

Importing Skill-Biased Technology*

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Abstract

Capital equipment—such as computers and industrial machinery—embodies skill-biased technology, in the sense that it is complementary to skilled labor. Most countries import a large share of their capital equipment, and by doing so import skill-biased technology. In this paper we develop a tractable, quantitative, multi-country model of international trade in capital goods to study the extent to which trade affects the skill premium through capital-skill complementarity. We provide simple analytic equations that link observable changes in domestic sectoral expenditure shares (international trade) to changes in the real wages of skilled and unskilled workers and, therefore, the skill premium. We find that while international trade raises the real wages of both skilled and unskilled workers, it benefits skilled workers disproportionately, especially in countries that rely heavily on imports for their capital equipment. Feeding into the model observed changes in trade shares between 1963 and 2000, we find that the percentage point change in the real wage is more than two times greater for skilled workers than for unskilled workers in the median country.

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1 Introduction

Capital equipment—such as computers and industrial machinery—embodies skill-biased technology, in the sense that it is complementary to skilled labor.¹ It is also highly traded, with production concentrated among a small group of countries; see e.g. Eaton and Kortum (2001).² Many countries import a large share of their capital equipment,³ and by doing so import skill-biased technology. In this paper we develop a tractable multi-country model of international trade in capital goods to study the extent to which trade, through capital-skill complementarity, affects real wages of skilled and unskilled workers and, hence, the skill premium.

In modeling the interaction between capital equipment, skilled labor, and unskilled labor, we build on Krusell, Ohanian, Rios-Rull, and Violante (2000), henceforth KORV. They introduce a parsimonious aggregate production function that allows for capital-skill complementarity, following Sato (1967) and Griliches (1969), to link the evolution of the US skill premium to the evolution of its observable stocks of capital, skilled labor, and unskilled labor. With capital-skill complementarity, an increase in the stock of capital equipment raises the demand for skilled relative to unskilled labor. KORV estimate the parameters of the aggregate production using US data between 1963-1992 and show that a large fraction of the historical variation in the US skill premium can be accounted for by observed changes in capital and labor endowments.⁴

Whereas KORV take changes in the aggregate stock of capital equipment in the US as given, our goal is to study how international trade shapes the equilibrium stock of capital equipment in many countries and, hence, the real wages of skilled and unskilled workers. Constructing empirical measures of the response of the aggregate stock of capital equipment in individual countries to changes in the extent of international trade is difficult in practice because international trade is one force, among many others, affecting the equilibrium determination of the stock of capital equipment. To deal with this measurement constraint, we use a quantitative multi-country model of international trade to infer how the stock of

¹Since Griliches (1969), various empirical papers provide support for this hypothesis; see e.g. Katz and Autor (1999), who summarize the literature documenting a positive correlation between the use of computer-based technologies and employment of skilled labor within industries, firms, and plants.

²For example, 80% of the world's capital equipment production occurred in just eight countries in the year 2000: the U.S., Japan, Germany, China, France, Korea, the U.K., and Italy. Source: Unido Industrial Statistics.

³For example, the share of domestic absorption imported from abroad in the equipment sector in the year 2000 was 73% in the U.K., 81% in Australia, 84% in Chile, and 96% in Cameroon. Source: our calculation using trade data from Feenstra et. al. (2005) and Unido Industrial Statistics.

⁴The approach has served as a basic building block in a number of other macroeconomic models of inequality; see e.g. Polgreen and Silos (2008) and Jaimovich, Pruitt, and Siu (2010)

capital equipment should respond, in general equilibrium, to changes in international trade. A similar motivation has led to the widespread use of structural models to infer the effects of international trade on average real wages.

Specifically, we embed the KORV aggregate production function into the multi-country model of international trade developed in Eaton and Kortum (2002), henceforth EK, extended to allow for trade in capital goods as in Eaton and Kortum (2001). With international trade, the aggregate stock of capital equipment in one country depends in general equilibrium on all foreign productivities and labor endowments and on trade costs between every pair of countries. We show, however, that in our model changes in trade costs, foreign productivities, and foreign labor endowments affect a country's steady-state stock of capital equipment only through changes in its domestic sectoral expenditure shares, i.e., the share of its sectoral absorption that is produced domestically. Hence, in the model steady-state changes in the real wages of skilled and unskilled workers in a country are determined only by changes in its domestic expenditure share in each sector, domestic productivity in each sector, and domestic labor endowments. Since our model yields gravity equations, these results follow from applying the insights of EK and Arkolakis, Costinot, and Rodriguez-Clare (2012), who show that—across a wide range of workhorse international trade frameworks—the impact on average domestic real wages (i.e. the stock of domestic consumption) of changes in trade costs and foreign technologies are transmitted only through changes in domestic expenditure shares.⁵ Our contribution relative to this trade literature is to take these insights and apply them to study not only how international trade affects average real wages, but also how it differentially affects the real wages of skilled and unskilled workers.

Combining a gravity model of trade with capital-skill complementarity we obtain simple analytic expressions relating steady-state changes—up to first-order approximations—in (i) the skill premium, (ii) the real wage of skilled workers, and (iii) the real wage of unskilled workers to changes in domestic expenditure shares, domestic productivities, and domestic labor endowments.

Three parameters are key in shaping the elasticities of (i)–(iii) with respect to changes in observable domestic expenditure shares in each sector. The first is the elasticity of trade with respect to variable trade costs (the trade elasticity), which depends only on the dispersion of productivities within sectors in our Ricardian model. This parameter is key in shaping the gains from trade in standard quantitative trade models and in determining the extent to which observable changes in domestic sectoral expenditure shares lead to changes in the domestic stock of capital equipment in our model. The other two important parameters—the

⁵While we embed capital-skill complementarity into a perfectly competitive Ricardian model of trade, our results hold more generally across a range of workhorse trade models yielding gravity equations.

production function elasticities that jointly determine the extent of capital-skill complementarity and the elasticity of substitution between skilled and unskilled labor—shape the response of the skill premium to a given change in the stock of capital equipment. Changes in real wages in a given country depend on production function parameters for that country alone, conditional on observed changes in domestic expenditure shares.

We pursue several strategies to parameterize these two production function elasticities using structural equations delivered by the model. We both calibrate and estimate the parameters using US data on changes between 1963 and 2000 in factor shares and factor supplies, in each case finding a significant and similar degree of capital-skill complementarity. Our results are very similar to those obtained in KORV, which is not surprising as we use their basic estimation strategy, but is reassuring as our data spans more years. We also obtain very similar results estimating these parameters using data between 1974 and 2000 in a developing country, Chile, that is a net importer of capital equipment.

Whereas we estimate the two key production function elasticities using more years of data in the US and using data from Chile and find similar results to KORV, our estimation strategy is subject to the same set of issues that have led to an active debate on the role of capital-skill complementarity in accounting for changes in the skill premium. First, the growth rate of the stock of capital equipment is nearly constant over our time horizon, so it is difficult to disentangle capital-skill complementarity from any other force resulting in constant skill-biased technical change; see e.g. Acemoglu (2002). We extend our analysis to allow for an exogenous trend in skill-biased productivity and find that the annual trend would have to be as large as 5% in order for capital-skill complementarity to be absent, but we do not have a way of determining the magnitude of this trend. Second, some existing papers find weak evidence of capital-skill complementarity in a panel of countries; see e.g. Duffy, Papageorgiou, and Perez-Sebastian (2004). Our estimation shows that the extent of capital-skill complementarity is similar in the US and Chile, but we do not provide evidence for any other countries.⁶ We view our main contribution not as providing new evidence on the strength of capital-skill complementarity, but instead as providing a simple set of analytic equations linking observable changes in domestic sectoral expenditure shares (international trade) to changes in the real wages of skilled and unskilled workers for any given parameter values.

We use our parameterized model to quantify the impact of changing trade flows on the skill premium and the real wages of skilled and unskilled workers. We conduct two counterfactuals. In the first, we determine how much each country’s skill premium and both

⁶Koren and Csillag (2011) document a positive link between capital imports and wages using cross-sectional evidence from Hungarian firms.

of its real wages would change if it were moved to autarky. In the second, we determine the impact of changes in observed trade flows on each country's skill premium and both of its real wages. Through these counterfactuals, we are interested in gauging the extent to which countries import skill-biased technology embedded in capital equipment and, hence, import a rise in the skill premium. We are not directly concerned with whether a change in trade patterns is driven by changing technologies, labor endowments, or trade costs.

These counterfactuals exploit the simple structure of our model, which allows us to conduct these exercises country-by-country because the impact of changes in any foreign technology, foreign labor endowment, or any trade cost is transmitted only through changes in domestic expenditure shares; this is true both in the exact solution and in the first-order approximation. By taking changes in trade flows as given, we are able to conduct each counterfactual without actually computing the model's full multi-country general equilibrium. Moreover, while we solve for exact changes in real wages and the skill premium in each of our counterfactuals, we also show that our first-order approximations are quite accurate, even for large changes in trade.

Given our parameter estimates, we find that while international trade raises the real wage of both skilled and unskilled workers, it benefits skilled workers disproportionately: in our counterfactuals the percentage point change in the real wage is more than two times greater for skilled workers than for unskilled workers in the median country. While international trade plays an important role in shaping the skill premium through capital-skill complementarity, we find that its importance varies widely across countries in our sample. For example, moving from the trade levels observed in the year 2000 to 1963, or the first year with available data, would imply a reduction in the skill premium of 0.05 log points (about 5%) for the median country in our sample. The decrease in the skill premium is relatively small in the US (0.04 log points), which has a comparative advantage in capital equipment, and is much larger in countries that rely heavily on imports for their capital equipment, including developed countries such as Canada (0.15 log points) and developing countries such as Latvia (0.24 log points). These quantitative results should be treated with caution since the extent of capital-skill complementarity is still an open question, as discussed above. The advantage of our analytic results is that they allow us to consider the impact on our quantitative results of choosing alternative parameter values.

We do not view our paper as providing a full quantitative assessment of the role of international trade in shaping the skill premium.⁷ Instead, our objective in this paper is to

⁷In a related paper, Burstein and Vogel (2012) study the impact of international trade on the skill premium arising from two mechanisms from which we abstract: (i) the Stolper-Samuelson effect and (ii) within-sector factor reallocation in the presence of skill-biased productivity. The presence of firm heterogeneity in skill intensity allows Burstein and Vogel (2012) to discipline their parameters using cross-sectional firm-level

study the impact of international trade in capital equipment, which embodies skill-biased technology, on real wages and the skill premium in a multi-country world. To isolate the impact of this mechanism in a simple and transparent way, we abstract from many other mechanisms through which trade affects relative wages.

Our paper builds on a growing literature empirically documenting the impact of international trade on technological change—see e.g. Pavcnik (2002), De Loeker (2010), Lileeva and Trefler (2010), and Bustos (2011a)—and on the skill intensity of production—see e.g. Verhoogen (2008), Bloom, Draca, and Van Reenen (2011), Bustos (2011b), and Koren and Csillag (2011)—using detailed firm, plant, and sector-level data. These papers provide empirical support for the hypothesis that international trade can generate skill-biased technological change, as posited by, e.g., Acemoglu (2003), Thoenig and Verdier (2003), and Yeaple (2005). Our contribution is to embed a mechanism studied in these papers into a multi-country general equilibrium trade model.

Our paper is most closely related to Parro (2010), who uses a similar model that incorporates capital-skill complementarity to study the impact of trade on the skill premium.⁸ There are two main differences between these two papers. First, we provide a simple expression for the elasticity of a country’s skill premium with respect to each sector’s domestic productivity and domestic expenditure share, which does not depend on changes in trade costs, foreign productivities, foreign labor endowments, or trade shares in other countries. Second, the counterfactuals that we perform are different: whereas we study the overall impact of given changes in trade patterns on the skill premium by exploiting the simple structure of the equilibrium of the model, Parro studies the impact of changing worldwide trade costs and technologies on the skill premium by estimating changes in trade costs and technologies.

2 The Model

Overview: We consider a world economy featuring I countries, indexed by $i = 1, \dots, I$. Within each country, a representative household acquires utility from consumption of manufactured goods and services. Each country is endowed with H_i and L_i efficiency units of skilled and unskilled labor, respectively. Heterogeneous producers of intermediate goods use labor in combination with capital equipment, capital structures, and intermediate inputs. To incorporate capital-skill complementarity, we allow for the elasticity of substitution between skilled labor and capital equipment to differ from that between unskilled labor and

evidence at the expense of losing analytic gravity equations and, hence, simple analytic results on changes in the skill premium.

⁸For an earlier theoretical treatment of trade in skill-complementary capital in a neo-classical growth model, see Stokey (1996).

equipment.

Producers differ in terms of productivity and the sector in which they produce. There are three sectors, indexed by j : (i) a manufacturing sector, $j = M$, in which firms produce tradable goods that are used for consumption and as intermediate inputs; (ii) a service sector, $j = S$, in which firms produce non-tradable goods that are used for consumption, intermediate inputs, and investment in structures; and (iii) a capital equipment sector, $j = E$, in which firms produce tradable goods that are used for investment in capital equipment.⁹ Tradable goods are subject to variable iceberg international trade costs. All labor and goods markets are perfectly competitive.

