Capital-Skill Complementarity and the Skill Premium in a Quantitative Model of Trade

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Abstract

The skill premium has risen in many countries over the last 20 years. This increase could be a result of skill-biased technological change. It might also be the result of the standard Stolper-Samuelson effect, which would raise the skill premium in some countries and reduce it in others. Still a third possibility is that a decline in trade costs fosters increasing trade in capital goods, raising the productivity of skilled relative to unskilled workers. I call this mechanism skill-biased trade. I construct a multi-country model of international trade with capital-skill complementarity that admits all these possibilities and estimate it over the period 1990-2007. The impact of skill-biased trade is much larger than that of Stolper-Samuelson effects, and comparable to the effect of skill-biased technical change, especially in developing countries. Reduction in trade costs explains approximately half of the predicted increase in the skill premium and decline in the relative price of capital goods in developing countries, while explaining approximately one-third of that in developed countries. Regarding welfare gains from trade, I empirically show that both skilled and unskilled labor gain from trade. I also find that capital-skill complementarity induces a positive relationship between the change in welfare and income inequality in open economy.

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1 Introduction

The skill premium, defined as the wage of skilled labor relative to that of unskilled labor, has increased across a broad set of developed and developing countries during the last two decades.[1] A large literature has focused on two distinct hypotheses for what has driven this trend: trade and skill-biased technical change, the latter being the most prominent explanation.[2] Even though there is not a consensus about an explicit economic mechanism for interpreting skill-biased technical change, many studies support the idea that technology is embodied in capital goods, and therefore the technical change of the last thirty years is reflected in a worldwide decline in the relative price of capital goods, as observed in Figure 1.[3] If capital substitutes more for unskilled than for skilled labor (Griliches, 1969), then this decrease in the relative price of capital goods increases the relative demand for skilled labor, and raises the skill premium across countries.

In this paper, I also deal with technology embodied in capital-goods, but I additionally consider that capital goods are traded across countries.[4] As a consequence, a technical change is not the only reason for a decline in the price of capital goods. A reduction in trade costs also decreases the price, fostering increasing trade in capital goods, and raising the productivity of skilled relative to unskilled workers because of capital-skill complementarity. I call this mechanism skill-biased trade. As a result, both trade and technical change are skill-biased, and both could potentially induce an increase in the skill premium across countries. I embed these two forces into a multi-country and multi-sector general equilibrium model of international trade, where the standard Stolper-Samuelson effect is also operating, and quantify the contribution of each of these forces to the increase in the skill premium. The model also delivers new evidence on the effect of trade on welfare in presence of capital-skill complementarity, as described below.

Since sectors and countries are interrelated in the World, I also consider the effect on the

[1] Table 1 reports the percentage change in the skill premium in 26 developed and developing countries during the last two decades. The skill premium has increased in most of these countries, and the increase has been especially prominent in developing countries.

[2] Predictions of traditional trade models are at odds with the empirical evidence in several aspects. The Stolper-Samuelson theorem predicts, for instance, a decrease in the skill premium in unskilled-labor-abundant countries, between-industry labor reallocation and an increase in the price of skilled-labor-intensive goods in developed countries after trade liberalization. Goldberg and Pavcnik (2007) show that these predictions fail in the data for several developing countries. Katz and Murphy (1992), among others, find a very small Stolper-Samuelson effect in developed countries such as the United States, and Lawrence and Slaughter (1993) find a decline in the relative price of skill-intensive goods in the United States during the 1980s.

[3] Hornstein et al. (2005) present an extensive review of literature with evidence on the idea of capital-embodied technical change.

[4] As of 2007, trade in capital goods represented around 30% of total World trade. Eaton and Kortum (2001) show that only a few developed countries are large producers of capital goods, and most countries import a large fraction of their domestic expenditure in capital goods.

skill premium coming from these interactions. For instance, if there is a bilateral tariff reduction between China and the United States, the United States can import cheaper intermediate goods from China and thus can be more efficient in producing capital goods. Therefore, a third country—say, Mexico—can import cheaper capital goods from the United States, which could increase the relative demand for skilled labor and the skill premium in Mexico. Also, if there is a technological improvement in the capital goods sector in Japan, it will affect the relative price of capital goods in Japan, so that a trading partner—say, Chile—can import cheaper capital goods from Japan, which could increase the relative demand for skilled labor, and hence the skill premium, in Chile.

The model builds on the multi-sector version of Eaton and Kortum (2002) developed in Caliendo and Parro (2011). The new elements are the introduction of two types of labor, skilled and unskilled, and trade in capital goods, with capital-skill complementarity as in Krusell et al. (2000).[5] The model is static; thus, capital goods are simply treated like intermediate goods.[6] I calibrate the model to the year 1990 for a set of developed and developing countries, and a constructed "Rest of the World". I then estimate the change in bilateral trade costs and the change in technology in the capital goods sector for the period 1990-2007. As explained later on, I use the implied gravity equation in the model to separate changes in trade costs from changes in technologies. Using the estimated parameters and introducing the change in trade costs, I use the model to calculate the implied change in the skill premium across countries purely due to reductions in trade costs. Similarly, using the estimated change in technology in the capital goods sector, I quantify the effect of this technical change on the skill premium.

Without capital-skill complementarity—that is, when only the standard Stolper-Samuelson effect is operating in the model—the effect of trade on the skill premium is very close to zero in almost all countries. With capital-skill complementarity, I find that the impact of skill-biased trade is much larger than that of the Stolper-Samuelson effect, the magnitude being larger in developing countries. In most countries, the skill-biased trade effect is of a similar magnitude to the effect of skill-biased technical change. Reduction in trade costs explains approximately half of the predicted increase in the skill premium and decline in the relative price of capital goods in developing

[5] Griliches (1969) was the first to formalize the idea of capital-skill complementarity. More recently, Stokey (1996) introduces capital-skill complementarity in a one-sector, two-country, neoclassical growth model to study the effect of trade integration on the skill premium. Krusell et al. (2000) calibrate a quantitative-closed-economy neoclassical growth model to study the role of capital-skill complementarity in order to explain the skill premium in the United States in the last thirty years. Autor et al. (1998) show micro-evidence on the effect of computerization on the relative demand for skilled labor.

[6] This treatment assumes full depreciation of capital goods during the period of analysis. The introduction of dynamics into the model and, specifically, capital accumulation over time, is left for a future work.

countries, while explaining approximately one-third of that in developed countries.

I also separate the effect of a technical change into two different effects: the impact of a domestic technical change and the impact of a foreign technical change that is transmitted through trade. I find that the first is much more important than the second.

The model also delivers new evidence on the welfare gains from trade in presence of capital-skill complementarity. Recent general equilibrium models that quantify welfare gains from trade only consider homogeneous labor, and thus cannot evaluate which types of workers gain and lose from trade.[7] At the theoretical level, the Stolper-Samuelson theorem predicts that the real wages of skilled and unskilled labor move in opposite directions after trade liberalization, while with trade in intermediate goods this result turns out to be ambiguous.[8] I empirically show that trade induces an increase in the real wages of both skilled and unskilled labor in all countries in the sample. This result holds both with and without the presence of capital-skill complementarity. The model also provides new evidence on the relationship between welfare and inequality in an open economy. Since a decline in the price of intermediate and capital goods contributes to an increase in welfare and, through capital-skill complementarity, to an increase in the skill premium, there is an inherent positive association between gains from trade and the effect of trade on income inequality, which is not present in a model without capital-skill complementarity, as we will see later on.

This paper is related to several strands of the literature that have studied the relationship between trade, skill-biased technical change and the skill premium. A large literature has used the change in the factor content of trade to quantify the effect of trade on the skill premium (Borjas et al., 1997; Katz and Murphy, 1992; Berman et al., 1994).[9] These papers tend to assign a small role to trade in affecting the skill premium, the residually measured skill-biased technical change being considered the main explanation. My paper departs from this literature in three important aspects. First, I add a skill-biased trade effect to the traditional Stolper-Samuelson effect. Second, skill-biased technical change is not simply measured as a residual. Third, I consider a quantitative general equilibrium model of international trade.

A more recent literature explores the impact of international trade on the relative demand

[7] Arkolakis et. al (2011) describe the implications of trade for welfare in a wide class of trade models with homogeneous labor.

[8] See Feenstra (2004), Chapter 4, for a theoretical example.

[9] Deardorff and Staiger (1988) show that, under the standard assumptions of the Heckscher-Ohlin model, the factor content of trade is a sufficient statistic to quantify the effect of trade on the skill premium. Deardorff (2000) extends this result to the case when all production functions take the CES form with identical elasticity of substitution among inputs. Burstein and Vogel (2011) generalize this result for the case of productivity heterogeneity, endogenous selection of firms into export markets, and endogenous firm entry.

for skilled labor through different mechanisms. Matsuyama (2007) assumes that exporting is a skill-biased activity; Verhoogen (2008) studies the change in the demand for skilled labor within industry when exporters produce higher-quality goods, and they pay higher wages to maintain a higher-quality workforce; Bustos (2011) explores how exporters are better able to adopt skill-intensive technologies; Helpman et al. (2010) introduce labor market frictions in a model where exporters increase their revenue after trade liberalization, which enhances their incentive to screen workers in order to have workforces of higher average ability and, as a result, they pay higher wages. Burstein and Vogel (2010) study the effect of trade and multinational production on the skill premium considering within- and between-industry reallocation in an Eaton and Kortum (2002)-type model calibrated to the U.S. data. The role of outsourcing is explored in Feenstra and Hanson (1997). Although complementary with my paper, none of these papers quantify the effect of trade and technical change on the skill premium in presence of capital-skill complementarity. Also, the fact that I construct a quantitative general equilibrium model calibrated to many countries provides an additional contribution to these previous papers.[10]

More closely related are the papers of Koren and Csillag (2011), who study the impact of imported machines on wages, using firm-level data; and Burstein et al. (2011), who, in parallel work, use a similar model to derive a sufficient statistic to estimate the effect of change in trade patterns on the skill premium. Different from these papers, I construct a quantitative model of trade where I separate the effect of a reduction of trade costs from the effect of a technical change and from the traditional Stolper-Samuelson effect. I also consider the general equilibrium effects coming from the interactions across sectors and countries.[11]

The rest of the paper is organized as follows: Section 2 develops the quantitative model to quantify the effects of trade and skill-biased technical change on the skill premium, and Section 3 explains how to calibrate the model, describes the data needed to perform the counterfactual exercises, and analyzes the empirical results. Section 4 concludes.

[10] Other theoretical papers that explore the relationship between trade, technology, and inequality are those of Acemoglu (2003), who develops a model of trade-induced technical change; Yeaple (2005), who studies the role of technology upgrading across firms; Garicano and Rossi-Hansberg (2006), who study the effect of a decrease in the cost of communication on the organization of firms and inequality; and Monte (2011), who explores the role of trade and technical change in the distribution of wages in the United States in a model with heterogeneous firms and workers.

[11] As shown later on, I also calibrate the model considering different factor intensities across sectors and countries.

2 A Quantitative Model of Skill-Biased Trade

In this section I develop a quantitative model with trade in capital goods and capital-skill complementarity. I first describe technology, endowments, and preferences, and then derive price equations and the gravity equation to finally define the general equilibrium. Appendix A describes in detail the derivation of the main equations of the model.

2.1 Endowments, Technology, and Preferences

Consider a world of I countries. I denote the source country by i and the destination country by n. Each country i is endowed with S_i units of skilled labor and U_i units of unskilled labor. There are three sectors in the economy indexed by $j \in J$, $J = \{K, M, NT\}$. Here K represents capital goods, M represents other tradable goods, which include non-capital manufacturing tradables and non-manufacturing tradables, and NT represents non-tradable goods. Households have Cobb-Douglas preferences, and the share of income spent in sector j and country i is given by α_i^j, with $\sum_{j \in J} \alpha_i^j = 1$.

Within each sector j a continuum of differentiated goods $\omega^j \in [0, 1]$ is produced. Let $q_i\left(\omega^j\right)$ be the production of good ω^j in country i. Each good ω^j is produced using skilled labor, unskilled labor, intermediate goods from sectors M and NT, and capital goods from sector K. Let $S_i\left(\omega^j\right)$ and $U_i\left(\omega^j\right)$ be the amounts of skilled and unskilled labor, respectively, used to produce good ω^j in country i. The amount of intermediate goods from sector $l \in \{M, NT\}$ used to produce good ω^j is given by $z_i^l\left(\omega^j\right)$, and the amount of capital goods used to produce ω^j is $z_i^K\left(\omega^j\right)$.

I introduce capital-skill complementarity in the production function of good ω^j by allowing the elasticity of substitution between capital goods and unskilled labor to be larger than that between capital goods and skilled labor. Specifically, capital goods and skilled labor are combined in a CES function with an elasticity of substitution given by ρ, and a share parameter δ_i^j :

$$h_i\left(\omega^j\right) = \left[\left[\delta_i^j\right]^{\frac{1}{\rho}} \left[z_i^K\left(\omega^j\right)\right]^{\frac{\rho-1}{\rho}} + \left[1 - \delta_i^j\right]^{\frac{1}{\rho}} \left[S_i\left(\omega^j\right)\right]^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}.$$

The output $h_i\left(\omega^j\right)$ of this CES function is then combined with unskilled labor in another CES function, with an elasticity of substitution equal to σ, and a share parameter μ_i^j :

$$v_i\left(\omega^j\right) = \left[\left[\mu_i^j\right]^{\frac{1}{\sigma}} \left[U_i\left(\omega^j\right)\right]^{\frac{\sigma-1}{\sigma}} + \left[1 - \mu_i^j\right]^{\frac{1}{\sigma}} \left[h_i\left(\omega^j\right)\right]^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}.$$

I denote by $v_i\left(\omega^j\right)$ the output of this CES function, which is combined with the remaining inputs (other tradable and non-tradable intermediate inputs) using a Cobb-Douglas aggregator:[12]

$$q_i\left(\omega^j\right) = \left[x_i^j\right]^{-\theta^j}\left[z_i^{NT}\left(\omega^j\right)\right]^{\gamma_i^{NT,j}}\left[z_i^{M}\left(\omega^j\right)\right]^{\gamma_i^{M,j}}\left[v_i\left(\omega^j\right)\right]^{1-\gamma_i^{M,j}-\gamma_i^{NT,j}}. \tag{1}$$

Notice that if $\sigma > \rho$, the production function of good ω^j exhibits capital-skill complementarity. The share of sector $l \in J$ goods used in the production of good ω^j is given by $\gamma_i^{l,j}$. The variable x_i^j represents the inverse of the TFP level in the production function of ω^j, and the parameter θ^j measures the dispersion of productivity in sector j, which is allowed to be sector specific.

2.2 Prices and Trade Costs

In tradable sectors, trade is at a cost. Specifically, there exist two types of trade costs. First, there is an iceberg trade cost as in Dornbusch et al. (1977). To ship one unit of a sector j good from country i to country n, $d_{ni}^j \geq 1$ units must be produced. I assume that $d_{nn}^j = 1$ for all $n \in \{1,..I\}$. Also, I assume that the triangular inequality holds $\left(d_{nl}^j d_{li}^j > d_{ni}^j \text{ for all } n,l,i \in \{1,..I\}\right)$. I also assume that in the non-tradable sector $d_{ni}^{NT} = \infty$ for all i,n. Second, there is an ad valorem flat-rate tariff τ_{ni}^j applied by country n to goods in sector j imported from country i. Revenues from tariffs are lump-sum transferred to the consumers in country n. I define $\kappa_{ni}^j = d_{ni}^j\left(1+\tau_{ni}^j\right)$ as the total trade cost of shipping one unit of sector j goods from country i to country n.

