Globalization, Technology, and the Skill Premium: A Quantitative Analysis*

Ariel Burstein
UCLA and NBER

Jonathan Vogel†
Columbia and NBER

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Abstract

We construct a model of international trade and multinational production (MP) to examine the impact of globalization on the skill premium in skill-abundant and skill-scarce countries. The key mechanisms in our framework arise from the interaction between three elements: asymmetric countries, technological heterogeneity across producers within sectors, and skill-biased technology. Reductions in trade and/or MP costs induce a reallocation of resources towards a country's comparative advantage sector (increasing the skill premium in skill-abundant countries and reducing it in skill-scarce countries) and within sectors towards more productive and skill-intensive producers (increasing the skill premium in all countries).

We parameterize the model to match salient features of the extent and composition of trade and MP between the U.S. and skill-abundant and skill-scarce countries in 2006. We show that a reduction in trade and MP costs, moving from autarky to 2006 levels of trade and MP, increases the skill premium by 5% in skill-abundant countries and 6% in skill-scarce countries. Globalization accounts for between $1/9^{\text{th}}$ and $1/6^{\text{th}}$ of the 24% rise in the U.S. skill premium between 1966 and 2006. MP is at least as important as international trade in generating this rise in the skill premium.

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†Corresponding author: jvogel@columbia.edu

1 Introduction

The nature of globalization has changed. The value of world trade as a share of world output, the sales of foreign affiliates as a share of world output, and the developing world's share of this global activity have grown tremendously over the last few decades. Over this period there was also a large increase in income inequality, both in developed and developing countries, as measured for example by the rise in the relative wage of skilled to unskilled workers—the *skill premium*. The changing nature of globalization and the increase in the skill premium raise a set of important questions. To what extent can the growth of trade and multinational production (MP) account for the rise in the skill premium in developed and developing countries? What are the different implications for the skill premium in developed countries of globalization with developing countries versus globalization with developed countries?

In this paper we construct a multi-country model of international trade and MP to address these and other questions. Our framework builds on the classic model of trade and inequality, the two-factor (skilled and unskilled labor) Heckscher-Ohlin (H-O) model, using the quantitative apparatus developed by Eaton and Kortum (2002) (henceforth EK).[1] We extend the H-O model in three key dimensions. First, as in much of the recent trade literature our framework incorporates productivity differences across producers within sectors, motivated by the large observed heterogeneity in size and export status within sectors; see e.g. Bernard and Jensen (1999). Second, our framework allows for an arbitrary factor bias of technology. When technology is skill biased, a producer's productivity is positively correlated with its skill intensity. This feature of the model enables us to address in a simple way the empirical evidence that exporters and large producers in manufacturing tend to be relatively skill intensive; see e.g. Bernard et. al. (2007) for the U.S., Bustos (2007) for Argentina, Verhoogen (2008) for Mexico, Alcalá and Hernández (2009) for Spain, and Molina and Muendler (2009) for Brazil. Third, motivated by the fact that sales of U.S. foreign affiliates are larger than the value of U.S. exports, our model incorporates multinational production (MP), giving producers the ability to use their technologies, at a cost, to produce in foreign countries, as in Ramondo and Rodriguez-Clare (2009).

In Section 3, we examine analytically the workings of simplified, two-country versions of our model that abstract from MP. We prove that starting in autarky, a reduction in trade costs generates what is often called the Stolper-Samuelson effect, but which we refer to as the between effect: labor reallocates between sectors as countries specialize in their comparative advantage sector, increasing the skill premium in the country with a comparative advantage in the skill-intensive sector and reducing the skill premium in the other country. Our model features a simple mechanism to

[1] Other models that combine elements of H-O and either Ricardian or Krugman-style models include Trefler (1993) and (1995), Davis (1995), Harrigan (1997), Davis and Weinstein (2001), Romalis (2004), Costinot (2005), Chor (2008), and Morrow (2008). While these papers focus on the role of endowment and technology differences in explaining observed trade patterns, our focus is on the impact of globalization on the skill premium.

explain the observation that the between effect is weak in the data—see e.g. Goldberg and Pavcnik (2007): for a fixed share of trade in output, greater productivity dispersion across producers within sectors mitigates the between effect. We show, however, that the strength of the between effect, conditional on trade volumes, is fully determined by between-sector trade patterns, which pin down the factor content of trade.[2]

Next, we show that if technology is skill biased, reductions in trade costs increase the skill premium in all countries through what we refer to as the within effect: as trade costs decline, the relative demand for skill increases because labor shifts within sectors towards the most productive producers, which have the highest skill intensities. Hence, trade liberalization increases the relative demand for skill, analogous to the effect of skill-biased technological change. This prediction receives empirical support in Bustos (2007) and Bloom et. al. (2009). We are not the first to model the potentially important interaction between skill-biased technology, international trade, and inequality; see e.g. Acemoglu (2003) and Yeaple (2005).[3] Our paper contributes to this literature by including both trade and MP, nesting the within and between effects, and quantitatively assessing the strength of these effects.

In Sections 4 and 5, we use a parameterized version of our model to quantify the impact of a trade liberalization on the skill premium in skill-abundant and skill-scarce countries via the between and within effects. We consider a four-country version of our model, with two symmetric skill-abundant countries and two symmetric skill-scarce countries, and initially abstract from MP. We calibrate the model to match—for the U.S. and the average skill-scarce country—trade shares and the composition of trade with skill-abundant and skill-scarce countries in 2006. We choose the degree of skill bias of productivity to target the relative skill intensity of exporters to non-exporters in Mexico. With skill-biased technology, a key implication of our model is that the share of trade in absorption is relatively higher in skill-intensive manufacturing sectors, a prediction borne out in U.S. manufacturing data.

We use the parameterized model to conduct a series of counterfactuals. We first consider a reduction in trade costs moving from autarky to the level of trade in 2006, holding all other exogenous variables fixed. This is a "but for" analysis (see Krugman 2000): What would the skill premium be, but for the availability of international trade opportunities? The rise in the skill premium is 1.7% in skill-abundant countries and 3.2% in skill-scarce countries. The skill premium rises in all countries because the within effect is relatively strong compared to the between effect. The between effect is weak because in our parameterization, as in the data, the share of U.S. imports from skill-abundant countries in the most skill-intensive sectors is not that much higher

[2] This result is an extension of the results in Deardorff and Staiger (1988) to our model with heterogeneous producers. Burstein and Vogel (2010) extend the results on the factor content of trade and the impact of within-sector heterogeneity on the skill premium to an imperfectly competitive environment with heterogeneous firms.

[3] See also the work of Matsuyama (2007), Zeira (2007), Helpman et. al. (2008), Vannoorenberghe (2008), Verhoogen (2008), and Costinot and Vogel (2009).

than in the least skill-intensive sectors. Because under our baseline parameterization the between effect is weaker than the within effect, the skill abundance of a country's trade partners is not as important for the impact of trade on the skill premium as is the country's total trade share. We conclude that how much a country trades matters more for the skill premium than with whom it trades.

The relatively small trade share in the U.S. plays a critical role in explaining the relatively small impact of trade on the U.S. skill premium in our model. International trade, however, is only one form of globalization. Multinational production (MP) is another important form of globalization. For example, in 2006, sales of majority-owned, non-bank U.S. foreign affiliates were more than twice as large as U.S. exports. To study the impact of MP on the skill premium, in Section 6 we extend our model and assume that producers are able to use their technologies to produce abroad, at a cost. Hence, MP reduces the technological gap between producers in different countries and increases the relative importance of factor endowment differences in shaping patterns of specialization. With Hicks-neutral technology, we show that this strengthens the between effect of globalization on the skill premium. With skill-biased technology, we show that MP strengthens the within effect: a reduction in MP costs between two symmetric countries leads to an increase in the skill premium in both countries because producers that engage in MP tend to be the most productive (and, thus, the most skill intensive). Previous theoretical work that finds an impact of MP on inequality requires that countries differ in their factor-endowment ratios and/or their TFP's.[4] The contribution of our finding is that we obtain a positive effect on the skill premium of MP even between countries with similar endowment ratios and TFP's, which in the data account for the vast majority of MP.[5]

We use the extended model to simulate a reduction in trade and MP costs moving from autarky to the volume and geographic composition of international trade and MP in 2006 in the U.S.—holding all other exogenous variables fixed. The rise in the skill premium is 4.8% in the skill-abundant countries and 5.9% in the skill-scarce countries. Combined with the previous counterfactual, this result suggests that MP is at least as important as international trade for determining the impact of globalization on the skill premium. In order to assess the extent to which the growth of trade and MP can account for the rise in the skill premium between 1966 and 2006 in the U.S., we consider a second counterfactual in which we choose parameters to match the growth of trade and MP between these years. In this counterfactual we do not hold endowments or technologies fixed, but instead we target the level of endowments in 1966 and 2006 and allow for exogenous skill-biased technology growth to match the 24% increase in the skill premium in the U.S. (see Acemoglu and Autor 2010). We show that in the absence of globalization, the rise in the skill premium in the

[4] See e.g. Feenstra and Hanson (1996) and (1997), Zhu and Trefler (2005), Antras et. al. (2006), Grossman and Rossi-Hansberg (2008), and Costinot and Vogel (2009).

[5] See e.g. Navaretti and Venables (2004) for evidence that most FDI flows take place between advanced countries, which typically have similar, high skill endowment ratios and TFPs.

U.S. would have been between $1/9^{\text{th}} - 1/6^{\text{th}}$ smaller than the observed rise in the skill premium over this time period.

Whereas in this paper we use a structural parameterized model to quantify the impact of international trade and MP on the skill premium in skill-abundant and skill-scarce countries, the literature has mostly focused on three alternative approaches that emphasize: the factor content of trade, as in Katz and Murphy (1992); the extent of between-sector factor reallocation, as in Berman et. al. (1997); and the mandated wage equation, as in Feenstra and Hanson (1999) We show that while each of these alternative approaches may provide estimates of the impact of globalization on the skill premium via the between effect, they do not capture the impact of the within effect. Using data generated by our model, in which the within effect is relatively strong, we show that these approaches underestimate the rise in the skill premium in skill-abundant and skill-scarce countries.