Preferences: Utility of the representative household is given by

$$\sum_{t=0}^{\infty} \beta^t u \left(C_{i,t}(M)^\phi C_{i,t}(S)^{1-\phi} \right),$$

where $C_{i,t}(M)$ and $C_{i,t}(S)$ denote consumption of manufactured goods and services, respectively, $u(\cdot)$ is a concave sub-utility function defined over aggregate consumption, $\phi \in [0, 1]$ is the share of manufactured goods in consumption, and $\beta \in (0, 1)$ is the discount rate. The household's budget constraint equates consumption and investment expenditures (investment is discussed below) with labor income, payments to capital, and the value of net exports. Given that our steady-state results do not depend on the value of the trade balance, we do not make assumptions on the availability of international financial assets. Given that we focus our attention on steady-state equilibria, in what follows we mostly abstract from time subscripts.

Sectoral output: Sector j uses a continuum of intermediate goods, each indexed by $\omega \in [0, 1]$, according to a CES production function with country- and sector-specific elasticity of substitution $\eta_i(j) > 1$,

$$Y_i(j) = \left\{ \int_0^1 q_i(\omega, j)^{[\eta_i(j)-1]/\eta_i(j)} d\omega \right\}^{\eta_i(j)/[\eta_i(j)-1]}, \quad (1)$$

where $q_i(\omega, j)$ is consumption of intermediate good (ω, j) in country i . Each intermediate good (ω, j) is potentially produced in every country.

Output from the manufacturing sector can be used for consumption, $C_i(M)$, and intermediate inputs, $X_i(M)$:

$$Y_i(M) = C_i(M) + X_i(M). \quad (2)$$

Output from the service sector can be used for consumption, $C_i(S)$, intermediate inputs,

⁹We abstract from government, agriculture, and mining.

$X_i(S)$, and structures investment, $I_i(S)$:

$$Y_i(S) = C_i(S) + X_i(S) + I_i(S). \quad (3)$$

Output from the equipment sector is used only for equipment investment, $I_i(E)$:

$$Y_i(E) = I_i(E). \quad (4)$$

The aggregate law of motion of structures and equipment is

$$K_{i,t+1}(j) = [1 - \delta_i(j)] K_{i,t}(j) + I_{i,t}(j), \text{ for } j = S, E,$$

where we have re-introduced time subscripts to indicate the dynamics, and where $\delta_i(j) \in (0, 1)$ is the depreciation rate of capital of type $j = S, E$ in country i .

Production of intermediate goods: All producers of intermediate good (ω, j) in country i produce according to the following constant returns to scale production function:

$$y_i(\omega, j) = A_i(j) z_i(\omega, j) (x_S^{\varepsilon_i} x_M^{1-\varepsilon_i})^{1-\zeta_i} k_S^{\alpha_i \zeta_i} \times \quad (5)$$

$$\left\{ \mu_i^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1 - \mu_i)^{\frac{1}{\sigma}} \left[\lambda_i^{\frac{1}{\rho}} k_E^{\frac{\rho-1}{\rho}} + (1 - \lambda_i)^{\frac{1}{\rho}} h^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho(\sigma-1)}{(\rho-1)\sigma}} \right\}^{\frac{\sigma(1-\alpha_i)\zeta_i}{\sigma-1}}$$

Producers combine intermediate inputs (of services, x_S , and manufactured goods, x_M) with structures, k_S , capital equipment, k_E , unskilled labor, l , and skilled labor h . The share of value added in gross output is given by ζ_i . As discussed in more detail below, the parameters σ and ρ determine the elasticities of substitution between capital equipment, unskilled labor, and skilled labor. A low value of ρ relative to σ implies that capital equipment is less substitutable with skilled labor than with unskilled labor. In particular, when $\sigma > \rho$ the production function exhibits capital-skill complementarity.¹⁰

Productivity of all country i producers in (ω, j) is given by the product of a country-sector-specific term, $A_i(j)$, shared by all sector j producers in country i , and a country-intermediate-good-specific productivity, $z_i(\omega, j)$, shared by all (ω, j) intermediate good producers in country i . The country-intermediate-good-specific productivity is equal to $z_i(\omega, j) = u^{-\theta_j}$, where u is an *i.i.d* random variable that is exponentially distributed with mean and variance 1. A higher value of θ_j increases the dispersion of productivities across producers within sector j .

¹⁰We use a nested CES so that the elasticities are constant globally. We follow the literature in nesting equipment and skilled labor together.

The production function (5) extends that in KORV to include (i) intermediate inputs; (ii) differences in productivities across sectors, as in a standard Ricardian model, so that countries can have sectoral comparative advantages; and (iii) exponentially distributed country-intermediate-good-specific productivities within a sector, as in EK, so that our multi-country framework remains tractable. In an extension we allow for skill-biased technical change by incorporating exogenous trend growth in the productivity of the composite of skilled labor and capital equipment relative to unskilled labor. While our analytic results are unchanged, our parameter estimates depend on this trend growth.

International trade: Delivering a unit of intermediate good (ω, j) from country i to country n requires producing $\tau_{in}(j) \geq 1$ units of that good in country i , where $\tau_{ii}(j) = 1$. We assume that services are not tradable, so that $\tau_{in}(S)$ is infinite for all $i \neq n$.

Equilibrium: Producers hire unskilled and skilled labor at wages w_i and s_i , respectively, and rent structures and capital equipment at rental rates v_i and r_i , respectively. The skill premium in country i is defined as s_i/w_i . To construct prices, it is useful to define the unit cost of producers of intermediate good (ω, j) producing in country i and selling in country n , $c_{in}(\omega, j)$, where

$$c_{in}(\omega, j) = \frac{c_i \tau_{in}(j)}{A_i(j) z_i(\omega, j)}.$$

Here, c_i is the unit cost of production for the domestic market of a producer of any intermediate (ω, j) in country i with productivity $A_i(j) z_i(\omega, j) = 1$, and is given by:

$$c_i = \kappa_i [P_i(S)^{\varepsilon_i} P_i(M)^{1-\varepsilon_i}]^{1-\zeta_i} v_i^{\alpha_i \zeta_i} \times \left\{ \mu_i w_i^{1-\sigma} + (1-\mu_i) [\lambda_i r_i^{1-\rho} + (1-\lambda_i) s_i^{1-\rho}]^{\frac{1-\sigma}{1-\rho}} \right\}^{\frac{(1-\alpha_i)\zeta_i}{1-\sigma}}$$

where κ_i is a constant, and $P_i(j)$ is the aggregate price of output in sector j .¹¹

The price of intermediate good (ω, j) in country n is:

$$p_n(\omega, j) = \min_i \{c_{in}(\omega, j)\},$$

where we have used the fact that good (ω, j) is perfectly substitutable across all potential source countries that can supply the good to country n . The aggregate price of sector j output in country n is given by

$$P_n(j) = \left[\int_0^1 p_n(\omega, j)^{1-\eta_i(j)} d\omega \right]^{1/[1-\eta_i(j)]}.$$

¹¹The constant is given by $\kappa_i = \left[(1-\zeta_i) \varepsilon_i^{\varepsilon_i} (1-\varepsilon_i)^{1-\varepsilon_i} \right]^{\zeta_i-1} \left[\zeta_i \alpha_i^{\alpha_i} (1-\alpha_i)^{1-\alpha_i} \right]^{-\zeta_i}$

The share of country n 's expenditure in sector j that is allocated to goods from country i , $\pi_{in}(j)$, is given by

$$\pi_{in}(j) = \int_0^1 p_n(\omega, j)_{in}^{1-\eta_i(j)} \mathbb{I}_{in}(\omega, j) d\omega / P_n(j)^{1-\eta_i(j)}.$$

where $\mathbb{I}_{in}(\omega, j)$ is an indicator variable that equals one if country n purchases intermediate good (ω, j) from country i , and equals zero otherwise. The domestic expenditure share is given by $\pi_{ii}(j)$. Using the assumption of exponentially distributed productivities, one can show (see e.g. EK 2002) that in equilibrium

$$\pi_{in}(j) = \left[\tau_{in}(j) \frac{c_i}{A_i(j)} \right]^{-1/\theta_j} / \sum_{k=1}^I \left[\tau_{kn}(j) \frac{c_k}{A_k(j)} \right]^{-1/\theta_j}. \quad (6)$$

In the following sections, we use Equation (6) to solve analytically for the change in the skill premium between any two steady states.

A competitive equilibrium is a set of prices and quantities such that all markets clear. Each producer must satisfy worldwide demand for its output. Sectoral output must satisfy the resource constraints (2), (3), and (4). The demand for unskilled and skilled labor across producers must equal the endowments L_i and H_i , respectively. The demand for intermediate inputs of services and manufacturing must equal $X_i(S)$ and $X_i(M)$, respectively. The demand for structures and capital equipment across producers must equal their supplies $K_i(S)$ and $K_i(E)$. The supplies of each type of capital must be consistent with the household's optimal investment decisions. The household's budget constraints must be satisfied. A steady-state equilibrium is an equilibrium in which all variables remain constant over time. We characterize the steady-state equilibrium in Appendix A.

3 Analytic Results

In this section, we examine the central forces that shape changes in the skill premium and in real wages for skilled and unskilled workers in our model.

3.1 The Skill Premium

Cost minimization implies that producers set the ratio of the marginal product of skilled labor to unskilled labor equal to the skill premium. Equation (5) and the fact that producers in

all sectors use the same factor intensity imply

$$\frac{s_i}{w_i} = \left(\frac{1 - \mu_i}{\mu_i} \right)^{\frac{1}{\sigma}} (1 - \lambda_i)^{\frac{1}{\rho}} \left(\frac{L_i}{H_i} \right)^{\frac{1}{\sigma}} \left[\lambda_i^{\frac{1}{\rho}} \left(\frac{K_i(E)}{H_i} \right)^{\frac{\rho-1}{\rho}} + (1 - \lambda_i)^{\frac{1}{\rho}} \right]^{\frac{\sigma-\rho}{(\rho-1)\sigma}}, \quad (7)$$

exactly as in KORV. From equation (7), changes in country i 's skill premium are fully determined by changes in country i 's endowments of skilled and unskilled labor and changes in its stock of capital equipment. An increase in unskilled labor relative to skilled labor increases the skill premium with an elasticity of $1/\sigma$. An increase in capital equipment relative to skilled labor increases the skill premium if and only if $\sigma > \rho$ (that is, if skilled labor is more complementary with capital equipment than is unskilled labor). This second component captures the capital-skill complementarity effect on the skill premium.

Of course, the stock of capital equipment, $K_i(E)$, is endogenous, and changes in $K_i(E)$ potentially depend on changes in bilateral trade costs (between each pair of countries and in each sector), changes in each country-sector-specific productivity, and changes in labor endowments in each country. We can show, however, that there is a small set of sufficient statistics that fully determine the equilibrium change in the stock of capital equipment and the skill premium across steady-states. Appendix A presents a set of five equations from which the steady-state change in the stock of capital equipment and the skill premium can be calculated for any country i .

For given values of the elasticities of substitution (σ and ρ), the dispersion of productivities θ_j , and factor shares in the initial equilibrium, the change in country i 's skill premium depends only on: (i) changes in domestic expenditure shares, $\pi_{ii}(j)$ for all j ; (ii) changes in domestic technologies, $A_i(j)$ for all j ; and (iii) changes in domestic endowments, H_i and L_i . Importantly, conditional on (i) – (iii), changes in trade costs, changes in other countries' technologies and endowments, and changes in all other trade shares do not affect the change in country i 's skill premium. That is, international trade, foreign technologies, and foreign endowments only affect country i 's skill premium through $\pi_{ii}(j)$. Moreover, for a given change in domestic expenditure shares $\pi_{ii}(j)$, we do not need to compute the multi-country general equilibrium model to calculate the change in country i 's skill premium.