The cost of a bundle of inputs in sector j and country i is given by:

$$c_i^j = B_i^j\left[p_i^M\right]^{\gamma_i^{M,j}}\left[p_i^{NT}\right]^{\gamma_i^{NT,j}}\left[p_i^{v,j}\right]^{1-\gamma_i^{M,j}-\gamma_i^{NT,j}}, \tag{2}$$

with

$$\begin{aligned} p_i^{v,j} &= \left[\mu_i^j\left[w_i^U\right]^{1-\sigma} + \left[1-\mu_i^j\right]\left[p_i^{h,j}\right]^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \\ p_i^{h,j} &= \left[\delta_i^j\left[p_i^K\right]^{1-\rho} + \left[1-\delta_i^j\right]\left[w_i^S\right]^{1-\rho}\right]^{\frac{1}{1-\rho}}, \end{aligned}$$

[12] Notice that, following Krusell et al. (2000), I am restricting the elasticity of substitution between unskilled labor and skilled labor to be the same as that between unskilled labor and capital goods. An alternative is to restrict the elasticity of substitution between capital goods and skilled labor to be the same as that between skilled labor and unskilled labor. Krusell et al. (2000) explain that this restriction is inconsistent with estimates that suggest that the elasticity of substitution between skilled labor and unskilled labor is higher than that between skilled labor and capital goods as shown in Hamermesh (1993).

and B_i^j is a constant.[13]

There is free entry; thus, firms price at unit cost. The price of good ω^j imported from country i by country n is given by:

$$p_{ni}\left(\omega^j\right) = \left[x_i^j\right]^{\theta^j} c_i^j \kappa_{ni}^j.$$

Each country n purchases good ω^j from the lowest-cost source; therefore, the effective price of this good in country n is:

$$p_n\left(\omega^j\right) = \min_i \left\{p_{ni}\left(\omega^j\right)\right\}.$$

Notice that in the non-tradable sector we have that $p_n\left(\omega^{NT}\right) = p_{nn}\left(\omega^{NT}\right)$.

Following Eaton and Kortum (2002), I adopt a probabilistic representation of technologies. The fraction of goods in sector j for which country i's efficiency is below $x \geq 0$ is given by the cumulative distribution function of an exponential distribution with parameter λ_i^j. The parameter λ_i^j determines the location of the distribution, and thus can be related to the sector-specific total factor productivity. This variable will represent the state of technology in sector j and country i. For instance, a technical change in the capital goods sector is represented as a change in λ_i^K. I assume that the distribution of productivities is independent across goods, sectors, and countries; thus, the joint density of x^j is given by $\phi^j\left(x^j\right) = \left[\prod_{i=1}^I \lambda_i^j\right] \exp\left[-\sum_{i=1}^I \lambda_i^j x_i^j\right]$.

I assume that goods within each sector j are aggregated as in Ethier (1982), with an elasticity of substitution η^j. Solving for the distribution of prices of goods in sector j, and then integrating over all prices, we can get an expression for the price index in each sector j and country n as a function of the cost of inputs, trade frictions and technology:

$$p_n^j = A^j \left[\sum_{i=1}^I \left[c_i^j \kappa_{ni}^j\right]^{-1/\theta^j} \lambda_i^j\right]^{-\theta^j}, \tag{3}$$

where A^j is a constant.[14] Notice how this equation captures the interaction across sectors and countries. For instance, assume that $j = K$. According to equation (2), a decline in the price of other tradable goods in any country i (change in p_i^M) affects the cost of producing capital goods in country i because sectors are interrelated. Moreover, a decline in the cost of producing capital goods in country i impacts the price of capital goods in any country $n \neq i$ (see equation 3). Therefore, this equation captures, for instance, the effect of a decline in the price of manufacturing goods in

[13] $B_i^j = (\gamma_i^{M,j})^{-\gamma_i^{M,j}} (\gamma_i^{NT,j})^{-\gamma_i^{NT,j}} (1-\gamma_i^{M,j}-\gamma_i^{NT,j})^{-\left(1-\gamma_i^{M,j}-\gamma_i^{NT,j}\right)}$

[14] Specifically, $A^j = \left[\int_0^\infty e^{-y^j}\left(y^j\right)^{\theta^j\left(1-\eta^j\right)} dy^j\right]^{\frac{1}{1-\eta^j}}$, where the integral is a Gamma function.

China on the price of capital goods in Mexico.

In the non-tradable sector we have $p_n^{NT} = A^{NT} c_n^{NT} [\lambda_n^{NT}]^{-\theta^j}$ by imposing $d_{ni}^{NT} = \infty$. Therefore, the price of non-tradable goods only reflects the domestic cost of producing.

2.3 Gravity Equation

Let X_{ni}^j be imports of sector j goods by country n from country i, and let $X_n^j = \sum_{i=1}^I X_{ni}^j$ be total expenditure in country n and sector j. Define π_{ni}^j as the imports of sector j goods by country n from country i expressed as a share of total expenditure in country n. Integrating over the set of goods in which country i is the lowest-cost supplier, I can solve for bilateral trade shares in each country n and sector j as a function of cost of inputs, prices, trade frictions and technology:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \left[A^j\right]^{\frac{-1}{\theta^j}} \left[\frac{c_i^j \kappa_{ni}^j}{p_n^j}\right]^{-1/\theta^j} \lambda_i^j. \tag{4}$$

This is the gravity equation that my model delivers. It adopts a similar functional form to those in other trade models such as Armington (1969), Krugman (1981), Eaton and Kortum (2002), Anderson and van Wincoop (2003), Melitz (2003), Chaney (2008), and the models considered in Arkolakis et al. (2011). The difference comes from the specification of the cost of the input bundle c_i^j. Unlike in the mentioned models, the cost of the input bundle considers heterogeneous labor, capital-skill complementarity, and the input-output structure of the economy.

2.4 Market Clearing Conditions and Equilibrium

I assume that labor is perfectly mobile across sectors but not across countries. Therefore, the labor market clearing condition is given by:[15]

$$w_i^S S_i = \sum_{j \in J} \gamma_i^{S,j} Y_i^j, \tag{5}$$

[15] I only describe the skilled-labor market clearing condition because in order to solve for the equilibrium I will use this condition and the trade balance condition. By Walras' law, if these two markets clear, then the unskilled-labor market also clears.

where Y_i^j is gross production in sector j, country i, measured in U.S. dollars. The wage of skilled labor in country i is w_i^S, and $\gamma_i^{S,j}$ represents the share of skilled labor in sector j.[16]

The goods market clearing condition is given by:

$$Y_i^j = \sum_{n=1}^{I} \frac{\pi_{ni}^j}{1+\tau_{ni}^j} X_n^j, \tag{6}$$

where X_n^j is total expenditure in country n and sector j. This condition states that gross production in country i and sector j has to be equal to the sum of total exports and domestic sales, net of tariffs.

Total expenditure in country n and sector j, X_n^j, is given by:

$$X_n^j = \alpha_n^j I_n + \sum_{l \in J} \gamma_n^{j,l} Y_n^l \quad \text{for} \quad j, l \in J, \tag{7}$$

where I_n is total income in country n, which is defined as $I_n = w_n^S S_n + w_n^U U_n + D_n + \sum_{j \in J} X_n^j (1 - \sum_{i=1}^{I} \frac{\pi_{ni}^j}{1+\tau_{ni}^j})$, where $w_n^S S_n + w_n^U U_n$ is labor income, D_n is aggregate trade deficit in country n, and $\sum_{j \in J} X_n^j (1 - \sum_{i=1}^{I} \frac{\pi_{ni}^j}{1+\tau_{ni}^j})$ are tariff revenues. The share of input l in sector j is $\gamma_1^{j,l}$. Hence, total expenditure in country n and sector j is the sum of the share of sector j in final demand and intermediate demand from all sectors.

The trade balance condition is given by:

$$\sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{in}^j}{1+\tau_{in}^j} X_i^j - D_i = \sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{ni}^j}{1+\tau_{ni}^j} X_n^j. \tag{8}$$

The left-hand side of this equation represents total imports net of tariffs minus the aggregate deficit in country i. The right-hand side is total exports, net of tariffs, in country i. I add domestic sales in sector j and country i to both sides of the trade balance.

The equilibrium in this model is defined as follows:

Given the aggregate deficit D_i, the skilled and unsilled labor endowments S_i and U_i, iceberg trade costs d_{ni}^j, tariffs τ_{ni}^j, technologies λ_i^j, dispersion of productivities θ^j, share parameters $\gamma^{S,j}$, $\gamma^{U,j}$, and $\gamma_i^{l,j}$ for each country $i, n \in \{1, ...I\}$ and sector $j, l \in J$, an equilibrium is a set of wages

[16] This share depends on the price of capital goods and the wages of skilled labor and unskilled labor, specifically: $\gamma_i^{S,j} = \left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right] \left[\left[\frac{\mu_i^j}{1-\mu_i^j}\right] \left[\frac{p_i^{h,j}}{w_i^U}\right]^{\sigma-1} + 1\right]^{-1} \left[\left[\frac{\delta_i^j}{1-\delta_i^j}\right] \left[\frac{w_i^S}{p_i^K}\right]^{\rho-1} + 1\right]^{-1}$

$\{w_i^S, w_i^U\}_{i\in\{1,...I\}}$ and a set of prices $\{p_i^j\}_{i\in\{1,..I\}}^{j\in J}$ that solve (2), (3), (4), (5), (6), (7), and (8).

2.5 Expressing the Model in Relative Changes

Following Dekle et al. (2008), I express the model in relative changes.[17] Let x' be the counterfactual value of variable x, and $\widehat{x}$ be the relative change $\frac{x'}{x}$. The equilibrium conditions in relative changes are expressed as follows:

The price equation (3) becomes:

$$\widehat{p}_n^j = \left[\sum_{i=1}^{I} \pi_{ni}^j \left[\widehat{c}_i^j \widehat{\kappa}_{ni}^j\right]^{-1/\theta^j} \widehat{\lambda}_i^j\right]^{-\theta^j}. \tag{9}$$

The cost of input bundles in relative changes is given by:

$$\widehat{c}_i^j = \left[\widehat{p}_i^M\right]^{\gamma_i^{M,j}} \left[\widehat{p}_i^{NT}\right]^{\gamma_i^{NT,j}} \left[\widehat{p}_i^{v,j}\right]^{\left(1-\gamma_i^{M,j}-\gamma_i^{NT,j}\right)}, \tag{10}$$

with

$$\begin{aligned}
\widehat{p}_i^{v,j} &= \left[1-\gamma_i^{M,j}-\gamma_i^{NT,j}\right]^{\frac{-1}{1-\sigma}} \left[\gamma_i^{U,j}\left[\widehat{w}_i^U\right]^{1-\sigma} + \left[\gamma_i^{S,j}+\gamma_i^{K,j}\right]\left[\widehat{p}_i^{h,j}\right]^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \\
\widehat{p}_i^{h,j} &= \left[\gamma_i^{S,j}+\gamma_i^{K,j}\right]^{\frac{-1}{1-\rho}} \left[\gamma_i^{K,j}\left[\widehat{p}_i^K\right]^{1-\rho} + \gamma_i^{S,j}\left[\widehat{w}_i^S\right]^{1-\rho}\right]^{\frac{1}{1-\rho}},
\end{aligned}$$

and $\gamma_i^{S,j}$, $\gamma_i^{U,j}$ and $\gamma_i^{K,j}$ represent the share of skilled and unskilled labor and the share of capital goods in sector j and country i at the initial year.

The gravity equation in relative changes takes the form:

$$\widehat{\pi}_{ni}^j = \left[\frac{\widehat{c}_i^j \widehat{\kappa}_{ni}^j}{\widehat{p}_n^j}\right]^{-1/\theta^j} \widehat{\lambda}_i^j. \tag{11}$$

The labor market clearing condition combined with the goods market clearing condition becomes:

$$w_i^S S_i \widehat{w}_i^S = \sum_{j\in J} \gamma_i^{S,j\prime} \sum_{n=1}^{I} \frac{\pi_{ni}^{j\prime}}{1+\tau_{ni}^{j\prime}} X_n^{j\prime}, \tag{12}$$

[17] This is convenient in order not to have to calibrate exogenous variables that are constants in the model.

$$X_n^{j'} = \alpha_n^j I_n' + \sum_{l \in J} \gamma_n^{j,l'} \sum_{i=1}^{I} \frac{\pi_{in}^{l'}}{1 + \tau_{in}^{l'}} X_i^{l'} \qquad j, l \in J, \tag{13}$$

with $I_n' = \widehat{w}_n^S w_n^S S_n + \widehat{w}_n^U w_n^U U_n + D_n + \sum_{j \in J} X_n^{j'} [1 - \sum_{i=1}^{I} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}}]$. The production function with capital-skill complementarity described by equation (1) implies that the shares of skilled and unskilled labor and the share of capital goods in sector j's gross output are not constant; they depend on the change in prices and wages, and the input shares at the initial year. Specifically, we have:

$$\gamma_n^{S,j\prime} = \left[1 - \gamma_n^{M,j} - \gamma_n^{NT,j}\right] \left[1 + \frac{\gamma_n^{U,j}}{\gamma_n^{S,j} + \gamma_n^{K,j}} \left[\frac{\widehat{p}_n^{h,j}}{\widehat{w}_n^U}\right]^{\sigma - 1}\right]^{-1} \left[1 + \frac{\gamma_n^{K,j}}{\gamma_n^{S,j}} \left[\frac{\widehat{w}_n^S}{\widehat{p}_n^K}\right]^{\rho - 1}\right]^{-1}, \tag{14}$$

$$\gamma_n^{U,j\prime} = \left[1 - \gamma_n^{NT,j} - \gamma_n^{M,j}\right] \left[1 + \frac{\gamma_n^{K,j} + \gamma_n^{S,j}}{\gamma_n^{U,j}} \left[\frac{\widehat{w}_n^U}{\widehat{p}_n^{h,j}}\right]^{\sigma - 1}\right]^{-1}, \tag{15}$$

and the share of capital goods in sector j in the counterfactual equilibrium can be recovered as: $\gamma_n^{K,j'} = 1 - \gamma_n^{M,j} - \gamma_n^{NT,j} - \gamma_n^{S,j'} - \gamma_n^{U,j'}$.

Finally, the trade balance condition in the counterfactual equilibrium is given by:

$$\sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{in}^{j\prime}}{1 + \tau_{in}^{j'}} X_i^{j\prime} - D_i = \sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{ni}^{j\prime}}{1 + \tau_{ni}^{j'}} X_n^{j\prime}. \tag{16}$$

2.6 Taking the Model to the Data

To solve for the counterfactual equilibrium, I first calibrate the model at the base year 1990. The parameters needed are the sectoral bilateral trade shares (π_{ni}^j), the shares of domestic sales in total expenditure in each sector (π_{nn}^j), the share of each input in gross production in each sector ($\gamma_i^{M,j}, \gamma_i^{K,j}, \gamma_i^{NT,j}, \gamma_i^{S,j}, \gamma_i^{U,j}$), the skilled and unskilled value added ($w_i^S S_i$, $w_i^U U_i$), the share of each sector in final demand (α_i^j), sectoral dispersion of productivities (θ^j), and the elasticities of substitution between skilled labor and capital goods (ρ) and between unskilled labor and capital goods (σ). These parameters and variables are obtained for each country $i, n \in \{1, ...I\}$, and sector $j \in J$. I collected these data for 27 developed and developing countries, and a constructed "rest of the world." Appendix B presents a detailed description of the sample of countries, data sources, and data construction.