Whereas in this paper we capture two important forces in the debate on globalization and the skill premium—the between and within effects—and incorporate both trade and MP, we abstract from other interesting and potentially important considerations discussed in the literature. For example, our model abstracts from additional factors of production (such as land, other natural resources, and capital) in order to focus on the impact of globalization on the skill premium. Additionally, our framework does not incorporate endogenous changes in the supply of skilled and unskilled labor, endogenous skill-biased technical change, product or process innovation, or capital accumulation with capital-skill complementarity.[6] Our analysis also abstracts from unemployment and within-group inequality.[7] Finally, our model abstracts from non-homothetic preferences, which can lead to differences between changes in the nominal and the real skill premia.[8]

2 Basic Model of International Trade

Our model economy features I countries indexed by $i = 1, ..., I$. Aggregate quantities of inelastically supplied unskilled and skilled labor in country i are L_i and H_i, respectively. Each country produces a final non-tradeable good using a continuum of intermediate goods that can be traded subject to an iceberg cost. Intermediate goods are grouped into J sectors, indexed by j, in order of increasing skill intensity of production. Within each sector j there are a continuum of subsectors, indexed by $\omega \in [0, 1]$. Within each subsector, intermediate good producers from the same country share the same level of productivity. Productivity varies across subsectors, sectors, and countries. Goods markets and factor markets are perfectly competitive, and factors are perfectly mobile across sectors and subsectors but are immobile across countries. We assume that countries have balanced trade every period. Given that equilibrium allocations and prices are determined in a static fashion, we

[6] See e.g. Grossman and Helpman (1991), Acemoglu (2003), Atkeson and Burstein (2009), and Krusell et. al. (2000), respectively

[7] See e.g., Davidson et. al. (1988) and Helpman et. al. (2008), respectively.

[8] See e.g. Broda and Romalis (2009) for an empirical investigation of this issue.

abstract from time subscripts.

The final non-tradeable good, denoted by Q_i, is produced in all countries by competitive producers that use an identical CES aggregator, which places equal weight on intermediate goods from all sectors and subsectors

$$\begin{aligned} Q_i &= \left(\sum_{j=1}^{J} Q_i\,(j)^{(\eta'-1)/\eta'} \right)^{\eta'/(\eta'-1)} \\ Q_i\,(j) &= \left(\int_0^1 q_i\,(\omega, j)^{(\eta-1)/\eta}\, d\omega \right)^{\eta/(\eta-1)} . \end{aligned}$$

Here, $Q_i\,(j)$ and $q_i\,(\omega, j)$ denote country i's use of the sector j aggregate good and the subsector (ω, j) good, respectively; and $\eta', \eta > 0$ are the elasticities of substitution between sectors and between subsectors, respectively.

Facing prices P_i, $P_i\,(j)$ and $p_i\,(\omega, j)$ for the final non-traded good, the aggregate sector j good, and the subsector (ω, j) good, respectively, profit maximization by the final good producers gives rise to the following demands

$$\begin{aligned} Q_i\,(j) &= \left(\frac{P_i\,(j)}{P_i} \right)^{-\eta'} Q_i \\ q_i\,(\omega, j) &= \left(\frac{p_i\,(\omega, j)}{P_i\,(j)} \right)^{-\eta} Q_i\,(j) . \end{aligned} \tag{1}$$

The output of each subsector is produced by intermediate good producers. Goods within each subsector are perfect substitutes and potentially produced by every country. The final good producer purchases each intermediate good from the lowest cost source of that good in the world.

Our assumptions on the production of intermediate goods are as follows. A country i producer in subsector (ω, j) hiring h units of skilled labor and l units of unskilled labor, produces output y according to a constant returns to scale production function

$$y = A_i\,(j) \left[\alpha_j^{1/\rho} \left(z^{2\widetilde{\varphi}} h \right)^{\frac{\rho-1}{\rho}} + (1-\alpha_j)^{1/\rho} \left(z^{2(1-\widetilde{\varphi})} l \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} , \tag{2}$$

where $\rho > 0$ is the elasticity of substitution between skilled and unskilled workers at the level of an individual producer, $\alpha_j \in [0, 1]$ determines the relative importance of skilled labor in sector j, $\widetilde{\varphi} \in [0, 1]$ shapes the skill bias of technology (as described below), $A_i\,(j) > 0$ is country i's Hicks-neutral productivity in sector j, and z is the producer's idiosyncratic component of productivity. To facilitate exposition, we decompose $A_i\,(j)$ into two components—national TFP, T_i, and sectoral TFP, $T_i\,(j)$—so that $A_i\,(j) = T_i \times T_i\,(j)$.

Note that if $\widetilde{\varphi} = 1/2$, then Equation (2) simplifies to a standard CES production function with multiplicative productivity $A_i(j)\,z$. If $\widetilde{\varphi} \neq 1/2$ and $\rho \neq 1$, then technology is not multiplicative. In general, facing wages of unskilled and skilled labor w and s respectively, a cost minimizing producer with productivity z in sector j chooses the following ratio of skilled-to-unskilled labor

$$\frac{h}{l} = \frac{\alpha_j}{1-\alpha_j}\left(\frac{w}{s}\right)^{\rho} z^{\varphi}, \tag{3}$$

where $\varphi \equiv 2\,(2\widetilde{\varphi}-1)\,(\rho-1)$ is the *skill-bias of technology*, which determines the effect of a producer's productivity on its relative demand for skill. We say that technology is Hicks-neutral if $\varphi = 0$ (i.e. if $\widetilde{\varphi} = 1/2$ or $\rho = 1$), so that h/l is independent of z. In contrast, we say that technology is skill biased if $\varphi > 0$ (i.e. if $\widetilde{\varphi} > 1/2$ and $\rho > 1$ or if $\widetilde{\varphi} < 1/2$ and $\rho < 1$), so that h/l increases with z.

Each country i draws a subsector-specific idiosyncratic component of productivity $z_i(\omega, j) > 0$, henceforth denoted z when the dependence on i and (ω, j) is clear. Within a given country, producers in each subsector have access to a common z. We model subsector-specific productivity draws as in Eaton and Kortum (2002) and Alvarez and Lucas (2007). In an arbitrary subsector and country $z = u^{-\theta}$, where u is an *i.i.d.* random variable that is exponentially distributed with mean and variance 1 in all countries. The parameter $\theta > 0$ determines the dispersion of productivity across subsectors.[9] Note that while the subsector-specific component of productivity z is *i.i.d.* across subsectors, sectors, and countries, the sectoral component of productivity $A_i(j)$ can potentially be systematically correlated with a sector's skill intensity and a country's factor endowment.

We introduce trade barriers using iceberg transportation costs: delivering a unit of intermediate good from country i to country n requires producing $\tau_{ni} \geq 1$ units in i, where $\tau_{ii} = 1$ for all i and $\tau_{ni} \leq \tau_{nk}\tau_{ki}$ for all $n, i, k \in I$. Denote by $c_{ni}(\omega, j)$ the unit cost of intermediate good producers in subsector (ω, j) producing in country i and selling in country n, which is given by

$$c_{ni}(\omega, j) = \frac{\tau_{ni}}{A_i(j)}\left[\alpha_j z^{\frac{\varphi}{2}+\rho-1} s_i^{1-\rho} + (1-\alpha_j)\, z^{\rho-1-\frac{\varphi}{2}} w_i^{1-\rho}\right]^{1/(1-\rho)}. \tag{4}$$

With $\widetilde{\varphi} = 1/2$ so that technology is Hicks-neutral, the unit cost of a given subsector (ω, j) can be written as the cost of the factor bundle for all subsectors in sector j, $v_i(j)$, divided by the subsector-specific productivity. Namely, $c_{ni}(\omega, j) = \tau_{ni} v_i(j)/z$, where $v_i(j)$ is defined as

$$v_i(j) = \frac{1}{A_i(j)}\left[\alpha_j s_i^{1-\rho} + (1-\alpha_j)\, w_i^{1-\rho}\right]^{1/(1-\rho)}.$$

This case corresponds to the EK setup with a factor bundle that combines skilled and unskilled labor.

[9] As in EK, we must constrain the values of η and θ to have a well-defined price index. In the skill-biased case, however, we cannot derive an analytic expression for this constraint. In all simulations, we check numerically that the price level is well defined.

With perfect competition, the price of the subsector (ω, j) good in country i is

$$p_i(\omega, j) = \min \{c_{ik}(\omega, j)\}_{k=1}^{I} \tag{5}$$

and the aggregate prices P_i and $P_i(j)$ are

$$\begin{aligned} P_i &= \left(\sum_{j=1}^{J} P_i(j)^{1-\eta'} d\omega \right)^{\frac{1}{1-\eta'}} \\ P_i(j) &= \left(\int_0^1 p_i(\omega, j)^{1-\eta} d\omega \right)^{\frac{1}{1-\eta}}. \end{aligned} \tag{6}$$

The total quantity produced of each intermediate good in country i must equalize its world demand

$$y_i(\omega, j) = \sum_{n=1}^{I} \tau_{ni} q_n(\omega, j) \mathbb{I}_{ni}(\omega, j)$$

where $\mathbb{I}_{ni}(\omega, j)$ is an indicator function that equals one if country n imports subsector (ω, j) goods from country i and equals zero otherwise.