First-Order Approximation for Changes in the Skill Premium: To better understand the role of changes in (i) domestic expenditure shares, (ii) domestic technologies, and (iii) domestic endowments in shaping changes in the skill premium, we log-linearize the steady-state equilibrium equations. In Appendix B we show that the change in the skill

premium is, to a first-order approximation, given by

$$\widehat{s}_i - \widehat{w}_i = -\frac{\xi_i^H + \xi_i^L}{\rho\xi_i^L + \sigma\xi_i^H} \left(\widehat{H}_i - \widehat{L}_i \right) + \Theta_i \sum_j \varkappa_i(j) \left[\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j) \right], \quad (8)$$

where variables with hats denote log differences, ξ_i^H denotes the initial steady-state ratio of skilled labor payments to capital equipment payments, and ξ_i^L denotes the initial steady-state ratio of unskilled labor payments to the sum of all labor payments and payments to capital equipment,

$$\xi_i^H = \frac{s_i H_i}{r_i K_i(E)} \quad \text{and} \quad \xi_i^L = \frac{w_i L_i}{w_i L_i + s_i H_i + r_i K_i(E)}.$$

The elasticity of the skill premium with respect to a change in $\left[\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j) \right]$ is given by $\Theta_i \varkappa_i(j)$, where

$$\Theta_i = \frac{\sigma - \rho}{\rho\xi_i^L + \sigma\xi_i^H} \quad (9)$$

is common across sectors, and where

$$\varkappa_i(j) = \begin{cases} \frac{(1-\zeta_i)\varepsilon_i + \zeta_i\alpha_i}{\zeta_i(1-\alpha_i)} & \text{if } j = S \\ \frac{(1-\zeta_i)(1-\varepsilon_i)}{\zeta_i(1-\alpha_i)} & \text{if } j = M \\ 1 & \text{if } j = E \end{cases} \quad (10)$$

is a function of production function parameters that varies across sectors.

Decomposing changes in the skill premium: Equation (8) decomposes the change in the skill premium into four components. The first component depends on the growth of skilled labor relative to unskilled labor and captures the relative supply effect already present in equation (7). All else equal, an increase in the relative supply of skilled labor reduces the skill premium with an elasticity of $(\xi_i^H + \xi_i^L) / (\rho\xi_i^L + \sigma\xi_i^H)$. Note that if $\sigma = \rho$, so that equipment is equally complementary to skilled and unskilled labor, then this elasticity reduces to $1/\rho$, exactly as in Tinbergen (1974, 1975) and Katz and Murphy (1992), what Autor and Acemoglu (2010) call the *canonical model*.

The second, third, and fourth components ($j = S, M$, and E) are all contained in the summation term in equation (8). Each component depends on changes in sector j 's productivity and domestic expenditure share and captures the capital-skill complementarity effect. All else equal, an increase in $\left[\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j) \right]$ raises the skill premium with an elasticity of $\Theta_i \varkappa_i(j)$, where $\varkappa_i(j) \geq 0$ for all j . If $\sigma > \rho$, so that $\Theta_i > 0$, then an increase in the supply of capital equipment relative to skilled labor increases the skill premium, as

shown in equation (7). Here, we describe why an increase in $\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j)$ for all j tends to raise $K_i(E)$, and hence the skill premium.

Intuitively, country i 's stock of equipment rises either through increased domestic production or increased imports of equipment. All else equal, country i produces more equipment as $A_i(E)$ rises and imports more equipment as $\pi_{ii}(E)$ falls.

Country i 's supply of equipment also rises with an increase in $\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j)$ for $j = S, M$. Intuitively, in equilibrium $X_i(S)$ and $X_i(M)$ rise with $\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j)$ for $j = S$ and $j = M$, respectively, for the same reason that $K_i(E)$ rises with $\widehat{A}_i(E) - \theta_j \widehat{\pi}_{ii}(E)$. Because $X_i(S)$ and $X_i(M)$ are used as inputs in the production of equipment, the stock of equipment rises as well. Moreover, the stock of capital equipment increases with $\widehat{A}_i(S)$ even if services are not used as intermediate inputs, i.e., even if $\varepsilon_i = 0$, because structures are used directly as an input in production if $\zeta_i > 0$.

The elasticity of the skill premium: Equation (8) provides the elasticity of a country's skill premium with respect to each of its sectoral productivities, $\Theta_i \varkappa_i(j)$, and each of its domestic sectoral expenditure shares, $-\Theta_i \varkappa_i(j) \theta_j$. These elasticities have clear economic interpretations that highlight the roles played by different model parameters and they allow us to conduct sensitivity analyses analytically.

A higher value of within-sector technological dispersion, θ_j , tends to magnify the impact of changes in trade shares on the skill premium. This follows from the fact that for a given domestic expenditure share in the equipment sector (as an example), the increase in the stock of equipment generated by trade is greater for higher values of θ_j . Intuitively, when productivity dispersion rises, the cost differential between imported varieties and the domestic varieties they replace becomes greater, so that the same reduction in the domestic expenditure share leads to a greater increase in the stock of equipment.

Similarly, a higher value of the elasticity $\Theta_i \varkappa_i(j)$ tends to magnify the impact of changes in $\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j)$ on the skill premium. A higher value of Θ_i corresponds to stronger capital-skill complementarity. Inspecting equation (10), it is apparent that sectors that are more important in the production of capital equipment have a higher value of $\varkappa_i(j)$, and hence have a higher elasticity of the skill premium with respect to $\widehat{A}_i(j) - \theta_j \widehat{\pi}_{ii}(j)$. Perhaps surprisingly, the sum of the elasticities of manufacturing and services can potentially be larger than that of equipment. Intuitively, this is more likely to occur when manufacturing and services play a larger role in the production of equipment, which occurs if the share of intermediate inputs in production is high (i.e., if ζ_i is low) and if the share of services in value added is high (i.e., if α_i is high). Note that the equipment stock and the skill premium rise if there is growth in technology and trade in manufacturing, equipment, or services—regardless of the sector in which growth is greatest—whereas the price of equipment relative

to consumption falls if technological and trade growth are relatively larger in the equipment sector, e.g.,

$$\widehat{P}_i(E) - \widehat{P}_i(M) = \widehat{A}_i(M) - \widehat{A}_i(E) + \theta_E \widehat{\pi}_{ii}(E) - \theta_M \widehat{\pi}_{ii}(M).$$

Hence, an increase in the stock of equipment is not necessarily accompanied by a decline in the relative price of equipment to consumption goods, and vice versa.

Summary: We summarize the previous results in the following Proposition.

Proposition 1 *In any equilibrium, the skill premium in country i is given by equation (7), and the change in the skill premium in country i across two steady-states is, to a first-order approximation, given by equation (8).*

3.2 Real wages

Whereas our previous focus has been on the skill premium, most of the quantitative trade literature focuses on gains from trade. Here we show that our framework also yields clear predictions on how changes in (i) domestic expenditure shares, (ii) domestic technologies, and (iii) domestic endowments shape changes in real wages for skilled and unskilled workers. Real wages of skilled and unskilled workers are simply $s_i/P_i(C)$ and $w_i/P_i(C)$ respectively, where

$$P_i(C) = \frac{P_i(S)^{1-\phi} P_i(M)^\phi}{\phi^\phi (1-\phi)^{1-\phi}}.$$

In Appendix B we show that changes in real skilled and unskilled wages are, to a first-order approximation, given by

$$\widehat{s}_i - \widehat{P}_i(C) = -\xi_i^L \frac{1 + \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} \left(\widehat{H}_i - \widehat{L}_i \right) + \sum_j \nu_i(j) \left[\widehat{A}_i(j) - \theta \widehat{\pi}_{ii}(j) \right] \quad (11)$$

and

$$\widehat{w}_i - \widehat{P}_i(C) = \frac{(1 - \xi_i^L) \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} \left(\widehat{H}_i - \widehat{L}_i \right) + \sum_j [\nu_i(j) - \Theta_i \varkappa_i(j)] \left[\widehat{A}_i(j) - \theta \widehat{\pi}_{ii}(j) \right], \quad (12)$$

where

$$\nu_i(j) = \begin{cases} \frac{\sigma(1+\xi_i^H)}{\rho \xi_i^L + \sigma \xi_i^H} \frac{\zeta_i + \varepsilon_i - \zeta_i \varepsilon_i}{\zeta_i(1-\alpha_i)} - \frac{\sigma - \rho \xi_i^L}{\rho \xi_i^L + \sigma \xi_i^H} - \phi & \text{if } j = S \\ \frac{\sigma(1+\xi_i^H)}{\rho \xi_i^L + \sigma \xi_i^H} \frac{(1-\zeta_i)(1-\varepsilon_i)}{\zeta_i(1-\alpha_i)} + \phi & \text{if } j = M \\ \frac{\sigma - \rho \xi_i^L}{\rho \xi_i^L + \sigma \xi_i^H} & \text{if } j = E \end{cases}$$

is a function of production function parameters and factor shares that varies across sectors. Note that equations (11) and (12) together imply equation (8).

Decomposing changes in real wages: Equations (11) and (12) decompose changes in real wages into four components. The first component depends on the growth of skilled labor relative to unskilled labor and captures the relative supply effect. All else equal, the real wage of a given factor is decreasing in its relative supply.

The second, third, and fourth components ($j = S, M,$ and E) are all contained in the summation terms in equations (11) and (12). Each component depends on changes in sector j 's productivity and domestic expenditure share, and captures both the effects of trade and productivity growth on the real wage in standard quantitative trade models as well as the capital-skill complementarity effect. To see the standard effects, consider the case in which capital is equally complementary with skilled and unskilled labor, $\sigma = \rho$. In this case $\Theta_i = 0$ so that changes in $\widehat{A}_i(j) - \theta\widehat{\pi}_{ii}(j)$, for any j , have the same effects on the real wages of skilled and unskilled workers. Specifically, in this case a rise in $\widehat{A}_i(j) - \theta\widehat{\pi}_{ii}(j)$ raises the real wage of both factors, as $\nu_i(j) > 0$ for all j . In the presence of capital-skill complementarity, however, changes in $\widehat{A}_i(j) - \theta\widehat{\pi}_{ii}(j)$ have different effects on skilled and unskilled workers as discussed above. Specifically, an increase in $\widehat{A}_i(j) - \theta\widehat{\pi}_{ii}(j)$, for any j , raises the real wage of skilled workers relatively more than the real wage of unskilled workers.¹²

As in the section on the skill premium, equations (11) and (12) provide the elasticity of skilled and unskilled real wages in country i with respect to each of i 's sectoral productivities and each of its domestic sectoral expenditure shares.

Summary: We summarize the previous results in the following Proposition.

Proposition 2 *The changes in real wages for skilled and unskilled workers in country i across two steady-states are, to a first-order approximation, given by equations (11) and (12), respectively.*

3.3 Differences in Factor Intensities Across Sectors

In the Online Addendum we briefly discuss an extension of our basic environment that relaxes our assumption that factor intensities are common across sectors. In particular,

¹²In response to increases in trade shares in any sector ($\widehat{\pi}_{ii}(j) < 0$), the real wage of unskilled workers increases for any value of σ and ρ , while the real wage of skilled workers may fall if skilled labor is sufficient substitutable with capital equipment ($\sigma \ll \rho$). However, this result depends on the specific form of our production function. Reversing the nest in the production function (i.e. nesting equipment and unskilled labor together) we obtain the opposite result: the real wage of skilled workers increases in response to $\widehat{\pi}_{ii}(j) < 0$ for any degree of capital-skill complementarity, while the real wage of unskilled workers may fall if unskilled labor is sufficient substitutable with equipment capital.

we allow for the parameters of the production function $\{\varepsilon, \zeta, \alpha, \mu, \lambda, \rho, \sigma\}$ to all vary across sectors. We show that changes in a country’s skill premium are not only determined by changes in domestic productivities, domestic labor endowments, and domestic expenditure shares—as in our baseline model—but also by changes in the factor-content of trade (i.e., the amount of each factor embodied in a country’s net exports).¹³ This extended model thus embeds the standard Stolper-Samuelson effect, through which international trade raises the relative return of the factor used intensively in the comparative advantage sector. We show, however, that conditional on observing changes in domestic productivities, domestic labor endowments, domestic expenditure shares, and the factor-content of trade in country i , one can still calculate changes in country i ’s skill premium without actually computing the multi-country general equilibrium model. To isolate the role of capital-skill complementarity on the skill premium, and because of data limitations on sectoral factor intensities for multiple countries, in our quantitative analysis we assume that factor intensities are common across sectors.

4 Quantitative Results

In this section we use our model to quantify the impact of changing trade flows on real wages of skilled and unskilled workers and the skill premium in multiple countries. We conduct two counterfactuals. In the first, we determine how much each country’s skill premium and its real wages would change if it were moved to autarky—in which case trade costs are set to infinity—starting in the baseline year 2000. In the second, we determine the impact of changes in observed trade flows between 2000 and 1963, or the first year for which we have data for the country under consideration.

Through these counterfactuals we are interested in addressing the extent to which countries import skill-biased technology embedded in capital equipment and, hence, import a rise in the skill premium. We are not directly concerned with whether a change in trade patterns is driven by changing technologies or by changing trade costs. Hence, we take as given changing trade flows in the second counterfactual, without determining their underlying causes.

These counterfactuals exploit the simple structure of our model, which allows us to conduct these exercises country-by-country because the impact of changes in any foreign technology, foreign factor endowment, or trade cost is transmitted only through changes in domestic expenditure shares, which we take as given. Hence, we are able to conduct each

¹³See Burstein and Vogel (2011) for a discussion of the factor content of trade in a general class of trade models.

counterfactual without computing the full multi-country general equilibrium.

While we solve for exact changes in the skill premium, using the system of equations provided in Appendix A, the intuition for our results all derive from equations (8), (11), and (12) which provide first-order approximations. We replicate these two counterfactuals using only equations (8), (11), and (12) and show that these approximations are quite accurate.

