) \ \Rightarrow\ (b_s/b_u)^{k_s} \geqslant 1 \ \Rightarrow b_s \geqslant b_u$, 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 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, $k_s \leqslant k_u$.

[15]The theoretical model yields that the standard deviation of log domestic sales equals $(\sigma - 1)/k$. Equating this to 0.84 and setting $\sigma = 3.8$ implies $k = 3.4$.

Since the elasticity (and hence, the shape) parameter was calibrated from the pooled data, it represents the (weighted) average of σ_s and σ_u (k_s and k_u), and note that this shape parameter, based on the above empirical evidence, is closer to σ_s. This together with the facts that $\sigma_u > \sigma_s$ and $k_j + 1 > \sigma_j$ suggest that $k_s \leq k_u$. In our analysis, we shall set $k_s = 3$ and $k_s = 6$ (consistent with $\sigma_s = 3.5$ and 6, respectively); and $k_u = \infty$ (consistent with $\sigma_u = \infty$).

We now consider the conditions related to Ω_j which measures the combined effects of variable and fixed costs of trade. In principle, there are two ways to evaluate whether $\Omega_s \gtrless \Omega_u$. The first way explores the the ratio of total trade (export plus import) to the total sectoral output (i.e. $(EX_j + IM_j)/P_jQ_j$), and it is easy to show that this ratio is given by

$$s_j = \frac{2\Omega_j}{1+\Omega_j} \qquad \Rightarrow \qquad \Omega_j = \frac{s_j}{2-s_j},$$

where $s_j = (EX_j + IM_j)/P_jQ_j$. Using the data on total trade between the US and the OECD countries,[16] we find that the total trade shares of the skill intensive industries (such as chemical and petroleum, industrial machinery, electronic, and transportation) are substantially higher than that of the labor intensive industries (such as food, textile, apparel, leather, and paper) in all available years. For example, in 2000, the average trade share of the skill intensive industries is 41 percent, while it is about 12 percent in labor intensive industries. This implies that $\Omega_s > \Omega_u$.[17]

The second way directly explores trade costs. In a recent work, Bernard et al. (2006) compile a data set about trade costs. Table 1 in their study summarizes average ad valorem tariff, freight, and total trade costs across two-digit SIC industries for 1982, 1987, and

[16]To be consistent with our theoretical exploration, here we only consider the trade between US and the OECD countries. In calculating trade share, we also corrected total output by subtracting the total trade to other countries. In calculations, we used OECD bilateral trade database (1998b) and (2007), which cover from 1970 to 2000.

[17]One point must be emphasized. The trade share of the skill intensive industries can be higher for some other reasons that are outside of the scope of the model presented here. For example, the substantially higher export share of the skill intensive industries relative to other industries may also reflect the fact that most labor intensive jobs have been outsourced to export processing developing countries.

1992.[18] According to this table, the total trade cost in the labor intensive industries (such as food, textile, apparel, leather, and stone) is substantially higher than those in the skill intensive industries (such as chemical and petroleum, industrial machinery, electronic, and transportation). In 1982, for example, the total costs (tariffs plus freight rates) in the labor intensive industries are around 17 percent, while they are around 9% percent in the skill intensive industries. The pattern remains similar in other years (see the last three columns in Table 1).[19] Since the total costs only cover variable trade costs, these results suggest that $\tau_s < \tau_u$. Comparison of Ω_s to Ω_u also requires the data on T_s and T_u. Unfortunately, there is no empirical study that measures industrial-level non-tariff barriers (NBT). However, given that governments want to protect the labor intensive jobs, it is reasonable to expect that NBTs in the labor intensive industries are substantially higher than those in the skill intensive industries. Combined with higher variable trade costs, this suggests that $\Omega_u < \Omega_s$.

In investigating quantitative implications of our model we will use equation (3.12). Setting $k_u \to \infty$ (which corresponds with $\sigma_u \to \infty$) as the benchmark case, we can derive the effect of trade on the skill premium. Table 1 represents the results for different parameter values and $\Omega_s = 1$ represents the maximum integration. The table shows that moving from autarky to maximum integration can raise the skill premium by up to 12 percent. These results are substantially lower than that reported in Epifani and Gancia (2007), who find that full integration can raise the skill premium up to 32 percent. The main differences in the size of the effect come from firm heterogeneity and the sunk entry cost of foreign markets.

It will be interesting to calculate how much trade has contributed to increases in the

[18] The costs for each year are the average of five-year proceeding the year; i.e. the costs for 1982, for example, are the average of costs from 1977 to 81.