The amount of skilled and unskilled labor demanded by subsector (ω, j) in country i in order to supply country n are

$$l_{ni}(\omega, j) = \left(\frac{\tau_{ni}}{A_i(j)} \right)^{1-\eta} Q_n P_n^{\eta} w_i^{-\eta} f\left(\frac{w_i}{s_i}, z, j \right) \mathbb{I}_{ni}(\omega, j) \tag{7}$$

and

$$h_{ni}(\omega, j) = \left(\frac{\tau_{ni}}{A_i(j)} \right)^{1-\eta} Q_n P_n^{\eta} s_i^{-\eta} g\left(\frac{w_i}{s_i}, z, j \right) \mathbb{I}_{ni}(\omega, j), \tag{8}$$

respectively, where

$$f\left(\frac{w_i}{s_i}, z, j \right) = (1-\alpha_j) z^{2(\eta-1)(1-\widetilde{\varphi})} \left[\alpha_j \left(\frac{w_i}{s_i} \right)^{\rho-1} z^{\varphi} + (1-\alpha_j) \right]^{\frac{\rho-\eta}{1-\rho}}$$

$$g\left(\frac{w_i}{s_i}, z, j \right) = \alpha_j z^{2\widetilde{\varphi}(\eta-1)} \left[\alpha_j + (1-\alpha_j) z^{-\varphi} \left(\frac{w_i}{s_i} \right)^{1-\rho} \right]^{\frac{\rho-\eta}{1-\rho}}.$$

Labor market clearing in each country requires

$$L_i = \sum_{j=1}^{J}\sum_{n=1}^{N}\int_0^1 l_{ni}(\omega,j)\,d\omega, \text{ and} \tag{9}$$

$$H_i = \sum_{j=1}^{J}\sum_{n=1}^{N}\int_0^1 h_{ni}(\omega,j)\,d\omega. \tag{10}$$

We assume that countries spend all of their income on the final non-traded good, which implies trade balance:

$$P_iQ_i = s_iH_i + w_iL_i. \tag{11}$$

An equilibrium of the world economy is a set of aggregate prices $[P_i, w_i, s_i]_{i\in I}$, aggregate quantities $[Q_i]_{i\in I}$, sector and subsector prices $[P_i(j)]_{i\in I, j\in J}$ and $[p_i(\omega,j)]_{\omega\in[0,1], i\in I, j\in J}$, sector and subsector quantities $[Q_i(j)]_{i\in I, j\in J}$ and $[q_i(\omega,j), y_i(\omega,j)]_{\omega\in[0,1], i\in I, j\in J}$ demanded and produced, and factor demands $[l_i(\omega,j), h_i(\omega,j)]_{\omega\in[0,1], i\in I, j\in J}$, that satisfy final and intermediate goods producers' optimality conditions, factor and goods market clearing conditions, and trade balance in each country.

Solution algorithm: Equilibrium factor prices can be solved as follows. Given factor prices, the marginal cost of each subsector/country is given by Equation (4). Given marginal costs, prices are calculated using Equations (5) and (6), and Equation (5) also gives the identity of the supplier of each good in each country, summarized by $\mathbb{I}_{ni}(\omega,j)$. Unskilled and skilled labor hired by each subsector, normalized by output of the final good, is obtained from Equations (1), (7), and (8) and output of the final good is then obtained using one of the labor market clearing equations in each country, either Equation (9) or (10). Equilibrium factor prices must satisfy the remaining labor market clearing equation in each country and balanced trade, Equation (11) (by Walras' Law, and given the choice of a numeraire, one of these equations is redundant).

In the solution procedure above, in order to calculate which country supplies each good in each country, we must compare marginal costs, Equation (4), across all potential suppliers, as indicated by the pricing equation (5). In the special case of Hicks-neutral technology, the marginal cost is given by the product of the inverse of productivity and the cost of the factor bundle. In this case, if productivities are exponentially distributed, we obtain simple analytic expressions that characterize the probability that country i supplies country n with an arbitrary sector j subsector (as in EK). This probability, denoted by $\pi_{ni}(j)$, is

$$\pi_{ni}(j) = \frac{[\tau_{ni}v_i(j)]^{-1/\theta}}{\sum_{k=1}^{I}[\tau_{nk}v_k(j)]^{-1/\theta}}. \tag{12}$$

EK show that $\pi_{ni}(j)$ is also equal to country i's revenue share of sector j in country n. This closed-form solution for $\pi_{ni}(j)$ considerably simplifies the solution algorithm to calculate equilibrium factor prices because it implies that the amount of unskilled (and skilled) labor used in country i sector j to supply n, which is $\int_0^1 l_{ni}(\omega, j)\, d\omega$ in Equation (9), can be written as a simple function of factor prices, aggregate prices, and aggregate quantities.

With non-Hicks-neutral technology, we do not obtain such analytic expressions because unit cost cannot be expressed as the product of the inverse of productivity and the cost of the factor bundle in the expression for marginal cost, Equation (4). Hence, we must simulate marginal cost draws across a large number of subsectors and for each subsector compare them numerically across countries.

3 International Trade and the Skill Premium

In this section, we conduct analytic comparative statics on the skill premium in our basic model of international trade under simplifying assumptions, which we relax in the quantitative section. The appendix provides proofs of all lemmas and propositions. Our goal is twofold: (*i*) to provide intuition for the key mechanisms operating in our framework and (*ii*) to gain insight into how to parameterize the model. We focus, in particular, on two central interactions: those between productivity heterogeneity and country differences, in Subsection 3.1, and those between productivity heterogeneity and skill-biased technology, in Subsection 3.2. In both subsections we maintain the following simplifying assumption.

GEN There are two countries, $I = \{1, 2\}$; trade costs are symmetric, $\tau \equiv \tau_{12} = \tau_{21}$; and the elasticity of substitution between sectors is one, $\eta' = 1$.

3.1 Hicks-Neutral Technologies and Asymmetric Countries

In this subsection, we conduct comparative statics exercises on the skill premium under Assumption GEN and the following assumption:

HN There are two sectors, $J = \{x, y\}$ with sector x relatively skill intensive, $\alpha_y < \alpha_x$; production functions are Cobb Douglas, $\rho = 1$ in Equation (2); and $\widetilde{\varphi} = 1/2$.

With Cobb-Douglas production functions, skilled labor's share of revenue in sector j is equal to α_j. With either $\rho = 1$ or $\widetilde{\varphi} = 1/2$, technology is Hicks-neutral, $\varphi = 0$. We assume that $\widetilde{\varphi} = 1/2$ so that the productivity of a z-type producer in sector j is $A_i(j)\, z$, as in standard models such as EK.

Under Assumptions GEN and HN, the labor market clearing conditions become

$$2s_iH_i = \sum_{j=x,y} \alpha_j \left[\pi_{ii}(j) Q_iP_i + \pi_{-ii}(j) Q_{-i}P_{-i}\right] \tag{13}$$

$$2w_iL_i = \sum_{j=x,y} (1-\alpha_j) \left[\pi_{ii}(j) Q_iP_i + \pi_{-ii}(j) Q_{-i}P_{-i}\right], \tag{14}$$

where $\pi_{ni}(j)$ is defined in Equation (12). Equations (13) and (14) are derived as follows. With a constant share of expenditure allocated to each sector, the value of country i's production supplied to country n in sector j is given by $\pi_{ni}(j) Q_nP_n/2$. With Cobb-Douglas production functions, the payments to each type of labor in each sector is given by the product of the constant factor shares and the total value of production in that sector. Using the factor market clearing conditions, the skill premium is given by

$$\frac{s_i}{w_i} = \frac{L_i}{H_i} \frac{\sum_{j=x,y} \alpha_j \left[\pi_{-ii}(j) Q_{-i}P_{-i} + \pi_{ii}(j) Q_iP_i\right]}{\sum_{j=x,y} (1-\alpha_j) \left[\pi_{-ii}(j) Q_{-i}P_{-i} + \pi_{ii}(j) Q_iP_i\right]} \tag{15}$$

Country i's skill premium depends on its endowment ratio, H_i/L_i; the skill intensities of the sectors, α_x and α_y; the ratio of countries' expenditures, Q_1P_1/Q_2P_2; and all the $\pi_{ni}(j)$'s. Lemma 1 in Appendix A shows that the π's and the ratio of countries' expenditures are pinned down by α_x, α_y, Δ_1, Δ_2, and Δ_3, where $\Delta_i = \frac{1}{2}\left[\pi_{i-i}(x) + \pi_{i-i}(y)\right]$ for $i = 1, 2$ is country i's expenditure share of trade and $\Delta_3 = \pi_{12}(y) - \pi_{12}(x)$ is the difference in import shares between sector x and sector y in country 1, where Δ_3 is a measure of the extent of between sector trade. A straightforward implication of Lemma 1 is that the skill premium s_i/w_i is pinned-down by factor endowments, αs, and Δs.

In order to study the effects of trade on the skill premium, we must introduce the concept of comparative advantage. We say that country 1 has a comparative advantage in sector x if $v_1(x)/v_1(y) < v_2(x)/v_2(y)$ in autarky. While comparative advantage is defined as a condition on relative composite input bundle costs in autarky, it is straightforward to show that if country 1 has a comparative advantage in the x sector, then $v_1(x)/v_1(y) < v_2(x)/v_2(y)$ in any trade equilibrium with positive trade costs. Hence, if country 1 has a comparative advantage in the x sector, then it is a net exporter in the x sector (i.e. $\Delta_3 > 0$) if trade shares are positive (i.e. if $\Delta_1, \Delta_2 > 0$). The necessary and sufficient condition under which country 1 has a comparative advantage in the skill-intensive sector is

$$a\left(\frac{H_1/L_1}{H_2/L_2}\right)^{\alpha_x-\alpha_y} > 1, \tag{16}$$

where $a = A_1(x) A_2(y)/A_1(y) A_2(x)$ indexes country 1's Ricardian comparative advantage (if $a > 1$) or disadvantage (if $a < 1$) in sector x. Condition (16), which we impose throughout this section, follows from the definition of $v_i(j)$ and Equations (12) and (15). To understand this condition, consider two special cases that are standard in the literature. First, if $a = 1$ so that there is no Ricardian comparative advantage, then country 1 has a comparative advantage in sector x if and only if $H_1/L_1 > H_2/L_2$, exactly as in the Heckscher-Ohlin model. Second, if endowment ratios are the same across countries so that there is no Heckscher-Ohlin-based comparative advantage, then country 1 has a comparative advantage in sector x if and only if $a > 1$, exactly as in the Ricardian model.

We are now equipped to study the effects of a trade liberalization on the skill premium. Starting in autarky, a reduction in trade costs leads to reallocation of factors between sectors towards a country's comparative advantage sector. This increases the relative demand and, therefore, the relative price of the factor that is used intensively in the comparative advantage sector. We refer to this force as the *between effect* of globalization on the skill premium. This result is summarized in the following proposition.

Proposition 1 *Suppose Assumptions GEN and HN hold. Reducing trade costs from autarky to any positive level of trade increases* s_1/w_1 *and decreases* s_2/w_2.

When there are no productivity differences between sectors and subsectors, our model is similar to the Heckscher-Ohlin model, in which the location of production of each subsector is determined solely by trade costs and factor endowments. In this case, Proposition 1 captures what is often called the Stolper-Samuelson effect. However, in our model a given subsector's location of production is determined not only by trade costs and factor endowments, but also by sectoral productivities and within-sector idiosyncratic productivities. A higher dispersion of productivities within sectors, a higher θ, increases the relative importance of the idiosyncratic component of production costs. Intuitively, if θ is very high, then in any subsector one country is likely to have a much higher subsector-specific productivity than the other, and this country is likely to export in this subsector even if it has a comparative disadvantage in the sector.