To conduct our counterfactuals we need information on domestic expenditure shares, $\pi_{ii}(j)$, and we need to assign values to our model's parameters. In what follows, we first describe how we construct domestic expenditure shares and how we parameterize the model. Further details are provided in Appendix C. Finally, we present the quantitative results.

4.1 Domestic Expenditure Shares

To construct domestic expenditure shares in equipment and manufacturing, $\pi_{ii}(E)$ and $\pi_{ii}(M)$, we use trade and production data and compute expenditures as the difference between gross output and net exports. Trade data comes from Feenstra et. al. (2005), which contains data by commodity, disaggregated at the 4-digit Standard International Trade Classification (SITC) level, for the 1962-2000 period. For gross output data, we use the UNIDO Industrial Statistics Database, which covers the 1963-2007 period and is arranged at the 2-digit level of the third revision of the International Standard Industrial Classification (ISIC Rev. 3). Recall that we abstract from trade in non-manufacturing industries (which, in our model, means that we abstract from trade in the non-manufacturing, non-equipment sectors).

We follow Eaton and Kortum (2001), who group manufactured commodities into equipment goods and other manufacturing goods using input-output tables and capital flows tables of domestic transactions (OECD, 1996) for the three major capital goods producers (Germany, Japan, and the US). For trade data, we match 4 digit SITC codes to a set of industry codes used by the Bureau of Economic Analysis (BEA). Following Eaton and Kortum, we define equipment trade as the sum of BEA industry codes 20-27 and 33.

For gross output data, Eaton and Kortum identify three ISIC Rev. 2 industries as equipment producers: non-electrical equipment, electrical equipment, and instruments. We define equipment producers as the ISIC Rev. 3 industries that most closely correspond to the ISIC Rev. 2 industries identified by Eaton and Kortum.¹⁴ In particular, we define equipment commodities to be the sum of ISIC Rev. 3 codes 29-33.

After combining these datasets, we are left with 53 countries for which data both on trade and output is available until at least 1995. For each country in our sample, our counterfactuals are based on the first and last year with available data. Importantly, we do

¹⁴UNIDO discontinued its Industrial Statistics Database using ISIC Rev. 2.

not require a balanced panel because we do not need data on changes in any country $n \neq i$ when solving for the change in the skill premium in country i in our counterfactuals.

We report the resulting domestic expenditure shares in Table 2. Two features are striking from the table. First, as noticed by Eaton and Kortum (2001), most countries import a significant fraction of their capital equipment. For the median country in our sample, the import share of equipment in the year 2000 is roughly $1 - 0.25 = 0.75$, more than twice as large as the import share for other manufactured goods. Note that these import shares are large for countries at different stages of the development process, including developed countries such as Canada and the UK. Second, most countries experienced sizable increases in their import shares over our sample period, especially in the equipment sector. A notable exception are the poorest countries in the sample, which were already importing almost all of their equipment at the beginning of the sample. The median values across countries for the changes in the domestic expenditure shares in equipment and manufacturing, $\hat{\pi}_{ii}(E)$ and $\hat{\pi}_{ii}(M)$, are -0.3 and -0.15 , respectively.

The fact that $\pi_{ii}(E)$ tends to be lower in developing countries might suggest that the relative price level of equipment is higher in these countries; see e.g. Eaton and Kortum (2001) and Hsieh and Klenow (2007). In our model, this relative price depends on a combination of trade costs and productivities in each country. Since our parameterization does not separately identify trade costs and productivities in each country, our paper is silent on our model's implications for these relative prices.¹⁵

4.2 Parameterization

By inspecting the set of equations that determines the change in the skill premium in our counterfactuals (described in Appendix A) and in the log-linearized equation (8), the parameters that we must choose are those that determine the elasticities of substitution between capital equipment, unskilled labor, and skilled labor, σ and ρ ; the within-sector dispersion of productivity, θ_j ; the constant share of value added in production, ζ_i ; the constant share of services in intermediate inputs, ε_i ; the constant share of structures in value added, α_i , and the constant share of manufacturing in consumption, ϕ_i . We must also assign values to relative factor shares ξ_i^L and ξ_i^H in the initial equilibrium (the year 2000). These parameters determine the elasticity of the skill premium with respect to trade shares given by $\Theta_i \varkappa_i(j) \theta_j$ in equation (8). Given values for these parameters, we do not need to assign values to other model parameters such as μ_i and λ_i . Because of data availability, we assume that all of

¹⁵Waugh (2010) shows that quantitative Ricardian models are consistent with observed differences across countries in the level of tradeable goods prices if one allows for asymmetric trade costs (e.g. $\tau_{in}(j) \neq \tau_{ni}(j)$), as we do in this paper.

the above parameters are common across countries and sectors. Given data availability it would be straightforward to run our counterfactuals allowing these parameters to vary across countries. We now provide an overview of our baseline procedure, the results of which are summarized in Table 1.

Baseline parameterization: We set $\theta_j = 0.2$ for all j . This parameter, which controls the within-sector dispersion of productivity, plays a central role in quantitative trade models because it determines the elasticity of imports with respect to trade costs in equilibrium, as can be seen in equation (6). Our choice of $\theta = 0.2$ implies an elasticity of 5, which is within the range of elasticities estimated in the trade literature; see, e.g., Eaton and Kortum (2002), Bernard, Eaton, Jensen, and Kortum (2003), Anderson and Van Wincoop (2004), Donaldson (2010), Simonovska and Waugh (2011), Eaton, Kortum and Kramarz (2011), and Costinot, Donaldson, and Komunjer (Forthcoming).

We pick $\phi, \zeta, \varepsilon, \alpha, \sigma, \rho, \xi^L, \xi^H$ to match certain features of US data between 1963 and 2000. The share of manufacturing in households' consumption, ϕ , the share of value added in gross output, ζ , and the share of services in intermediate inputs, ε , are set at their average shares in 1995 and 2000 from the OECD Input-Output database.¹⁶ We calibrate the share of structures in value added, α , and relative factor shares in the initial equilibrium (the year 2000), ξ^L and ξ^H , to match observed factor shares in the US. Annual estimates for these shares are obtained as follows. We calculate the labor share in value added from NIPA as the ratio of compensation for employees to value added less taxes, in the corporate and non-corporate business sector. We disaggregate labor payments into skilled and unskilled labor using data on quantities and prices of skilled and unskilled labor from Polgreen and Silos (2008), who use detailed CPS data. We disaggregate capital payments into structures and equipment using data on the value of capital stocks and, since rental rates are not directly observable, using the steady-state Euler equations of our model for the accumulation of each type of capital, where a time period represents a year. We set α equal to the share of payments to structures capital in total factor payments on average between 1963 and 2000. We set ξ^L and ξ^H in the original equilibrium (year 2000) equal to the respective relative factor shares on average between 1996 and 2000.¹⁷ This procedure implies $\alpha = 0.1$, $\xi^L = 0.44$, and

¹⁶In calculating these statistics, we only consider consumption, valued added, gross output, and intermediates of manufacturing (which includes equipment and non-equipment manufacturing in our model) and service industries in the IO tables. The resulting parameter values are $\phi = 0.2$, $\zeta = 0.54$ and $\varepsilon = 0.62$.

¹⁷Consistent with our model, factor shares ξ^H and ξ^L in the U.S. changed considerably in our time period (e.g. the payments to capital equipment rise over time relative to the payments to skilled labor). While our baseline year (the initial equilibrium) is 2000, we use the average estimated shares in the period 1996-2000 to reduce measurement error. Using instead the average estimates of factor shares between 1963 and 2000, the elasticity of the skill premium to trade flows is significantly larger than in our baseline parameterization.

$\xi^H = 1.37$.¹⁸ Further details are provided in Appendix C.

The two final and key parameters whose values we need to pick are σ and ρ . We pursue several strategies to parameterize these. In our baseline parameterization, we calibrate σ and ρ so that our model reproduces the observed *cumulative* changes in factor shares and the skill premium in the US between 1963 and 2000, given the observed changes in the supplies of capital equipment and of skilled and unskilled labor. In particular, we use the two following equations

$$\rho^{-1} = 1 + \frac{\widehat{\xi^H}}{\widehat{K(E)/H}} \quad (13)$$

$$\sigma = \frac{(\rho - 1) \widehat{(H/L)} + \rho \widehat{(1 + 1/\xi^H)}}{(1 - \rho) \widehat{(s/w)} + \widehat{(1 + 1/\xi^H)}}, \quad (14)$$

where variables with hats denote log differences between 1963 and 2000. Equation (13) is obtained by log-differentiating the producers' first-order condition for capital equipment relative to skilled labor. Equation (14) is obtained by log-differentiating equation (7). In solving for ρ and σ , we use data on changes in the skill premium and on the stocks of (quality adjusted) capital equipment, skilled labor and unskilled labor from Polgreen and Silos (2008). This procedure implies $\rho = 0.63$ and $\sigma = 1.56$.¹⁹

With these parameters, the elasticity of the skill premium with respect to $\widehat{A}_i(j) - \theta \widehat{\pi}_{ii}(j)$ in all countries is $\Theta = 0.39$ for equipment goods and $\Theta_{\varkappa_i}(M) = 0.39 \times 0.36 = 0.14$ for manufacturing goods, from equation (8).²⁰ Together with our value of θ , this implies an elasticity of the skill premium with respect to domestic expenditure shares $\theta \Theta_{\varkappa}(j)$ in equipment and manufacturing of 0.077 and 0.028, respectively. Conducting sensitivity analyses of these elasticities with respect to changes in parameter values is straightforward using equation (8).

Alternative parameterizations of σ and ρ : We pursue several alternative strategies to

¹⁸We assume that factor shares are identical across countries because of data limitations only. If, contrary to our assumption, developing countries have lower equipment shares (or lower skill shares), then Θ_i would be lower (higher) in developing countries. Our assumption that the labor share is not systematically correlated with a country's level of development is consistent with evidence in Gollin (2002). In our model the labor share changes in response to the changes in trade shares we feed in from the data, but quantitatively these changes are very small.

¹⁹In a multi-factor production function there are several alternative definitions of the elasticity of substitution between two factors. In our baseline parameterization, the Allen partial elasticity of substitution between skilled and unskilled labor is 1.56 while the direct partial elasticity of substitution between these two factors is 1.04, using the definitions in Sato (1967).

²⁰Using measures of changes in labor supplies and the skill premium from Acemoglu and Autor (2010) we obtain $\Theta = 0.40$. If we parameterize our model using data from 1963 to 1992 as in KORV (as opposed to 1963-2000), we obtain $\Theta = 0.35$. Using the values of the elasticities σ and ρ estimated in KORV we obtain $\Theta = 0.39$.

parameterize ρ and σ . First, rather than calibrating ρ and σ so that our model reproduces the observed *cumulative* changes in factor shares and the skill premium in the US between 1963 and 2000, we estimate ρ and σ via non-linear least squares, using equations (13) and (14) and annual changes in factor shares and the skill premium in the US over the same time period. We obtain $\rho = 0.66$ and $\sigma = 1.47$,²¹ which imply $\Theta = 0.35$.

Second, we calibrate our model allowing for skill-biased technical change, an additional mechanism to capital-skill complementarity that raises the skill premium over time. Specifically, we allow for exogenous trend growth in the productivity of the composite of skilled labor and capital equipment relative to unskilled labor, extending the approach of Katz and Murphy (1992). To do so we replace the term $(1 - \mu_i)^{1/\sigma}$ in equation (5) with $A(t)(1 - \mu_i)^{1/\sigma}$, where $A(t) = \exp(\varphi t)$ and φ denotes the annual trend.²² We adjust equation (14) accordingly. Feeding in a value of $\varphi = 0.01, 0.02, \text{ or } 0.03$ into our calibration procedure lowers Θ from 0.39 to 0.30, 0.22, or 0.15, respectively. The annual trend would have to be as large as $\varphi = 0.052$ in order for capital-skill complementarity to be absent, i.e. $\rho \geq \sigma$.

Finally, to assess the degree of capital-skill complementarity in a developing country that is a net importer of capital equipment, we re-parameterize ρ and σ using data from Chile. We use data on changes in the skill premium and on the stocks of capital equipment (not adjusted for quality), skilled labor and unskilled labor for the time period 1974-2000 from Gallego (Forthcoming). We adjust the stock of capital equipment using the same adjustment factor as in the US, obtained from Polgreen and Silos (2008). We calculate the labor share in value added as the ratio of the sum of compensation for employees and the surplus of enterprises owned by households to the sum of compensation for employees and all operating surplus.²³ Due to a lack of data on prices and on depreciation rates of capital equipment and structures, we assume that the share of structures in value added is the same in Chile as in the US, $\alpha = 0.1$. Since the Chilean data series is much more volatile than that in the US, our baseline calibration is more sensitive to the two years chosen. Nevertheless, we always find that there is strong capital-skill complementarity. When we estimate ρ and σ using annual changes in factor shares and the skill premium in Chile over the years 1974-2000 we obtain $\rho = 0.53$ and $\sigma = 1.54$.²⁴ Together with the factor shares, these elasticities imply $\Theta = 0.54$. Given our Chilean parameter estimates, the elasticity of the skill premium with respect to $\hat{A}_i(j) - \theta\hat{\pi}_{ii}(j)$ is $\Theta = 0.54$ for equipment goods and is $\Theta\kappa_i(M) = 0.54 \times 0.46$

²¹The standard errors on our estimates of ρ and σ are 0.016 and 0.076, respectively.