To construct the bilateral trade shares (π_{ni}^j), I first use data on trade and production to calculate domestic sales (X_{nn}^j) in each sector as the difference between gross production and total exports.

Then I compute total expenditure in each sector and each country (X_n^j) as the sum of domestic sales and total imports. Finally, I construct the bilateral trade shares for each sector as the share of imports from each country in total expenditure ($\pi_{ni}^j = X_{ni}^j / X_n^j$), and I also construct the share of domestic sales in total expenditure ($\pi_{nn}^j = X_{nn}^j / X_n^j$). Aggregate skilled and unskilled value added ($w_i^S S_i$, $w_i^U U_i$) comes from the data, and using data on sectoral intermediate consumption, skilled and unskilled value added, and gross production, I compute the share of each input in gross production in each sector and country ($\gamma_i^{M,j}, \gamma_i^{K,j}, \gamma_i^{NT,j}, \gamma_i^{S,j}, \gamma_i^{U,j}$). Appendix C shows an example of the heterogeneity of the inputs shares across sectors and countries.

My measure of skilled versus unskilled labor is a classification into non-production and production workers. Berman et al. (1998) show that non-production workers have higher educational attainment than production workers; thus, this method is very similar to using educational achievement as a proxy for skill. The main advantage of my measure is its availability at the industry level.[18]

The share of each sector in final demand is calculated from the model as $\alpha_i^j = \frac{1}{X_i}[X_i^j - \sum_{l \in J} \gamma_i^{j,l} Y_i^l]$ for $j, l \in J$. It is equal to total expenditure in sector j less intermediate demand from all sectors over total expenditure in country i. The discussion of the estimation of the sectoral dispersion of productivity will be postponed to the next section, where I describe the estimation of the change in trade costs. The elasticities of substitution between skilled labor and capital goods (ρ) and between unskilled labor and capital goods (σ) are obtained from Krusell et al. (2000).[19] Specifically, I set $\rho = 0.67$ and $\sigma = 1.67$; thus, capital goods substitute more for unskilled than for skilled labor.[20]

Having calibrated the model in 1990, the next subsection describes how the model is solved to perform counterfactual analysis.

2.7 Solving the Model

In this subsection, I sketch the algorithm used to solve for the counterfactual equilibrium, which is described in detail in Appendix D. The shocks I will introduce in the model are the relative

[18] Unfortunately, this measure is not available for the non-tradable sectors. Therefore, to construct the share of skilled and unskilled labor in that sector I followed the methodology proposed in Blum (2008), which consists of using wages and employment data across occupations in service sectors to obtain measures of the shares of production and non-production workers. See Appendix B for details.

[19] To estimate these elasticities, Krusell et al. (2000) use a simulated pseudo maximum likelihood estimation (SPMLE) algorithm to match three moments in the U.S. data: the share of labor in output, the ratio of earnings of skilled workers to unskilled workers, and the rate of return on structures investment.

[20] These elasticities of substitution are similar to those reported in the micro literature (Hamermesh, 1993).

change in the bilateral trade frictions ($\widehat{\kappa}^j_{ni}$) and the change in technology in the capital goods sector ($\widehat{\lambda}^K_i$) for the period 1990-2007. Depending on the counterfactual exercise, these shocks will be introduced together, individually, for all countries, or for individual countries. In any case, the model is solved as follows: First, I guess the change in the skilled and unskilled wages in each country $\{\widehat{w}^S_i, \widehat{w}^U_i\}_{i\in\{1,...I\}}$. Given the parameters calibrated to 1990, π^j_{ni}, π^j_{nn}, $\gamma^{M,j}_i$, $\gamma^{K,j}_i$, $\gamma^{NT,j}_i$, $\gamma^{S,j}_i$, $\gamma^{U,j}_i$, $w^S_i S_i$, $w^U_i U_i$, α^j_i, θ^j, ρ, σ, the change in trade frictions $\widehat{\kappa}^j_{ni}$, the change technology in the capital goods sector $\widehat{\lambda}^K_i$, and the initial guess of change in wages, I solve for prices in each sector and country $\widehat{p}^j_n$ using equation (9). Plugging this solution into (11), I obtain $\widehat{\pi}^j_{ni}$. Using the solution for prices and the guess of wages, I calculate the new shares of skilled and unskilled labor ($\gamma^{S,j'}_n$ and $\gamma^{U,j'}_n$) according to equations (14) and (15), and recover the share of capital goods in the counterfactual equilibrium as $\gamma^{K,j'}_n = 1 - \gamma^{M,j}_n - \gamma^{NT,j}_n - \gamma^{S,j'}_n - \gamma^{U,j'}_n$. Using the new shares, together with $\widehat{\pi}^j_{ni}$, the guess of wages, and bilateral tariff data for 2007 ($\tau^{j'}_{ni}$), I solve for total expenditure in each country and sector $X^{j'}_n$ according to equation (13). Substituting the solution for $\widehat{\pi}^j_{ni}$, $\gamma^{S'j}_i$, and $X^{j'}_n$, I solve for the change in the wage of skilled labor using the labor market clearing condition (12). Using the solution for the change in the wage of skilled labor, together with the solution for $\widehat{\pi}^j_{ni}$ and $X^{j'}_n$, and the initial guess of change in the wage of unskilled labor, I verify wether trade balance (16) holds. If not, I adjust the guess of $\widehat{w}^U_i$ and repeat the process until it does.

3 Empirical Analysis

I proceed by using the quantitative model presented in Section 2 to quantify the effects of trade and technical change on the skill premium across countries between 1990 and 2007. The goal is to quantify the effect of a change in trade costs on the skill premium, first, when only the Stolper-Samuelson effect is operating, and second, when I introduce the possibility of a skill-biased trade effect into the model. With this quantification, I will proceed to compare these magnitudes with the effect of a change in technology in the capital goods sector. Also, I will derive some implications for the welfare gains from the model. In the next subsection, I proceed to estimate the change in bilateral trade costs for the period 1990-2007.

3.1 Estimation of the Change in Trade Costs

This section describes the methodology used to estimate the change in bilateral trade costs between 1990 and 2007 across sectors and countries.

The relative change in bilateral trade costs is given by $\widehat{\kappa}^j_{ni} = \widehat{d}^j_{ni}\widehat{(1+\tau^j_{ni})}$, where $\widehat{d}^j_{ni}$ is the relative change in iceberg trade costs and $\widehat{(1+\tau^j_{ni})}$ is the relative change in tariffs applied in country n to sector j goods imported from country i. To compute the change in total trade costs, the goal is to estimate the unobservable part $\widehat{d}^j_{ni}$ and then use tariff data to recover $\widehat{\kappa}^j_{ni}$.

I start from the gravity equation in relative changes described by equation (11). Notice that when $n = i$, the change in domestic expenditure as a share of total expenditure in sector j is given by:

$$\widehat{\pi}^j_{ii} = \left[\frac{\widehat{c}^j_i}{\widehat{p}^j_i}\right]^{-1/\theta^j} \widehat{\lambda}^j_i \ . \tag{17}$$

According to equations (11) and (17), a change in technology in country i and sector j $(\widehat{\lambda}^j_i)$ impacts exports from country i to any trading partner, but also affects domestic expenditure in country i. Therefore, the ratio between the two equations is invariant to changes in technology in country i:

$$\frac{\widehat{\pi}^j_{ni}}{\widehat{\pi}^j_{ii}} = \left[\frac{\widehat{p}^j_i \widehat{\kappa}^j_{ni}}{\widehat{p}^j_n}\right]^{-1/\theta^j} \ . \tag{18}$$

Analogously, the bilateral trade share flow from country n to country i as a share of the domestic expenditure share in country n is invariant to changes in technology in country n.

$$\frac{\widehat{\pi}^j_{in}}{\widehat{\pi}^j_{nn}} = \left[\frac{\widehat{p}^j_n \widehat{\kappa}^j_{in}}{\widehat{p}^j_i}\right]^{-1/\theta^j} \ . \tag{19}$$

Taking the product between equations (18) and (19) we get:

$$\frac{\widehat{X}^j_{ni}\widehat{X}^j_{in}}{\widehat{X}^j_{ii}\widehat{X}^j_{nn}} = \left[\widehat{d}^j_{in}\widehat{(1+\tau^j_{in})}\widehat{d}^j_{ni}\widehat{(1+\tau^j_{ni})}\right]^{-1/\theta^j} \ .$$

This expression relates trade flows between country n and country i as a share of domestic absorptions in both countries, trade frictions, and the dispersion of productivity θ^j. It is invariant to changes in technology, prices and total expenditures in sector j. This statistic is similar to that in Head and Ries (2001); the only difference is that here it is augmented by tariffs.

I assume that controlling by tariffs, the remaining part of trade costs is symmetric.[21] Applying this property, I solve for the change in bilateral iceberg costs:

[21] Section 3.5 presents robustness checks, where I estimate bilateral trade costs in an alternative way.

$$\widehat{d}_{ni}^{j} = \left[\frac{\widehat{X}_{ni}^{j}\widehat{X}_{in}^{j}}{\widehat{X}_{ii}^{j}\widehat{X}_{nn}^{j}}\right]^{-\theta^{j}/2} \left[(\widehat{1+\tau_{in}^{j}})(\widehat{1+\tau_{ni}^{j}})\right]^{-1/2}. \tag{20}$$

This equation relates the change in iceberg trade costs to observable variables such as trade flows, domestic absorption and tariffs. The only parameter that we need to know in order to recover the bilateral iceberg trade costs is the dispersion of productivity θ^j.

To estimate θ^j, I follow the methodology proposed in Caliendo and Parro (2011). This methodology has two main advantages. First, it is consistent with any trade model that delivers a gravity equation of the form $\pi_{ni} = T_i \left[\frac{\kappa_{ni}c_i}{p_n}\right]^{-\theta}$. This is the case for a wide class of trade models such as those described in Arkolakis et al. (2011). As explained above, equation (4) shows that it is also the case for the model presented in this paper. Second, the estimation requires only information on tariffs; thus, I do not need information on the iceberg trade costs. These two advantages make the estimation internally consistent with the model presented in Section 2.

The basic idea of the methodology to estimate the dispersion of productivity in Caliendo and Parro (2011) is to start with the gravity equation (4). Then we take the product of sector j goods shipped between three countries in one direction, from country n to country i, from country i to country m, and from country m to country n; and the product of the same trade flows but in the opposite direction, from country n to country m, from country m to country i, and from country i to country n, The ratio between these two products is invariant to prices, costs, and technologies, and only depends on trade frictions and the dispersion of productivity in sector j:

$$\frac{X_{ni}^{j}X_{im}^{j}X_{mn}^{j}}{X_{nm}^{j}X_{mi}^{j}X_{in}^{j}} = \left[\frac{\kappa_{ni}^{j}\kappa_{im}^{j}\kappa_{mn}^{j}}{\kappa_{nm}^{j}\kappa_{mi}^{j}\kappa_{in}^{j}}\right]^{-1/\theta^{j}}.$$

Using our definition of κ_{ni}^{j}, assuming a remoteness deviation from symmetry in the iceberg trade costs ε_{ni}^{j} that is orthogonal to tariffs, and taking logs, we get:

$$\log\left(\frac{X_{ni}^{j}X_{im}^{j}X_{mn}^{j}}{X_{nm}^{j}X_{mi}^{j}X_{in}^{j}}\right) = -\frac{1}{\theta^{j}}\log\frac{(1+\tau_{ni}^{j})}{(1+\tau_{nm}^{j})}\frac{(1+\tau_{im}^{j})}{(1+\tau_{mi}^{j})}\frac{(1+\tau_{mn}^{j})}{(1+\tau_{in}^{j})} + \widetilde{\varepsilon}^{j} \quad \text{for } n,i,m \in \{1,..I\}. \tag{21}$$

To estimate the dispersion of productivities, I collect sectoral bilateral tariffs for the base year 1990 and then I run the above regression. Table 2 shows the estimated dispersion of productivity. The result of the estimation indicates that the dispersion of productivity for the capital goods sector

(θ^K) is 0.22 and for other tradables (θ^M) is 0.19.[22] Using these estimates, together with data on trade flows and domestic sales, I recover the change in iceberg trade costs using equation (20). Finally, I recover total trade costs as:

$$\widehat{\kappa}^j_{ni} = \widehat{d}^j_{ni}(\widehat{1+\tau^j_{ni}}).$$

Notice that total trade costs are asymmetric; only part of trade costs is assumed to be symmetric. This is consistent with research that finds asymmetric trade costs in the data.[23] To give an idea of the size of the change in bilateral trade costs, Figure 2 presents an histogram of the relative change in trade costs ($\widehat{\kappa}^j_{ni}$) between 1990 and 2007 in capital goods and other tradable sectors. We observe that the decline in trade costs has been larger for capital goods than for other tradables. On average, trade costs decrease by 24% ($\widehat{\kappa}^K_{ni} = 0.76$) in the capital goods sector and by 12% ($\widehat{\kappa}^M_{ni} = 0.88$) in other tradable sectors. The reduction in trade costs has been larger in developing than in developed countries. On average, trade costs have declined by 35% in the capital goods sectors and by 19% in other tradable goods in developing countries, while the corresponding reductions in trade costs have been 17% and 8% in developed countries.

Having estimated the change in trade costs for the period 1990-2007, I proceed in the next section to estimate the effect of this trade cost reduction on the skill premium across countries.

3.2 Estimation of the Effect of a Reduction of Trade Costs on the Skill Premium

In this section I estimate the effect of a reduction in trade costs on the skill premium across countries. To do so, I introduce the estimated change in bilateral trade costs, holding constant other exogenous variables, and solve (9), (10), (11), (12), (13), (14), (15) and (16). With this counterfactual exercise I determine how much the skill premium would have changed in each country if nothing but bilateral trade costs had changed in the World between 1990 and 2007.

3.2.1 The Stolper-Samuelson Effect

I start by estimating the effect of a reduction in bilateral trade costs on the skill premium when there is no capital-skill complementarity. To do so, I set the elasticity of substitution among all

[22] These values are in the range of the elasticities estimated in other papers. For instance, Caliendo and Parro (2011) estimate sectoral dispersion of productivities between 0.01 and 0.33, Eaton and Kortum (2002) estimate an aggregate trade cost elasticity between 0.08 and 0.28, Donaldson (2010) estimates a mean value of 0.19, Burstein and Vogel (2010) estimate an elasticity of 0.25, and Waugh and Simonovska (2010) find a value of 0.22.

[23] For instance, Waugh (2009) finds that asymmetric trade costs are consistent with gravity-type trade models and the cross-country variation in prices and trade volume observed in the data.

inputs equal to one (a "Cobb-Douglas" World). Without capital-skill complementarity, we are back in a traditional trade model where only the Stolper-Samuelson effect is operating. Deardorff and Staiger (1988), Deardorff (2000), and Burstein and Vogel (2011) show that in this type of model the change in the factor content of trade is the only force affecting the skill premium. The first column in Table 3 presents the results.[24] As we can see from the table, the magnitude of the Stolper-Samuelson effect is very close to zero in almost all countries; the skill premium slightly increases in some countries and decreases in others. This effect reflects a small amount of specialization across sectors after the reduction in trade costs.

