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THE SKILL BIAS OF WORLD TRADE

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The Skill Bias of World Trade*

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Abstract

We argue that, with an elasticity of substitution in consumption greater than one and higher scale economies in the skill-intensive sectors, the entire volume of world trade matters for wage inequality. This implies that trade integration, even among identical countries, is likely to increase the skill premium. This result can also explain the increase in skill premia in developing countries that have experienced drastic trade liberalizations. Further, we argue that evidence of a falling relative price of skill-intensive goods can be reconciled with the fast growth of world trade and that the intersectoral mobility of capital exacerbates the effect of trade on inequality. We provide new empirical evidence in support of our results and a quantitative assessment of the skill bias of world trade.

JEL classification: F12, F16.

Keywords: Skill Premium, Scale Effect, Intra-Industry and Inter-Industry Trade.

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1 Introduction

Wage inequality has widened over the last two decades. This fact has stimulated a growing body of research, which pointed at skill-biased technical change and international trade as major explanations. It has been argued that technology can be at the root of the increase in inequality because recent innovations in the production process, such as the widespread introduction of computers, have boosted the relative productivity of skilled workers.[1] In contrast, trade models generally attribute the rising skill premium in OECD countries to the growing competition of imports from low-wage producers due to globalization.[2] However, the current consensus is that the role of international trade is of small empirical relevance when compared to the role of technology. There are three main reasons why the conventional trade explanation fails to convince. First, although the last two decades have witnessed a substantial increase in the volume of North-South trade, advanced countries still trade too little with developing countries and hence, the effect of low-price imports is not likely to be quantitatively relevant.[3] Second, the rise in the skill premium has also occurred in many developing countries, which runs counter to the conventional trade story.[4] Third, most studies suggest that the relative price of skill-intensive goods did not increase during the period of rising inequality,[5] whereas trade models imply an unambiguous positive relationship between prices of factors and goods.

In this paper, we illustrate how to reconcile the empirical evidence with a new role of international trade in explaining wage inequality. We do so by revisiting the *new trade theory*'s account of the distributional effects of intra-industry trade. The conventional wisdom is that, since, by definition, intra-industry trade is trade in goods with similar factor intensities, it has

[1] See, among others, Autor et al. [1998].

[2] In particular, Wood [1994, 1998] proposes an augmented Heckscher-Ohlin theory based on specialized trading equilibria. Feenstra and Hanson [1996, 1999] instead emphasize the role played by intensive outsourcing of less skill-intensive activities.

[3] Wood [1998] reports that imports of manufactures from developing countries constitute a small fraction of OECD GDP (about 3%), although this share has almost tripled between 1980 and 1995. The point that these volumes of trade are too small to have an important effect on wage inequality has been forcefully made by Krugman [2000].

[4] For evidence on wage inequality in developing countries see Robbins [1996], Hanson and Harrison [1999] and Berman, Bound and Machin [1998].

[5] Lawrence and Slaughter [1993], in particular, document a decline in the relative price of US skill-intensive goods in the 1980s.

no impact on relative factor demand and therefore it cannot explain the evolution of the skill premium. We argue that this seemingly plausible result critically hinges on either of the following assumptions: a) Cobb-Douglas preferences; b) perfect symmetry between sectors. We relax these assumptions to show that an elasticity of substitution in consumption greater than one and higher scale economies in the skill-intensive sectors imply that any increase in the volume of trade, even between identical countries, tends to be skill-biased. The intuition behind this result is very simple. Trade expands the market size of the economy, which is beneficial because of increasing returns. In relative terms, however, output increases by more in the skill-intensive sector, since it is characterized by stronger economies of scale, and the relative price of the skill-intensive good therefore falls. With an elasticity of substitution in consumption greater than one, the demand for skill-intensive goods increases more than proportionally, raising their share of total expenditure and the relative wage of skilled workers.

This result has important implications. First, it is the entire volume of world trade that matters for inequality and not the small volumes of North-South trade only. In this respect, we show that the skill bias of trade is quantitatively relevant, since under reasonable parameter values trade integration between two identical countries can increase skill premia by almost 10%. Second, if the skill-biased scale effect is strong enough to overcome the standard factor proportions effect, international trade will spur inequality even in the skill-poor developing economies, making the model consistent with the evidence of rising skill-premia in developing countries that have experienced trade liberalizations. In particular, we show in a simple numeric exercise that trade integration between Mexico and the United States can account for a significant increase in the Mexican skill premium. Third, our model can explain the decline in the relative price of skill-intensive goods during the period of rising skill premia and growing volumes of world trade: in the framework we propose, the so-called price puzzle (the empirical finding that relative factor and good prices moved in opposite directions) simply disappears.

We also extend our analysis by introducing physical capital. As the capital stock is an important component of economic size, we find that its accumulation leads to higher skill premia. More interestingly, we show that the intersectoral mobility of capital is likely to exacerbate the effects of trade integration on wage inequality. Our findings are consistent with both the evidence on capital relocation towards skill-intensive sectors (Caselli, [1999])

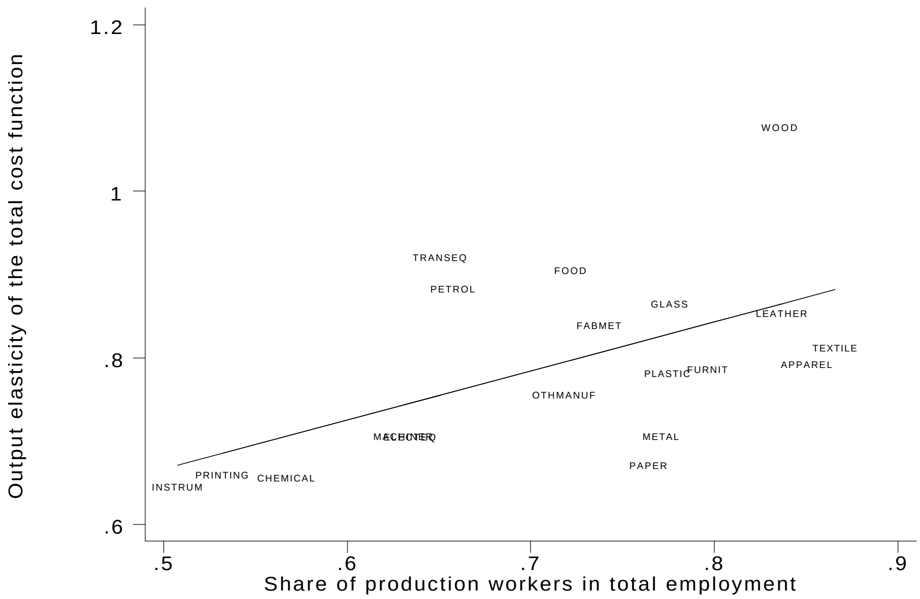

Figure 1: Skill-intensity and increasing returns

and the large literature on capital-skill complementarity.