On the other hand, a higher value of a increases the relative importance of the systematic Ricardian component of comparative advantage given the assumption that country 1 has a comparative advantage in the x sector. Intuitively, if a is very high, then country 1's comparative advantage in the x sector is likely to be sufficiently strong to overcome even large idiosyncratic productivity disadvantages in a given sector x subsector, so that country 1 is likely to export in this sector x subsector. The following proposition confirms this intuition.[10]

[10] In Proposition 2 we hold trade shares constant, rather than holding trade costs constant, while varying θ and a for two reasons. First, as we increase θ holding trade costs constant, the impact on the the skill premium is ambiguous because trade shares rise and greater volumes of trade tend to strengthen the between effect, all else equal. Second, in our quantitative analysis we assess the strength of the between effect by calibrating the model to match observed trade shares rather than (unobserved) trade costs.

Proposition 2 *Suppose Assumptions GEN and HN hold. If τ and T_1/T_2 are chosen to match fixed values of trade shares, then the increase in the s_1/w_1 and the decrease in s_2/w_2 caused by moving from autarky to these trade shares is decreasing in θ and increasing in a.*

Proposition 2 provides comparative static results on the impact of key parameters on the strength of the between effect. However, from the discussion above, the percentage change in the skill premium of moving from autarky to any positive trade shares is fully pinned down by factor endowments, factor intensities, country 1 and country 2's expenditure shares of trade (Δ_1 and Δ_2), and the difference in import shares between sector x and sector y in country 1 (Δ_3). In particular, conditional on keeping these variables fixed, the percentage change in the skill premium is independent of our particular choice of θ, a, and factor endowments. This logic, which can be generalized easily to any number of sectors (see Burstein and Vogel 2010) and countries, guides our choice of targets when quantifying the strength of the between effect in Section 4.

3.2 Skill-Biased Technology and Symmetric Countries

In this subsection, we conduct comparative static exercises on the skill premium under Assumption GEN and the following assumption.

SB There is one sector: $J = 1$; the sector-level aggregator is Cobb Douglas: $\eta = 1$; technology is skilled biased: $\varphi > 0$; and countries are symmetric: $H_1 = H_2$, $L_1 = L_2$, & $A_1(j) = A_2(j) = 1$.

With symmetric countries, factor prices are equalized across countries, $s = s_1 = s_2$ and $w = w_1 = w_2$. The assumption that $\eta = 1$ simplifies the algebra: a consequence of $\eta = 1$ is that, in the factor demand equations, the direct effect of a reduction in trade costs—less labor is required to sell a given quantity of output in the foreign market—and the indirect effect—falling export prices increase the quantity sold in export markets—exactly offset each other. With skill-biased technology, we cannot solve explicitly for $\pi_{ni}(j)$, unlike under Assumptions GEN and HN; however, we are able to obtain analytic comparative static results without this explicit solution.[11]

If countries are symmetric and technology is Hicks-neutral, $\varphi = 0$, then reductions in the cost of trade do not affect the skill premium. On the other hand, if technology is skill biased, $\varphi > 0$, then reductions in the cost of trade increase the skill premium. The intuition behind this result is as follows. As in standard models with heterogeneous productivities (Ricardian or heterogeneous firm models), reductions in trade costs induce a reallocation of factors of production within sectors towards relatively productive producers. With skill-biased technology, relatively productive producers are also relatively skill intensive; see Equation (3). Hence, trade liberalization increases the relative demand for skill and the skill premium. This result is summarized in Proposition 3.

[11] Because we do not require a closed-form solution for $\pi_{ni}(j)$, our results in this subsection do not make use of the assumption that costs are distributed exponentially.

Proposition 3 *If Assumptions GEN and SB hold, then s/w is strictly decreasing in τ.*

Summary of comparative statics on international trade and the skill premium: To summarize the findings in this section, the results in Propositions 1 and 3 suggest that the between effect and the within effect both lead to an increase in the skill premium in skill-abundant countries in response to a reduction in trade costs. On the other hand, these effects push the skill premium in opposite directions in skill-scarce countries. According to Proposition 2, a higher value of idiosyncratic productivity dispersion weakens the between effect—and, as we quantitatively show below, strengthens the within effect—and hence increases the likelihood that the skill premium also rises in skill-scarce countries. Which force dominates and by how much is a quantitative question that we address in our quantitative analysis.

4 Baseline Parameterization with International Trade

In this section, we study the quantitative implications of a reduction in trade costs on the skill premium in a parameterized version of our model. We first present the quantitative model, which relaxes Assumptions GEN, HN, and SB and introduces a non-tradeable sector. We then calibrate our model to match salient features of the data on U.S. and the average skill-scarce country's trade with skill-abundant and skill-scarce countries. Finally, we present our baseline results on the implications of reductions in trade costs on the skill premium.

4.1 Quantitative model

We extend our analytic model by introducing a non-tradeable sector (matched to service producing sectors in the data) in addition to the tradeable sector (mainly matched to goods producing sectors and merchandise trade in the data, although sometimes matched to manufacturing due to data availability). We do so to account for the relatively high share of non-traded service sectors in the U.S. and many other countries. In particular, we assume that the final good in country i is produced according to $(Q_i)^{\gamma}(N_i)^{1-\gamma}$, where Q_i denotes output of the final tradeable good, as modeled in Section 2, and N_i denotes output of the final non-tradeable good.[12] We model production of non-tradeable goods exactly as in Section 2, but we abstract from trade in services by assuming that trade costs in these sectors are infinite. We assume that labor is perfectly mobile between the tradeable and non-tradeable sectors.

We consider a world economy that is composed of four countries: two ex-ante identical skill-abundant countries, countries 1 and 2, and two ex-ante identical skill-scarce countries, countries 3 and 4. That is, countries 1 and 2 (and countries 3 and 4) are identical in all respects but in their

[12] In our sensitivity analysis, we allowed for an elasticity of substitution between tradeable and non-tradeable sectors different from one. Our quantitative results are largely unaffected by varying this elasticity over a wide range of values.

ex-post realizations of country/subsector-specific productivity draws. We parameterize country 1 to match U.S. data, and country 3 to match data for the average skill-scarce country, as described below.

We believe that our four-country setup is not too restrictive to quantify the strength of the between effect on the skill premium since, as we showed above, under Assumptions GEN and HN this effect is pinned down by the extent of between-sector trade, which we target in our calibration. To assess the role of our assumption that there are four countries for the strength of the within effect, we performed a sensitivity exercise in which we change the number of symmetric skill-abundant or skill-scarce countries and find that, following our calibration strategy, the percentage change in the skill premium does not vary much.[13]

4.2 Parameterization

The parameters that we must choose are the skill bias of technology, φ; the within-sector dispersion of productivity, θ; the elasticity of substitution across sectors and subsectors, η' and η; the elasticity of substitution between skilled and unskilled labor at the level of an individual producer, ρ; the share of tradeables in final output, γ; the country-sector TFP levels, $A_i(j) = T_i \times T_i(j)$; the labor endowments, H_i, L_i for $i = 1, 3$; the sectoral skill intensities, α_j's; and the trade costs τ_{12}, τ_{13}, and τ_{34}. It is straightforward to show that, for given endowment ratios H_i/L_i and other parameter values, trade shares and the skill premia only depend on population size and aggregate TFP through the ratio $(T_1 L_1) / (T_3 L_3)$. Hence, without loss of generality we set $T_1 = L_1 = L_3 = 1$. We assume that the sectoral component of TFP, $T_i(j)$, is a linear function of skill-intensity α, with $T_i(\text{median } j) = 1$. We normalize $T_1(j) = 1$, which leaves us with one parameter left to choose, which determines the extent of sectoral productivity differences in country 3: $t_3 = \log\left(\frac{T_3(j_{\alpha\ \min})}{T_3(j_{\alpha\ \max})}\right)$, where $j_{\alpha\ \min}$ and $j_{\alpha\ \max}$ are the sectors with the lowest and highest α's, respectively. A positive value of t_3 means that country 3 is relatively more productive in unskill-intensive sectors.

General strategy: Our central objective is to quantify the strength of the between and within effects of globalization on the skill premium. We use our theoretical results to guide our calibration strategy. Consider first the between effect. Lemma 1 implies that the strength of this effect in a two-country, two-sector model (under Assumptions GEN and HN) is fully determined by the trade

[13] We do not consider a world economy with a larger number of asymmetric countries because with many countries it becomes computationally infeasible to choose bilateral trade costs to exactly match bilateral trade shares. This is because, with skill-biased technology, to solve the model we must simulate productivity draws across a large number of subsectors, and for each subsector compare marginal costs numerically across countries, as discussed above. Two common aproaches to reduce the number of parameters have been used in environments with Hicks-neutral productivities. The first approach is to choose a parametric relationship between bilateral trade costs and bilateral country characteristics (see e.g. EK 2002, Fieler 2007, and Waugh 2009). However, this approach does not match bilateral trade volumes for each country, which are essential for determining the strength of the between and within effects. The second approach is to make use a model's implied analytic sectoral gravity equations, which summarize all relevant information about trade costs, as in Dekle et. al. (2008). However, this aproach is infeasible with skill-biased technology, where no such analytic solutions exist.

shares in each country and by $\Delta_3 = \pi_{12}(y) - \pi_{12}(x)$. It is straightforward to extend this result to our four-country model (under a four-country version of Assumptions GEN and HN). In this case, the strength of the between effect is determined by the trade shares in each country, the share of imports in country 1 from country 2, the share of imports in country 3 from country 4, and the difference between country 1's share of imports from country 2 in the skill-intensive sectors and in the unskill-intensive sectors, which in the two-sector model is given by $\Delta_3^* = \frac{\pi_{12}(y)}{\pi_{12}(y)+\pi_{13}(y)} - \frac{\pi_{12}(x)}{\pi_{12}(x)+\pi_{13}(x)}$. Note that, conditional on matching these five moments, the strength of the between effect is independent of the level of the skill premium and endowments in every country. Motivated by this result, our calibration targets these five moments, where Δ_3^* is constructed to accommodate a multi-sector version of the model. We acknowledge, however, that these five moments do not exactly pin down the strength of the between effect in our quantitative model, which relaxes Assumptions GEN, HN and the two-sector assumption imposed in our analytic work.