This result qualitatively replicates the findings by Katz and Murphy (1992) and other studies (mainly for the United States) that quantify the effect of trade on the skill premium by calculating the change in the factor content of trade, and find a very small effect of trade on the skill premium. However, I generalize this conclusion by demonstrating that the magnitude of the Stolper-Samuelson effect is very small in general equilibrium and in a broad set of developed and developing countries.

Notice also that the sign of the effect in several countries is not the one expected from the original Stolper-Samuelson theorem. In particular, we would expect an increase in the skill premium in developed (skill-abundant) countries and a decrease in the skill premium in developing (skill-scarce) countries. However, the results in Table 3 are not very surprising since we are far from the assumptions of the Stolper-Samuelson theorem.[25] When this is the case, we do not expect a tight relationship between the skilled-labor endowment and the skill premium. For instance, China, an unskilled-labor-abundant country, became a large net exporter of capital goods between 1990 and 2007.

[24] Three countries in the sample present some peculiarities in the data when estimating the change in bilateral trade costs. In the Philippines, Thailand, and Chile in 2007 domestic expenditure in the capital goods sector is zero, and thus it is not possible to estimate the iceberg trade costs according to equation (20). Therefore, I aggregate Chile with Colombia, and the Philippines and Thailand with Malaysia in order to estimate bilateral trade costs in these combined countries. Dekle et al. (2008) follow the same approach in cases like this. They also discuss some possible explanations for these pecularities in the data.

[25] In particular, the multi-country and multi-sector (with a non-tradable sector) dimensions, the heterogeneity in technology, the heterogeneity in trade costs, the introduction of trade in intermediate and capital goods, unbalanced trade and the fact that the initial year is not an autarky point are some of the departures from the assumptions in the original Stolper-Samuelson theorem. Davis and Mishra (2007) also explains the concept of a "local" comparative advantage by which the direction of the change in the skill premium in a given country after trade liberalization depends on its skilled-labor abundance relative to its main trading partners.

3.2.2 The Skill-Biased Trade Effect

I now introduce capital-skill complementarity into the model and reestimate the effect of a reduction in bilateral trade costs on the skill premium. To do so, I set the elasticities of substitution between capital goods and skilled labor and between capital goods and unskilled labor equal to 0.67 and 1.67, respectively. The second column in Table 3 presents the results. Contrary to the case when only the Stolper-Samuelson effect is operating, we observe that with capital-skill complementarity, the reduction in bilateral trade costs leads to an increase in the skill premium in all countries. It is also important to notice that the effect tends to be larger in developing than in developed countries. The countries where the estimated effect on the skill premium is largest are the combined Malaysia-Philippines-Thailand, China, Mexico, the combined Chile-Colombia, and Peru. This result is consistent with the fact that developing countries experienced a larger reduction in trade costs, as shown in Section 3.1.

In the next subsection, I estimate the effect of a technical change on the skill premium across countries compared with the results presented in this subsection.

3.3 Effect of a Technical Change on the Skill Premium

To estimate the effect of skill-biased technical change on the skill premium, I first estimate the change in technology in the capital goods sector across countries during the period 1990-2007. Then I introduce these estimates into the model and determine how much the skill premium would have changed in each country if nothing but technical change had occurred in the World between 1990 and 2007.

As explained above, the parameter that governs the state of technology in the capital goods sector in each country is λ_i^K.[26] To estimate this parameter, I start from the bilateral equation (11). Taking the ratio with respect to this equation for $n = i$, and allowing for a random deviation ε_{ni}^j around symmetry in the iceberg trade costs, we get:

$$\frac{\widehat{\pi}_{ni}^K}{\widehat{\pi}_{nn}^K}\left[\frac{\widehat{c}_i^K\widehat{\kappa}_{ni}^K}{\widehat{c}_n^K}\right]^{1/\theta^K} = \frac{\widehat{\lambda}_i^K}{\widehat{\lambda}_n^K}e^{\varepsilon_{ni}^K}. \tag{22}$$

Taking logs from this equation, we get an equation we can estimate for the change in technology in the capital goods sector:

[26] Later on, I show that there is a close relationship between λ_i^K in the model and the TFP in the capital goods sector in the data.

$$\log \Theta_{ni}^K = \log \widehat{\lambda}_i^K - \log \widehat{\lambda}_n^K + \varepsilon_{ni}^K, \tag{23}$$

where $\Theta_{ni}^K = \frac{\widehat{\pi}_{ni}^K}{\widehat{\pi}_{nn}^K} \left[\frac{\widehat{c}_i^K \widehat{\kappa}_{ni}^K}{\widehat{c}_n^K} \right]^{1/\theta^K}$ and ε_{ni}^K is a random error term orthogonal to the change in technology. $\log \widehat{\lambda}_i^K$ and $\log \widehat{\lambda}_n^K$ are dummy variables that take the value of 1 if the country is equal to country i and -1 if the country is equal to country n. To construct Θ_{ni}^K, I obtain $\widehat{\pi}_{ni}^K$ and $\widehat{\pi}_{nn}^K$ as explained in Section 2.6, and I also use the dispersion-of-productivity parameter θ^K and the change in bilateral trade costs $\widehat{\kappa}_{ni}^K$ calculated in Section 3.1. To construct $\widehat{c}_n^K$, I collect sectoral price data and to get the change in the wage of skilled and unskilled labor I divide the change in the skilled and unskilled value added by the change in the supply of skilled and unskilled labor. Appendix B presents more detail on the construction of these variables.

Notice that the coefficient of the dummy $\log \widehat{\lambda}_i^K$ gives us the change in technology in country i relative to the reference country whose dummy was dropped from the regression. Therefore, in order to recover the change in technology in each country, I use TFP data to estimate the change in technology in the capital goods sector in the United States in the period 1990-2007, and then I recover λ_i^K for each country. Using sectoral TFP data from the EU KLEMS database and the concordance used to define capital goods in the data, I estimate the change in the TFP in the capital goods sector in the United States ($\widehat{TFP}_{US}^K$). To recover the change in the state of technology in the capital goods sector in the United States ($\widehat{\lambda}_{US}^K$), I follow Finicelli et al. (2009), and Costinot et al. (2011) and use the following map between $\widehat{TFP}_{US}^K$ in the data and $\widehat{\lambda}_{US}^K$ in the model:

$$\widehat{TFP}_{US}^K = \left(\widehat{\lambda}_{US}^K \right)^{\theta^K} \left(\widehat{\pi}_{US,US}^K \right)^{-\theta^K}. \tag{24}$$

The right-hand side of equation (24) is the average productivity in the capital goods sector, that is, the mean of $\left(1/x_i^K\right)^{\theta^K}$ when x_i^K comes from an exponential distribution with parameter λ_i^K, conditional on the fact that goods with inefficient domestic productivity draws will not be produced and will be imported instead. The estimated $\widehat{\lambda}_{US}^K$ is equal to 4.58.

Table 4 shows the estimates of $\widehat{\lambda}_i^K$ for all countries in the sample. On average, the estimated $\widehat{\lambda}_i^K$ is larger in developing than in developed countries, which can be related to a catch-up process. China and India have registered the largest technical change. The second column in Table 4 shows the implied relative change in the TFP in the capital goods sector.

With these estimates of the change in technology in the capital goods sector, I estimate the change in the skill premium across countries due to skill-biased technical change. To do so, I introduce the estimated change in technology in the capital goods sector, keeping fixed other exogenous variables, then solve for the global equilibrium and calculate the implied change in the skill premium across countries. The third column in Table 3 presents the results. The effect on the skill premium of a reduction in trade costs is of a similar magnitude to the effect of a technical change in the capital goods sector in most countries, and especially in developing countries. On average, in developing countries the reduction in trade costs explains 48% of the predicted increase in the skill premium, and skill-biased technical change explains 52%, while in developed countries 31% of the predicted increase in the skill premium is attributable to trade openness, and 69% is explained by skill-biased technical change.[27]

The fourth column of Table 3 presents the combined effect of a reduction in trade costs and skill-biased technical change on the skill premium in order to explore the interaction effect between trade openness and skill-biased technical change. As we can see from the table, the interaction term is positive for some countries and negative for others. This result indicates that skill-biased technical change can either complement or substitute with trade. For instance, a technical change in a trading partner has a larger effect on the skill premium in a country when this country is more open to trade. However, a domestic technical change has a larger effect on the skill premium when the country is more closed to trade, since in this case this technical change has a larger impact on the price of capital goods. In general, the interaction between trade and skill-biased technical change does not have an important impact on the skill premium.

The model is able to distinguish two effects of technical change: the effect of a change in technology in the home country and the effect of a change in technology in other countries. The first effect influences the cost of producing in the home country, while the second influences the price of imported capital goods. Table 5 reports the results. The first column shows the effect on the skill premium in country i of a change in technology in that same country, holding constant technologies in other countries. Under this scenario, I shut down any effect on the skill premium due to a change in technology in other countries that is transmitted through trade. The second column presents the results for the effect on the skill premium of a change in technology that is exclusively transmitted through trade flows. In this counterfactual scenario, I estimate the effect on the skill premium in country i of a change in technologies in all other countries $n \neq i$, holding constant technology in country i. This exercise captures, for instance, the effect on the skill premium in Chile of a technological improvement in Japan that decreases the price of capital goods, and so

[27] This calculation excludes the interaction effect between trade openness and skill-biased technical change.

makes Chile import cheaper capital goods from Japan, thus affecting the relative demand for skilled labor in Chile. The results indicate that although both a domestic technical change and a foreign technical change that is transmitted through trade flows have a positive effect on the skill premium in all countries, the magnitude of the domestic technical change is much more important in most countries. One implication of this result is that the main impact of developed countries on the skill premium in developing countries occurs because developing countries have decreased trade costs, rather than because of a technical change in developed countries.[28]

One important question my model allows to answer is whether the decrease in the relative price of capital goods shown in Figure 1 is mainly driven by a reduction in trade costs or a technical change in the capital goods sector. To my knowledge there is no answer to that question in the literature, since models with capital-skill complementarity such as that in Krusell et al. (2000) take the price of capital goods as exogenous. Table 6 estimates the change in the relative price of capital goods between 1990 and 2007 due to the reduction in trade costs and due to a technical change in the capital goods sector. On average, the reduction in trade costs explains 43% of the predicted change in the relative price of capital goods in developing countries and 31% in the case of developed countries.

Comparing the predicted effect of trade openness and skill-biased technical change on the skill premium presented in the fourth column of Table 3 with the observed change shown in Table 1, we can see that in most countries the model explains an important portion of the observed increase in the skill premium across countries. Among developing countries, the model explains almost all of the increase in the skill premium in Argentina, around half or more of the increase in the skill premium in China, India, Mexico and the average change in Chile and Colombia, and between 20% and 30% of the increase in Brazil, Peru and Uruguay. Among the developed countries that experienced an increase in the skill premium, the model explains nearly all of the increase in the United Kingdom and the United States, 61% of the increase in Sweden, between 25% and 30% in Germany, Portugal and Spain, around 5% in Italy, and it overestimates the increase in the skill premium in Finland.

[28] I consider an alternative counterfactual exercise. I quantify the effect of a domestic technical change as the difference between the effect on the skill premium of both a change in trade costs and technical change in every country and the effect on the skill premium when keeping fixed the technology in the domestic country. Similarly, I quantify the effect of a technical change in other countries as the difference between the effect on the skill premium of both a change in trade costs and technical change in every country and the effect on the skill premium when keeping fixed the technology in other countries. Although in this counterfactual exercise the effect of a domestic technical change is smaller and the effect of technical change in other countries is larger compared with the effects displayed in Table 5, it is still true that the main effect of developed countries on the skill premium in developing countries comes from the reduction in trade costs in developing countries.

3.4 Robustness Check

In this section I follow Eaton et al. (2011) to estimate trade costs in an alternative way. Starting from equation (11) and taking the ratio between the share of imports of sector j goods by country n from country i and the share of domestic sales in country i, we get:

$$\widehat{\kappa}_{ni}^{j} = \left[\frac{\widehat{\pi}_{ni}^{j}}{\widehat{\pi}_{ii}^{j}}\right]^{-\theta^{j}} \frac{\widehat{p}_{n}^{j}}{\widehat{p}_{i}^{j}}.$$

Therefore, using price data, the estimated bilateral trade shares, and the dispersion of productivity, we can obtain the relative change in bilateral trade costs $\widehat{\kappa}_{ni}^{j}$. I then use these estimates to calculate the change in the skill premium due to a change in trade costs. Using these new estimates of bilateral trade costs, I reestimate the change in technology in the capital goods sector and its impact on the skill premium across countries. Table 7 presents the results. The conclusions set out in Sections 3.2 and 3.3 are still valid. The first column shows the effect of a reduction in trade cots on the skill premium. We can see that the magnitudes are similar to those presented in Table 3, and the effect also tends to be larger in developing countries. The second column presents the effect of skill-biased technical change on the skill premium, which is of similar magnitude to the effect of trade openness in most countries. Compared with the results in Table 3, the reduction in trade costs now makes a slightly larger contribution to the increase in the skill premium. Of the predicted change in the skill premium in developing countries, 53% is attributable to the reduction in trade costs and 47% to skill-biased technical change, and in developed countries, 41% is due to trade openness and 59% to skill-biased technical change.[29]

3.5 Welfare Gains from Trade

Can both types of labor gain from trade? The standard answer to this question using the results of the Stolper-Samuelson theorem has been no. With trade in intermediate goods, this result turns out to be ambiguous (Feenstra, 2004). In this section I use my quantitative model to empirically explore this question.

I first estimate the effect of the reduction in trade costs on real wages when only the Stolper-Samuelson effect is operating ($\rho = 1$, $\sigma = 1$). The first column of Table 8 presents the results. We

[29] Predictions of the model on changes in relative prices, and the relative contributions of domestic and foreign technical change using this alternative estimate are qualitatively similar to those presented in Sections 3.3 and 3.4, and are available upon request.

can see that both skilled and unskilled labor gain from trade in all countries, and the increase in real wages is larger in developing than in developed countries. On average, in developing countries the reduction in trade costs induces an increase in the real wages of skilled and unskilled labor of 6.71% and 6.68%, respectively, while this increase is 3.14% and 3.26%, respectively, in developed countries.

By how much does capital-skill complementarity benefit skilled workers and hurt unskilled workers? The second column of Table 8 shows the effect of the reduction in trade costs on the real wages of skilled and unskilled labor with capital-skill complementarity. The results indicate that there is an increase in the real wage of skilled labor and a decrease in the real wage of unskilled labor relative to the case when only the Stolper-Samuelson effect is operating, although both types of labor still gain from trade. The impact of capital-skill complementarity on welfare is also more important in developing than in developed countries. On average, capital-skill complementarity adds 1.7 percentage points to the increase in the real wage of skilled labor while subtracting 1.6 percentage points from the increase in the real wage of unskilled labor in developing countries. In the case of developed countries, capital-skill complementarity adds 0.6 percentage points to the increase in the real wage of skilled labor while subtracting 0.6 percentage points from the increase in the real wage of unskilled labor in a model without capital-skill complementarity. When I introduce the combined effect of trade openness and skill-biased technical change (third column), the effect of capital-skill complementarity on real wages is larger. Capital-skill complementarity adds, on average, 11.5 percentage points to the increase in the real wage of skilled labor while subtracting 2.3 percentage points for unskilled labor in developing countries. In developed countries, the real wage of skilled labor increases by 5.5 additional percentage points, while the increase in the real wage of unskilled labor is 1.8 percentage points lower than in the case without capital-skill complementarity.