As mentioned above, our results rest on two crucial assumptions. Scale economies must be relatively stronger in the skill-intensive sectors and the elasticity of substitution between goods of different skill-intensity must be greater than one. How realistic are these assumptions? We review here some evidence. Paul and Siegel [1999] estimate returns to scale in US manufacturing industries at the two-digit industry level for the period 1979-1989. Figure 1 plots their estimates against a measure of sectoral skill-intensity. For each industry, the vertical axis reports the output elasticity of the long-run total cost function (an inverse measure of internal and external scale economies) and the horizontal axis shows each sector's share of production workers in total employment in 1990 (an inverse measure of skill-intensity). The diagram clearly shows a positive correlation between skill-intensity and scale economies. We also report a weighted regression line, whose slope coefficient and standard error are 0.588 and 0.214, respectively. Similar results are reported by Antweiler and Trefler [2000], using international trade data for 71 countries and a very different methodology: they find that skill-intensive sectors, such as Petroleum Refineries and Coal Products, Pharmaceuticals, Electric and Electronic machinery and Non-Electrical Machinery, have an average scale elasticity around 1.2, whereas traditional less skill-intensive sectors, such as Apparel, Leather, Footwear and Food, are characterized by constant returns.[6] Finally, note that many skill-intensive activities (such as R&D and Marketing) have the nature of fixed costs and therefore tend to generate scale economies.

Moving to our second hypothesis, several observations suggest that the elasticity of substitution among goods with different skill-intensity is greater than one. Notice, first, that a unit elasticity would imply constant expenditure shares over time, but this is contradicted by US data: between 1970 and 1994, the expenditure share (relative to total manufacturing) in the less skill-intensive textile-apparel-footwear sectors has fallen by more than 30%, whereas those in modern skill-intensive sectors such as office machinery, pharmaceuticals and electrical machinery have risen by 160%, more than 100% and almost 50%, respectively.[7] More interestingly, we show that in our model an elasticity of substitution in production between skilled and unskilled workers greater than one implies an elasticity of substitution in consumption also greater than one. We can then refer to studies that provide estimates of the former parameter. Freeman [1986] concludes his review of the empirical evidence suggesting a value of the elasticity of substitution between more and less educated labor in the range between 1 and 2. Hamermesh and Grant [1979] review 20 estimates of the elasticity of substitution between production and non-production workers and find a mean estimate of 2.3. Finally, using a different macroeconomic approach, Krusell et al. [2000] report an estimate of 1.67 for the US economy and Katz and Murphy [1992] find a value of 1.41.

We also confront our result with the data, by considering a panel of 35 countries observed around 1980 and 1990. Our model suggests that the skill premium is higher the higher is a country's openness to trade, the greater its size and the lower its endowment of skilled workers. We therefore regress the

[6]More precisely, simple calculations on their results show that manufacturing sectors with strong evidence of increasing returns have an average index of skill-intensity (the normalized ratio of workers who completed high school to those who did not) equal to 0.4, while those with constant returns have an average value of 0.12. The remaining sectors, with non-robust estimates of returns to scale, lie in the intermediate range, with an average skill-intensity of 0.23.

[7]The source of the data used to calculate these figures is the OECD STAN Database.

skill premium on the ratio of imports plus exports to GDP, the size of the labor force and the share of workers with secondary education. The results are striking. The coefficients of these variables have the expected sign and are highly significant. Ceteris paribus, a doubling of the degree of openness is associated with a 41% increase in the skill premium; a doubling of the scale is associated with a 9% increase in the skill premium, and a doubling in the share of workers with secondary education leads to a 21% fall in the skill premium. These results turn out to be robust with respect to the method of estimation and the specification of the regression equation.

We are not the only one to reconsider the role of international trade in explaining wage inequality. Neary [2001], Thoenig and Verdier [2001] and Ekholm and Midelfart-Knarvik [2001] develop models where trade liberalization between similar countries can lead to skill-biased technical change. The idea underling Neary [2001] and Thoenig and Verdier [2001] is that of "defensive innovation": increased competition makes skill-intensive technologies more profitable because they deter the entry of new firms. In Ekholm and Midelfart-Knarvik [2001], instead, the market size expansion induced by trade increases the profitability of firms characterized by a high (skill-intensive) fixed cost and a low (unskilled labor-intensive) marginal cost, thus inducing the adoption of the more skill-biased technology. In contrast, we show that even abstracting from technical change and strategic considerations, the trade-induced expansion in market size is sufficient to increase inequality. Our result is also related to Acemoglu [1999] and Acemoglu and Zilibotti [2001]. In their view, North-South trade induces skill-biased technical change by making skill-complement innovations more profitable. However, trade between identical countries plays no role and trade opening in a developing country is unlikely to have an effect on the direction of technical change, since no single developing country has the economic size to affect world incentives. Another related work is Dinopoulos et al. [2001]. In their model, intra-industry trade expands firm size, which is assumed to be skill-biased, and hence rises the skill premium. In this respect, a fundamental contribution of our approach is to show how an increase in scale leads to skill-biased demand shifts without relying on non-homotheticities. Further, they consider a one-sector economy only, thereby missing some general equilibrium implications of trade models (i.e., the evolution of good prices). Finally, Manasse and Turrini [2001] study the effects on inequality of trade between identical countries, but they address a different question, as they show how, in the presence of heterogeneity among skilled workers, trade can spur within-group wage differentials.

The plan of the paper is as follows. Section 2 illustrates the basic model, analyzes the effects of international trade on the skill premium and shows that the intersectoral mobility of physical capital may exacerbate the skill-biased scale effect. Section 3 reconciles the role of trade in explaining wage inequality with the main stylized facts. Section 4 tests the implications of the model using data from a panel of countries. Section 5 concludes.

2 A Simple Model

2.1 Preferences

Consider a country endowed with H units of skilled workers and L units of unskilled workers, where two final goods are produced. Consumers have identical homotetic preferences, represented by the following CES utility function:

$$U = \left[(Y_l)^{\frac{\varepsilon-1}{\varepsilon}} + (Y_h)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{1}$$

where Y_h and Y_l stand for the consumption of final goods h and l, respectively, and $\varepsilon > 1$ is the elasticity of substitution between the two goods. The relative demand for the two goods implied by (1) is:

$$\frac{P_h}{P_l} = \left[\frac{Y_l}{Y_h} \right]^{1/\varepsilon}, \tag{2}$$

where P_h and P_l are the final prices of goods l and h, respectively. Note that $\varepsilon > 1$ implies that a fall in the relative price induces a more than proportional increase in relative demand. This is a crucial assumption for our results.

2.2 Production and Market Structure

Goods h and l are produced by perfectly competitive firms by costlessly assembling n_i $(i = l, h)$ own-industry differentiated intermediate goods. In particular, we assume that the production functions for final goods take the following CES form:

$$Y_i = \left[\int_0^{n_i} y_i(v)^{\frac{\sigma_i-1}{\sigma_i}} dv \right]^{\frac{\sigma_i}{\sigma_i-1}}, \tag{3}$$

where $y_i(v)$ is the amount of the intermediate good type v used in the production of good i, and σ_i is the elasticity of substitution among any two varieties of intermediates used in sector i. In the following, we assume that $\sigma_l > \sigma_h > \varepsilon$. In words, the elasticity of substitution among intermediates is greater in sector l than in sector h. Further, the elasticity of substitution among intermediates used in each sector is greater than that between the final goods.

The price for final good i (equal to the average cost) implied by (3) is:

$$P_i = \left[\int_0^{n_i} p_i(v)^{1-\sigma_i} \, dv \right]^{1/(1-\sigma_i)}, \tag{4}$$

where $p_i(v)$ is the price of the intermediate good type v used in the production of good i.