²²As an example, $\varphi = 0.01$ implies that the skill premium rises by 1% per year, all else equal.

²³We only have data on surplus of enterprises owned by households (Mixed Income) between 1996-2002. We assume that in the years 1974-2000, the ratio of Mixed Income to Operating Surplus equals 0.196, which is the average for the 1996-2002 period. The source of this data is the National Accounts Official Country Data from the United Nations Statistics Division.

²⁴The standard errors on our estimates of ρ and σ are 0.037 and 0.202, respectively.

= 0.25 for manufacturing goods.²⁵ The elasticities ρ and σ are very close to those that we had calibrated and estimated using US data, as is $\varkappa_i(M)$, while Θ is larger due to differences in our measures of factor shares between Chile and the US. The Chilean parameter values are listed in Table 1.

4.3 Results

We now quantify the impact of international trade, through capital-skill complementarity, on real wages and the skill premium.²⁶ We perform two counterfactual exercises using our baseline parameterization. We do not report the results from the alternative parameterizations since these can be calculated immediately using the analytic expressions presented above.

Counterfactual 1—Autarky: In our first counterfactual, we ask: By how much would real wages and the skill premium change if countries move from the trade levels observed in 2000 to autarky in both equipment and manufacturing (by increasing trade costs to infinity)? The counterfactual implications for real wages and the skill premium are reported in Table 3. The results of our first counterfactual exercise are summarized in Figures 1 and 2. Figure 1 plots the logarithmic change in real wages of skilled and unskilled workers in each country (y-axis). Given our emphasis on international trade in capital goods, we plot on the x-axis the log change of the domestic expenditure share in the equipment sector moving from the year 2000 to autarky. Figure 1 establishes two results. First, moving to autarky, real wages fall for both skilled and unskilled workers in all countries, and, as in most standard models, fall relatively more in countries that experience a larger increase in domestic expenditure shares, both in equipment and in manufacturing, as implied by equations (11) and (12). Second, the losses from moving to autarky are unevenly distributed within countries. While both factors lose, skilled workers lose disproportionately. The ratio of the change in a skilled worker’s real wage relative to the change in an unskilled worker’s real wage, $\Delta \log(s_n/P_n)/\Delta \log(w_n/P_n)$, is 2.26 in the median country.

This ratio can be expressed as a function of the log change in the skill premium

$$\frac{\Delta \log(s_n/P_n)}{\Delta \log(w_n/P_n)} = 1 + \frac{\Delta \log(s_n/w_n)}{\Delta \log(w_n/P_n)}.$$

Figure 2 plots the logarithmic change in the skill premium (y-axis)—i.e. the vertical distance

²⁵The share of value added in gross output ζ , and the share of services in intermediate inputs, ε , used to compute $\varkappa_i(M)$ for Chile are set at their average shares in 1996 and 2003 from the OECD Input-Output database.

²⁶In our model, real wages do not equal welfare because net exports are not zero.

between changes in log real wages of skilled and unskilled workers plotted in Figure 1—and the log change in the domestic expenditure share in the equipment sector moving from the year 2000 to autarky (x-axis). Absent international trade in both capital equipment and manufactures the skill premium falls in all countries. The log of the skill premium falls by roughly 0.13 in the median country. While the skill premium falls everywhere, the decrease is much larger for countries that are very dependent on imports of capital equipment, such as Cameroon and the Czech Republic. On the other extreme, the decline in the log of the skill premium is only 0.02 for Japan and 0.04 for the US.

Figure 2 also shows the log change in the skill premium resulting from shutting down trade in equipment goods only, while keeping trade shares in the manufacturing sector constant; recall that we refer to non-equipment manufacturing simply as manufacturing. The skill premium falls by less when only equipment trade is shut down because manufacturing imports raise the stock of equipment and, therefore, the skill premium. The role of (non-equipment) manufacturing trade in shaping the skill premium is large for some countries such as Bulgaria, Slovakia, and Greece, which import a substantial share of their manufacturing absorption. However, for most countries, trade in equipment is significantly more important than trade in manufacturing in driving the change in the skill premium, because both the 2000 import share and the elasticity of the skill premium with respect to a change in the import share are larger for equipment than for manufacturing.

The first-order approximation of the change in the skill premium from going to autarky implied from equation (8) is quite accurate. Across our set of countries, the median and maximum differences between the exact and approximated changes in the skill premium are 0.01 and 0.08 log points, respectively (which represent 7% and 20%, respectively, of the exact changes in the skill premium). Of course, the approximation error is larger for countries with lower domestic expenditures shares. The first-order approximations of the changes in the real wages of skilled and unskilled workers are similarly accurate.

Counterfactual 2—Observed changes in trade shares: In our second counterfactual, we ask: By how much would the skill premium change if countries move from the trade levels observed in 2000, or the closest year with available information, to those observed at the beginning of the sample period? This counterfactual shows the impact of observed changes in trade flows on each country’s skill premium during our sample period. This counterfactual change in trade disproportionately impacts skilled workers: the ratio of the change in a skilled worker’s real wage relative to the change in an unskilled worker’s real wage, $\Delta \log (s_n/P_n) / \Delta \log (w_n/P_n)$, is 2.29 in the median country.

The results on the skill premium are summarized in Figure 3, which plots the logarithmic change in the skill premium (y-axis) and the logarithmic change in the domestic expenditure

share in the equipment sector (x-axis). International trade plays an important role in shaping the skill premium through capital-skill complementarity, but its importance varies widely across countries in our sample depending on the magnitude of the changes in the domestic expenditure shares in equipment and other manufactured goods. While the counterfactual change in the skill premium is -0.05 log points for the median country of our sample and -0.04 log points for the US, the decline in the skill premium is quite large in various developing countries such as Argentina, Chile, Colombia, Greece, and Uruguay, and in some developed countries such as Canada and the UK.²⁷ Note that for countries in the northwest corner of Figure 3, domestic expenditure shares in the equipment sector rose during our sample period, so that moving from the domestic expenditure shares in equipment observed in 2000 to those in the base year contributes to increasing the skill premium. Once again, trade in equipment plays a more significant role than trade in other manufactured goods in shaping the change in skill premium.

As in the previous counterfactual exercise, the first-order approximation of the change in the skill premium from equation (8) is quite accurate. The median and maximum differences between the exact and approximated changes in the skill premium are only 0.002 and 0.03 log points, respectively (which represent 4% and 13% of the exact changes in the respective skill premia). The first-order approximations of the changes in the real wages of skilled and unskilled workers are similarly accurate.

5 Conclusions

Given the difficulty of empirically measuring the impact of international trade on the aggregate stock of capital equipment and, through capital-skill complementarity, the skill premium, we use a model to do so in this paper. Our framework combines a standard quantitative trade model with a basic component of macroeconomic models of inequality, an aggregate production function that exhibits capital-skill complementarity. We provide simple analytic expressions relating steady-state changes in the skill premium and the real wages of skilled and unskilled workers to changes in domestic expenditure shares, domestic productivities, and domestic labor endowments. Changes in domestic expenditure shares fully summarize the effects of all changes in trade patterns, whether generated by changes in

²⁷For some countries, these number are quite large when compared to the observed increase in the skill premium over a similar time period. For example, the skill premium increased 22% in Canada between 1978-2006, 12% in the UK between 1978-2005, 20% in Argentina between 1992-1998, and 16% in Colombia between 1986-1998; see Krueger et. al. (2010) and Goldberg and Pavnick (2007). For the U.S., the number is not very large relative to the 25% rise in the composition-adjusted skill premium between 1963-2000; see Acemoglu and Autor (2010). Unfortunately, there is not reliable data on changes in the skill premium for many countries.

foreign technologies, domestic technologies, or trade costs. Using these results, we perform a range of simple counterfactual exercises to assess the importance of international trade on real wages and, through capital-skill complementarity, on the skill premium. We find that international trade can have a substantial impact on the skill premium, especially in countries that import a large fraction of their equipment. While our quantitative analysis is only suggestive—as there is an active debate on the role of capital-skill complementarity in accounting for changes in the skill premium—we view our main contribution as providing a simple set of analytic equations linking observable changes in domestic sectoral expenditure shares to changes in the real wages of skilled and unskilled workers for any given parameter values.

In our quantitative analysis, we make three choices in the pursuit of tractability that deserve further discussion. First, we focus on steady-state equilibria, abstracting from transition dynamics as countries open up to trade and gradually accumulate capital; see e.g. Stokey (1996). Second, we parameterize the degree of capital-skill complementarity to match observed changes in aggregate factor shares and the skill premium in the US and in Chile. An alternative approach would be to make use of micro-level evidence on the relationship between skill intensity and capital intensity at the producer level. This would require extending the model to allow for heterogeneity in factor intensities across producers within a country and sector.²⁸ Third, we assume that the degree of capital-skill complementarity is common across each type of capital equipment. If, however, different types of equipment exhibit different degrees of capital-skill complementarity, then countries might choose to invest in and import different mixes of equipment depending on their relative endowment of skilled to unskilled labor; see e.g. Caselli and Wilson (2004).²⁹

While we focus on the implications of changes in trade patterns for real wages and the skill premium, our framework can be applied to study the importance of skill-biased technical change as well. In particular, by incorporating factor-specific technical change into our production function, as we do in the sensitivity analysis in Section 4.2, we obtain an equation that extends Tinbergen’s (1974, 1975) pioneering work—what Autor and Acemoglu (2010) call the *canonical model*—to include the effects on the skill premium not only of labor endowment and skill-biased technical changes, but also of changes in the pattern of international trade.

²⁸Burstein and Vogel (2012) provide a related model in which producer productivity is positively correlated with skill intensity. With this heterogeneity, one loses the tractable gravity structure of the model, even at the sectoral level.

²⁹Such an extension would have to be consistent with our finding that the extent of capital-skill complementarity is similar in the US and Chile. Moreover, if imported capital exhibits a greater degree of capital-skill complementarity than domestically produced capital, then trade would raise the skill premium.

Finally, in this paper we model the international transfer of skill-biased technology through trade in capital goods. We abstract from other potentially important channels by which technologies diffuse across countries, such as multinational production, see, e.g., Burstein and Monge-Naranjo (2009) and Ramondo and Rodriguez-Clare (2010); migration, see, e.g., Gandal, Hanson, and Slaughter (2004); or spillovers, see, e.g., Coe and Helpman (1995) and Gancia, Müller, and Zilibotti (2010). We also abstract from endogenous skill-biased technical change through innovation, see, e.g., Acemoglu (2003). Understanding the quantitative link between globalization and inequality through these alternative channels remains an important area for future research.