Now consider the within effect of going from autarky to fixed trade shares. Based on our theoretical results, for a given share of sales accounted for by exporters (which for given trade shares depends only on the share of sales accounted for by exporters in their home country), the strength of the within effect is largely shaped by the difference in skill intensity between exporting and non-exporting producers within a sector. Given trade shares, the larger is either the share of sales of exporters or the difference in skill intensities between exporters and non-exporters, the larger is the increase in the demand for skill as labor shifts towards exporting producers in response to a trade liberalization. Motivated by this logic, our calibration targets these two moments. Note that the difference in skill intensity between exporters and non-exporters is increasing in the elasticity of skill intensity to productivity φ, while the share of sales accounted for by exporters (for a fixed trade share) is increasing in the dispersion of subsector productivities θ when $\eta > 1$.[14]

Specifics of calibration: We calibrate our model using data for 2006 or the closest years with available information. We first determine the set of skill-abundant and skill-scarce countries that we map into our four-country model economy. Using the educational attainment dataset described in Barro and Lee (2000), we rank countries by their most recent data on the average years of education for the population over age 25. We consider a country to be skill abundant if this average is greater than 6.9 years. According to this cutoff, Mexico is the most skilled of the skill-scarce countries and Italy is the least skilled of the skill-abundant countries. We set the ratio of endowment ratios $(H_1/L_1)/(H_3/L_3) = 0.49$ to match the population-weighted average of education levels in the skill-abundant countries relative to the unskill-abundant countries, and we set $H_1/L_1 = 0.71$ as in Acemoglu (2002). Recall that, under Assumptions GEN and HN, if we hold endowments fixed then endowments and country-sector TFP's do not affect the strength of the between effect of moving

[14] If $\eta = 1$, then with symmetric countries, export sales equal domestic sales, independent of trade costs. Hence, in this case, matching trade shares immediately pins down the share of sales accounted for by exporters in their home country.

from autarky to fixed trade shares.

We set the share of tradeable goods in final output, $\gamma = 0.26$, to match the share of good producing sectors in U.S. gross output in 2006, exclusive of government sectors.[15] We assume that there are 100 sectors in both tradeables and non-tradeables, and that each sector contains 900 subsectors. As noted above, we calibrate many of our parameters using manufacturing data, as opposed to data from all goods producing sectors. The sectoral skill intensities, α, are uniformly distributed over the range 0.1 and 0.6 to roughly match the range of skill intensities of manufacturing sectors in the U.S.[16] For symmetry, we assume that the elasticity of substitution between sectors equals the elasticity of substitution between subsectors, $\eta' = \eta$.[17] We set the value of this elasticity at $\eta = 2.7$, to match the median sectoral elasticity for SITC 5-digit industries in the U.S. estimated by Broda and Weinstein (2006).

We choose the elasticity of substitution between skilled and unskilled labor at the level of an individual producer, $\rho = 1.2$, to roughly match the aggregate elasticity of substitution of 1.4 between skilled and unskilled labor estimated by Katz and Murphy (1992). In particular, we set ρ so that, given other parameter values, a change in the relative endowment of skilled labor results in a change in the skill premium that is consistent with that estimated by Katz and Murphy (1992). This procedure yields a value of ρ that is lower than 1.4 because of inter- and intra-sectoral labor reallocation in response to a change in factor endowments.

We set the value of the seven remaining parameters, (i) aggregate TFP in country 3, T_3, (ii) the parameter that controls the linear slope of sectoral productivities, t_3, (iii) the dispersion of subsector productivities θ, (iv) the skill-bias of technology φ, and $(v - vii)$ trade costs τ_{12}, τ_{13}, and τ_{34}, to match seven moments. These are (i) the overall share of U.S. imports in manufacturing from skill-abundant countries;[18] (ii) the absolute difference between the U.S.'s share of imports in manufacturing from skill-abundant countries in the 50% most skill-intensive sectors and in the 50% least skill-intensive sectors, which is a multi-sector version of Δ_3^* defined above, and which we refer to as *the extent of between sector trade* (Panel A of Figure 1 displays a positive but very noisy relation between the share of U.S. imports from skill-abundant countries and the sector's skill intensity—across manufacturing SIC sectors—from which we calculate the extent of between sector trade);[19]

[15] This is based on data from the Bureau of Economic Statistics. Good producing sectors include agriculture, forestry, fishing, hunting, mining, and manufacturing.

[16] Our measure of sectoral skill intensity is the sectoral share of non-production worker employment, obtained from the NBER-CES Manufacturing Industry Database for 2002.

[17] In our sensitivity analysis, we considered a lower elasticity of substitution across sectors η'. This reduces the strength of the within effect, so that globalization induces a smaller rise in the skill premium, because trade liberalization induces less factor reallocation towards skill-intensive sectors in all countries.

[18] The share of U.S. imports in manufacturing from skill-abundant countries was equal to 0.59 in 2006.

[19] In particular, we target a difference of 11%, as in U.S. manufacturing trade data in 2006. To derive this statistic, we created a second measure of skill intensity—the average worker wage in the sector—and dropped all SIC sectors that are in the top 20% of one measure of skill intensity and in the bottom 20% of the other measure. Without dropping these sectors the difference would have been much smaller (2%), and the between effect of trade on the skill premium would be even weaker than the one we obtain in our baseline parameterization. In Section 5, we report how

(*iii*) the ratio of aggregate sales of exporters relative to non-exporters in U.S. manufacturing;[20] (*iv*) the average (across sectors) of the logarithm of the skill intensity of exporters relative to non-exporters in Mexican (i.e. country 3) manufacturing;[21] (*v*) the average of merchandise exports and imports relative to gross output of goods producing sectors in the U.S.;[22] (*vi*) the average of merchandise exports and imports relative to gross output of goods producing sectors in skill-scarce countries;[23] and (*vii*) the ratio of merchandise trade between skill-scarce countries relative to total merchandise trade of skill-scarce countries.[24] In constructing moments (*ii*) and (*iii*) in our model, we assume that within each exporting subsector, all producers export. This is one among many other configurations because, with perfect competition and constant returns to scale, the distribution of size and exporting status across producers within subsectors is not uniquely pinned down.

Table 1 displays the parameter values in our baseline parameterization and Table 2 reports the targets that we used in our calibration. Our baseline value of $\theta = 0.2$ falls within the range of θ's estimated by others, although the gravity equations that give rise to these estimates do not apply with skill-biased technology. For example, EK estimate $\theta \in [0.08, 0.28]$, Donaldson (2008) estimates $\theta \in [0.14, 0.26]$, Ramondo and Rodriguez-Clare (2009) estimate $\theta = 0.14$, Simonovska and Waugh (2010) estimate $\theta = 0.22$, and Waugh (2009) estimates $\theta = 0.18$. In our baseline parameterization, skill-scarce countries have a relatively low productivity in skill-intensive sectors (i.e. $T_3(j)$ is negatively sloped). However, with $t_3 = 0.02$, the variation in the systemic component of productivity across sectors is very small, only a 2% difference between the least and most skill-intensive sectors.[25] With these values of θ and t_3, the model implies a positive but relatively flat relation between country 1's import share from skill-abundant countries and the sector's skill intensity (see Panel B of Figure 1, which also displays the steeper relationship that would arise

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the strength of the between effect varies with this moment.

[20] Using data from the 1992 U.S. Census of Manufactures (reported in Bernard et. al. 2003), this ratio equals 1.49.

[21] From unpublished Mexican manufacturing plant-level data for 1998 from Verhoogen (2008), we calculate by sector the share of skilled workers (relative to the sector's employment) in exporting and non-exporting plants, where skilled workers are those with 12 or more years of education. The average across sectors of the relative skill intensity of exporters to non-exporters is 0.19. For the U.S. we do not observe educational attainment by plant for a comprehensive number of plants. Bernard et. al. (2007) use U.S. Census data to construct a more imperfect measure of a plant's skill intensity, the fraction of non-production workers, and find that averaging across plants within sectors, the skill intensity of exporters relative to non-exporters is 0.11.

[22] Merchandise trade is given by trade in goods from the BEA, and gross output of goods includes the sectors listed above. The resulting goods trade share in country 1 is 25.3%. We match the share of trade in gross output as opposed to value added, because our model abstracts from intermediate inputs in production.

[23] We first obtain the share of merchandise trade in total output as the product of the two following numbers: (i) the average of merchandise exports and imports relative to the combined GDP of skill-scarce countries, equal to 26.6% in 2006 based on information from the IMF's Direction of Trade Statistics and WDI; and (ii) the median share of value added in gross output, equal to 0.5, across the set of unskill-abundant countries with available input-output data as reported by the OECD. The implied share of trade in gross output in goods' producing sectors is equal to $0.266/2/\gamma = 50.9\%$.

[24] This statistic is based on information from the IMF's Direction of Trade Statistics, and is equal to 20.6% in 2006.

[25] This is consistent with empirical evidence in Morrow (2008) that country-sector productivities are not very correlated with the sectors' factor intensities or country endowments.

if we used a lower value of θ). Our calibrated value of the degree of skill bias in technology is $\varphi = 0.33$. In our parameterization, the resulting share of trade (i.e. the average of exports and imports) in total output is equal to 6.6% in country 1 and 13.3% in country 3. Finally, we obtain a relatively low level of aggregate productivity in country 3, $T_3 = 0.29$—which implies that country 3 is relatively small in terms efficiency units—because the skill-scarce countries' share of global trade is less than 50% while their average trade share is greater than in the U.S., country 1.

Our parameterized model with skill-biased technology implies a positive relation between a sector's skill intensity and the level of normalized trade (defined as the ratio of exports plus imports to output minus net exports). This is illustrated in Figure 2 under our baseline parameterization. Figure 2 also shows that this relation is essentially flat in a parameterization of our model with Hicks-neutral technology. We prove this result analytically, in Proposition 6 in the Appendix under Assumption GEN and a two-sector version of Assumption SB. Intuitively, the interaction between skill intensity and subsector-specific productivity—which implies that z is relatively more important in the production function in skill-intensive sectors—causes the same distribution of underlying productivities in all sectors to yield a more dispersed distribution of unit costs in skill-intensive sectors. Hence, a given productivity advantage, $z_i > z_{-i}$, provides country i producers in skill-intensive sectors a relatively larger cost advantage than in the unskill-intensive sector. With positive trade costs, it is more likely that a good in a skill intensive sector is traded.[26]

We find some supportive evidence of this prediction of the model by regressing measures of U.S. normalized trade—defined as the average of exports plus imports, divided by gross output plus net imports—in manufacturing sectors, using the BEA's detailed IO tables for the 2002 Benchmark, on skill intensity, measured by the share of non-production workers. In all specifications we considered, the coefficient on skill intensity is positive and significant at the 1% level.[27]

5 Baseline Results with International Trade

In this section we study the implications of international trade on the skill premium. To do so, we use our parameterized model to conduct the following counterfactual. We consider a reduction in trade costs starting in autarky ($\tau_{in} = \infty$) to the levels of trade costs that generate the volumes of international trade observed in 2006, while holding fixed all other parameters at our baseline level. One way to interpret this counterfactual is that it answers the question: But for international trade, by how much would the skill premium change?