The two sectors producing intermediates are monopolistically competitive *a là* Dixit and Stiglitz [1977]. Firms operating in each sector are symmetric. The production of each intermediate in sector i involves a fixed requirement, F_i, and a constant marginal requirement, c_i, of labor. In order to keep the algebra as simple as possible, we assume that the two sectors are extreme in terms of skill-intensity, so that sector h uses only skilled workers H, whereas sector l uses only unskilled workers L. In the Appendix, we generalize our results to a context where both sectors use both types of labor. Hence, the total cost function of a single variety produced in sector i is:

$$TC_i = (F_i + c_i y_i) w_i, \tag{5}$$

where w_h and w_l are the wage rate of skilled and unskilled workers, respectively.

Profit maximization by intermediate firms in the two sectors implies a markup pricing rule:

$$p_i(v) = p_i = \left(1 - \frac{1}{\sigma_i}\right)^{-1} c_i w_i = w_i, \tag{6}$$

where the latter equality follows from the choice of units such that $c_i = \left(1 - \frac{1}{\sigma_i}\right)$.[8] Hence, we have:

$$\frac{p_h}{p_l} = \omega, \tag{7}$$

[8] This normalization is innocuous as it does not affect the *elasticity* of the skill premium to a change of any parameters (it only affects its *level*).

where $\omega = w_h/w_l$ is the skill premium. Intuitively, the relative price of any variety of sector h intermediates is an increasing function of the skill premium, since h is skill-intensive relative to l.

A free-entry condition implies zero profits in equilibrium:

$$\pi_i(v) = \pi_i = \left(\frac{y_i}{\sigma_i} - F_i\right) w_i = 0$$

and hence:

$$y_i = F_i \sigma_i = 1, \tag{8}$$

where the latter equality follows from the choice of units such that $F_i = 1/\sigma_i$.[9]

Equations (6) and (8) imply that the expressions for P_i and Y_i simplify to:

$$Y_i = n_i^{\frac{\sigma_i}{\sigma_i - 1}} \tag{9}$$

$$P_i = n_i^{\frac{1}{1-\sigma_i}} p_i. \tag{10}$$

Note that equation (9) implies that the elasticity of Y_i with respect to n_i is greater the lower is σ_i. Hence, σ_i can be interpreted as an inverse measure of sectoral scale economies. Our assumption $\sigma_l > \sigma_h$ is thus equivalent to assuming stronger increasing returns to scale in sector h than in sector l.

2.3 General Equilibrium

Conditions for full employment of skilled and unskilled workers determine the number of varieties produced in each sector:

$$n_l = L \quad \text{and} \quad n_h = H. \tag{11}$$

Let $\theta = H/\overline{L}$ be the country share of skilled workers in the total workforce, where $\overline{L} = H + L$. Equations (11) can then be rewritten as follows:

$$n_l = (1-\theta)\,\overline{L} \quad \text{and} \quad n_h = \theta\overline{L}. \tag{12}$$

Substituting (9), (10), (7) and (12) into (2), and rearranging gives:

$$\left[\theta\overline{L}\right]^{\frac{\sigma_h - \epsilon}{\epsilon(\sigma_h - 1)}} \omega = \left[(1-\theta)\,\overline{L}\right]^{\frac{\sigma_l - \epsilon}{\epsilon(\sigma_l - 1)}}. \tag{13}$$

This equation defines the skill-premium.

[9] For the purpose of the paper, this normalization is also innocuous.

2.4 Trade and the Skill Premium

We can now analyze the effects of trade integration on the skill premium. Since we focus on equilibria with factor price equalization (FPE), we can obtain the free trade prices by applying the above results to a hypothetical integrated economy whose endowments are the sum of those of each country. In particular, totally differentiating equation (13) and using the implicit function theorem, we can decompose the change in the skill premium into the following components:

$$\frac{d\omega}{\omega} = \left[\frac{(\epsilon - 1)(\sigma_l - \sigma_h)}{\epsilon\,(\sigma_h - 1)\,(\sigma_l - 1)}\right]\frac{d\overline{L}}{\overline{L}} - \left[\frac{\sigma_h - \epsilon}{\epsilon\,(\sigma_h - 1)} + \frac{\sigma_l - \epsilon}{\epsilon\,(\sigma_l - 1)}\frac{\theta}{1-\theta}\right]\frac{d\theta}{\theta}. \quad (14)$$

Equation (14) shows how the skill premium is affected by a variation in the size of the economy ($d\overline{L}/\overline{L}$) and the relative scarcity of skilled workers ($d\theta/\theta$). We use equation (14) to first study the effect of intra-industry trade on wage inequality. As shown by Krugman [1979], in a Dixit-Stiglitz framework trade integration among two identical countries is formally equivalent to an increase in country size, $\overline{L}$. Given that $\sigma_l > \sigma_h > \epsilon > 1$, equation (14) implies that the coefficient of $\frac{d\overline{L}}{\overline{L}}$ is positive, and that its magnitude depends positively on the elasticity of substitution ϵ and the sectoral asymmetries $(\sigma_l - \sigma_h)$ in the degree of returns to scale. Thus, purely intra-industry trade among identical countries, often presumed to have no distributional effects, turns out to be skill-biased.

Equation (14) also shows the effect of inter-industry trade on wage inequality. Integration between dissimilar countries still implies an increase in the overall size of the economy, but will also change the perceived relative scarcity of factors. Since the coefficient of $d\theta/\theta$ is negative, an increase (fall) in the relative supply of skilled labor has the effect of reducing (increasing) the skill premium.[10] This effect works through the well-known mechanics of the Heckscher-Ohlin-Samuelson theorem, and can mitigate or exacerbate the upward pressure on the skill premium due to the market size effect.

To see what drives the skill bias of trade note, from (10), that an equiproportional increase in n_l and n_h lowers the relative price of the skill-intensive good, since it enjoys stronger economies of scale. This implies that, by expanding market size, international trade raises the relative productivity of

[10]Note that the coefficient of $d\theta/\theta$ is negatively affected by the elasticity of substitution ϵ, as a high substitutability implies a weak price effect of an increase in the relative supply.

the skill-intensive good and is thus formally equivalent to skill-biased technical change. Further, since the elasticity of substitution in consumption is greater than one, the share of the skill-intensive good in total output raises after trade integration. It follows that trade increases the share of skilled labor in total income and hence the skill premium.