Finally, I also use the model to explore the relationship between welfare and inequality in an open economy. Does welfare increase more in countries that experience a larger increase in the skill premium after trade openness? Does capital-skill complementarity affect this relationship? Figure 3 shows the relationship between the change in welfare due to the reduction in trade costs and the change in the skill premium in a model without capital-skill complementarity. We can see from the figure that there is no clear relationship between the change in welfare and the change in the skill premium after the reduction in trade costs; countries that experienced a larger increase in the skill premium registered either a larger or smaller increase in welfare compared to countries with a small change in the skill premium. Intuitively, the lack of a tight connection between the change in welfare and the change in the skill premium can be explained because the former mainly comes from the decline in the price of intermediate goods and the latter is the result of sectoral specialization (or the change in the factor content of trade), and the two mechanisms are not necessarily linked. For instance, if we assume that production functions are similar across sectors and countries, a decline in the price of intermediate goods after trade liberalization will impact welfare but the skill premium will not change.

What is the relationship between the change in welfare and the change in the skill premium with capital-skill complementarity? Figure 4 shows that there is a strong positive relationship between the two. The decline in the price of capital goods links the change in welfare to the change in the skill premium when there is capital-skill complementarity. A decline in the price of intermediate and capital goods contributes to an increase in welfare as explained above and, through capital-skill complementarity, to an increase in the skill premium. Given that this mechanism is stronger than the Stolper-Samuelson effect as described above, a positive relationship between the change in welfare and the change in the skill premium arises.

4 Conclusion

The skill premium has increased in many countries over the last 20 years. Microeconomic evidence suggests that capital goods are complementary to skilled labor. This fact together with a decline in the relative price of capital across countries provides a natural explanation to this increase in the skill premium.

In this paper I constructed a model of international trade with trade in capital goods and capital-skill complementarity, and I separate the contribution to the increase in the skill premium of a decline in the relative price of capital goods due to a reduction in trade cost (skill-biased trade effect) from the effect due to a technical change in the capital goods sector. I also consider the impact on the skill premium of standard Stolper-Samuelson effects.

I find that the impact of skill-biased trade is much larger than that of Stolper-Samuelson effects, and comparable to the effect of skill-biased technical change, especially in developing countries. I find that reduction in trade costs explains approximately half of the predicted increase in the skill premium and decline in the relative price of capital goods in developing countries, while explaining approximately one-third of that in developed countries. I also empirically show that both skilled and unskilled labor gain from trade. Finally, I show that capital-skill complementarity induces a positive relationship between the change in welfare and income inequality in open economy.

My results, showing a substantial effect of trade in a static model, suggest a deeper analysis is worth pursuing. The main focus of future research should be to introduce dynamics into the model. Considering the fact that capital goods are not only traded across countries but also accumulated over time, such research would give us a fuller picture of the effects of trade and technical change on the skill premium, when there is capital-skill complementarity. I have also abstracted from the effect of human capital accumulation on the skill premium, which is also an interesting avenue for future research.

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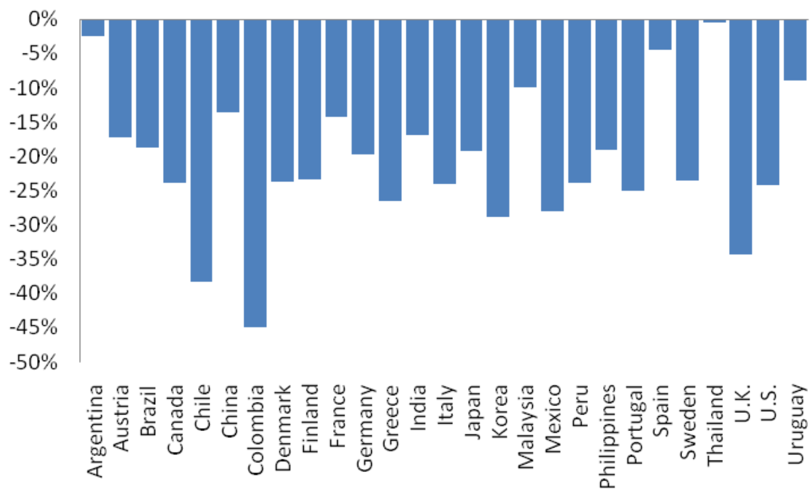
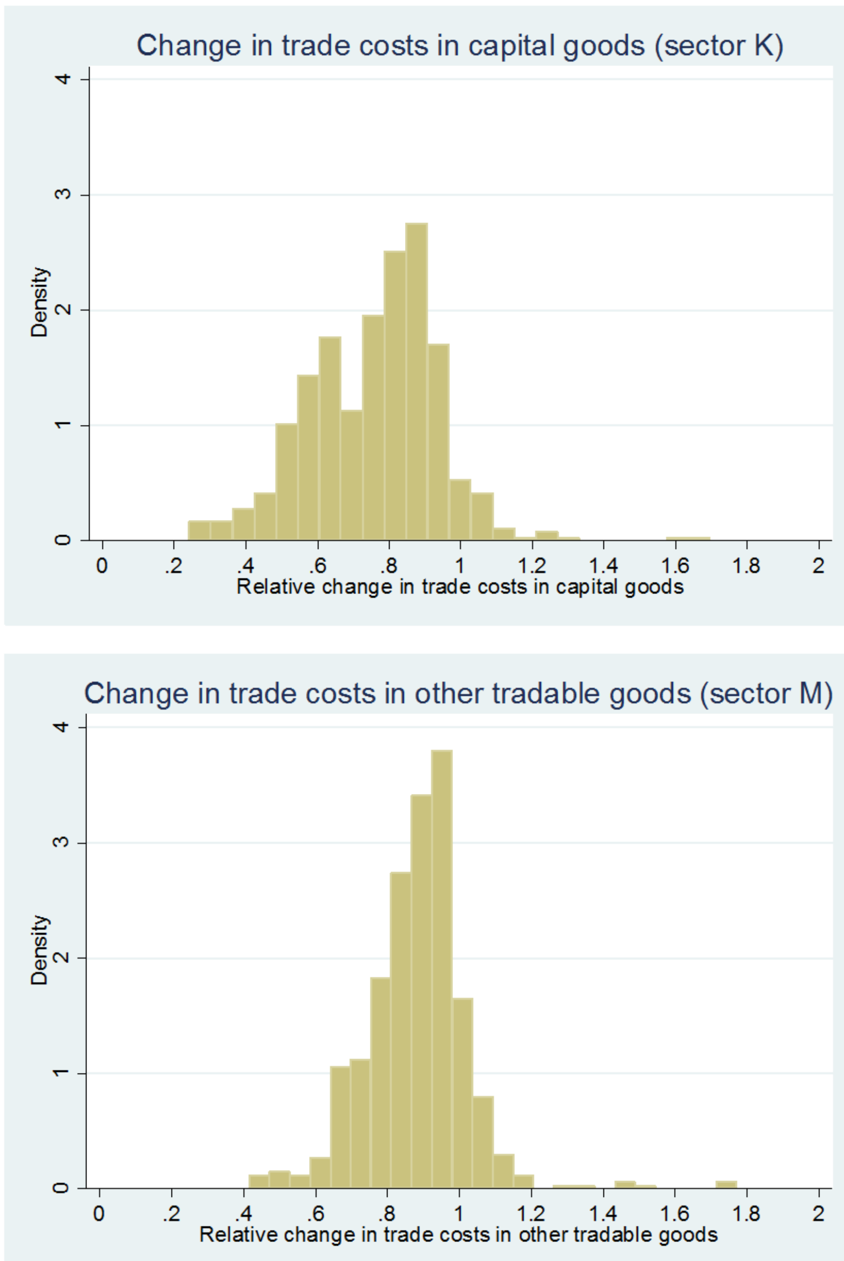
Figures and Tables

Figure 1: Change in the relative price of capital goods (1990-2007)



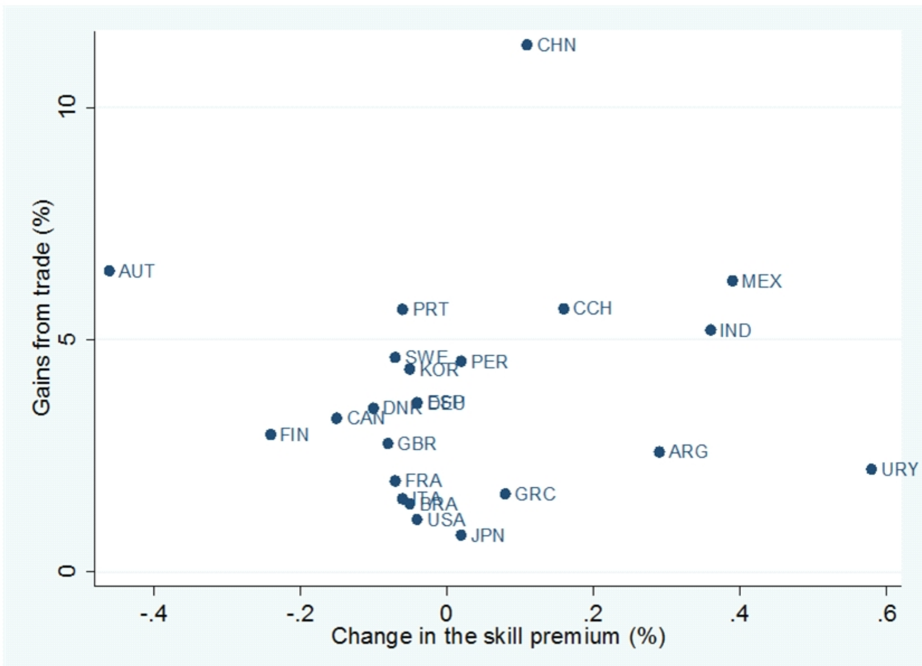
Note: This figure presents the percentage change in the relative price of capital goods in the period 1990-2007. The relative price of capital goods is defined as the ratio between the price of investment and the price of consumption. Source: Penn World Tables 6.3.

Figure 2: Changes in bilateral trade costs (1990-2007)



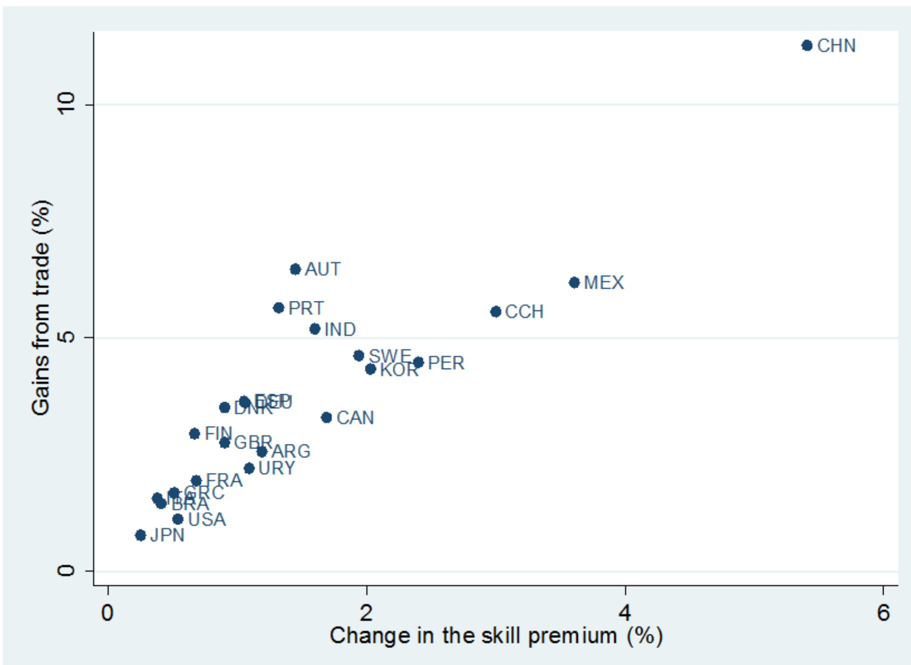
Note: This figure presents the histogram for the relative change in bilateral trade costs ($\widehat{\kappa}^j_{ni}$=$\widehat{d}^j_{ni}\widehat{(1+\tau^j_{ni})}$) in capital goods (sector K) and other tradables (sector M), estimated for the period 1990-2007.

Figure 3: Gains from trade and the skill premium without capital-skill complementarity (1990-2007)



Note: The vertical axis measures gains from trade openness constructed as a weighted average of the predicted change in skilled and unskilled real wages after the change in trade costs. The weights used correspond to the shares of skilled and unskilled labor in GDP. The horizontal axis measures the percentage change in the skill premium due to a reduction in trade costs. Both effects are calculated by setting the elasticities of substitution equal to one, so that only the Stolper-Samuelson effect is operating. To simplify the visual inspection of this figure, it excludes Mal-Phil-Tha, which registers an increase in welfare of 21.1% and a decrease in the skill premium of -1.35%.

Figure 4: Gains from trade and the skill premium with capital-skill complementarity (1990-2007)



Note: The vertical axis measures gains from trade openness constructed as a weighted average of the predicted change in skilled and unskilled real wages after the change in trade costs. The weights used correspond to the shares of skilled and unskilled labor in GDP. The horizontal axis measures the percentage change in the skill premium due to a reduction in trade costs. Both effects are calculated using the model with capital-skill complementarity. To simplify the visual inspection of this figure, it excludes Mal-Phil-Tha, which registers an increase in welfare of 20.7% and an increase in the skill premium of 8.8%.

Table 1: Change in the skill premium during the last two decades

Country	Observed change in the skill premium	Period	Definition of skill premium
Argentina	2.1%	1990-1999	college/high school wage ratio
Austria	-9.9%	1990-2005	college/high school wage ratio
Brazil	5.6%	1996-2007	non-prod./prod. workers wage ratio
Canada	-1.2%	1990-2004	college/high school wage ratio
Chile	-5.0%	1990-2000	college/high school wage ratio
China	40.2%	1992-2006	college/high school wage ratio
Colombia	26.4%	1990-2000	non-prod./prod. workers wage ratio
Denmark	-2.3%	1990-2005	college/high school wage ratio
Finland	1.4%	1990-2005	college/high school wage ratio
France	-16.8%	1990-2005	college/high school wage ratio
Germany	14.4%	1990-2005	college/high school wage ratio
Greece	-2.4%	1990-2005	college/high school wage ratio
India	11.9%	1987-2004	college/high school wage ratio
Italy	29.8%	1990-2005	college/high school wage ratio
Japan	-3.4%	1990-2005	college/high school wage ratio
Korea	-6.6%	1990-2005	college/high school wage ratio
Mexico	12.5%	1990-2001	non-prod./prod. workers wage ratio
Peru	23.9%	1994-2000	non-prod./prod. workers wage ratio
Portugal	12.3%	1992-2005	college/high school wage ratio
Philippines	5.0%	1988-2006	college/high school wage ratio
Spain	8.2%	1990-2005	college/high school wage ratio
Sweden	9.0%	1990-2002	college/high school wage ratio
Thailand	17.2%	1990-2004	college/high school wage ratio
United Kingdom	2.0%	1990-2005	college/high school wage ratio
United States	3.1%	1990-2007	non-prod./prod. workers wage ratio
Uruguay	11.1%	1990-1999	college/high school wage ratio

Sources: Argentina: Acosta and Montes-Rojas (2008), Brazil: Own calculation with data from the Brazilian annual survey of industries, Chile: Gallego (2011), China: Ge and Tao Yang (2009), Colombia: Gutierrez (2009), India: Azam (2009), Mexico: Verhoogen (2008), Peru: Mazumdar and Quispe-Agnoli (2004), Philippines and Thailand: di Gropello and Sakellariou (2010), Sweden: Domeij and Ljungqvist (2009), Uruguay: Casacuberta and Vaillant (2002), United States: Own calculation with data from the U.S. annual survey of manufactures. The change in the skill premium for the rest of the countries was constructed with data from the EU KLEMS database. Specifically, I use data on the share in total hours worked by skilled and unskilled males over 15 years old and the share in total labor compensation to skilled and unskilled males over 15 years old.