[19] It must be noted that this trade cost measure is constructed only from US import data. The above theoretical analysis threats countries symmetric and assumes that they implement the same policy. US trade policy or inbound transportation rates can be different from those in other countries; as a result, trade costs may over or underestimate the costs implemented by other countries. However, using a database compiled by United Nations (UNCTD), Bernard et al. (2006) find that the correlation of the U.S. and the E.U. ad valorem tariff rate changes across SIC4 industries is positive and significant at 1 percent level. This suggests that inward and outward tariffs are moving in the same directions.

skill-premium over the last several decades. In 1965, the total trade share in the skill intensive industry[20] was about 10%, which implies that $\Omega_s = 0.05$. In 2000, however, the total trade share was about 41%, which implies that $\Omega_s = 0.260$. For $k_s = 3$ and $\varepsilon = 2$, these measures imply about a 3% increase in the skill premium. Given that there has been about a 25 percent increase in the wage gap between skilled and unskilled labor (e.g. Autor (2007)), this further implies that the trade between US and OECD countries can explain up to about 12% increase in the US skill-premium. With $\varepsilon = 1.5$, this contribution drops to 8%.

Table 1: Increase in the Skill Premium (%)

	$k_s = 3$		$k_s = 6$	
Ω_s	$\varepsilon = 2$	$\varepsilon = 1.5$	$\varepsilon = 2$	$\varepsilon = 1.5$
0.25	3.8	2.5	1.9	1.2
0.50	7.0	4.6	3.4	2.3
0.75	9.8	6.4	4.8	3.2
1.00	12.2	8.0	5.9	3.9

5 Concluding Remarks

In this paper, we study the effects of intra-industry trade between similar countries on the skill premium. We develop 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. We show that under some plausible conditions supported by the data, trade between similar countries can increase the skill premium. In particular, we find that when the productivity distribution of firms in the skill intensive sector dominates that in the labor intensive sector, and the skill intensive sector is relatively more open to trade than the labor intensive sector, the exposure to trade increases the wage inequality between skilled and unskilled labor. Our quantitative analysis shows that moving

[20]The trade data goes back to 1970 and we estimated the trade share in 1965 by using the time trend between 1970 and 2000.

from autarky to maximum integration can increase the skill premium by 12 percent. When the model is calibrated with the US data, we find that increases in trade can explain up to 12 percent of increases in the skill premium.

Although firms in the model are forward looking, there is no technical change, and hence, no growth in the model. In an earlier version of this paper, we 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 (2002).[21] However, this extension requires that $\sigma_s = \sigma_u$; otherwise, there would not be a balanced growth path. We also assume that final output can either be consumed or used in production as capital-goods. Thus, firms in the skill (labor) intensive sector use final goods and the skilled (unskilled) labor. We assume that R&D is conducted by a fixed supply of scientists (e.g. Acemoglu (2002)), and using insights from Baldwin and Robert-Nicoud (2008), we reformulate the product development process in a stochastic fashion similar to that in our model. We then show that the skill premium is given by

$$\omega_o = \left(\frac{\varphi_{sd}/\varphi_s}{\varphi_{ud}/\varphi_u}\right)^{\lambda} \omega_a, \qquad \lambda = \frac{(\varepsilon-1)(\sigma-1)}{(1-\beta)(\varepsilon-1)(\sigma-1)+(\sigma-\varepsilon)},$$

where ω_o and ω_a represent the skill premia in the open economy and the autarky, respectively; and β is the capital share in production.

Note that $\lambda > (\varepsilon-1)/\varepsilon$, which implies the effects of trade on the skill premium is stronger under this set-up than that in the previous section (provided that $(\varphi_{sd}/\varphi_s)/(\varphi_{ud}/\varphi_u)$ is the same under both cases). Second, $d\lambda/d\beta < 0$, i.e. the impact of trade on the skill premium is magnified, when the capital-goods share increases. Using $\varepsilon = 1.5$, $\sigma = 4$, and $\beta = 1/3$ implies that the elasticity of the skill premium with respect to the relative cutoff levels is about 0.43 (i.e. $\lambda = 0.43$). The same elasticity in our basic model is about 0.33 ($\approx (\varepsilon-1)/\varepsilon$). Hence, the effect of trade on the skill premium in this set-up is similar to that in our basic model. In this extension, however, the market size effect will disappear due to the restriction

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

that $\sigma_s = \sigma_u$.