2.5 Introducing Physical Capital

We now show how the introduction of physical capital, assumed to be mobile across sectors, exacerbates the skill-biased scale effect of trade. Consider then a third production factor, physical capital (K). The total cost function of a single variety produced in sector i now becomes:

$$TC_i = (F_i + c_i y_i) r^{\gamma} w_i^{1-\gamma}, \tag{15}$$

where r is the rental rate and γ is the share of capital in sector i total cost. For simplicity, and without loss of generality, equation (15) considers the knife-edge case where capital intensity is the same in both sectors ($\gamma = \gamma_h = \gamma_l$). The relative price of skill-intensive varieties implied by (15) and profit maximization becomes:

$$\frac{p_h}{p_l} = \frac{r^{\gamma} w_h^{1-\gamma}}{r^{\gamma} w_l^{1-\gamma}} = \omega^{1-\gamma}. \tag{16}$$

Equations (2), (9) and (10) are unchanged; together with (16) they imply:

$$n_h^{\frac{\sigma_h - \epsilon}{\epsilon(\sigma_h - 1)}} \omega^{1-\gamma} = n_l^{\frac{\sigma_l - \epsilon}{\epsilon(\sigma_l - 1)}}. \tag{17}$$

The demand for each factor can be found using Shephard's lemma on the total cost function (15). After noting that $\frac{\partial}{\partial w_i} r^{\gamma} w_i^{1-\gamma} = (1-\gamma) r^{\gamma} w_i^{-\gamma}$ and $\frac{\partial}{\partial r} r^{\gamma} w_i^{1-\gamma} = \gamma r^{\gamma-1} w_i^{1-\gamma}$, we have that the conditions for full employment of physical capital, skilled and unskilled workers are given by:

$$\begin{aligned} K &= \gamma r^{\gamma-1} w_h^{1-\gamma} n_h (F_h + c_h y_h) + \gamma r^{\gamma-1} w_l^{1-\gamma} n_l (F_l + c_l y_l) \\ H &= (1-\gamma) r^{\gamma} w_h^{-\gamma} n_h (F_h + c_h y_h) \\ L &= (1-\gamma) r^{\gamma} w_l^{-\gamma} n_l (F_l + c_l y_l). \end{aligned} \tag{18}$$

After setting w_l equal to the numeraire, we can use (18) to express n_h and n_l as functions of the skill premium and the exogenous variables:

$$n_h = \frac{H\omega^\gamma}{(1-\gamma)^{1-\gamma}} \left(\gamma \frac{L + H\omega}{K}\right)^{-\gamma} \quad \text{and} \quad n_l = \frac{L}{(1-\gamma)^{1-\gamma}} \left(\gamma \frac{L + H\omega}{K}\right)^{-\gamma}. \tag{19}$$

Substituting (19) into (17) and solving for ω gives the equilibrium skill premium. Differentiating with respect to ω, K and $\overline{L} = H + L$, and using the implicit function theorem, we find the elasticity of the skill premium to a change in the scale of the economy to be:

$$\frac{d\omega}{\omega} = \frac{\left[\gamma \frac{dK}{K} + (1-\gamma)\frac{d\overline{L}}{\overline{L}}\right] \frac{(\epsilon-1)(\sigma_l - \sigma_h)}{\epsilon(\sigma_h - 1)(\sigma_l - 1)}}{1 - \gamma\left[\frac{\epsilon-1}{\epsilon} \frac{1}{1-\theta+\theta\omega}\left(\frac{\sigma_h(1-\theta)}{\sigma_h - 1} + \frac{\sigma_l \theta \omega}{\sigma_l - 1}\right)\right]}, \tag{20}$$

where again $\theta = H/\overline{L}$ is the share of skilled workers in the total labor force.[11] Note that the coefficient multiplying the scale variables in the square bracket of the numerator is equal to the scale elasticity in (14). But now the denominator in (20) is less than one and decreasing in γ.[12] Therefore, the effect on the skill premium of trade integration among two identical countries, i.e., a doubling of both K and $\overline{L}$, is now greater, the greater is the share γ of capital in the total cost. Further, equation (20) shows that capital accumulation and capital inflows tend to increase the skill premium, as they contribute to expand the scale of the economy. This result is consistent with the literature documenting capital-skill complementarities (see Krusell et al. [2000], among others). To see why capital exacerbates the effects of trade integration on the skill premium, it is instructive to study the change in the allocation of capital between the two sectors:[13]

$$\frac{K_h/n_h}{K_l/n_l} = \omega^{1-\gamma}. \tag{21}$$

[11] The elasticity to a change in the relative skill-endowment θ is here omitted, though straightforward to calculate, because we are interested in showing how capital reallocation affects the scale effect.

[12] Note that, assuming decreasing marginal returns to capital in both sectors, we have $\gamma\frac{\sigma_i}{\sigma_i - 1} < 1$ for $i = h, l$. This ensures that the denominator of (20) is positive.

[13] To find (21), note that $K_i r = \gamma P_i Y_i$ then use (9), (10) and (16).

Equation (21) shows that the trade-induced rise in the skill premium is associated with a relative increase in capital intensity of firms operating in sector h. The reason is that, by expanding market size, trade integration increases the relative productivity of the resources used in the sector enjoying stronger economies of scale. Hence, trade implies an increase in the relative marginal productivity of capital in sector h. Since in equilibrium the rental rate must be equalized between the two sectors, the only way of restoring the equality after trade integration is by shifting capital out of the less skill-intensive sector and into the skill-intensive sector. As a consequence, the endowment of capital per worker rises for the skilled and falls for the unskilled, which further increases wage inequality.

A similar mechanism is at work in Caselli [1999], where a skill-biased technological revolution induces a reallocation of capital toward the skill-intensive sectors. He also provides evidence of a substantial increase in the US sectoral dispersion of capital intensities since the mid-seventies. In particular, he documents that during the period of rising wage inequality capital flew to skill-intensive industries. Our contribution is to show that such a reallocation of capital can be also due to trade integration. More important, this section shows that capital mobility exacerbates the effects of trade integration on the skill premium and therefore strengthens the quantitative relevance of our analysis.

3 Trade and Wages: Reconsidering the Facts

In this section, we show how our model can reconcile an important role of trade in explaining the rising skill premia with the main stylized facts. The first critique to traditional trade-based explanations is on their quantitative relevance: North-South trade flows simply do not seem to be large enough to affect significantly wage premia. Compared to the Heckscher-Ohlin approach, our model is less exposed to this criticism as it shows that the entire volume of world trade matters for inequality and not its net factor content only. It remains to be proven that the trade-induced skill-biased scale effect has a significant magnitude. To do so, we compute the scale elasticity of the skill premium given by equation (20). We select parameters for γ, ϵ, σ_h and σ_l as follows. A conventional value for for the capital share, γ, is 1/3. In the model we use, the elasticity of substitution between goods of different skill-intensity is the same as the elasticity of substitution between skilled