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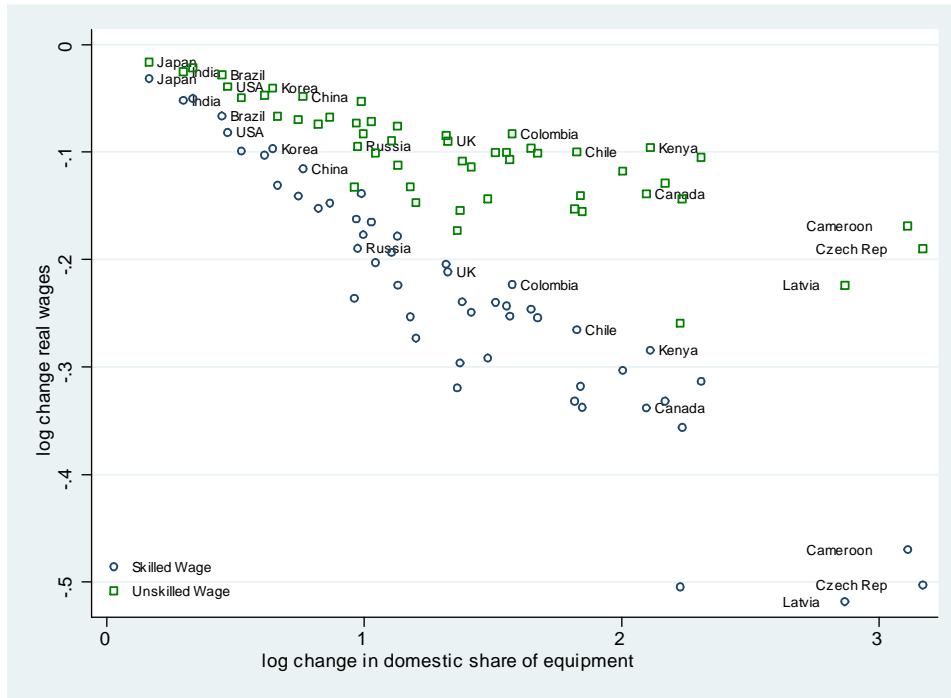
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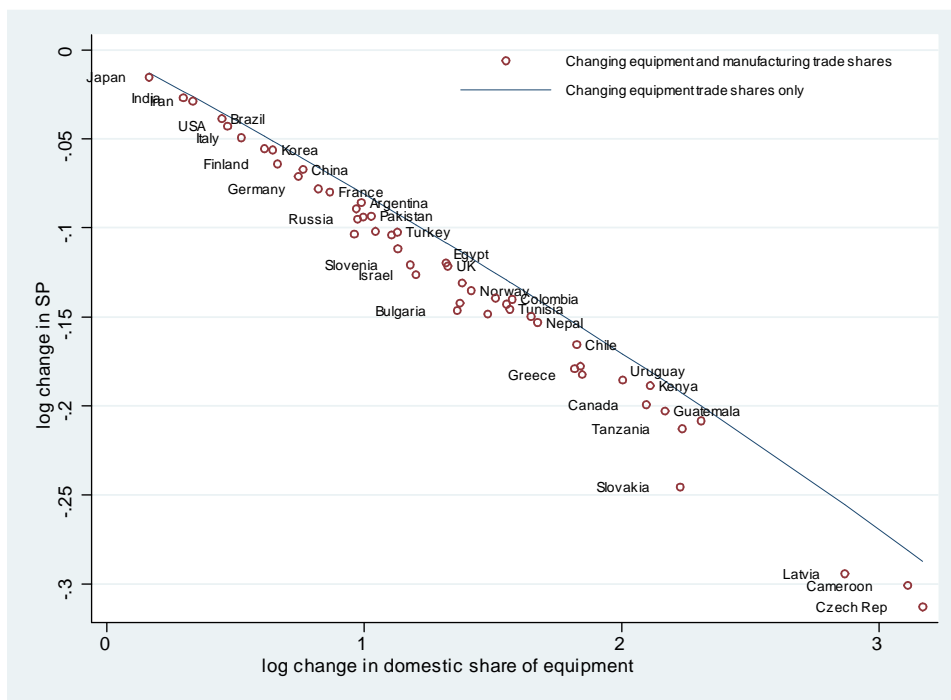
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Figure 1: Move to autarky, change in real wages



Note: Malawi (log changes in the skilled and unskilled real wages are -0.6 and -0.2, respectively) is excluded from the figure.

Figure 2: Move to autarky, change in the skill premium



Note: Malawi (log change in skill premium of -0.4) is excluded from the figure.

Figure 3: Observed changes in trade shares, change in the skill premium

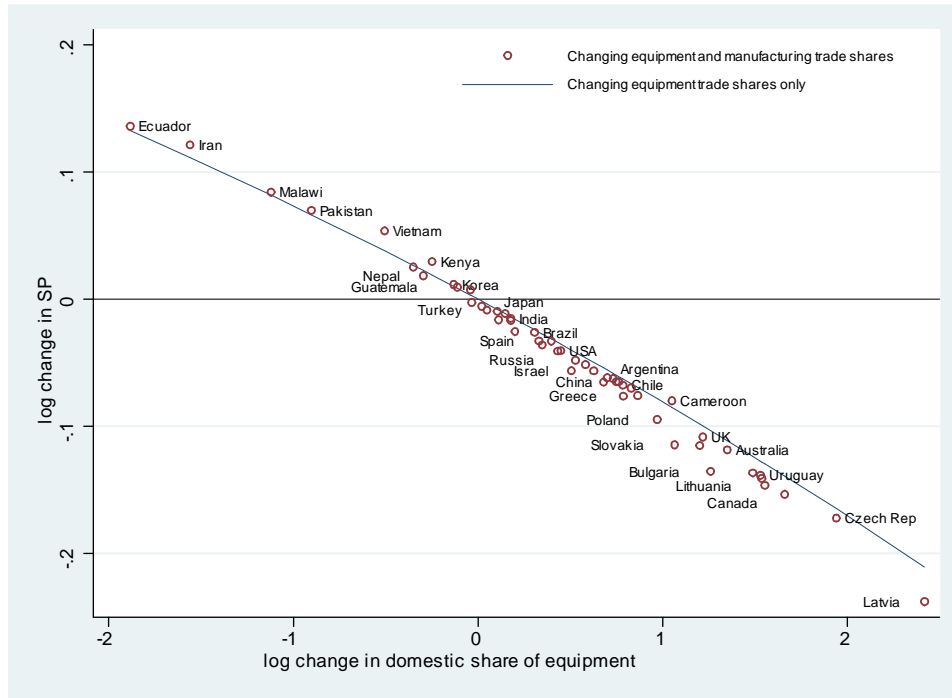


Table 1: Baseline parameter values

	US	Chile
σ	1.56	1.54
ρ	0.63	0.53
ζ	0.54	0.49
ε	0.62	0.6
ξ_i^H	1.37	1.12
ξ_i^L	0.44	0.31
ϕ	0.2	0.34
α	0.1	0.1
θ	0.20	0.20

We impose that α and θ are equal in Chile and the US

Table 2: Domestic Expenditure Shares

Country	Initial eq. yr	Counterf. eq. yr	$\pi_{ii}(E)$	$\pi'_{ii}(E)$	$\pi_{ii}(M)$	$\pi'_{ii}(M)$	Country	Initial eq. yr	Counterf. eq. yr	$\pi_{ii}(E)$	$\pi'_{ii}(E)$	$\pi_{ii}(M)$	$\pi'_{ii}(M)$
Argentina	2000	1984	0.37	0.77	0.83	0.95	Kyrgyzstan	2000	1992	0.21	0.98	0.66	0.98
Australia	2000	1963	0.19	0.74	0.70	0.87	Latvia	2000	1992	0.06	0.64	0.36	0.76
Austria	2000	1963	0.16	0.54	0.47	0.79	Lithuania	2000	1992	0.16	0.75	0.52	0.87
Bangladesh	1998	1972	0.37	0.43	0.65	0.65	Malawi	2000	1965	0.02	0.01	0.59	0.54
Brazil	2000	1990	0.64	0.87	0.89	0.95	Nepal	1996	1986	0.19	0.14	0.68	0.79
Bulgaria	2000	1980	0.26	0.90	0.35	0.95	Norway	2000	1963	0.24	0.43	0.57	0.68
Cameroon	2000	1970	0.04	0.13	0.60	0.50	Pakistan	2000	1963	0.36	0.15	0.72	0.63
Canada	2000	1963	0.12	0.65	0.56	0.87	Poland	2000	1982	0.35	0.93	0.57	0.97
Chile	2000	1963	0.16	0.35	0.71	0.84	Portugal	2000	1963	0.25	0.28	0.59	0.77
China	2000	1977	0.47	0.99	0.81	0.97	Romania	2000	1985	0.22	0.98	0.65	0.97
Colombia	2000	1963	0.21	0.44	0.76	0.88	Russia	2000	1996	0.38	0.58	0.59	0.75
Czech Rep	2000	1995	0.04	0.29	0.51	0.64	Slovakia	2000	1993	0.11	0.31	0.22	0.54
Denmark	2000	1963	0.23	0.54	0.46	0.56	Slovenia	2000	1992	0.31	0.44	0.46	0.62
Ecuador	2000	1963	0.10	0.02	0.78	0.68	Spain	2000	1963	0.38	0.53	0.70	0.90
Egypt	1998	1964	0.27	0.27	0.70	0.81	Sweden	2000	1963	0.33	0.67	0.64	0.78
Finland	2000	1963	0.52	0.50	0.68	0.83	Switzerland	2000	1986	0.25	0.58	0.41	0.45
France	2000	1963	0.42	0.79	0.72	0.90	Macedna	2000	1993	0.38	0.47	0.43	0.61
Germany	2000	1991	0.44	0.65	0.67	0.71	Tanzania	1999	1965	0.11	0.08	0.56	0.59
Greece	1998	1963	0.16	0.35	0.46	0.71	Tunisia	2000	1963	0.21	0.20	0.63	0.54
Guatemala	1998	1968	0.11	0.10	0.62	0.61	Turkey	2000	1963	0.32	0.34	0.72	0.85
India	1999	1963	0.74	0.89	0.88	0.92	UK	2000	1963	0.27	0.90	0.67	0.89
Iran	2000	1963	0.72	0.15	0.91	0.60	USA	2000	1963	0.63	0.98	0.82	0.97
Israel	2000	1963	0.30	0.50	0.41	0.72	Ukraine	2000	1992	0.48	0.94	0.68	0.99
Italy	2000	1967	0.59	0.71	0.76	0.84	Uruguay	2000	1968	0.13	0.62	0.65	0.91
Japan	2000	1963	0.85	0.94	0.91	0.96	VietNam	2000	1998	0.32	0.19	0.53	0.29
Kenya	2000	1963	0.12	0.09	0.80	0.54	Zimbabwe	1996	1964	0.54	0.92	0.79	0.99
Korea	2000	1963	0.53	0.46	0.84	0.80							

Note: *Initial eq. yr.* refers to the year used to obtain the trade shares for the initial steady state of our counterfactuals. *Counterf. eq. yr.* refers to the year used to obtain the trade shares in the new steady state of counterfactual 2.

A Solving for Changes in the Skill Premium

In this section, we show how to solve for the change in country i 's skill premium as a function of changes in domestic expenditure shares, $\pi_{ii}(j)$'s, changes in domestic technologies, $A_i(j)$'s; and changes in domestic endowments, H_i and L_i . We proceed in three steps. First, we derive the marginal costs functions and equilibrium input demands. Then, we characterize the steady state equilibrium. Finally, using the steady state equilibrium conditions, we derive the system of equations that completely characterizes the change in country i 's skill premium.

A.1 Marginal Cost Functions and Intermediate Inputs Demands

We first derive the formulas for the marginal cost functions and the intermediate input demands. To simplify notation, we write the production function of (ω, j) intermediate good producers as

$$y_i(\omega, j) = A_i(j) z_i(\omega, j) b_{3,i}^{\zeta_i} b_{4,i}^{1-\zeta_i}$$

where

$$b_{4,i} = x_S^{\varepsilon_i} x_M^{1-\varepsilon_i}, \quad b_{2,i} = \left[\mu_i^{1/\sigma} l^{(\sigma-1)/\sigma} + (1-\mu_i)^{1/\sigma} b_1^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)},$$

$$b_{3,i} = k_S^{\alpha_i} b_2^{1-\alpha_i}, \quad \text{and } b_{1,i} = \left[\lambda_i^{1/\rho} k_E^{(\rho-1)/\rho} + (1-\lambda_i)^{1/\rho} h^{(\rho-1)/\rho} \right]^{\rho/(\rho-1)}.$$

The unit cost of production for the domestic market of a producer with productivity $A_i(j) z_i(\omega, j) = 1$, which we denote by c_i , can then be expressed as

$$c_i = p_{b_{3,i}}^{\zeta_i} p_{b_{4,i}}^{1-\zeta_i} / \zeta_i^{\zeta_i} (1-\zeta_i)^{1-\zeta_i}$$

where

$$p_{b_{4,i}} = \frac{P_i(S)^{\varepsilon_i} P_i(M)^{1-\varepsilon_i}}{\varepsilon_i^{\varepsilon_i} (1-\varepsilon_i)^{1-\varepsilon_i}}, \quad p_{b_{2,i}} = \left[\mu_i w_i^{1-\sigma} + (1-\mu_i) p_{b_{1,i}}^{1-\sigma} \right]^{1/(1-\sigma)},$$

$$p_{b_{3,i}} = \frac{v_i^{\alpha_i} p_{b_{2,i}}^{1-\alpha_i}}{\alpha_i^{\alpha_i} (1-\alpha_i)^{1-\alpha_i}}, \quad \text{and } p_{b_{1,i}} = \left[\lambda_i r_i^{1-\rho} + (1-\lambda_i) s_i^{1-\rho} \right]^{1/(1-\rho)}.$$

Here, $p_{b_{4,i}}$, $p_{b_{3,i}}$, $p_{b_{2,i}}$, and $p_{b_{1,i}}$ denote the unit costs of the input bundles $b_{4,i}$, $b_{3,i}$, $b_{2,i}$, and $b_{1,i}$ in country i .