Rows 12 and 13 in Table 2 report the log-percentage change in the skill premium, s_i/w_i, resulting

[26] This result is similar to that in Fieler (2007), which predicts that one sector is more traded than another, but unlike Fieler (2007) does not rely on an assumption that the distribution of productivities is more dispersed in one sector than in another.

[27] To our knowledge, we are the first to identify this relationship in the data. We acknowledge that there are alternative mechanisms that could also lead to this pattern in the data. For example, an alternative hypothesis is that trade costs are lower in skill-intensive sectors.

from this experiment. Countries 1 and 2 experience a 1.7% increase in the skill premium while countries 3 and 4 experience an 3.2% increase in the skill premium. The two central messages from these results are as follows. First, the within effect is stronger than the between effect. This is evident from the rising skill premium in the skill-scarce countries. Second, the magnitudes of the changes in the skill premium of moving from autarky to 2006 levels of trade are quite small relative to, for example, the 24% rise in the U.S. College-High School wage gap between 1966 and 2006 (see, e.g., Acemoglu and Autor 2010). In what follows, we explain in detail the key features of our parameterized model that give rise to these two findings.

5.1 Within Effect Stronger Than Between Effect

The rise in the skill premium in the skill-scarce countries reveals that the between effect is weak relative to the within effect. This can be understood in two parts. First, we show that, consistent with Proposition 2, the parameters that determine (*i*) the dispersion of subsector productivities and (*ii*) sectoral productivity differences play a central role in shaping the strength of the between effect. Given the information we use to calibrate these two parameters, we obtain a weak between effect. Second, we show that the dispersion of subsector productivities and the skill bias of technology play a central role in determining the strength of the within effect. Given the information we use to calibrate these two parameters, we obtain a relatively stronger within effect. We also examine the implications of the relative strength of the within effect for how the skill abundance of a country's trade partners determines the effect of a trade liberalization on that country's skill premium.

5.1.1 Between Effect

The strength of the between effect is largely shaped by two parameters: the dispersion of subsector productivities, θ, and the extent of sectoral productivity differences, $t_3 = \log\left(\frac{T_3(j_{\alpha \min})}{T_3(j_{\alpha \max})}\right)$. Proposition 2 states that the magnitude of the change in the skill premium resulting from the between effect is decreasing in θ and increasing in t_3. We now illustrate the quantitative relevance of this proposition in our parameterized model, which relaxes Assumptions GEN and HN. We focus on the role of the parameter θ although a similar exercise could be conducted with t_3.

To isolate the quantitative effect of θ on the between effect, we assume that technology is Hicks-neutral, $\varphi = 0$, as in Proposition 2. Figure 3 depicts the percentage change in the skill premium in countries 1 and 3 as they move from autarky to the baseline shares of trade in output, for levels of θ ranging from 0.02 to 0.35. Note that the strength of the between effect is significantly weakened as we raise θ. For example, increasing θ from 0.02 to 0.10 (which is at the low range of the value of this parameter used in the literature) reduces the change in the skill premium in all countries by about 2/3.

While different values of θ and of t_3 are consistent with a weak or strong between effect, our choice of the combination of these parameters is constrained by the small extent of between sector trade, which can be observed in Figure 1 and can be summarized—as in our calibration—by the relatively small difference between country 1's share of imports in manufacturing from country 2 in the 50% most skill-intensive sectors and in the 50% least skill-intensive sectors. Any combination of θ and t_3 that yields a small extent of between sector trade will imply a weak between effect. This result is consistent with low estimates of the factor content of trade that have lead others in the labor and trade literatures to conclude that the between effect is weak.

5.1.2 Within Effect

The strength of the within effect is largely shaped by two parameters: the skill bias of technology, φ, and the dispersion of subsector productivities, θ. Panel A of Figures 4 and 5 depict the percentage change in the skill premia in countries 1 and 3 as they move from autarky to the baseline shares of trade in output, for values of φ ranging from -0.2 to 0.7 and θ ranging from 0.02 to 0.35, respectively.

Panel A of Figure 4 reveals that the change in the skill premium is increasing in φ. Intuitively, the difference in skill intensities of a high-z producer and a lower-z producer is strictly greater, the higher is φ. Hence, when a reduction in trade costs induces low-z producers to contract and high-z producers to expand, the increase in the relative demand for skill is strictly greater, the higher is φ. When $\varphi = 0$, only the between effect is active, and hence the skill premium rises in country 1 and falls in country 3, as in Figure 3. When $\varphi > 0$, both the between and within effects are active. For $\varphi \geq 0.15$, the within effect dominates the between effect in country 3, in the sense that the skill premium increases there. Note that changes in φ have a relatively larger impact on the change in the skill premium in country 3 than in country 1. This is because—under our parameterization—country 3 is relatively small (in efficiency units), so that export sales relative to domestic sales are relatively greater in country 3, which implies that the fraction of exporters is lower in country 3 than in country 1. Hence, the difference between the skill intensity of exporters and non-exporters is greater in country 3 than in country 1 (our target moment (*iv*) defined above is 0.19 in country 3 and 0.17 in country 1), and the sales of exporters relative to non-exporters is greater in country 3 than in country 1 (our target moment (*iii*) defined above is 2.1 in country 3 and 1.5 in country 1). Hence, because country 3 is relatively smaller, the within effect is stronger in country 3 than in country 1. This explains why, in our baseline parameterization, the skill premium rises by more in country 3 than in country 1, despite the fact that the between effect reduces the skill premium in country 3.

Panel A of Figure 5 reveals that the change in the skill premium is increasing in θ in country 3 and is non-monotonic in θ in country 1. This is because the impact of increasing θ on the between and within effects push the skill premium in the same direction in country 3 but in opposite directions in country 1: the between effect is weakened with a higher value of θ, as shown in Figure

3, and the within effect is strengthened with a higher value of θ. Intuitively, as θ rises the within effect becomes stronger because the relative difference in productivity between expanding (high-z) and contracting (low-z) producers increases. Thus, labor reallocation across producers as a result of a decline in trade costs induces a greater increase in the relative demand for skill, the greater is θ.

While different values of φ and θ are consistent with a weak or strong within effect, Panel B of Figures 4 and 5 illustrates how our choices of $\varphi = 0.33$ and $\theta = 0.2$ are constrained by (i) the difference in skill intensity between exporting and non-exporting producers and (ii) the share of sales of exporters relative to non-exporters, both of which we target in our calibration. At $\varphi = 0.33$, $\theta = 0.2$, and $t_3 = 0.02$, the within effect is stronger than the between effect.

How robust is our conclusion that the within effect is stronger than the between effect to our measure, in the data, of the extent of between sector trade? In order to address this question, we vary the extent of between sector trade by changing the extent of sectoral differences in productivity, t_3. Panel A of Figure 6 illustrates the impact of changing t_3 on the skill premium and Panel B illustrates the impact of such a change on the extent of between sector trade. As t_3 increases, so that country 3 becomes relatively more productive in unskill-intensive sectors, the between effect becomes stronger. Note that in order for the between effect to become stronger than the within effect in country 3, we require $t_3 \geq 0.42$, so that country 3 has a substantial Ricardian disadvantage in skill-intensive sectors. At this value of t_3, the extent of between sector trade is 0.36, more than three times the value of 0.11 used in our baseline parameterization. This sensitivity analysis on how the extent of between sector trade affects the relative strength of the between effect helps address concern, see e.g. Krugman (2008) and Feenstra (2010), that aggregation at the sector level—which implies that the extent of between sector trade observed in the data underestimates the true factor content of trade—may bias downward the estimated strength of the between effect. Our results show that this aggregation bias would need to be substantial (i.e. increasing our target by more than a factor of three) in order to overturn our result that the within effect is relatively strong.

5.1.3 Trade partners' skill endowment and the skill premium

To what extent does the skill abundance of a country's trade partners matter for determining the impact of trade liberalization on that country's skill premium? To address this question, we conduct a counterfactual in which we hold trade shares fixed but shut down international trade between skill-abundant and skill-scarce countries (so that the between effect is inactive). In particular, we calculate the change in the skill premium in country 1 of moving from autarky to a modified version of our baseline 2006 parameterization in which (i) skill-abundant and skill-scarce countries do not trade with each other and (ii) trade shares in skill-abundant countries are fixed at their 2006 baseline level. The skill premium rises by 1.3% in country 1, which corresponds to roughly 75% of the 1.7% rise in the skill premium of moving from autarky to our baseline that includes trade between skill-abundant and skill-scarce countries.

We also consider an alternative counterfactual in which we move from autarky to a modified version of our baseline 2006 parameterization in which H_3/L_3 is set equal to H_1/L_1. We obtain a similar result: the skill premium rises by 1.2% in country 1.

We conclude from these counterfactuals that factor endowment differences across countries only account for roughly 1/4 of the increase in the skill premium in country 1 generated by international trade. This suggests that how much a country trades may matter more for the skill premium than with whom a country trades, a point that we now address.

5.1.4 Trade Shares and Small Changes in Skill Premium

To what extent are small trade shares responsible for the small impact of trade liberalization on the skill premium that we find in our baseline parameterization? To answer this question, we consider two alternative counterfactual exercises in which we increase trade shares.