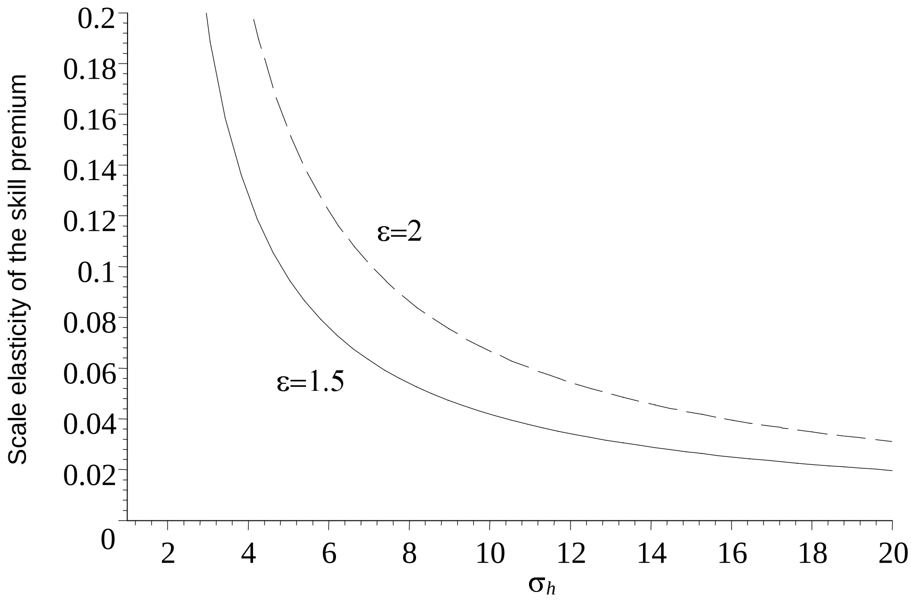

Figure 2: Scale elasticity of the skill premium

and unskilled workers. As already mentioned in the Introduction, estimates of the latter elasticity are in the range (1.5 - 2). We therefore choose the benchmark values of 1.5 and 2. For the remaining parameters, we refer to Antweiler and Trefler [2000] who find that skill-intensive sectors have an average scale elasticity around 1.2 and that traditional less skill-intensive sectors show no departure from constant returns. We therefore set $\sigma_l = \infty$ and let σ_h vary. To have a sense of the economic meaning of σ_h, note that it can be interpreted as an inverse index of the degree of increasing returns; in particular, the production function (9) implies that a scale elasticity of output in the range from 1.1 to 1.2 corresponds to a σ_h between 11 and 6.

The result is depicted in Figure 2, which shows the scale elasticity of the skill premium (on the vertical axis) as a function of σ_h (on the horizontal axis).[14] The broken line corresponds to $\epsilon = 2$, whereas the solid one represents the case with $\epsilon = 1.5$. Figure 2 can be used to perform simple

[14]Note from equation (20) that $d\omega/\omega$ also depends on θ and ω. Numerical simulations show their effect to be negligible. To draw Figure 2, we have used values of 0.35 and 1.4, respectively.

experiments. For example, with $\sigma_h = 6$ (a value often used in trade models to describe manufacturing sectors and consistent with several studies[15]) and $\epsilon = 1.5$, the graph shows that the elasticity of the skill premium to the scale of the economy implied by the model is around 0.08. In this case, trade integration between two identical countries would imply a 8% increase in the skill premium. More in general, the important lesson from Figure 2 is that even small asymmetries in the sectoral returns to scale are enough to produce a significant effect of market size on wage inequality. This simple quantification suggests that empirical studies focusing on North-South trade might be missing an important mechanism through which globalization enhances skill premia.

A second observation which is at odds with trade models is that commercial liberalizations in developing countries seem to be followed by increases in wage preima (e.g., Hanson and Harrison [1999] and Robbins [1996]). Our model can rationalize this fact if the skill-biased scale effect is strong enough to overcome the factor proportions effect in skill-scarce countries. To see whether this is more than just a theoretical possibility, we use our model to study the episode of trade integration between Mexico and the United States. This case is of particular interest for prior to 1985 Mexico could be considered a closed economy due to heavy policies of trade protection. In 1985, Mexico announced its decision to join the GATT and undertook major reforms leading to a reduction in tariffs by 45% and import licenses by more than 75% within three years. During the same period, the skill premium, starting from a value of 1.84, rose by at least 17%. The Mexican experience is also interesting because the major trade partner of this country is the skill-abundant United States. We then perform the following thought experiment. Assuming that Mexico was in autarky in 1985, we use our model to compute the effect of a complete and instantaneous trade integration with the United States. Using data[16] for the manufacturing sector and the share of white-collar workers as a measure of skilled labor, we have that a move from autarky to the integrated equilibrium implies a 4.8 fold increase in the total labor force, a 10.1 fold increase in the aggregate capital stock and a 28.4% increase in the share of white-collar workers. Using these numbers

[15] See, for example, Feenstra [1994] and Lai and Trefler [1999].

[16] Berman, Bound and Griliches [1994] provide the share of US white-collar workers. The equivalent share for Mexico is reported in Hanson and Harrison [1999]. The labor force in manufacturing is taken from the World Development Indicators. The total capital stock is computed from the Penn World Tables.

together with the above mentioned parameter values ($\gamma = 1/3$, $\epsilon = 1.5$, $\sigma_h = 6$, $\sigma_l = \infty$), our model predicts the following change in the Mexican skill premium:

$$\frac{d\omega}{\omega} = +0.49 - 0.27 = 0.22$$

where the first number represents the positive scale effect and the second number the negative factor proportions effect. Overall, trade opening in the skill-scarce Mexico can lead to an impressive 22% increase of the skill premium. We recognize that this number is likely to be an over-estimation, due to the extreme nature of our exercise; still, its magnitude suggests that the market size effect can play a significant role in developing countries that experience drastic trade liberalizations.

The third puzzling fact that a satisfactory model should explain is the evolution of relative prices: though the empirical findings are sometimes mixed, they tend to suggest a *decline* in the relative price of skill-intensive goods during the period of rising skill premia. Our model can help understand this evidence, as it breaks the simple positive relation between good prices and factor prices of standard trade theory. In fact, on the one hand, a trade-induced expansion in market size lowers the relative final price of the skill-intensive good:

$$\frac{P_h}{P_l} = \left[\frac{n_l^{\frac{\sigma_l}{\sigma_l - 1}}}{n_h^{\frac{\sigma_h}{\sigma_h - 1}}} \right]^{1/\varepsilon}.$$

Our assumption $\sigma_l > \sigma_h$ implies that a larger market is associated with a lower relative price of the skill-intensive final good: as the skill-intensive sector is characterized by stronger returns to scale, its output grows more after an increase in the market size and this depresses its relative price. On the other hand, trade increases the relative price of each variety of intermediates in the skill-intensive sector, together with the skill premium, because of the stronger productivity gain:

$$\frac{p_h}{p_l} = \omega^{1-\gamma}.$$

These contrasting implications concerning the effects of international trade on the relative price of goods may shed light on the mixed results emerging from the different methodologies and levels of sectoral aggregation used in empirical studies. In particular, it is suggestive that Lawrence and Slaughter [1993] show a decline in the relative price of skill-intensive goods using a high level of aggregation, whereas Krueger [1997] finds an increase using highly disaggregated data.

4 Empirical Evidence

4.1 The Determinants of Skill-Premia in a Panel of Countries

We now want to test some empirical implications of our model by considering a panel of countries observed in the years 1980 and 1990. As shown in section 2, in the case of complete integration and FPE equilibria, the skill premium does not depend on country characteristics, but only on the size and the endowment of the world economy. More generally, in the presence of some kind of trade barriers, our model suggests that the skill premium is higher, the higher is a country's openness to trade, the greater its size and the lower the share of skilled workers in its labor force. We have therefore collected data on skill-premia, trade openness, measures of country size and skill endowments. Unfortunately, international data on wages for different categories of workers are difficult to find. Following other empirical studies,[17] we have used the U.N. General Industrial Statistics database to compute the skill premium as the ratio of nonproduction to production (operatives) wage in total manufacturing. Due to the limitations of this dataset, our sample comprises 35 countries[18] only, at various stages of economic development (from Ethiopia to the United States, with an average real GDP per capita equal to 41% of the US value in 1990). We have then regressed the log(skill premium) on log(openness), measured as the ratio of imports plus exports to GDP, log(labor force) and log(secondary schooling), measured as the share of

[17] For an example, see Berman et al. [1998].