Profit maximization by final good producers gives rise to the following demand for (ω, j) :

$$q_i(\omega, j) = \left(\frac{p_i(\omega, j)}{P_i(j)} \right)^{-\eta_i(j)} Y_i(j).$$

Factors demanded in the production of intermediate good (ω, j) in country i for goods sold in country n are given by

$$l_{in}(\omega, j) = \mu_i \left[\frac{p_{b_{2,i}}}{w_i} \right]^{\sigma} b_{2,in}(\omega, j), \quad h_{in}(\omega, j) = (1-\lambda_i) \left[\frac{p_{b_{1,i}}}{s_i} \right]^{\rho} b_{1,in}(\omega, j),$$

$$k_{S,in}(\omega, j) = \alpha_i \frac{p_{b_{3,i}} b_{3,in}(\omega, j)}{v_i}, \quad k_{E,in}(\omega, j) = \lambda_i \left[\frac{p_{b_{1,i}}}{r_i} \right]^{\rho} b_{1,in}(\omega, j),$$

$$x_{S,in}(\omega, j) = \varepsilon_i \frac{p_{b_{4,i}} b_{4,in}(\omega, j)}{P_i(S)}, \quad \text{and } x_{M,in}(\omega, j) = (1-\varepsilon_i) \frac{p_{b_{4,i}} b_{4,in}(\omega, j)}{P_i(M)},$$

where

$$b_{4,in}(\omega, j) = (1 - \zeta_i) \frac{p_n(\omega, j) q_n(\omega, j)}{p_{b_{4,i}}} \mathbb{I}_{in}(\omega, j), \quad b_{2,in}(\omega, j) = (1 - \alpha_i) \frac{p_{b_{3,i}} b_{3,in}(\omega, j)}{p_{b_{2,i}}},$$

$$b_{3,in}(\omega, j) = \zeta_i \frac{p_n(\omega, j) q_n(\omega, j)}{p_{b_{3,i}}} \mathbb{I}_{in}(\omega, j), \quad b_{1,in}(\omega, j) = (1 - \mu_i) \left[\frac{p_{b_{2,i}}}{p_{b_{1,i}}} \right]^\sigma b_{2,in}(\omega, j),$$

and where $\mathbb{I}_{in}(\omega, j)$ is an indicator function that takes the value of one when country i supplies country n with intermediate good (ω, j) and is zero otherwise.

A.2 Steady State Equilibrium

We now use the above equations to characterize steady-state equilibrium aggregate variables. In what follows, we let

$$\Phi_i \equiv \sum_n \sum_j \pi_{in}(j) P_n(j) Y_n(j)$$

denote total revenue accruing to all country i producers across all sectors. Integrating factor demands across producers, and adding across all destination countries n and sectors j , we have equilibrium in factor markets,

$$v_i K_i(S) = \zeta_i \alpha_i \Phi_i, \quad (15)$$

$$w_i L_i = \zeta_i \mu_i (1 - \alpha_i) (p_{b_{2,i}}/w_i)^{\sigma-1} \Phi_i, \quad (16)$$

$$r_i K_i(E) = \zeta_i \lambda_i (1 - \alpha_i) (1 - \mu_i) \left(\frac{p_{b_{1,i}}}{r_i} \right)^{\rho-1} \left(\frac{p_{b_{2,i}}}{p_{b_{1,i}}} \right)^{\sigma-1} \Phi_i, \quad (17)$$

$$s_i H_i = \zeta_i (1 - \alpha_i) (1 - \mu_i) (1 - \lambda_i) \left(\frac{p_{b_{1,i}}}{s_i} \right)^{\rho-1} \left(\frac{p_{b_{2,i}}}{p_{b_{1,i}}} \right)^{\sigma-1} \Phi_i, \quad (18)$$

intermediate input markets,

$$P_i(S) X_i(S) = \varepsilon_i (1 - \zeta_i) \Phi_i, \quad (19)$$

$$P_i(M) X_i(M) = (1 - \varepsilon_i) (1 - \zeta_i) \Phi_i. \quad (20)$$

and goods markets,

$$Y_i(M) = C_i(M) + X_i(M), \quad (21)$$

$$Y_i(S) = C_i(S) + X_i(S) + \delta_i(S) K_i(S), \quad (22)$$

$$Y_i(E) = \delta_i(E) K_i(E), \quad (23)$$

EK show that, with exponentially distributed productivities, the price indices for final goods are given by:

$$P_i(j) = \gamma_i(j) \left\{ \sum_{k=1}^I \left[\tau_{kn}(j) \frac{c_k}{A_k(j)} \right]^{-1/\theta_j} \right\}^{-\theta_j} \quad (24)$$

where $\gamma_i(j) = \{\Gamma(1 + \theta_j [1 - \eta_i(j)])\}^{1/[1 - \eta_i(j)]}$ and Γ is the Gamma function. Finally, the house-

hold optimality conditions in steady state are given by the Euler equations

$$1/\beta = r_i/P_i(E) + 1 - \delta_i(E), \quad (25)$$

$$1/\beta = v_i/P_i(S) + 1 - \delta_i(S), \quad (26)$$

the intra-temporal consumption equation

$$P_i(M) C_i(M) = \frac{\phi}{1-\phi} P_i(S) C_i(S), \quad (27)$$

and the budget constraint

$$w_i L_i + s_i H_i + v_i K_i(S) + r_i K_i(E) + N X_i = P_i(M) C_i(M) + P_i(E) \delta_i(E) K_i(E) + P_i(S) [C_i(S) + \delta_i(S) K_i(S)] \quad (28)$$

where $N X_i$ denotes net exports, which we take as a parameter. Equations (15) – (28) characterize the steady-state equilibrium.

A.3 Changes in the Skill Premium and Real Wages

The skill premium: Here we show that we can solve for changes in country i 's skill premium using the following system of five equations:

$$\tilde{r}_i = \left[\tilde{A}_i(S) / \tilde{A}_i(E) \right] \tilde{\pi}_{ii}(E)^{\theta_E} \quad (29)$$

$$\tilde{s}_i^\rho / \tilde{w}_i^\sigma = \tilde{p}_{b_{1,i}}^{\rho-\sigma} \left(\tilde{L}_i / \tilde{H}_i \right) \quad (30)$$

$$\tilde{p}_{b_{1,i}} = \left[\frac{1}{1 + \xi_i^H} \tilde{r}_i^{1-\rho} + \frac{\xi_i^H}{1 + \xi_i^H} \tilde{s}_i^{1-\rho} \right]^{1/(1-\rho)} \quad (31)$$

$$\tilde{p}_{b_{3,i}}^{1/1-\alpha_i} = \left[\xi_i^L \tilde{w}_i^{1-\sigma} + (1 - \xi_i^L) \tilde{p}_{b_{1,i}}^{1-\sigma} \right]^{1/(1-\sigma)} \quad (32)$$

$$\tilde{p}_{b_{3,i}} = \tilde{A}_i(S)^{(\varepsilon_i + \zeta_i - \varepsilon_i \zeta_i) / \zeta_i} \left[\tilde{A}_i(M) / \tilde{\pi}_{ii}(M)^{\theta_M} \right]^{(1-\varepsilon_i)(1-\zeta_i) / \zeta_i} \quad (33)$$

where, $\tilde{x} \equiv x'/x$ denotes the ratio of a variable between the new and initial equilibrium, and where $\xi_i^H = \frac{s_i H_i}{r_i K_i(E)}$ and $\xi_i^L = \frac{w_i L_i}{w_i L_i + s_i H_i + r_i K_i(E)}$ denote relative factor shares in the initial equilibrium.

We proceed in order. By equations (6) and (24), we have

$$P_i(j) = \gamma_i(j) c_i \pi_{ii}(j)^{\theta_j} / A_i(j)$$

and taking changes between the new and initial equilibrium gives

$$\tilde{P}_i(j) = \tilde{c}_i \tilde{\pi}_{ii}(j)^{\theta_j} / \tilde{A}_i(j). \quad (34)$$

Similarly, by equation (27), we have

$$\tilde{r}_i = \tilde{P}_i(E). \quad (35)$$

Equations (34) and (35) imply equation (29). By equations (16) and (18), we have

$$\frac{s_i^\rho}{w_i^\sigma} \frac{H_i}{L_i} = (1 - \lambda_i) \frac{1 - \mu_i}{\mu_i} p_{b,i}^{\rho-\sigma}.$$

Expressing the previous equation in changes gives equation (30). In addition, expressing the definition of $p_{b_{1,i}}$ in changes gives equation (31).

To obtain the remaining two equations, (32) and (33), we express the remaining marginal cost equations in changes:

$$\tilde{c}_i = \tilde{p}_{b_{3,i}}^{\zeta_i} \tilde{p}_{b_{4,i}}^{1-\zeta_i} \quad (36)$$

$$\tilde{p}_{b_{4,i}} = \tilde{P}_i(S)^{\varepsilon_i} \tilde{P}_i(M)^{1-\varepsilon_i} \quad (37)$$

$$\tilde{p}_{b_{3,i}} = \tilde{v}_i^{\alpha_i} \tilde{p}_{b_{2,i}}^{1-\alpha_i} \quad (38)$$

$$\tilde{p}_{b_{2,i}} = \left[\xi_i^L \tilde{w}_i^{1-\sigma} + (1 - \xi_i^L) \tilde{p}_{b_{1,i}}^{1-\sigma} \right]^{1/1-\sigma} \quad (39)$$

Letting $P_i(S) = 1$ be the numeraire, equation (26) implies $\tilde{v}_i = \tilde{P}_i(S) = 1$. Hence, equations (38) and (39) imply equation (32). Finally, by equation (34) and $\pi_{ii}(S) = 1$, we have

$$\tilde{c}_i = \tilde{A}_i(S). \quad (40)$$

By equations (36), (37), and (40), we have

$$\tilde{A}_i(S) = \tilde{p}_{b_{3,i}}^{\zeta_i} \tilde{p}_{b_{4,i}}^{1-\zeta_i}$$

and

$$\tilde{p}_{b_{4,i}} = \tilde{P}_i(M)^{1-\varepsilon_i} = \left\{ \tilde{A}_i(S) \tilde{\pi}_{ii}(M)^{\theta_M} / \tilde{A}_i(M) \right\}^{1-\varepsilon_i}.$$

The two previous equations imply (33). Hence, we can solve for changes in country i 's skill premium using equations (29)-(33).

Real wages: We conclude this section by showing how to solve for changes in the real wages of skilled and unskilled workers as a function of changes in productivities and trade shares. We define the real wage as the change in wage relative to the consumption price index, $P_i(C)$. We write the change in the consumption price index as

$$\tilde{P}_i(C) = \left(\frac{\tilde{\pi}_{ii}(M)^{\theta_M} \tilde{A}_i(M)}{\tilde{A}_i(S)} \right)^\phi, \quad (41)$$

using equation (34) and taking $P_i(S)$ as the numeraire. Equations (29) (30), (31), (32), (33), and (41) give a system of equations that can be used to solve for $\tilde{s}_i/\tilde{P}_i(C)$ and $\tilde{w}_i/\tilde{P}_i(C)$.

B Proofs

In this section, we prove Proposition 1.

B.1 Derivation of Equation (7)

Here, we derive equation (7). By equations (16) and (18), we have

$$\left(\frac{r_i}{s_i}\right)^{1-\rho} = \left[\frac{1 - \lambda_i K_i(E)}{\lambda_i H_i}\right]^{\frac{\rho-1}{\rho}} \quad (42)$$

From the definition of $p_{b_{1,i}}$ and equation (42), we have

$$\frac{p_{b_{1,i}}}{s_i} = (1 - \lambda_i)^{-\frac{1}{\rho}} \left\{ \lambda_i^{\frac{1}{\rho}} \left[\frac{K_i(E)}{H_i}\right]^{\frac{\rho-1}{\rho}} + (1 - \lambda_i)^{\frac{1}{\rho}} \right\}^{\frac{1}{1-\rho}}. \quad (43)$$

In addition, equations (16) and (18) imply

$$\frac{s_i}{w_i} = (1 - \lambda_i)^{\frac{1}{\sigma}} \left(\frac{1 - \mu_i}{\mu_i}\right)^{\frac{1}{\sigma}} \left(\frac{p_{b_{1,i}}}{s_i}\right)^{\frac{\rho-\sigma}{\sigma}} \left(\frac{L_i}{H_i}\right)^{\frac{1}{\sigma}}. \quad (44)$$

From equations (43) and (44), we obtain equation (7).