Table 2: Dispersion-of-productivity parameter

Sector	$1/\theta^j$	std.error	obs.
Capital goods (sector K)	4.6	(0.25)	7980
Other tradable goods (sector M)	5.2	(0.26)	7980

Note: This table presents the estimated coefficient of equation (21) for capital goods and other tradable sectors. I used data from 1990 or the closest available year. The sample of countries includes all countries in the World with available tariff data: Argentina, Austria, Brazil, Canada, Chile, China, Colombia, the European Union, India, Japan, Korea, Malaysia, Mexico, Peru, the Philippines, Thailand, Turkey, the United States, and Uruguay.

Table 3: Change in the skill premium due to change in trade costs and technical change in the capital goods sector (1990-2007)

Country	(1) Stolper-Samuelson effect $\widehat{\kappa}_{ni}^{j}$ for all i,n	(2) Effect of a change in trade costs with capital-skill complement. $\widehat{\kappa}_{ni}^{j}$ for all i,n	(3) Effect of tech. change in capital goods sector $\widehat{\lambda}_{i}^{K}$ for all i	(4) Combined effect of trade and skill-biased tech. change $\widehat{\kappa}_{ni}^{j}$, $\widehat{\lambda}_{i}^{K}$ for all i,n
Argentina	0.29%	1.19%	0.60%	2.01%
Austria	-0.46%	1.45%	1.24%	2.67%
Brazil	-0.05%	0.41%	0.49%	1.20%
Canada	-0.15%	1.69%	3.47%	5.16%
Chile-Colombia	0.16%	3.00%	1.85%	5.16%
China	0.11%	5.41%	17.43%	25.59%
Denmark	-0.09%	0.90%	3.05%	3.75%
Finland	-0.24%	0.67%	2.84%	3.39%
France	-0.07%	0.68%	1.49%	2.22%
Germany	-0.04%	1.06%	2.66%	3.84%
Greece	0.08%	0.51%	1.11%	1.61%
India	0.36%	1.60%	6.34%	8.93%
Italy	-0.06%	0.38%	1.05%	1.48%
Japan	0.02%	0.25%	0.77%	1.14%
Korea	-0.05%	2.03%	6.78%	8.74%
Mal-Phil-Tha	-1.35%	8.83%	3.87%	14.44%
Mexico	0.39%	3.61%	2.46%	6.56%
Peru	0.02%	2.40%	2.92%	5.42%
Portugal	-0.06%	1.32%	2.29%	3.58%
Spain	-0.04%	1.05%	1.04%	2.21%
Sweden	-0.07%	1.94%	3.77%	5.48%
United Kingdom	-0.08%	0.90%	1.66%	2.55%
United States	-0.04%	0.54%	2.81%	3.26%
Uruguay	0.58%	1.10%	1.84%	3.00%

Note: The change in the skill premium is computed as $(\widehat{w}_i^S/\widehat{w}_i^U - 1) * 100$. Column (1) presents the effect on the skill premium of a worldwide reduction in trade costs ($\widehat{\kappa}_{ni}^{j}$ for all i,n) when $\rho = 1$ and $\sigma = 1$. Column (2) shows the effect of a worldwide reduction in trade costs ($\widehat{\kappa}_{ni}^{j}$ for all i,n) when $\rho = 0.67$ and σ=1.67. Column (3) presents the effect of a worldwide technical change in the capital goods sector ($\widehat{\lambda}_{i}^{K}$ for all i). Column (4) shows the combined effect of trade openness and skill-biased technical change ($\widehat{\kappa}_{ni}^{j}$ and $\widehat{\lambda}_{i}^{K}$ for all i,n).

Table 4: Technical change in capital goods sector (1990-2007)

Country	(1) Change in technology in the capital goods sector ($\widehat{\lambda}_i^K$)	(2) Change in TFP in the capital goods sector ($\widehat{TFP}_i^K$)
Argentina	1.55	1.38
Austria	1.19	1.23
Brazil	1.13	1.06
Canada	4.47	1.62
Chile-Colombia	3.64	2.01
China	13.50	1.88
Denmark	6.77	1.67
Finland	3.45	1.31
France	1.84	1.23
Germany	3.02	1.40
Greece	2.94	1.34
India	20.19	2.03
Italy	1.56	1.14
Japan	1.41	1.12
Korea	4.19	1.37
Mal-Phil-Tha	3.06	2.16
Mexico	2.84	1.74
Peru	6.50	1.88
Portugal	4.15	1.58
Spain	1.40	1.19
Sweden	3.75	1.58
United Kingdom	2.11	1.37
United States	4.58	1.51
Uruguay	4.17	1.45

Note: Column (1) presents the estimated change in technology in the capital goods sector ($\widehat{\lambda}_i^K$). Column (2) shows the implied change in TFP in the capital goods sector calculated as $\widehat{TFP}_i^K = (\widehat{\lambda}_i^K)^{\theta^K} (\widehat{\pi}_{ii}^K)^{-\theta^K}$.

Table 5: Change in the skill premium due to a change in technology (1990-2007)

Country	(1) Effect of a domestic technical change in the capital goods sector $\widehat{\lambda}_i^K$ for each country i	(2) Effect of a foreign technical change in the capital goods sector transmitted through trade $\widehat{\lambda}_n^K$ for all countries $n \neq i$
Argentina	0.48%	0.19%
Austria	0.17%	1.15%
Brazil	0.22%	0.32%
Canada	2.84%	2.11%
Chile-Colombia	1.16%	1.26%
China	18.64%	0.56%
Denmark	3.30%	0.84%
Finland	2.67%	1.02%
France	1.13%	0.70%
Germany	2.69%	0.44%
Greece	0.64%	0.71%
India	6.67%	0.29%
Italy	0.80%	0.43%
Japan	0.83%	0.05%
Korea	7.22%	1.37%
Mal-Phil-Tha	3.34%	1.57%
Mexico	2.74%	0.72%
Peru	2.87%	1.14%
Portugal	2.16%	0.86%
Spain	0.43%	0.75%
Sweden	3.54%	1.39%
United Kingdom	1.30%	0.76%
United States	2.79%	0.43%
Uruguay	1.75%	0.66%

Note: Column (1) presents the effect on the skill premium of a change in technology in the capital goods sector ($\widehat{\lambda}_i^K$) for each country i, holding $\widehat{\lambda}_{n\neq i}^K = 1$. The second column presents the effect on the skill premium in each country i of a change in technology in every other country $n \neq i$, holding $\widehat{\lambda}_i^K = 1$.

Table 6: Change in the relative price of capital goods due to a change in trade costs and skill-biased technical change (1990-2007)

Country	(1) Effect of a change in trade costs with capital-skill complement. $\widehat{\kappa}_{ni}^{j}$ for all i, n	(2) Effect of a technical change in the capital goods sector $\widehat{\lambda}_{i}^{K}$ for all i
Argentina	-18.86%	-12.99%
Austria	-15.48%	-15.19%
Brazil	-4.88%	-6.27%
Canada	-16.23%	-30.71%
Chile-Colombia	-34.79%	-24.97%
China	-14.86%	-44.69%
Denmark	-11.89%	-31.69%
Finland	-6.81%	-25.26%
France	-7.27%	-16.52%
Germany	-8.21%	-21.97%
Greece	-8.62%	-19.77%
India	-13.33%	-53.86%
Italy	-3.91%	-12.46%
Japan	-2.19%	-9.96%
Korea	-10.83%	-32.58%
Mal-Phil-Tha	-38.24%	-23.36%
Mexico	-31.51%	-30.15%
Peru	-29.69%	-34.47%
Portugal	-13.95%	-23.32%
Spain	-11.90%	-13.30%
Sweden	-13.28%	-26.32%
United Kingdom	-9.03%	-17.68%
United States	-7.14%	-31.33%
Uruguay	-9.82%	-24.44%

Note: Column (1) presents the effect on the relative price of capital goods of a change in trade costs $(\widehat{\kappa}_{ni}^{j})$ when there is capital-skill complementarity. Column (2) presents the effect on the relative price of capital goods of a change in technology in the capital goods sector in all countries $\widehat{\lambda}_{i}^{K}$ for all $i \in \{1, ..I\}$.

Table 7: Robustness check: Change in the skill premium due to a change in trade costs and skill-biased technical change (1990-2007). Estimation of trade costs using price data.

Country	(1) Effect of a change in trade costs with capital-skill complement. $\widehat{\kappa}_{ni}^{j}$ for all i, n	(2) Effect of technical change in the capital goods sector $\widehat{\lambda}_{i}^{K}$ for all i
Argentina	1.24%	1.70%
Austria	1.75%	0.77%
Brazil	2.81%	1.37%
Canada	2.24%	2.88%
Chile-Colombia	2.54%	1.47%
China	5.46%	11.33%
Denmark	1.33%	0.86%
Finland	0.32%	1.28%
France	1.02%	1.87%
Germany	1.05%	1.62%
Greece	1.07%	1.13%
India	1.23%	4.11%
Italy	0.36%	0.46%
Japan	0.65%	3.63%
Korea	5.48%	13.52%
Mal-Phil-Tha	7.27%	2.36%
Mexico	3.43%	0.31%
Peru	2.56%	3.04%
Portugal	0.90%	1.23%
Spain	0.99%	0.59%
Sweden	3.77%	3.23%
United Kingdom	1.13%	1.19%
United States	0.80%	2.83%
Uruguay	0.21%	2.49%

Column (1) shows the effect of a worldwide reduction in trade costs ($\widehat{\kappa}_{ni}^{j}$ for all i, n) when $\rho = 0.67$ and σ=1.67. Column (2) presents the effect of a worldwide technical change in the capital goods sector ($\widehat{\lambda}_{i}^{K}$ for all i). The largest and smallest 5 percentiles of trade friction shocks are excluded from the estimations (they are outliers generally associated with small countries).

Table 8: Change in real wages (1990-2007)

	(1) Change in real wages without capital-skill complementarity $\widehat{\kappa}_{ni}^{j}$ for all i, n		(2) Change in real wages with capital-skill complementarity $\widehat{\kappa}_{ni}^{j}$ for all i, n		(3) Change in real wages with capital-skill complementarity $\widehat{\kappa}_{ni}^{j}$, $\widehat{\lambda}_{i}^{K}$ for all i, n	
Country	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor	Skilled labor	Unskilled labor
Argentina	2.74%	2.44%	3.19%	1.98%	4.70%	2.64%
Austria	6.23%	6.72%	7.27%	5.73%	9.84%	3.98%
Brazil	1.44%	1.48%	1.67%	1.26%	3.15%	1.92%
Canada	3.22%	3.37%	4.19%	2.46%	10.02%	4.62%
Chile-Colombia	5.76%	5.59%	7.24%	4.12%	10.70%	5.27%
China	11.42%	11.29%	14.58%	8.70%	55.19%	23.59%
Denmark	3.47%	3.57%	3.99%	3.05%	10.11%	6.14%
Finland	2.82%	3.07%	3.30%	2.62%	9.19%	5.61%
France	1.91%	1.99%	2.30%	1.61%	5.37%	3.09%
Germany	3.61%	3.65%	4.18%	3.09%	10.35%	6.27%
Greece	1.72%	1.64%	1.94%	1.42%	4.36%	2.71%
India	5.41%	5.04%	6.09%	4.42%	21.52%	11.55%
Italy	1.53%	1.59%	1.75%	1.37%	4.19%	2.67%
Japan	0.79%	0.77%	0.90%	0.65%	2.91%	1.74%
Korea	4.33%	4.38%	5.45%	3.35%	19.22%	9.63%
Mal-Phil-Tha	20.18%	21.83%	26.23%	15.99%	40.52%	22.78%
Mexico	6.48%	6.07%	8.15%	4.38%	12.43%	5.51%
Peru	4.54%	4.52%	5.78%	3.3%	9.75%	4.10%
Portugal	5.61%	5.68%	6.36%	4.98%	12.14%	8.27%
Spain	3.62%	3.66%	4.19%	3.11%	6.51%	4.20%
Sweden	4.58%	4.66%	5.65%	3.64%	11.82%	6.01%
United Kingdom	2.72%	2.80%	3.23%	2.31%	6.99%	4.33%
United States	1.10%	1.14%	1.39%	0.85%	6.83%	3.45%
Uruguay	2.51%	1.91%	2.77%	1.66%	6.25%	3.15%

Note: Column (1) presents the percentage change in skilled and unskilled real wages due to the Stolper-Samuelson effect, that is, by imposing $\rho = 1$ and $\sigma = 1$ in the model. Column (2) presents the percentage change in skilled and unskilled real wages due to a reduction in trade costs in a model with capital-skill complementarity, that is, by imposing $\rho = 0.67$ and $\sigma = 1.67$ in the model. Column (3) presents the combined effect of trade openness and skill-biased technical change on the real wages of skilled and unskilled labor.