[18] The list of countries is the following: Australia, Austria, Bangladesh, Canada, Chile, Colombia, Cyprus, Czechoslovakia, Denmark, Egypt, Ethiopia, Finland, Germany (West), Greece, Guatemala, Hungary, India, Ireland, Italy, Japan, Korea (Republic), Malaysia, Malta, Mexico, Spain, Sweden, Tanzania, Pakistan, Panama, Peru, Philippines, Turkey, United Kingdom, United States of America, Uruguay. Note: the skill premium for Mexico goes back to 1986 only. Due to data availability, the other Mexican observations for 1980 are replaced by those in year 1985.

workers with secondary education.[19] The main results are reported in Table 1.

Table1. Skill premia across countries

Variable	Pooled OLS	SUR	Random-effects
log(Openness)	0.416	0.368	0.320
	(0.110)	(0.077)	(0.079)
log(Labor force)	0.091	0.085	0.063
	(0.031)	(0.027)	(0.029)
log(Secondary schooling)	-0.214	-0.164	-0.202
	(0.051)	(0.043)	(0.050)
Dummy: Latin America	0.461	0.456	0.424
	(0.067)	(0.079)	(0.089)
Dummy: 1990	0.086	—	0.087
	(0.030)		(0.029)
Number of observations	70	35, 35	70
R-squared	0.58	0.51, 0.59	0.57

Notes: the dependent variable is log(Skill premium). Standard errors are reported in parentheses. In the Pooled OLS regression, robust standard errors are calculated in the presence of repeated observations on individual countries. The R-squared values for the SUR refer to the two periods, 1980 and 1990, respectively.

In the first column, estimation is by pooled OLS with a fixed time effect and a dummy for Latin America. The dummy for 1990, which may capture the effect of skill-biased technical change, is positive and highly significant. The three variables of interest have the expected sign and are highly significant. Ceteris paribus, a doubling of the degree of openness is associated with a 41% increase in the skill premium; a doubling of the scale is associated with a 9% increase in the skill premium,[20] and a doubling in the share of workers

[19] Data on openness are from the Penn World Tables (Mark 5.6). Labor Force is taken from the World Development Indicators (World Bank). The educational attainment of the total population aged 25 and above is provided by Barro-Lee (School attainment for Ethiopia is available for 1995 only. In the case of Tanzania, school attainment is proxied by the average for sub-Saharan countries).

[20] This estimated value for the scale elasticity of the skill premium is in line with the quantitative implications of the model discussed in Section 3.

with secondary education leads to a 21% fall in the skill premium. Finally, note that the dummy for Latin America is positive, highly significant and of very large magnitude: being a Latin American country implies, ceteris paribus, a higher skill premium by more than 40%. This result is in line with other studies on the determinants of inequality, where a dummy for Latin America generally features prominently.[21]

Figure 3 and 4 provide a graphical representation of the partial relation between the skill premium and our two scale variables, log(openness) and log(labor force). The vertical axis reports the value of the skill premium after filtering out the estimated effects of the variables other than openness (Figure 3), and labor force (Figure 4). Looking at the plots, it is apparent that the regression lines are not driven by outliers and that they fit well even widely different observations (such as those for India and Malta).[22]

In the second column, estimation is by the seemingly-unrelated (SUR) technique. The coefficients of the variables of interest have the expected sign, are highly significant and similar in magnitude to the previous estimation. We have also tested whether these coefficients shift over time. The system estimated by SUR was extended to allow for different coefficients on the explanatory variables in the two periods. A Wald test for all sets of coefficients, either taken individually or jointly, finds no significant variation over time, suggesting parameter stability in the period of analysis.

To better exploit the limited time variation in the sample, the third column reports random-effects GLS estimates. Once more, all the regressors are highly significant and of the same order of magnitude, although the coefficients are somewhat lower than the previous estimates. The Hausman specification test is not significant, with a *p-value* of 0.123, suggesting that individual effects are uncorrelated with the regressors, and hence the appropriateness of the random-effects estimator.

Finally, Table 2 shows that results are robust to the specification of the

[21] See, for instance, Barro [2000]. We have also included continent dummies for Europe, Africa, Asia and North America. They turn out not significant, either individually or jointly.

[22] In order to test more rigorously for the presence of influential observations, we have computed the dfbetas for the coefficients of the scale variables (the difference between the regression coefficients when each observation is included and excluded, scaled by the standard error of the coefficients). We have found that only one observation (Malaysia in 1990) shifts the estimates by more than 0.5 standard errors. Omitting this observation from the sample leaves the significance of our results unchanged.

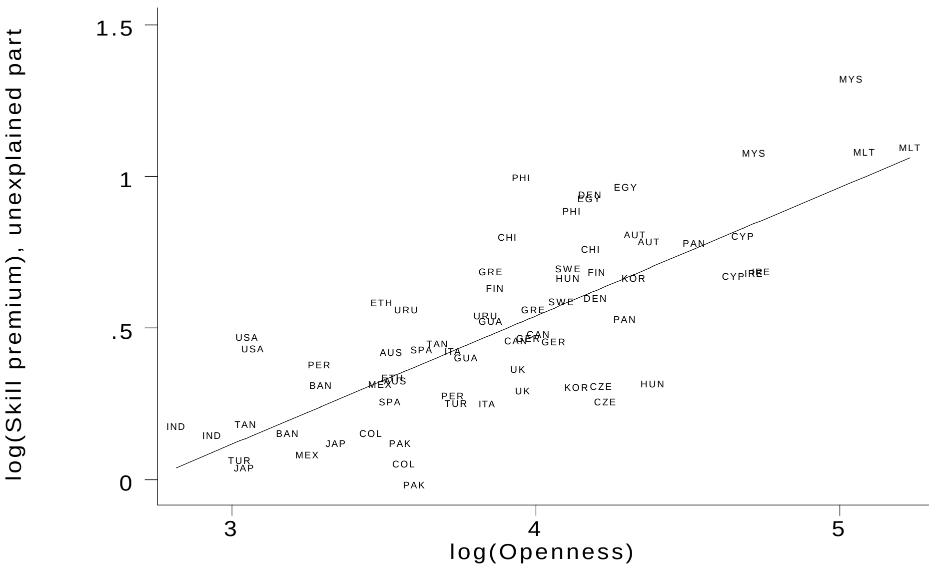

Figure 3: Skill premia and trade openness

regression equation. In particular, using total GDP[23] as a proxy for market size (instead of labor force) or college attainment as a proxy for education (instead of secondary schooling) has a small impact on the estimates. We also control for log(per capita GDP) and its square, i.e., for a Kuznets-type relation between wage inequality and per capita GDP. Independent of the method of estimation, the coefficients on the per capita GDP polynomial are not significant and with the unexpected sign. In contrast, the estimated coefficients on log(openness) and log(labor force) are unaffected. The coefficient of the schooling variable is the only one whose magnitude and significance are affected by the inclusion of the polynomial in log(per capita GDP). This is hardly surprising, given the high collinearity between log(per capita GDP) and log(secondary schooling) (the coefficient of linear correlation between the two variables equals 0.85 in both periods).