B.2 Derivation of Equation (8)

We now derive our first order approximation for the change in the skill premium. Let $\hat{x} \equiv \log(\tilde{x})$. Using this notation, we express equations (29), (30), and (33) as

$$\hat{r}_i = \hat{A}_i(S) - \hat{A}_i(E) + \theta_E \hat{\pi}_{ii}(E) \quad (45)$$

$$\rho \hat{s}_i - \sigma \hat{w}_i = (\rho - \sigma) \hat{p}_{b_{1,i}} - (\hat{H}_i - \hat{L}_i). \quad (46)$$

$$\hat{p}_{b_{3,i}} = \frac{\zeta_i + \varepsilon_i - \zeta_i \varepsilon_i}{\zeta_i} \hat{A}_i(S) + \frac{(1 - \zeta_i)(1 - \varepsilon_i)}{\zeta_i} [\hat{A}_i(M) - \theta_M \hat{\pi}_{ii}(M)] \quad (47)$$

Using the first-order approximation, $\exp(\hat{x}) \approx 1 + \hat{x}$, we express equations (32) and (31) as

$$\hat{p}_{b_{1,i}} = \frac{1}{(1 - \xi_i^L)} \frac{\hat{p}_{b_{3,i}}}{(1 - \alpha_i)} - \frac{\xi_i^L}{1 - \xi_i^L} \hat{w}_i \quad (48)$$

$$\hat{p}_{b_{1,i}} = \frac{1}{1 + \xi_i^H} \hat{r}_i + \frac{\xi_i^H}{1 + \xi_i^H} \hat{s}_i \quad (49)$$

We now solve equations (45)-(49) for $\hat{s}_i - \hat{w}_i$. By equations (48) and (46), we have

$$\hat{s}_i = \frac{\rho - \sigma}{\rho} \frac{1}{(1 - \xi_i^L)} \frac{\hat{p}_{b_{3,i}}}{(1 - \alpha_i)} + \left(\frac{\sigma}{\rho} - \frac{\rho - \sigma}{\rho} \frac{\xi_i^L}{1 - \xi_i^L}\right) \hat{w}_i - \frac{1}{\rho} (\hat{H}_i - \hat{L}_i), \quad (50)$$

whereas by equations (48) and (49), we have

$$\hat{s}_i = \frac{1 + \xi_i^H}{\xi_i^H (1 - \xi_i^L)} \frac{\hat{p}_{b_{3,i}}}{(1 - \alpha_i)} - \frac{\xi_i^L (1 + \xi_i^H)}{(1 - \xi_i^L) \xi_i^H} \hat{w}_i - \frac{1}{\xi_i^H} \hat{r}_i.$$

Equating the two previous expressions and solving for \widehat{w}_i , we have

$$\widehat{w}_i = \frac{\rho + \sigma \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} \frac{\widehat{p}_{b_{3,i}}}{(1 - \alpha_i)} - \frac{\rho (1 - \xi_i^L)}{\rho \xi_i^L + \sigma \xi_i^H} \widehat{r}_i + \frac{(1 - \xi_i^L) \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} (\widehat{H}_i - \widehat{L}_i), \quad (51)$$

Equation (50) implies

$$\widehat{s}_i - \widehat{w}_i = \frac{\sigma - \rho}{\rho} \frac{1}{1 - \xi_i^L} \left[\widehat{w}_i - \frac{\widehat{p}_{b_{3,i}}}{(1 - \alpha_i)} \right] - \frac{1}{\rho} (\widehat{H}_i - \widehat{L}_i) \quad (52)$$

Equation (51) implies

$$\widehat{w}_i - \frac{\widehat{p}_{b_{3,i}}}{1 - \alpha_i} = \frac{\rho (1 - \xi_i^L)}{\rho \xi_i^L + \sigma \xi_i^H} \left[\frac{\widehat{p}_{b_{3,i}}}{(1 - \alpha_i)} - \widehat{r}_i + \xi_i^H \frac{1}{\rho} (\widehat{H}_i - \widehat{L}_i) \right]. \quad (53)$$

By equations (52) and (53), we have

$$\widehat{s}_i - \widehat{w}_i = \frac{\sigma - \rho}{\rho \xi_i^L + \sigma \xi_i^H} (\widehat{p}_{b_{2,i}} - \widehat{r}_i) - \frac{\xi_i^H + \xi_i^L}{\sigma \xi_i^H + \rho \xi_i^L} (\widehat{H}_i - \widehat{L}_i) \quad (54)$$

Finally, by equations (45), (47), and (54), we have equation (8).

B.3 Derivation of Equations (11) and (12)

We now derive a first order approximation for the change in real wages. First, we can write the log change in the consumption price index as:

$$\widehat{P}_i(C) = \phi \widehat{A}_i(S) - \phi \left[\widehat{A}_i(M) - \theta_M \widehat{\pi}_i(M) \right] \quad (55)$$

Equations (50) and (51) give

$$\widehat{s}_i = \frac{\sigma (1 + \xi_i^H)}{\rho \xi_i^L + \sigma \xi_i^H} \frac{\widehat{p}_{b_{3,i}}}{(1 - \alpha_i)} - \frac{\sigma - \rho \xi_i^L}{\rho \xi_i^L + \sigma \xi_i^H} \widehat{r}_i - \xi_i^L \frac{1 + \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} (\widehat{H}_i - \widehat{L}_i),$$

Together with equations (45) and (47), the previous expression gives

$$\begin{aligned} \widehat{s}_i &= -\xi_i^L \frac{1 + \xi_i^H}{\rho \xi_i^L + \sigma \xi_i^H} (\widehat{H}_i - \widehat{L}_i) + \left[\frac{\sigma (1 + \xi_i^H)}{\rho \xi_i^L + \sigma \xi_i^H} \frac{\zeta_i + \varepsilon_i - \zeta_i \varepsilon_i}{\zeta_i (1 - \alpha_i)} - \frac{\sigma - \rho \xi_i^L}{\rho \xi_i^L + \sigma \xi_i^H} \right] \widehat{A}_i(S) \\ &+ \left[\frac{\sigma (1 + \xi_i^H)}{\rho \xi_i^L + \sigma \xi_i^H} \frac{(1 - \zeta_i)(1 - \varepsilon_i)}{\zeta_i (1 - \alpha_i)} \right] \left[\widehat{A}_i(M) - \theta_M \widehat{\pi}_{ii}(M) \right] + \frac{\sigma - \rho \xi_i^L}{\rho \xi_i^L + \sigma \xi_i^H} \left[\widehat{A}_i(E) - \theta_E \widehat{\pi}_{ii}(E) \right], \end{aligned}$$

which, combined with equation (55), gives

$$\begin{aligned}\widehat{s}_i - \widehat{P}_i(C) &= -\xi_i^L \frac{1 + \xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} (\widehat{H}_i - \widehat{L}_i) + \left[\frac{\sigma(1 + \xi_i^H)\zeta_i + \varepsilon_i - \zeta_i\varepsilon_i}{\rho\xi_i^L + \sigma\xi_i^H} \frac{\zeta_i}{\zeta_i(1 - \alpha_i)} - \frac{\sigma - \rho\xi_i^L}{\rho\xi_i^L + \sigma\xi_i^H} - \phi \right] \widehat{A}_i(S) \\ &\quad + \left[\frac{\sigma(1 + \xi_i^H)(1 - \zeta_i)(1 - \varepsilon_i)}{\rho\xi_i^L + \sigma\xi_i^H} \frac{1}{\zeta_i(1 - \alpha_i)} + \phi \right] [\widehat{A}_i(M) - \theta_M \widehat{\pi}_{ii}(M)] \\ &\quad + \frac{\sigma - \rho\xi_i^L}{\rho\xi_i^L + \sigma\xi_i^H} [\widehat{A}_i(E) - \theta_E \widehat{\pi}_{ii}(E)].\end{aligned}$$

The previous expression and the definitions of $\nu_i(j)$, Θ_i , and $\varkappa_i(j)$ yield equation (11).

Equations (47), (45), and (51) give

$$\begin{aligned}\widehat{w}_i &= \frac{(1 - \xi_i^L)\xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} (\widehat{H}_i - \widehat{L}_i) + \left[\frac{\rho + \sigma\xi_i^H}{(1 - \alpha_i)} \frac{\zeta_i + \varepsilon_i - \zeta_i\varepsilon_i}{(\rho\xi_i^L + \sigma\xi_i^H)\zeta_i} - \frac{\rho(1 - \xi_i^L)}{\rho\xi_i^L + \sigma\xi_i^H} \right] \widehat{A}_i(S) \\ &\quad + \frac{\rho + \sigma\xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} \frac{(1 - \zeta_i)(1 - \varepsilon_i)}{(1 - \alpha_i)\zeta_i} [\widehat{A}_i(M) - \theta_M \widehat{\pi}_{ii}(M)] + \frac{\rho(1 - \xi_i^L)}{\rho\xi_i^L + \sigma\xi_i^H} [\widehat{A}_i(E) - \theta_E \widehat{\pi}_{ii}(E)]\end{aligned}$$

which, combined with equation (55), gives

$$\begin{aligned}\widehat{w}_i - \widehat{P}_i(C) &= \frac{(1 - \xi_i^L)\xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} (\widehat{H}_i - \widehat{L}_i) + \left[\frac{\rho + \sigma\xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} \frac{\zeta_i + \varepsilon_i - \zeta_i\varepsilon_i}{\zeta_i(1 - \alpha_i)} - \frac{\rho(1 - \xi_i^L)}{\rho\xi_i^L + \sigma\xi_i^H} - \phi \right] \widehat{A}_i(S) \\ &\quad + \left[\frac{\rho + \sigma\xi_i^H}{\rho\xi_i^L + \sigma\xi_i^H} \frac{(1 - \zeta_i)(1 - \varepsilon_i)}{\zeta_i(1 - \alpha_i)} + \phi \right] [\widehat{A}_i(M) - \theta_M \widehat{\pi}_{ii}(M)] \\ &\quad + \frac{\rho(1 - \xi_i^L)}{\rho\xi_i^L + \sigma\xi_i^H} [\widehat{A}_i(E) - \theta_E \widehat{\pi}_{ii}(E)].\end{aligned}$$

The previous expression and the definitions of $\nu_i(j)$, Θ_i , and $\varkappa_i(j)$ yield equation (12).

C Data and Parameterization

Domestic Expenditure Shares: For trade data, we define equipment trade as the sum of BEA industry codes 20-27 and 33. These codes are: Farm and Garden Machinery; Construction, Mining, etc.; Computer and Office Equipment; Other Nonelectric Machinery; Household Appliances; Household Audio and Video, etc.; Electronic Components; Other Electrical Machinery; and Instruments and Apparatus.

For gross output data, we define capital equipment goods as the sum of ISIC Rev. 3 codes 29-33. These codes are: Manufacture of machinery and equipment n.e.c.; Manufacture of office, accounting and computing machinery; Manufacture of electrical machinery and apparatus n.e.c.; Manufacture of radio, television and communication equipment and apparatus; and Manufacture of medical, precision and optical instruments, watches and clocks.

Disaggregating capital payments into structures and equipment: For a given share of

payments to capital in value added, i.e.

$$\frac{v_i K_i(S) + r_i K_i(E)}{s_i H_i + w_i L_i + v_i K_i(S) + r_i K_i(E)},$$

the parameter α_i determines the ratio of payments to capital structures relative to the payments to equipment capital, i.e. $v_i K_i(S) / [r_i K_i(E)]$. Given the difficulty of measuring capital rental rates, we construct them using the steady-state Euler equations for the accumulation of each type of capital,

$$\begin{aligned} 1 + R_i &= \frac{P_{i,t+1}(S) / P_{i,t+1}(C)}{P_{i,t}(S) / P_{i,t}(C)} \left\{ 1 - \delta_i(S) + \frac{v_{i,t+1}}{P_{i,t+1}(S)} \right\} \\ &= \frac{P_{i,t+1}(E) / P_{i,t+1}(C)}{P_{i,t}(E) / P_{i,t}(C)} \left\{ 1 - \delta_i(E) + \frac{r_{i,t+1}}{P_{i,t+1}(E)} \right\} \end{aligned}$$

where R_i denotes the consumption-based real-interest rate and $P_{i,t}(C)$ denotes the price of the final consumption good in year t . Note that, in this calculation we allow for trends in relative prices (as above, introducing growth into our model does not change our results on the impact of trade on the skill premium).

To solve for the rental rates, we use data from NIPA for the 1963-2000 period. We define non-residential equipment and software as the equipment sector E , and non-residential structures as the structure sector, S . We take $P_{i,t+1}(E) / P_{i,t}(E)$ and $P_{i,t+1}(S) / P_{i,t}(S)$ from NIPA's price indices for private investment (NIPA table 5.3.4). We use the GDP deflator from NIPA for $P_{i,t+1}(C) / P_{i,t}(C)$. We construct the annual depreciation rates of equipment and structures, $\delta_i(E)$ and $\delta_i(S)$, as the ratio of the current-cost depreciation (NIPA fixed assets table 4.4) to the current cost capital stock (NIPA fixed assets table 4.1) in these two sectors. We set the real interest rate R_i to 4%.

We use the 1963-2000 average of these variables and the Euler equations to obtain the relative return for equipment and structures $v_i / P_i(S) / [r_i / P_i(E)]$. We multiply this by the relative value of the capital stocks $[P_i(S) K_i(S) / P_i(E) K_i(E)]$ to obtain $v_i K_i(S) / [r_i K_i(E)]$. We use the 1963-2000 average current cost capital stock of non-residential equipment and non-residential structures (NIPA fixed assets table 4.1) for $P_i(E) K_i(E)$ and $P_i(S) K_i(S)$. Finally, to compute the share of payments to structures capital in value added, α , we use the relative payments to structures and equipment and the share of payments to capital in value added (equal to one minus the average labor share, as defined in the body of the paper). We obtain a very similar value for α if we first calculate, year by year, the relative payments to equipment and structures and the share of capital, and then average these over time.