A Appendix

A.1 Skill-Premium When Each Sector Uses Both Factors

We assume that the cost function takes the following form

$$c_j(w_s, w_u)\left[f_j + \frac{q_j}{\varphi}\right] \qquad \text{with} \qquad c_j(w_s, w_u) = w_s^{\alpha_j} w_u^{1-\alpha_j}$$

where α_j is the labor share of skilled workers in sector j 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

$$p_j(\varphi) = \frac{c_j(w_s, w_u)}{\rho_j \varphi}.$$

We assume that firms first must make an initial investment of $c_j f_{je} > 0$, which is thereafter sunk. Firms then draw their initial productivity parameter φ from a common distribution $g_j(\cdot)$, which is assumed to be common for firms in sector j. After entry, firms then face a constant probability δ in every period of a bad shock that would force to exit. All of the analysis that we had in section (2) remains the same except, instead of w_j, we have c_j. Thus the zero profit and free-entry conditions are now given by

$$\bar{\pi}_j = c_j f_j \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma_j - 1} - 1\right] \qquad \text{and} \qquad \frac{1 - G_j(\varphi_j)}{\delta}\bar{\pi}_j = c_j f_{je}, \tag{A.1}$$

where $\tilde{\varphi}_j$ is defined as in (2.13). Obviously, the above two equations yield equation (2.15), which yields the identical cutoff level with that in section (2).

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

$$\left[f_j + \frac{q_j}{\varphi}\right]\frac{\partial c_j}{\partial w_s} = \frac{\alpha_j}{w_s}\left[\rho_j r_j(\varphi) + c_j f_j\right] = \frac{\alpha_j}{w_s}\left[(\sigma_j - 1)\pi_j(\varphi) + \sigma_j c_j f_j\right].$$

Similarly, the total amount of unskilled labor used in production is given by $(1-\alpha_j)[\rho_j r_j(\varphi) + c_j f_j]/w_u$. It then follows that the total amount of skilled labor used in the production process of sector j is given by

$$L_{jsp} = N_j \frac{\alpha_j}{w_s} \left[(\sigma_j - 1)\bar{\pi}_j + \sigma_j c_j f_j \right], \tag{A.2}$$

where $\bar{\pi}_j$ represents the average profit.

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

$$L_{jse} = \left(\frac{\partial c_j}{\partial w_s} \right) f_{ej} N_{je} = N_j \frac{\alpha_j}{w_s} \frac{\delta c_j f_{ej}}{1 - G_j(\varphi_j)} = \frac{N_j \alpha_j \bar{\pi}_j}{w_s}. \tag{A.3}$$

Combining (A.2) and (A.3) gives total amount of skilled labor used in sector j :

$$L_{js} = \alpha_j N_j \sigma_j \left[\bar{\pi}_j + c_j f_j \right] / w_s = \alpha_j N_j \bar{r}_j / w_s. \tag{A.4}$$

Using this in the labor market clearing conditions, we have

$$\begin{aligned} w_s L_s &= \alpha_s N_s \bar{r}_s + \alpha_u N_u \bar{r}_u \\ w_u L_u &= (1 - \alpha_s) N_s \bar{r}_s + (1 - \alpha_u) N_u \bar{r}_u. \end{aligned}$$

These two equations yield

$$N_s = \frac{(1 - \alpha_u) w_s L_s - \alpha_u w_u L_u}{[(1 - \alpha_u)\alpha_s - (1 - \alpha_s)\alpha_u] \bar{r}_s} \qquad \text{and} \qquad N_u = \frac{\alpha_s w_u L_u - (1 - \alpha_s) w_s L_s}{[(1 - \alpha_u)\alpha_s - (1 - \alpha_s)\alpha_u] \bar{r}_u}. \tag{A.5}$$

To derive the skill-premium, we again consider equation (2.3). Multiplying both sides by P_s/P_u and using $R_s/R_u = N_s \bar{r}_s / N_u \bar{r}_u$ together with (A.5), we have

$$\left(\frac{P_s}{P_u} \right)^{1-\varepsilon} = \frac{(1 - \alpha_u) w_s L_s - \alpha_u w_u L_u}{\alpha_s w_u L_u - (1 - \alpha_s) w_s L_s}. \tag{A.6}$$