In the first counterfactual, we calculate the rise in the skill premium of moving to free trade in the traded sector of the economy by eliminating trade costs in the traded sector ($\tau_{in} = 1$ for all $i, n \in I$). The overall trade share is 15% in country 1, instead of 6.6%, and is 23% in country 3, instead of 13.3%. Starting in autarky, the skill premium rises by 2.4% in country 1, instead of 1.7%, and by 3.8% in country 3, instead of 3.2%.[28]

In the second counterfactual, we calculate the rise in the skill premium of moving to free trade in the both traded and nontraded sectors, by setting the share of tradeables in gross output γ to 1, and by eliminating trade costs ($\tau_{in} = 1$ for all $i, n \in I$). The overall trade share is now 59% in country 1 and 88% in country 3. Starting in autarky, the skill premium rises by 9.5% in country 1 and by 13.3% in country 3.[29]

We conclude from these counterfactuals that, in our model, it is possible to obtain large changes in the skill premium from trade, but this requires unreasonably high trade shares relative to current U.S. and skill-scarce trade shares. This suggests that, given the relatively small current trade shares in the U.S., international trade may not be the central force shaping its skill premium.

[28] We also consider a less extreme counterfactual in which we keep the current share of trade in tradeables and raise the share of tradeables γ in final output so that the overall share of trade in country 1 coincides with the 8.4% U.S. trade share including trade in both goods and services (recall that in our baseline calibration we only consider trade in goods due to a lack of services data in many other countries), while keeping the share of trade in skill-scarce countries unchanged. The rise in the skill premium of going from autarky to this modified baseline is 2.3% in country 1, instead of 1.7%.

[29] We also consider a less extreme counterfactual in which we set $\gamma = 1$ and match the current share of trade in tradeables. That is, we abstract from the nontradeable sector of the economy or, similarly, assume that there is no labor mobility between tradeable and nontradeable sectors. This results in an overall share of trade in country 1 of 25.3%, and a rise in the skill premium, starting in autarky, of 6.6%.

6 Multinational Production

In this section, we extend our model by incorporating multinational production (MP). In Section 6.1 we introduce MP into our model and conduct comparative static exercises on the skill premium. In Section 6.2 we parameterize the full model with international trade and MP and study the implications for the skill premium of moving from autarky to 2006 levels of international trade and MP. Finally, In Section 6.3 we calculate the contribution of globalization to the observed rise in the U.S. skill premium between 1966 to 2006.

6.1 MP and the Skill Premium

We model MP as enabling intermediate good producers to use their technologies in foreign countries. Producers choosing to engage in MP incur a per-unit cost. In particular, country k producers in subsector (ω, j) that operate in country i incur a per-unit cost of MP given by $\mu_{ik} \times m_{ik}(\omega, j)$. The country-level per-unit cost of MP, $\mu_{ik} \geq 1$, is analogous to the per-unit cost of exporting and we similarly assume $\mu_{ii} = 1$. As in Ramondo and Rodriguez-Clare (2009), we introduce a country/subsector-specific efficiency loss of MP, with $m_{ik}(\omega, j) = m_{nk}(\omega, j) \geq 1$ for all $i, n \neq k$ and $m_{ii}(\omega, j) = 1$, in order to obtain an interior equilibrium for the subsectors that engage in MP versus exports; if we did not include this idiosyncratic MP cost, then producers from one country supplying a foreign country would all do so either by exporting or by MP.

Goods in subsector (ω, j) can be supplied to country n in I^2 ways: production can take place in any of the I countries and production can use productivity from any of the I countries. We denote by $c_{ni}^k(\omega, j)$ the per-unit cost of supplying (ω, j) to country n by producing in country i and using country k's productivity:

$$c_{ni}^k(\omega, j) = \frac{\mu_{ik} m_{ik} \tau_{ni}}{A_k(j)} \left[\alpha_j z_k^{\frac{\varphi}{2}+\rho-1} s_i^{1-\rho} + (1-\alpha_j) z_k^{\rho-1-\frac{\varphi}{2}} w_i^{1-\rho}\right]^{1/(1-\rho)}$$

where we omit the dependence of m_{ik} and z_k on (ω, j). Note that if country k producers locate in country i, then they use their own productivity z_k and TFP $A_k(j)$, but they use country i labor and hence incur country i's labor costs, s_i and w_i. For simplicity, in what follows in this section we consider the case with two countries and symmetric country-level MP costs (we drop this assumption in the quantitative analysis in Sections 6.2 and 6.3).

As before, we conduct comparative static exercises under two different sets of simplifying assumptions to obtain analytic solutions.

Hicks-neutral technology and asymmetric countries: We first consider the specification of our model with $\widetilde{\varphi} = 1/2$ so that technology is Hicks-neutral. In this case, the cost of the factor bundle can be disentangled from the productivity z, so that the cost $c_{ni}^k(\omega, j)$ can be expressed as

$$c_{ni}^{k}(\omega, j) = \frac{v_i(j)}{z_k(\omega, j)} \frac{A_i(j)}{A_k(j)} \tau_{ni} \mu_{ik} m_{ik}(\omega, j)$$

The cost of supplying country 1 (omitting the dependence on sector j) is (i) v_1/z_1 if production is carried-out in country 1 using country 1's productivity; (ii) $\tau v_2/z_2$ if production is carried-out in country 2 using country 2's productivity and output is exported to country 1; (iii) $\mu m_{12} v_1 A_1/A_2 z_2$ if production is carried-out in country 1 via MP (using country 2's productivity); and, (iv) $\tau \mu m_{21} v_2 A_2/A_1 z_1$ if production is carried-out in country 2 via MP and output is exported to country 1. Each good is supplied by the lowest cost of the four alternatives, which is determined by factor prices, productivity draws, trade costs, and MP costs.

We now derive analytic results on the impact of changes in MP costs on the skill premium under assumptions GEN and HN. We solve for our model as in Subsection 3.1, where $\pi_{ni}(j)$ is now the fraction of subsectors in sector j that are supplied in country n by producers located in country i, defined as

$$\pi_{ni}(j) = \Pr\left[\min_{k=1,2}\left\{c_{ni}^{k}(j)\right\} \leq \min_{k=1,2}\left\{c_{n-i}^{k}(j)\right\}\right]. \tag{17}$$

With Hicks-neutral technology, MP does not affect the relative demand for skill within a sector at fixed factor costs because skill intensity is common across all producers in that sector; MP can only affect the between-sector allocation of factors. In the absence of international trade, $\pi_{nn}(j) = 1$ so MP does not affect the between-sector allocation of factors either. Combining these two implications, we obtain the result that, in the absence of international trade, the cost of MP has no impact on the skill premium.

Consider now the case with international trade. As the cost of MP decreases, the expected technological gap across locations decreases. With international trade, this increases the importance of factor endowment and sectoral technology differences in determining the pattern of specialization. Hence, as μ and m_{ik} decline, a country moves towards specializing in its comparative advantage sector, as in the model with no technological dispersion ($\theta \to 0$). In fact, under Assumptions GEN and HN, the skill premium with costless MP is equivalent to the skill premium with no technological dispersion.

Proposition 4 summarizes these two results.

Proposition 4 *Suppose Assumptions GEN and HN hold and that* $A_1(j) = A_2(j)$ *for* $j = x, y$. *Then*

1. $\lim_{\tau \to \infty}(s_i/w_i) = 0$ *is independent of* μ *for* $i = 1, 2$; *and*

2. $\lim_{\mu m_{ik}(\omega,j) \to 1 \forall (\omega,j),k,i} \frac{s_l}{w_l} = \lim_{\theta \to 0} \frac{s_l}{w_l}$ *for* $l = 1, 2$.

The central implication of Proposition 4 is that a lower MP cost strengthens the between effect by making the systematic components of comparative advantage (i.e. factor endowments and sectoral productivities) more important in determining patterns of specialization. That is, trade liberalization has a larger effect on the skill premium in both countries in the presence of costless MP. We return to this in our quantitative analysis.

Skill-biased technology and symmetric countries: We now consider the impact of MP on the skill-premium in the specification of our model with skill-biased technology and two symmetric countries.

A reduction in the cost of MP—from a level at which there is a positive volume of MP, $\mu < \tau$—increases the skill premium. If $\mu < \tau$, then a reduction in MP costs increases the fraction of subsectors in a country that produce using foreign productivity. If a domestic subsector produces using foreign productivity, producers in the foreign subsector must be more productive than those in the domestic one. Hence, a reduction in MP costs weakly increases the productivity of all subsectors and strictly increases the productivity of some subsectors. With skill-biased technology, relatively productive subsectors are also relatively skill intensive. Hence, reductions in the cost of MP increase the relative demand for skill and the skill premium. Proposition 5 summarizes this result.

Proposition 5 *If Assumptions GEN and SB hold and $\mu < \tau$, then s/w is strictly decreasing in μ.*

Note that Proposition 5 holds even in the absence of positive trade flows. This is in contrast to the case of Hicks-neutral technology, in which MP does not impact the skill premium in the absence of trade.

6.2 Baseline Parameterization and Results with Trade and MP

In this section, we discuss how we parameterize the extended model with international trade and MP and study the quantitative implications of a reduction in trade and MP costs for the skill premium.

Parameterization with trade and MP: To calibrate the model with MP, we assume that the country/subsector-specific efficiency loss of MP, $m_{ni}(\omega, j)$, is given by $1+\widetilde{u}$, where $\widetilde{u} \geq 0$ is an *i.i.d.* random variable that is exponentially distributed with mean and standard deviation θ_m. We also assume that the country-level MP cost, μ_{ni}, is symmetric between pairs of countries, $\mu_{ni} = \mu_{in}$, and is equal in the tradeable and nontradeable sectors. We allow for MP in the non-traded sector because in 2006 more than half of majority-owned non-bank U.S. foreign affiliate sales are in service-producing sectors.

The new, MP-specific parameters that we must choose are the country-level per-unit costs of MP (μ_{12}, μ_{13}, and μ_{34}) and the parameter that governs the mean and standard deviation of country/subsector-specific MP costs, θ_m. We set $\mu_{34} = \infty$ since most outward MP originates from skill-abundant countries (see Navaretti and Venables 2004) and choose μ_{12} and μ_{13} to match the two following observations on U.S. outward multinational activity in 2006, obtained from the BEA: (i) the local sales of majority-owned non-bank U.S. foreign affiliates divided by U.S. merchandise exports is 2.45 and (ii) the share of local sales of majority-owned non-bank U.S. foreign affiliates located in skill-abundant countries is 0.85.[30] We set $\theta_m = 0.1$. We considered alternative values of this parameter, $\theta_m = 0.2$ and $\theta_m = 1$, and found that the change in the skill premium was largely unaffected. The remaining parameters are chosen using the same procedure described in Section 4. Column 2 of Tables 1 and 2 report the parameter values and calibration targets in the model with trade and MP.