Appendices

Appendix A: Derivation of the Main Equations of the Model

Derivation of the cost of the input bundle: The problem of the intermediate producer of good ω^j is given by:

$$p_i(\omega^j)q_i(\omega^j) = \min_{S_i^j(\omega^j),\, U_i^j(\omega^j), \left\{z_i^l(\omega^j)\right\}_{l\in J}} \sum_{l\in J} p_i^l z_i^l(\omega^j) + w_i^S S_i(\omega^j) + w_i^U U_i(\omega^j),$$

$$s.t: \left[x_i^j\right]^{-\theta^j} \left[z_i^M\left(\omega^j\right)\right]^{\gamma_i^{M,j}} \left[z_i^{NT}\left(\omega^j\right)\right]^{\gamma_i^{NT,j}} \left[v_i\left(\omega^j\right)\right]^{1-\gamma_i^{M,j}-\gamma_i^{NT,j}} \geqslant q_i(\omega^j), \tag{A.1}$$

with

$$v_i\left(\omega^j\right) = \left[\left[\mu_i^j\right]^{\frac{1}{\sigma}} \left[U_i\left(\omega^j\right)\right]^{\frac{\sigma-1}{\sigma}} + \left[1-\mu_i^j\right]^{\frac{1}{\sigma}} \left[h_i\left(\omega^j\right)\right]^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{A.2}$$

$$h_i\left(\omega^j\right) = \left[\left[\delta_i^j\right]^{\frac{1}{\rho}} \left[z_i^K\left(\omega^j\right)\right]^{\frac{\rho-1}{\rho}} + \left[1-\delta_i^j\right]^{\frac{1}{\rho}} \left[S_i\left(\omega^j\right)\right]^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}. \tag{A.3}$$

Using the first-order conditions for $S_i(\omega^j)$ and $z_i^K\left(\omega^j\right)$ we get:

$$z_i^K\left(\omega^j\right) = \frac{\delta_i^j}{1-\delta_i^j}\left[\frac{w_i^S}{p_i^K}\right]^{\rho} S_i\left(\omega^j\right). \tag{A.4}$$

Plugging $(A.4)$ into $(A.3)$ we get:

$$h_i\left(\omega^j\right) = S_i\left(\omega^j\right)\left[\left[\delta_i^j\right]^{\frac{1}{\rho}}\left[\frac{\delta_i^j}{1-\delta_i^j}\left[\frac{w_i^S}{p_i^K}\right]^{\rho}\right]^{\frac{\rho-1}{\rho}} + \left[1-\delta_i^j\right]^{\frac{1}{\rho}}\right]^{\frac{\rho}{\rho-1}}. \tag{A.5}$$

Let us first define $p_i^{h,j}h_i\left(\omega^j\right) = p_i^K z_i^K\left(\omega^j\right) + w_i^S S_i\left(\omega^j\right)$. Using equations $(A.4)$ and $(A.5)$ we get:

$$p_i^{h,j} = \left[\left[\delta_i^j\right]\left[p_i^K\right]^{1-\rho} + \left[1-\delta_i^j\right]\left[w_i^S\right]^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{A.6}$$

Analogously, using the first-order conditions for $U_i\left(\omega^j\right)$ and $h_i\left(\omega^j\right)$ we obtain:

$$h_i\left(\omega^j\right) = \frac{1-\mu_i^j}{\mu_i^j}\left[\frac{w_i^U}{p_i^{h,j}}\right]^{\sigma} U_i\left(\omega^j\right). \tag{A.7}$$

Defining $p_i^{v,j}v_i\left(\omega^j\right) = p_i^{h,j}h_i\left(\omega^j\right) + w_i^U U_i\left(\omega^j\right)$ and using $(A.2)$ and $(A.7)$ we get:

$$p_i^{v,j} = \left[\left[\mu_i^j\right]\left[w_i^U\right]^{1-\sigma} + \left[1-\mu_i^j\right]\left[p_i^{h,j}\right]^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{A.8}$$

Using the first order-conditions with respect to $z_i^M\left(\omega^j\right), z_i^{NT}\left(\omega^j\right)$ and $v_i\left(\omega^j\right)$ we get:

$$z_i^{NT}\left(\omega^j\right) = \frac{p_i^M}{p_i^{NT}}\frac{\gamma_i^{M,j}}{\gamma_i^{NT,j}} z_i^M\left(\omega^j\right) \tag{A.9}$$

$$v_i\left(\omega^j\right)=\frac{1-\gamma_i^{M,j}-\gamma_i^{NT,j}}{\gamma_i^{NT,j}}\frac{p_i^M}{p_i^{v,j}}z_i^M\left(\omega^j\right). \tag{A.10}$$

Defining $p_i\left(\omega^j\right)q_i\left(\omega^j\right)=p_i^{NT}z_i^{NT}\left(\omega^j\right)+p_i^M z_i^M\left(\omega^j\right)+p_i^{v,j}v_i\left(\omega^j\right)$ and using $(A.1)$, $(A.9)$, and $(A.10)$ we obtain:

$$p_i\left(\omega^j\right)=\left[x_i^j\right]^{\theta^j}B_i^j\left[p_i^M\right]^{\gamma_i^{M,j}}\left[p_i^{NT}\right]^{\gamma_i^{NT,j}}\left[p_i^{v,j}\right]^{1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}}, \tag{A.11}$$

with $B_i^j=\left[\gamma_i^{M,j}\right]^{\text{-}\gamma_i^{M,j}}\left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right]^{\text{-}\left(1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right)}\left[\gamma_i^{NT,j}\right]^{\text{-}\gamma_i^{NT,j}}$.

Hence, the cost of the input bundle is given by:

$$c_i^j=B_i^j\left[p_i^M\right]^{\gamma_i^{M,j}}\left[p_i^{NT}\right]^{\gamma_i^{NT,j}}\left[p_i^{v,j}\right]^{1-\gamma_i^{M,j}-\gamma_i^{NT,j}}.$$

Derivation of price of the aggregate composite good in sector j We have that the price in country n of good ω^j is the minimum price for all producers in the World:

$$p_n\left(\omega^j\right)=\min_i\left\{\left[x_i^j\right]^{\theta^j}c_i^j\kappa_{ni}^j\right\}.$$

From the properties of the exponential distribution we also know that if $x_i^j\sim\exp\left(\lambda_i^j\right)$ then $\left[p_n\left(\omega^j\right)\right]^{1/\theta^j}\sim\exp\left(\chi\right)$, with $\chi=\sum_{i=1}^I\lambda_i^j\left[c_i^j\kappa_{ni}^j\right]^{-1/\theta^j}$.

Hence we have:

$$\begin{aligned}p_n^j &= \left[\int p_n^j\left(\omega^j\right)^{1-\eta^j}\phi\left(x^j\right)dx^j\right]^{\frac{1}{1-\eta}}\\ \left[p_n^j\right]^{1-\eta^j} &= \int u^{\theta^j\left(1-\eta^j\right)}e^{-\chi u}du.\end{aligned}$$

Using the change of variables $y=\chi u$ we have:

$$\left[p_i^j\right]^{1-\eta^j}=\chi^{-\theta^j\left(1-\eta^j\right)}\left[A^j\right]^{1-\eta^j}$$

with $A^j=\left[\int\left[y^j\right]^{\theta^j\left(1-\eta^j\right)}e^{-y^j}dy\right]^{\frac{1}{1-\eta^j}}$.

Hence:

$$p_n^j=A^j\left[\left[\sum_{i=1}^I c_i^j\kappa_{ni}^j\right]^{-1/\theta^j}\lambda_i^j\right]^{-\theta^j}.$$

Derivation of bilateral trade shares Eaton and Kortum (2002) show that the bilateral trade share π_{ni}^j is equivalent to the probability of country i being the lowest-cost supplier in the World for country n. Hence:

$$\begin{aligned}\pi_{ni}^j &= prob\left(p_{ni}^j \leq \min_{k \neq i} p_{nk}^j\right) \\ &= prob\left(x_i^j\left[c_i^j \kappa_{ni}^j\right]^{\frac{1}{\theta^j}} \leq x_k^j\left[c_k^j \kappa_{nk}^j\right]^{\frac{1}{\theta^j}}\right).\end{aligned}$$

Solving for this probability we obtain:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \left[A^j\right]^{\frac{-1}{\theta^j}}\left[\frac{\kappa_{ni}^j c_i^j}{p_n^j}\right]^{-1/\theta^j} \lambda_i^j.$$

Derivation of the labor shares Using the first-order conditions of the problem of the intermediate producer of good ω^j we have:

$$\gamma_i^{S,j} = \Psi\left[\left[\delta_i^j\right]^{\frac{1}{\rho}}\left[\frac{z_i^K\left(\omega^j\right)}{S_i\left(\omega^j\right)}\right]^{\frac{\rho-1}{\rho}} + \left[1\text{-}\delta_i^j\right]^{\frac{1}{\rho}}\right]^{-1}\left[\left[\mu_i^j\right]^{\frac{1}{\sigma}}\left[\frac{U_i\left(\omega^j\right)}{h_i\left(\omega^j\right)}\right]^{\frac{\sigma-1}{\sigma}} + \left[1\text{-}\mu_i^j\right]^{\frac{1}{\sigma}}\right]^{-1}, \tag{A.12}$$

with $\Psi = \left[1\text{-}\mu_i^j\right]^{\frac{1}{\sigma}}\left[1\text{-}\delta_i^j\right]^{\frac{1}{\rho}}\left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right]$.

From the first-order conditions we also know that:

$$\frac{U_i\left(\omega^j\right)}{h_i\left(\omega^j\right)} = \frac{\mu_i^j}{1-\mu_i^j}\left[\frac{p_i^{h,j}}{w_i^U}\right]^{\sigma} \tag{A.13}$$

$$\frac{z_i^K\left(\omega^j\right)}{S_i\left(\omega^j\right)} = \frac{\delta_i^j}{1-\delta_i^j}\left[\frac{w_i^S}{p_i^K}\right]^{\rho}. \tag{A.14}$$

Plugging $(A.13)$ and $(A.14)$ into $(A.12)$ we get:

$$\gamma_i^{S,j} = \left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right]\left[\left[\frac{\mu_i^j}{1-\mu_i^j}\right]\left[\frac{p_i^{h,j}}{w_i^U}\right]^{\sigma-1} + 1\right]^{-1}\left[\left[\frac{\delta_i^j}{1-\delta_i^j}\right]\left[\frac{w_i^S}{p_i^K}\right]^{\rho-1} + 1\right]^{-1}.$$

To derive the share of skilled labor in the counterfactual equilibrium I use $(A.13)$, $(A.14)$, and the fact that $w_i^{U\prime} = w_i^U \widehat{w}_i^U$, $p_i^{h,j\prime} = p_i^{h,j}\widehat{p}_i^{h,j}$, $w_i^{S\prime} = w_i^S \widehat{w}_i^S$, and $p_i^{K,j\prime} = p_i^{K,j}\widehat{p}_i^{K,j}$. Then we get:

$$\gamma_n^{S,j\prime} = \left[1-\gamma_n^{M,j}-\gamma_n^{NT,j}\right]\left[1+\frac{\gamma_n^{U,j}}{\gamma_n^{S,j}+\gamma_n^{K,j}}\left[\frac{\widehat{p}_n^{h,j}}{\widehat{w}_n^U}\right]^{\sigma-1}\right]^{-1}\left[1+\frac{\gamma_n^{K,j}}{\gamma_n^{S,j}}\left[\frac{\widehat{w}_n^S}{\widehat{p}_n^K}\right]^{\rho-1}\right]^{-1}.$$

From the first-order conditions of the problem of the intermediate producer of good x_i^j we can also derive the following relationships:

$$\frac{w_i^S U_i^j}{p_i^{v,j} v_i(\omega^j)} = \left[1 + \left[\frac{1-\mu^j}{\mu^j}\right]^{\frac{1}{\sigma}} \left[\frac{h_i(\omega^j)}{U_i(\omega^j)}\right]^{\frac{\sigma-1}{\sigma}}\right]^{-1}. \tag{A.15}$$

Using $(A.13)$ and the fact that $\frac{p_i^{v,j} v_i(\omega^j)}{p_i^j q_i^j(\omega^j)} = \left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right]$, we have:

$$\gamma_i^{U,j} = \left[1\text{-}\gamma_i^{M,j}\text{-}\gamma_i^{NT,j}\right] \left[1 + \left[\frac{1-\mu^j}{\mu^j}\right] \left[\frac{w_i^U}{p_i^{h,j}}\right]^{\sigma-1}\right]^{-1}.$$

To derive the share of unskilled labor in the counterfactual equilibrium I use $(A.13)$ and the fact that $w_i^{U\prime} = w_i^U \widehat{w}_i^U$ and $p_i^{h,j\prime} = p_i^{h,j} \widehat{p}_i^{h,j}$. Then we have:

$$\gamma_n^{U,j\prime} = \left[1 - \gamma_n^{NT,j} - \gamma_n^{M,j}\right] \left[1 + \frac{\gamma_n^{K,j} + \gamma_n^{S,j}}{\gamma_n^{U,j}} \left[\frac{\widehat{w}_n^U}{\widehat{p}_n^{h,j}}\right]^{\sigma-1}\right]^{-1}.$$

Cost of the input bundle in relative changes We can express the cost of input bundle in relative changes as:

$$\widehat{c}_i^j = \left[\widehat{p}_i^M\right]^{\gamma_i^{M,j}} \left[\widehat{p}_i^{NT}\right]^{\gamma_i^{NT,j}} \left[\widehat{p}_i^{v,j}\right]^{1-\gamma_i^{M,j}-\gamma_i^{NT,j}} \tag{A.16}$$

$$\widehat{p}_i^{v,j} = \frac{1}{p_i^{v,j}} \left[\mu_i^j \left[w_i^U\right]^{1-\sigma} \left[\widehat{w}_i^U\right]^{1-\sigma} + \left[1-\mu_i^j\right] \left[p_i^{h,j}\right]^{1-\sigma} \left[\widehat{p}_i^{h,j}\right]^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{A.17}$$

Using the first-order conditions and doing some algebra we can derive the following conditions:

$$\mu_i^j \left[w_i^U\right]^{1-\sigma} = \frac{\gamma_i^{U,j}}{1-\gamma_i^{M,j}-\gamma_i^{NT,j}} \left[\mu_i^j \left[w_i^U\right]^{1-\sigma} + \left[1-\mu_i^j\right] \left[p_i^{h,j}\right]^{1-\sigma}\right] \tag{A.18}$$

$$\left[1-\mu_i^j\right] \left[p_i^{h,j}\right]^{1-\sigma} = \frac{\gamma_i^{S,j}+\gamma_i^{K,j}}{1-\gamma_i^{M,j}-\gamma_i^{NT,j}} \frac{p_i^{h,j} h_i^j}{Y_i^j} \left[\mu_i^j \left[w_i^U\right]^{1-\sigma} + \left[1-\mu_i^j\right] \left[p_i^{h,j}\right]^{1-\sigma}\right]. \tag{A.19}$$

Plugging $(A.18)$ and $(A.19)$ into $(A.17)$ we get:

$$\widehat{p}_i^{v,j} = \left[1-\gamma_i^{M,j}-\gamma_i^{NT,j}\right]^{\frac{-1}{1-\sigma}} \left[\gamma_i^{U,j} \left[\widehat{w}_i^U\right]^{1-\sigma} + \left[\gamma_i^{S,j}+\gamma_i^{K,j}\right] \left[\widehat{p}_i^{h,j}\right]^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{A.20}$$

Analogously, we have:

$$\widehat{p}_i^{h,j} = \frac{1}{p_i^{h,j}} \left[\delta_i^j \left[p_i^K\right]^{1-\rho} \left[\widehat{p}_i^K\right]^{1-\rho} + \left[1-\delta_i^j\right] \left[w_i^S\right]^{1-\rho} \left[\widehat{w}_i^S\right]^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{A.21}$$

Again, using the first-order conditions and doing some algebra I derive the following equations:

$$\left[1-\lambda_i^j\right]\left[w_i^S\right]^{1-\rho}=\frac{\gamma_i^{S,j}}{\gamma_i^{S,j}+\gamma_i^{K,j}}\left[\delta_i^j\left[p_i^K\right]^{1-\rho}+\left[1-\delta_i^j\right]\left[w_i^S\right]^{1-\rho}\right] \tag{A.22}$$

$$\lambda_i^j\left[p_i^K\right]^{1-\rho}=\frac{\gamma_i^{K,j}}{\gamma_i^{S,j}+\gamma_i^{K,j}}\left[\delta_i^j\left[p_i^K\right]^{1-\rho}+\left[1-\delta_i^j\right]\left[w_i^S\right]^{1-\rho}\right] \tag{A.23}$$

Plugging $(A.22)$ and $(A.23)$ into $(A.21)$ we have:

$$\widehat{p}_i^{h,j}=\left[\gamma_i^{S,j}+\gamma_i^{K,j}\right]^{\frac{-1}{1-\rho}}\left[\gamma_i^{K,j}\left[\widehat{p}_i^k\right]^{1-\rho}+\gamma_i^{S,j}\left[\widehat{w}_i^S\right]^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{A.24}$$

Therefore the change in the cost of the input bundle is given by equations $(A.16)$, $(A.20)$ and $(A.24)$.

Appendix B: Data Construction and Sources

List of countries Argentina, Austria, Brazil, Canada, Chile, China, Colombia, Denmark, Finland, France, Germany, Greece, India, Italy, Japan, Korea, Malaysia, Mexico, Peru, Philippines, Portugal, Spain, Sweden, Thailand, United Kingdom, United States, Uruguay, and Rest of the World.