We know that $P_j = N_j^{1/(1-\sigma_j)} c_j / \rho_j \tilde{\varphi}_j$ and notice that equation (2.9) together with the zero profit condition implies that $\bar{r}_j = (\tilde{\varphi}_j / \varphi_j)^{\sigma_j - 1} \sigma_j c_j f_j$. Using these together with (A.5) in (A.6) yields

$$\frac{\varphi_s}{\varphi_u} = \tilde{\gamma} \left\{ \frac{\left[(1 - \alpha_u)\omega L_s - \alpha_u L_u \right]^{\frac{\sigma_s - \varepsilon}{(\sigma_s - 1)(\varepsilon - 1)}}}{\left[\alpha_s L_u - (1 - \alpha_s)\omega L_s \right]^{\frac{\sigma_u - \varepsilon}{(\sigma_u - 1)(\varepsilon - 1)}}} \right\} \omega^{\left(\frac{\alpha_s \sigma_s}{\sigma_s - 1} - \frac{\alpha_u \sigma_u}{\sigma_u - 1} \right)}, \tag{A.7}$$

where $\tilde{\gamma}$, like γ in equation (2.18), is a constant that depends on the parameters and the exogenous variables in the model, and $\omega = w_s / w_u$ represents the skill-premium. Since

$\sigma_u > \sigma_s > \varepsilon > 1$, it is easy to see that the expression in the curly bracket is an increasing function of ω. Furthermore, since $\alpha_s > \alpha_u$ and $\sigma_u > \sigma_s$, the power of ω in the last term is positive,[22] i.e. the last term is an increasing function of ω. Thus, the skill premium, ω, is an increasing function of the relative cutoff levels, φ_s/φ_u.

Similarly, following the same steps under the open economy yields

$$\frac{\varphi_{sd}}{\varphi_{ud}} = \tilde{\gamma} \left\{ \frac{\left[(1-\alpha_u)\omega L_s - \alpha_u L_u\right]^{\frac{\sigma_s-\varepsilon}{(\sigma_s-1)(\varepsilon-1)}}}{\left[\alpha_s L_u - (1-\alpha_s)\omega L_s\right]^{\frac{\sigma_u-\varepsilon}{(\sigma_u-1)(\varepsilon-1)}}} \right\} \omega^{\left(\frac{\alpha_s\sigma_s}{\sigma_s-1} - \frac{\alpha_u\sigma_u}{\sigma_u-1}\right)}, \tag{A.8}$$

φ_{sd} and φ_{ud} are domestic cutoff levels as described in section (3). If exposure to trade increase the relative cutoff levels as in section (3), then the skill-premium in the open economy will be higher than that in autarky. Thus, the results obtained in section (3) qualitatively remain the same.

A.2 The Skill Premium in the Open Economy

As in the closed economy, using the free entry condition it is easy to show that $R_j = w_j L_j$. We also know that $R_j = N_j \bar{r}_j$, which then implies that $N_j = w_j L_j / \bar{r}_j$. Using equations (3.3) and (3.5), we obtain

$$\bar{r}_j = \sigma w_j \left[f_j \left(\frac{\tilde{\varphi}_{jd}}{\varphi_{jd}} \right)^{\sigma_j - 1} + f_{jx} \left(\frac{\tilde{\varphi}_{jx}}{\varphi_{jx}} \right)^{\sigma_j - 1} \right].$$

By using equation (3.4), this equation can further be written as

$$\bar{r}_j = \sigma_j w_j f_j \left[\frac{\tilde{\varphi}_{jd}^{\sigma_j-1} + \zeta_{jx} \left(\tau_j^{-1} \tilde{\varphi}_{jx} \right)^{\sigma_j-1}}{\varphi_{jd}^{\sigma_j-1}} \right].$$

Inserting this into $N_j = w_j L_j / \bar{r}_j$ implies that

$$N_j = \frac{L_j \varphi_{jd}^{\sigma_j-1}}{\sigma_j f_j \left[\tilde{\varphi}_{jd}^{\sigma_j-1} + \zeta_{jx} \left(\tau_j^{-1} \tilde{\varphi}_{jx} \right)^{\sigma_j-1} \right]}.$$

[22]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 $\sigma_s < \sigma_u$.

It is easy to show that the aggregate price index, P_j, is now given by

$$P_j = N_j^{\frac{1}{1-\sigma_j}} \frac{w_j}{\rho} \left[\tilde{\varphi}_{jd}^{\sigma_j - 1} + \zeta_{jx} \left(\tau_j^{-1} \tilde{\varphi}_{jx} \right)^{\sigma_j - 1} \right]^{\frac{1}{1-\sigma_j}} = \left(\frac{L_j}{\sigma_j f_j} \right)^{\frac{1}{1-\sigma_j}} \frac{w_j}{\rho_j \varphi_{jd}}. \qquad \text{(A.9)}$$

Inserting this into $(P_s/P_u)^{1-\varepsilon} = w_s L_s / w_u L_u$ and rearranging terms yields the skill premium equation described in (3.8).

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