[23] Although total GDP captures well the economic size of a country, its correlation with per capita GDP makes it a less attractive scale proxy. As shown in Table 2, GDP per capita has negative and non significant effect on wage premia. This may explain why total GDP fits the data slightly worse than labor force.

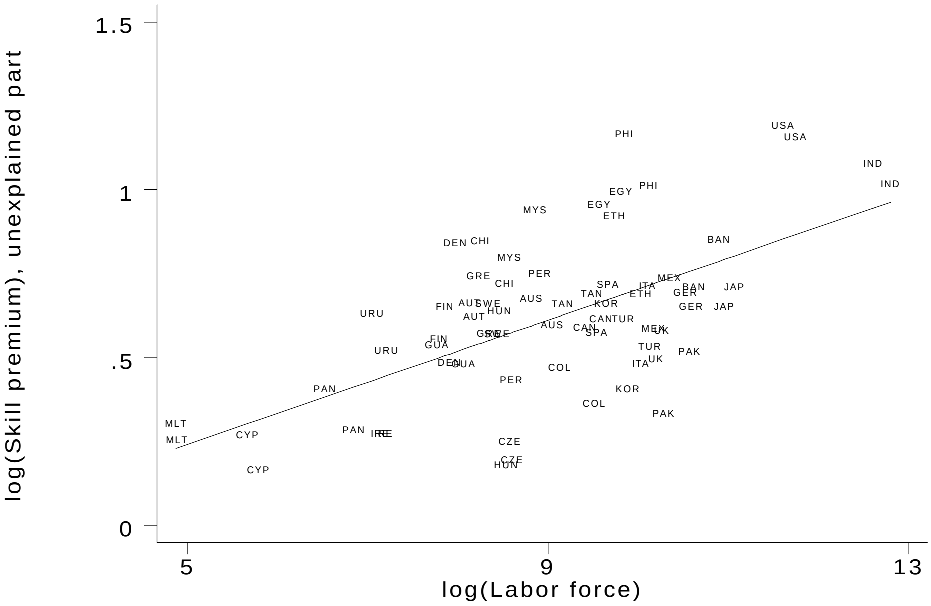

Figure 4: Skill premia and country size

Table 2. Sensitivity analysis

Variable	Pooled OLS			Random-effects		
log(Openness)	0.336 (0.108)	0.348 (0.113)	0.445 (0.111)	0.272 (0.075)	0.270 (0.082)	0.329 (0.083)
log(Labor force)	-	0.084 (0.035)	0.093 (0.032)	-	0.059 (0.031)	0.060 (0.030)
log (GDP)	0.060 (0.029)	-	-	0.040 (0.028)	-	-
log(Secondary schooling)	-0.286 (0.076)	-	-0.159 (0.110)	-0.249 (0.061)	-	-0.132 (0.086)
log(College Education)	-	-0.115 (0.035)	-	-	-0.105 (0.038)	-
log(GDP per capita)	-	-	-0.517 (0.341)	-	-	-0.350 (0.500)
log(GDP per capita) squared	-	-	0.029 (0.023)	-	-	0.018 (0.030)
Dummy: Latin America	0.411 (0.071)	0.504 (0.068)	0.504 (0.081)	0.390 (0.089)	0.470 (0.097)	0.445 (0.101)
Dummy: 1990	0.101 (0.030)	0.081 (0.032)	0.073 (0.033)	0.098 (0.029)	0.081 (0.031)	0.076 (0.031)
Observations	70	70	70	70	70	70
R-squared	0.54	0.50	0.59	0.53	0.50	0.58

Notes: the dependent variable is log(Skill premium). Standard errors are reported in parentheses. In the Pooled OLS regression, robust standard errors are calculated in the presence of repeated observations on individual countries.

4.2 Evidence from other studies

Other observations lend support to our result. We mention here the evidence from a few related studies. Antweiler and Trefler [2000], using trade data for 71 countries and 5 years, show that a rise in output tends to increase the relative demand for skilled workers. Historical evidence seems consistent with a skill-biased scale effect too: Lindert and Williamson [2001], for example, show that inequality widened during the globalization booms and after massive immigration, whereas it decreased in the period 1914-1950 of protectionism and in the presence of massive emigration. Finally, Hine and Wright [1998] report indirect evidence in support of the mechanism illustrated in the paper. With reference to the United Kingdom, they estimate the magnitude of trade-induced productivity effects. Their most interesting result is that trade with other OECD countries has a much stronger effect on productivity than trade with developing countries. This is consistent with our model, *in primis*, because the economic size of the OECD countries (and therefore the trade generated scale effect) is much larger than that of developing countries; *in secundis*, because the UK trade with advanced countries is mainly intra-industry trade in skill-intensive goods characterized by strong scale economies (therefore the more pronounced productivity gain).

5 Concluding Remarks

The most original result of our analysis is to show that the scale of an economy can be a key determinant of wage inequality. This is a general result which applies to different contexts. In this paper, we have focussed on the role played by a trade-induced scale effect, instead of other country-specific scale effects, such as factor accumulation or technical progress, for the following reasons. First, we consider trade as the most interesting scale variable because it is the only one that can change abruptly as a consequence of policy reforms. Second, if globalization goes far enough, factor prices will mainly be determined at the world level and country-specific variables will lose their importance. Third, trade is a fundamental element of our story because the scale effect operates through the increase in the number of available intermediates made possible by some form of trade. Finally, our framework shows that a "new trade theory" explanation (i.e., based on intra-industry trade) for the increase in wage inequality can be reconciled with the empirical evidence often used to discredit more traditional trade explanations. We consider this as an important result per se. Our empirical findings lend support to this choice of emphasis, as they suggest that trade is a major determinant of wage inequality in a panel of countries.

We conclude by discussing how our result is related to the main alternative explanations for the rising skill premia: models of directed technical change, in which the skill bias of technical progress is endogenous, and models of outsourcing. In models of directed technical change (initiated by Acemoglu [1998]), a market size effect plays a key role: the skill bias of the technology depends positively on the size of the relative endowment of skilled workers. However, since there are no sectoral asymmetries, the skill premium can only be affected by asymmetric changes in the economic environment. Our mechanism is complementary, as it shows that once sectoral asymmetries are introduced, even a purely symmetric endowment shock affects income distribution. This complementarity is reflected also by our econometric results, as they show that both the proxy for skill-biased technical change and scale variables are important to explain worldwide wage inequality.[24] In models of outsourcing, instead, it is the relocalization in developing countries of some phases of the production process by OECD countries (through trade in intermediates) that increases the demand for skilled labor.[25] This happens because the outsourced activities are unskilled-labor intensive relative to those performed in the developed world, but skilled-labor intensive relative to those performed in the developing countries. Our approach shares the basic insight that trade in intermediate inputs does not only affect the import-competing sector, but also the input-using sector. Despite this similarity, the two models apply to quite different situations, as outsourcing can take place between dissimilar countries only, whereas we emphasize the role of trade in intermediates among industrial countries.

Finally, in this paper we have chosen a specific market structure (monopolistic competition) and specific functional forms on the basis of our reading of the empirical evidence, to better quantify the effect we discuss. Much of the intense dispute on the role of trade in explaining inequality is, in fact, centered on assessing the magnitude of the trade-induced effects. But our model is a specific example of a more general principle, surprisingly neglected in the

[24] Other evidence in support of the role of technology over time is within-industry demand shifts in favor of skilled labor. Katz and Murphy [1992], among others, document this phenomenon for the United States.