Sectoral definition and concordance links I divide ISIC revision 3 industries into capital goods, other tradable goods and non-tradable goods. The capital goods concordance was constructed according to the U.S. import end-use classification. I thank John Romalis for supplying this concordance. When data is expressed in a classification system different from ISIC revision 3, I use a concordance link to map the data to ISIC revision 3 industries. I use the World's trade volumes in 2007 to calculate the weights used to create the concordance links.

Trade data Bilateral trade flows are from the United Nations Statistical Division (UNSD) Commodity Trade (COMTRADE) database. The data come in U.S. dollars and products are classified according to SITC revision 2. I used the appropriate concordance link to classify products into capital goods and other tradable goods.

Tariff data Bilateral tariff data are from the United Nations Statistical Division-Trade Analysis and Information System (UNCTAD-TRAINS). Products are classified according to HS 1988/1992. I used concordance links to map products to ISIC revision 3 industries and then to classify industries into the two relevant tradable sectors used in this paper. I used weighted tariffs for 1990 and 2007. When tariffs were not available for 1990, I used the closest available year between 1988 and 1994.

Production and value added data Production and value added data are from the OECD Structural Analysis Database (STAN), the United Nations National Accounts Database, and United Nations Industrial Statistics. When production data were not directly available, I used value added data and calculated the appropriate shares obtained from the input-output tables to convert value added data into production data. Using a sample of OECD countries I checked that this procedure gives an accurate measure of gross production. Data on production and value added are classified according to ISIC revision 3.

Input-output coefficients Shares of capital goods, other tradables and non-tradables in gross production were calculated using the OECD's and national agencies' input-output tables for the closest available year to 1990. Input-output tables for China, the Philippines, Malaysia and Thailand were obtained from Thailand's Office of the National Economic and Social Development Board. To construct the input-output table for the rest of the world, I computed the average input-output coefficients of all countries.

Shares of skilled and unskilled labor The shares of skilled and unskilled labor in each sector were calculated in the following way. For the case of tradable sectors, I first calculated the shares of skilled and unskilled labor in value added. I used the United Nations General Industrial Statistics Database, which includes data on employment and wagebill for several countries. It covers twenty-eight tradable industries at the ISIC revision 2 and 3-digit levels. My measure of skill in these data is the classification into non-production and production workers. A production worker is usually defined as an employee directly engaged in production or related activities of the establishment, including clerks or working supervisors whose function is to record or expedite any step in the production process. Therefore, production workers are the measure of unskilled labor. Berman et al. (1998) show that non-production workers have higher educational attainment than production workers. Unfortunately, only a small number of countries present complete and consistent data on skilled and unskilled value added for the year 1990. Therefore, I decided to use the median share of skilled value added to split value added into skilled and unskilled value added. I then used the share of value added in gross production for each country to determine the shares of skilled and unskilled labor in the tradable sectors. Notice that these shares are different across countries.

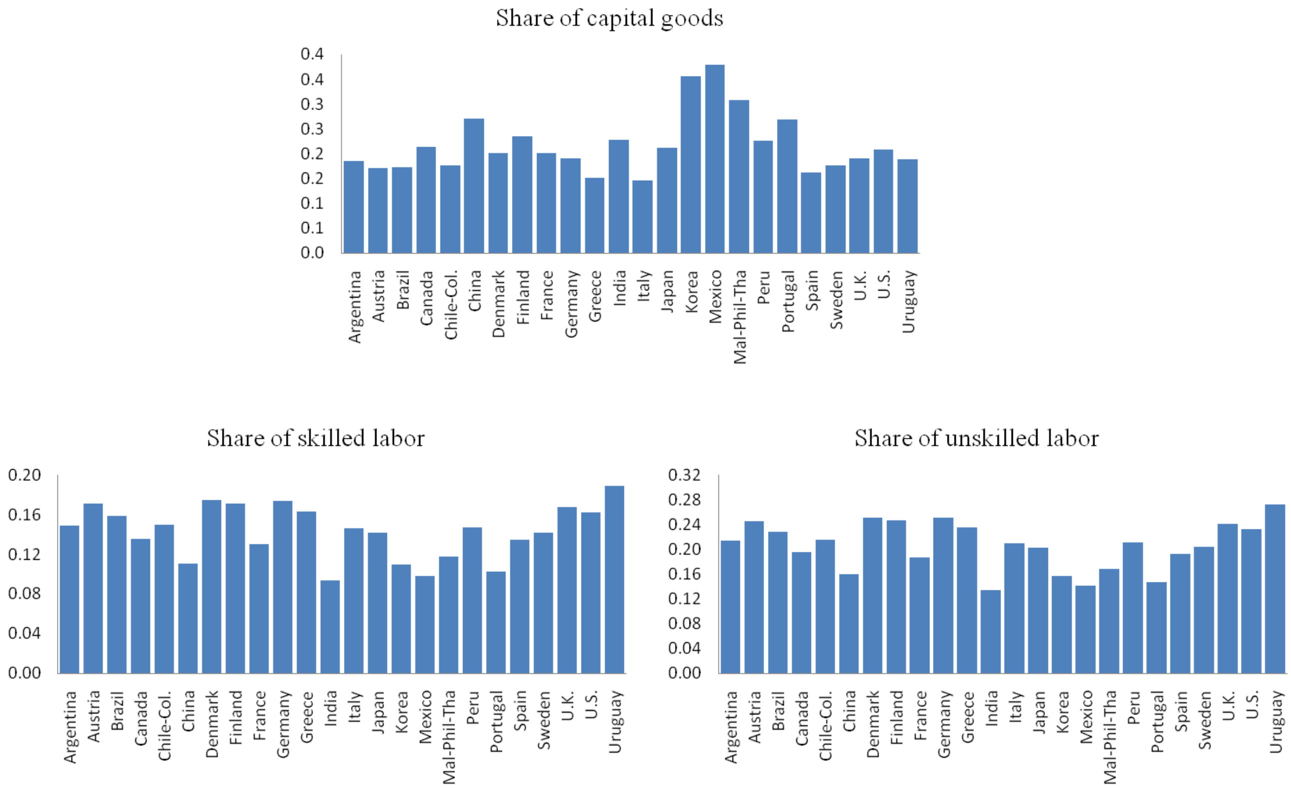
For the case of the non-tradable sector, I followed the methodology proposed in Blum (2008). Following Winchester et al. (2006), I classified managers, professionals, technicians and technologists as non-production workers and workers in every other occupation as production workers. Using the Occupational Employment Statistics (OES) Survey from the Bureau of Labor Statistics for the year 1997, which is the closest available year to 1990, I calculated the shares of skilled and unskilled labor in value added in the Retail Trade, Wholesale Trade and Service industries. I obtained the result that 51% of value added is skilled and 49% is unskilled. Using the share of value added in gross production for each country I obtained the shares of skilled and unskilled labor in the non-tradable sector.

Construction of price indices and the cost of the input bundle To construct the change in the cost of the input bundle used to estimate the change in technology in the capital goods sector, I first collected disaggregated price data. Sectoral producer price index data for Argentina, Austria, Canada, Chile, China, Colombia, Denmark, Finland, France, Germany, Greece, India, Italy, Japan, Korea, Mexico, Portugal, Spain, Sweden, the United Kingdom, and the United States are from the Datastream database. Price data for Brazil are from Fundacao Getulio Vargas; for Malaysia, from the Department of Statistics; for Peru, from the Instituto de Estadistica e Informatica (INEI); for the Philippines, from the National Statistics Office; for Thailand, from the Bureau of Trade and Economic Indices; and for Uruguay, from the Instituto Nacional de Estadisticas (INE). Unfortunately, not all countries have time series price data from 1990 to 2007; I use the closest available year to 1990 and 2007 in cases where the data for those years are missing. I only include countries that present data for at least eleven years between 1990 and 2007. Using the constructed concordance links I created the price indices for capital goods and other tradable goods. To avoid fluctuations of these indices due to exchange rates, I expressed all price indices in U.S. dollars. In order to do so, I obtained exchange rates from the OECD Main Indicators and the International Financial Statistics databases. To construct the change in the cost of skilled and unskilled labor, I divide the change in skilled and unskilled value added by the change in their labor supply. In order to make consistent the change in the cost of skilled and unskilled labor with the change in the skill premium reported in Table 1, I calibrate the change in the share of skilled labor in total value added to match the change in skilled labor reported in Table 1. The skilled labor supply was defined as the population over 15 years old with tertiary education. Similarly, the unskilled labor supply was computed as the population over 15 years old with secondary, primary and no education. These data were obtained from the Barro and Lee database (www.barrolee.com). Finally, using the constructed change in price indices for capital goods and other tradables and the change in skilled and unskilled wages I computed the change in the price of non-tradables.

Appendix C: Heterogeneity of Production Functions Across Countries and Countries

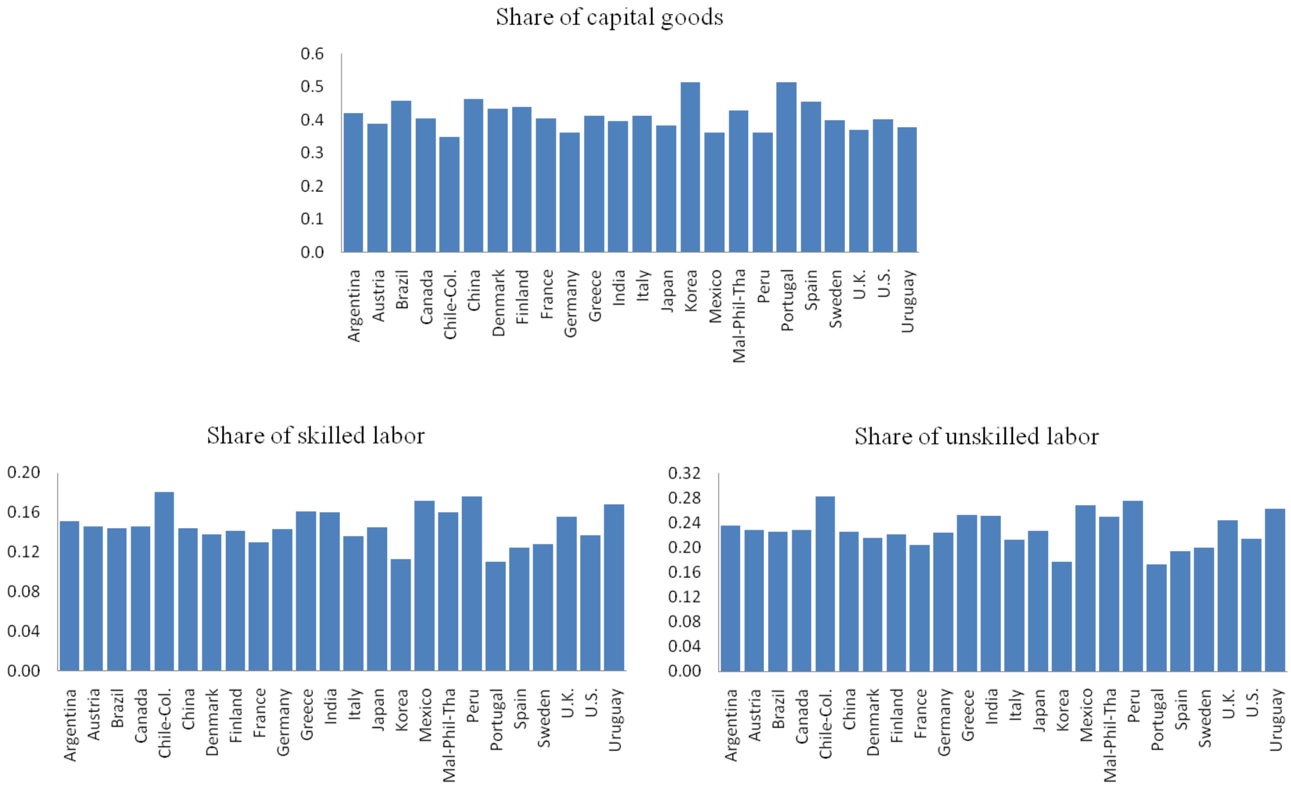
In this appendix I show an example of the heterogeneity in the production functions across sectors and countries. Figure C.1 and Figure C.2 show the shares of capital goods, skilled labor, and unskilled labor across countries in the capital goods sector (sector K) and in the non-capital goods sector (sector M), respectively.

Figure C.1: Shares of capital goods, skilled labor, and unskilled labor in the capital goods sector (sector K)



Note: The share of each factor is constructed as the ratio between each factor's payment and gross production.

Figure C.2: Shares of capital goods, skilled labor, and unskilled labor in the non-capital goods sector (sector M)



Note: The share of each factor is constructed as the ratio between each factor's payment and gross production.

Appendix D: Solving for the Global Equilibrium

In this appendix, I describe the algorithm used to solve for the counterfactual equilibrium. First, I guess the change in skilled and unskilled wages in each country $\left\{\widehat{w}_i^S, \widehat{w}_i^U\right\}_{i\in I}$; for instance $\widehat{w}_i^S = 1$ and $\widehat{w}_i^U = 1$ $\forall i \in I$. Given the parameters calibrated to 1990 π_{ni}^j, π_{ii}^j, $\gamma_i^{M,j}$, $\gamma_i^{K,j}$, $\gamma_i^{NT,j}$, $\gamma_i^{S,j}$, $\gamma_i^{U,j}$, $w_i^S S_i$, $w_i^U U_i$, α_i^j, θ^j, ρ, σ, the change in trade frictions $\widehat{\kappa}_{ni}^j$ and technology in the capital goods sector $\widehat{\lambda}_i^K$, and the initial guess of wages, I solve for prices in each sector and country $\widehat{p}_n^j$ using equation (9). Plugging this solution into (11), I obtain $\widehat{\pi}_{ni}^j$. Using the solution for prices and the guess of wages, I calculate the new shares of skilled and unskilled labor ($\gamma_n^{S,j'}$ and $\gamma_n^{U,j'}$) according to equations (14) and (15), and recover the share of capital goods in the counterfactual equilibrium as $\gamma_n^{K,j'} = 1 - \gamma_n^{M,j} - \gamma_n^{NT,j} - \gamma_n^{S,j'} - \gamma_n^{U,j'}$. I solve for total expenditure in each country and sector $X_n^{j'}$. To do so I follow the approach developed in Caliendo and Parro (2011).

Total expenditure in each sector j and country i in the counterfactual equilibrium is given by:

$$X_n^{j'} = \alpha_n^j I_n' + \sum_{l\in J} \gamma_n^{j,l'} \sum_{n\in I} \frac{\pi_{in}^{l'}}{1+\tau_{in}^{l'}} X_i^{l'} \qquad \text{for } j, l \in J,$$

with $I_n' = \widehat{w}_n^S w_n^S S_n + \widehat{w}_n^U w_n^U U_n + D_n + \sum_{j\in J} X_n^{j'}[1 - \sum_{i=1}^{I} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}}]$. This equation holds for each country and each sector. Therefore, given the initial guess of wages, we can solve for total expenditure in each sector j and country n. Substituting the solutions for $\widehat{\pi}_{ni}^j$, $\gamma_i^{S'j}$, and $X_n^{j'}$, I solve for the change in the wage of skilled labor using the labor market clearing condition (12). Using the solution for the change in the wage of skilled labor, together with the solution for $\widehat{\pi}_{ni}^j$ and $X_n^{j'}$, and the initial guess of change in the wage of unskilled labor, I verify wether trade balance (16) holds. If not, I adjust the guess of $\widehat{w}_i^U$ and repeat the process until it does.