[25] For a survey, see Feenstra and Hanson [2001].

ongoing debate: with sectoral asymmetries in the degree of returns to scale and a non-unitary elasticity of substitution in consumption, any increase in market size due to trade integration is non-neutral on income distribution.

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6 Appendix

6.1 The General Model

We study now the more general case in which each good is a Cobb-Douglas composite of H, L and K. We assume that the total cost function of a single variety produced in sector i is:

$$TC_i = (F_i + c_i y_i) r^{\gamma} (w_h^{\alpha_i} w_l^{1-\alpha_i})^{1-\gamma}, \tag{22}$$

where r is the rental rate, γ is the share of capital in total cost, and α_i $(i = h, l)$ is the wage-bill share of skilled workers in sector i. We assume that $\alpha_h > \alpha_l$, namely that sector h is skill-intensive relative to sector l. The relative price of skill-intensive varieties implied by (22) and profit maximization becomes:[26]

$$\frac{p_h}{p_l} = \frac{r^{\gamma}(w_h^{\alpha_h} w_l^{1-\alpha_h})^{1-\gamma}}{r^{\gamma}(w_h^{\alpha_l} w_l^{1-\alpha_l})^{1-\gamma}} = \omega^{(1-\gamma)(\alpha_h - \alpha_l)}. \tag{23}$$

[26] Prices are a markup over marginal cost, and we have again used the normalization $c_i = \left(1 - \frac{1}{\sigma_i}\right)$.

Free-entry and the choice of units such that $F_i = 1/\sigma_i$ fix the scale of production of each variety to one: $y_i = 1$. Equations (2), (9) and (10) are unchanged; together with (23) they imply:

$$n_h^{\frac{\sigma_h-\epsilon}{\epsilon(\sigma_h-1)}}\omega^{(1-\gamma)(\alpha_h-\alpha_l)} = n_l^{\frac{\sigma_l-\epsilon}{\epsilon(\sigma_l-1)}}. \tag{24}$$

The demand for each factor can be found using Shephard's lemma on the total cost function (22). After setting w_l as the numeraire, the conditions for full employment of capital, skilled and unskilled workers become:

$$\begin{aligned} K &= \gamma r^{\gamma-1}\omega^{(1-\gamma)\alpha_h}n_h + \gamma r^{\gamma-1}\omega^{(1-\gamma)\alpha_l}n_l \\ H &= (1-\gamma)\alpha_h r^{\gamma}\omega^{(1-\gamma)\alpha_h-1}n_h + (1-\gamma)\alpha_l r^{\gamma}\omega^{(1-\gamma)\alpha_l-1}n_l \\ L &= (1-\gamma)(1-\alpha_h)r^{\gamma}\omega^{(1-\gamma)\alpha_h}n_h + (1-\gamma)(1-\alpha_l)r^{\gamma}\omega^{(1-\gamma)\alpha_l}n_l. \end{aligned}$$

Solving for n_h and n_l gives:

$$\begin{aligned} n_i &= \frac{(1-\alpha_j)H\omega - \alpha_j L}{(1-\gamma)(\alpha_i-\alpha_j)\omega^{\alpha_i(1-\gamma)}}\left(\frac{\gamma}{1-\gamma}\frac{L+H\omega}{K}\right)^{-\gamma} \\ &= \frac{\overline{L}^{1-\gamma}K^{\gamma}\left[(1-\alpha_j)\theta\omega - \alpha_j(1-\theta)\right](1-\theta+\theta\omega)^{-\gamma}}{(1-\gamma)^{1-\gamma}\gamma^{\gamma}(\alpha_i-\alpha_j)\omega^{\alpha_i(1-\gamma)}}, \end{aligned}$$

for $i, j = l, h$, $i \neq j$, $\overline{L} = H + L$ and $\theta = H/\overline{L}$. Simple derivation yields:

$$\frac{\partial n_h}{\partial \omega} > 0, \frac{\partial n_l}{\partial \omega} < 0, \frac{\partial n_h}{\partial \theta} > 0, \frac{\partial n_l}{\partial \theta} < 0. \tag{25}$$

These partial derivatives come from the production side of the economy. They imply that the higher the supply of one factor, the larger the size of the sector which uses that factor intensively, and that the larger the size of one sector, the higher the relative reward for the factor which is used intensively in that sector. Using the expressions for n_h and n_l in (24) and differentiating it with respect to θ, K and $\overline{L}$, we find the elasticity of the skill premium:

$$\frac{d\omega}{\omega} = \frac{\frac{(\epsilon-1)(\sigma_l-\sigma_h)}{(\sigma_h-1)(\sigma_l-1)}\left[\gamma\frac{dK}{K} + (1-\gamma)\frac{d\overline{L}}{\overline{L}}\right] - \left(\frac{\sigma_h-\epsilon}{\sigma_h-1}\frac{\partial n_h}{\partial\theta}\frac{\theta}{n_h} - \frac{\sigma_l-\epsilon}{\sigma_l-1}\frac{\partial n_l}{\partial\theta}\frac{\theta}{n_l}\right)\frac{d\theta}{\theta}}{(1-\gamma)(\alpha_h-\alpha_l)\epsilon + \frac{\sigma_h-\epsilon}{\sigma_h-1}\frac{\partial n_h}{\partial\omega}\frac{\omega}{n_h} - \frac{\sigma_l-\epsilon}{\sigma_l-1}\frac{\partial n_l}{\partial\omega}\frac{\omega}{n_l}}.$$

Given the inequalities in (25) and our assumption $1 < \epsilon < \sigma_h < \sigma_l$, it can be seen that the skill premium is increasing in the scale and decreasing in the share of skilled workers. Equations (14) and (20) are all special cases of this formula.

Finally, it is possible to show that the elasticity of substitution between skilled and unskilled workers (holding the other variables constant) is given by:

$$\varepsilon_w = -\frac{d(H/L)}{d\omega}\frac{\omega}{H/L}\bigg|_{n_h,n_l,K_h,K_l} = \frac{(\alpha_h - \alpha_l)(\epsilon - 1)}{\left(\frac{\alpha_h}{1-\alpha_h}\frac{L}{H\omega} - 1\right)^{-1} + \left(1 - \frac{\alpha_l}{1-\alpha_l}\frac{L}{H\omega}\right)^{-1}} + 1.$$

Rearranging, we can write the elasticity of substitution in consumption (ϵ) as a function of the elasticity of substitution in production (ε_w):

$$\epsilon = 1 + \frac{(\varepsilon_w - 1)}{\alpha_h - \alpha_l}\left[\left(\frac{\alpha_h}{1-\alpha_h}\frac{L}{H\omega} - 1\right)^{-1} + \left(1 - \frac{\alpha_l}{1-\alpha_l}\frac{L}{H\omega}\right)^{-1}\right].$$

Note that $\varepsilon_w > 1$ implies $\epsilon > 1$ and that $\varepsilon_w = \epsilon$ if $\alpha_h = 1$ and $\alpha_l = 0$, as in the model with extreme factor intensities in the main text.

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