Baseline results with trade and MP: We now study the implications of international trade and MP for the skill premium. To do so, we use our parameterized model to conduct the following counterfactual. We consider a reduction in trade and MP costs starting in autarky to the levels of trade and MP costs that generate the volumes of international trade and MP observed in 2006, while holding fixed all other parameters at our baseline level. This exercise extends the counterfactual conducted in Section 5 by incorporating MP. As in Section 5, one way to interpret this counterfactual is that it answers the question: But for international trade and MP, by how much would the skill premium change?

Rows 12 and 13 in Table 2 report the log-percentage change in the skill premium resulting from this experiment. Countries 1 and 2 experience a 4.8% increase in the skill premium while countries 3 and 4 experience a 5.9% increase in the skill premium.

The two central messages from these results are as follows. First, MP appears to be at least as important as international trade in determining the impact of globalization on the skill premium: incorporating both international trade and MP implies an increase in the skill premium that is almost three times as large in countries 1 and 2 (4.8% compared to 1.7%) and almost two times as large in countries 3 and 4 (5.9% compared to 3.2%) as our counterfactual incorporating only international trade. To further explore the importance of incorporating MP, we conduct an additional, more extreme, counterfactual in which we move from autarky to zero trade and MP costs ($\tau_{in} = \mu_{in} = 1$). Here we obtain drastically different implications than when we set trade costs in the traded sector to one in the absence of MP. In particular, the skill premium rises by 7% (as opposed to 2.4% without MP) in countries 1 and 2 and falls by 24% (as opposed to rising by 3.8% without MP) in countries 3 and 4. The logic of this result follows from Proposition 4, according to which in the presence of international trade, MP strengthens the between effect.

Second, in contrast to the model with trade only, the magnitudes of the changes in the skill premium of moving from autarky to 2006 levels of trade and MP are sizeable. To put the 4.8% rise of the skill premium in country 1 in perspective, it represents 1/5 of the 24% rise in the U.S.

[30] Note in Table 1 that our calibration with trade and MP requires a high $\mu_{13} = 4.7$. This is because country 3 has a low relative TFP, so that producers from countries 1 and 2 have a large incentive to produce in country 3. An alternative strategy to match our targets is to assume a lower location-specific TFP in country 3, as in Burstein and Monge-Naranjo (2008). This does not have a significant impact on our baseline calibration.

College-High School wage gap between 1966 and 2006. However, the world in 1966 was not in autarky, which motivates the counterfactual we conduct in the following section.

6.3 Accounting for the U.S. Skill Premium, 1966 to 2006

In what follows, we conduct an additional counterfactual to assess the contribution of globalization to the actual rise in the U.S. skill premium between 1966 and 2006, taking into account changes in endowments and technologies while matching the observed rise in the levels of trade and MP.

We first partially reparameterize the model to 1966 data. In order to match the growth in the U.S. skill premium between 1966 and 2006, given that in this period there was an increase in the relative supply of skilled labor, we must allow for an additional force to increase the skill premium, which we assume to be exogenous skill-biased technical change. We then ask, by how much would the skill premium in country have risen if endowments and technologies had evolved as in our parameterization, but country 1 were in autarky? One way to interpret this counterfactual is that it answers the question: But for globalization, by how much would the skill premium have changed in the U.S. between 1966 and 2006?

1966 Parameterization: We re-calibrate the following nine parameters: $(i)-(ii)$ skill endowment ratios, H_1/L_1 and H_3/L_3; (iii) the tradeable share in final output, γ; (iv) aggregate TFP in country 3, T_3; $(v)-(vii)$ trade costs, τ_{12}, τ_{13}, and τ_{34}; and $(viii)-(ix)$ MP costs, μ_{12} and μ_{13}. For $(ii)-(vii)$ we use the same procedure as in our baseline parameterization with trade only, using data from 1966 or the closest year with available information.[31] For (i), we set $H_1/L_1 = 0.51$ to match the 40% growth between 1966 and 2006 in the average years of education for the U.S. population over age 25. To choose parameters $(viii)$ and (ix), while the 1966 MP data from the BEA provides sales by majority-owned foreign affiliates by location, it does not separately report these sales for non-bank affiliates, which is the data we use in the 2006 parameterization. Hence, this data overestimates the amount of MP in 1966. To address this concern, we parameterize the 1966 levels of μ_{12} and μ_{13} under two alternative assumptions. First, we assume that there was no MP in 1966, and set $\mu_{12} = \mu_{13} = \infty$. This underestimates the level of MP in 1966 and, therefore, overestimates the growth of MP. Second, we use the 1966 data assuming that all MP sales are by non-bank affiliates, and use the same procedure to parameterize μ_{12} and μ_{13} as we did in the 2006 parameterization.[32] This overestimates the level of MP in 1966 and, therefore, underestimates the growth of MP.

Finally, to match the observed 24% increase in the U.S. skill premium between 1966 and 2006,

[31] These moments are: the ratio of endowment ratios in the skill-abundant countries relative to the unskill-abundant countries in 1966, $(H_1/L_1)/(H_3/L_3) = 0.32$; the U.S. trade share of tradeables, 0.041; the average skill-abundant country's total trade share, 0.097; the share of U.S. imports from skill-abundant countries, 0.89; the share of skill-scarce countries imports from skill-scarce countries, 0.083; and the U.S. share of good producing sectors in gross output, 0.49.

[32] In 1966, the local sales of majority-owned U.S. foreign affiliates divided by total U.S. exports is 2.5; and the share of local sales of majority-owned U.S. foreign affiliates located in skill-abundant countries is 0.87.

we include one additional parameter—the aggregate skill-bias of technology—which we assume to be common across countries and sectors and varying across time. In particular, we extend the producer-level production function, Equation (2), to allow for exogenous skill-biased technological growth, which is parameterized by A_h:

$$y = A_i(j)\left[\alpha_j^{1/\rho}\left(A_h z^{2\widetilde{\varphi}} h\right)^{\frac{\rho-1}{\rho}} + (1-\alpha_j)^{1/\rho}\left(z^{2(1-\widetilde{\varphi})} l\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}. \quad (18)$$

We maintain $A_h = 1$ in 2006, in which case Equations (2) and (18) are identical, and choose A_h in 1966 as a residual to fully match the 24% growth in the skill premium in the U.S. between 1966 and 2006.

Accounting Results: By how much would the skill premium in country 1 have changed if endowments and technologies had evolved as in our parameterization, but country 1 were in autarky in 1966 and in 2006? If the skill premium in country 1 rose by $X\%$ in the absence of all trade and MP, then we would conclude that, in the absence of globalization, the rise in country 1's skill premium would have been $(1 - X/24)^{\text{th}}$ smaller than in the presence of globalization. Note that, by calculating the rise in country 1's skill premium from changes in endowments and technologies assuming that country 1 is in autarky, we are attributing to globalization the impact on the skill premium **from** the interaction between changes in endowments, technologies, international trade, and MP.

Because we do not have a good measure of the level of MP in 1966, we conduct this counterfactual twice, once using the parameters calculated under the extreme assumption that in 1966 there was no MP by non-bank affiliates, and once using the parameters calculated under the opposite assumption that in 1966 all MP was done by non-bank affiliates.

In the first counterfactual, we find that the skill premium in country 1 would have risen 20.2% in autarky between 1966 and 2006. This implies that, in the absence of globalization, the rise in country 1's skill premium would have been $1/6^{\text{th}}$ smaller than what it was in the presence of globalization. In the second counterfactual, we find that the skill premium in country 1 would have risen 21% in autarky between 1966 and 2006. This implies that, in the absence of globalization, the rise in country 1's skill premium would have been roughly $1/9^{\text{th}}$ smaller than what it was in the presence of globalization.

From these counterfactuals we conclude that, but for globalization, the skill premium would have risen between 1/9 and 1/6 less than what is actually did in the U.S. between 1966 and 2006.

7 Implications for Alternative Approaches

In this section, we use our model and quantitative results to revisit three common alternative approaches used in the international trade and labor literatures to study the impact of globalization on the skill premium. We show that while each of these alternative approaches may provide estimates of the impact of globalization on the skill premium via the between effect, they do not capture the impact of the within effect. Hence, they tend to underestimate the increase in the skill premium from globalization in skill-abundant and skill-scarce countries.

The factor content of trade: As stated in Krugman (2000), "...many economists studying the impact of trade on wages have been reluctant to commit themselves to a specific CGE model. Instead, they have tried to use a shortcut, by estimating the 'factor content' of trade (FCT)." A typical approach to calculating the FCT is to estimate the factors of production used to produce exports and subtract from this an estimate of the factors of production that would have been used to produce imports. Raising the ratio of the percentage change in the effective ratio of skilled to unskilled endowments that is induced by trade to a power that is an estimate of the elasticity of substitution between skilled and unskilled workers gives an estimate of the impact of trade on the skill premium.

In practice, estimating the factors used to produce exports and that would have been used to produce imports is an extremely difficult task. A standard approach—the "equal allocation" procedure of Katz and Murphy (1992)—measures these factors using the country's average unit labor requirements by sector. We can show analytically that our model justifies the use of this approach to estimate the impact of trade on the skill premium via the between effect under Assumptions GEN and HN.

We investigate to what extent this is an accurate approach to determining the change in the skill premium from a reduction in trade costs in our general model, in which we do not impose Assumptions GEN and HN. To do so we replicate the FCT exercise on data generated by our model with trade and MP and compare the estimated changes in the skill premium with the actual changes in the skill premium that result from the full model.

Consider first a parameterization of the model in which we impose that technology is Hicks-neutral ($\varphi = 0$), so that only the between effect is active, and otherwise follow our baseline calibration procedure. In this case, the actual change in the skill premium in countries 1 and 3 is 0.36% and -1.4%, respectively. According to the FCT approach, the change in the skill premium in countries 1 and 3 is 0.4% and -1.6%, respectively. Although the results are not exactly identical because our quantitative model does not satisfy Assumptions GEN and HN, the FCT approach quite accurately captures the impact of globalization, via the between effect, on the skill premium.

Consider now the baseline parameterization of the model with skill-biased technology. In this case, the actual change in the skill premium in countries 1 and 3 is 4.8% and 5.9%, respectively. According to the FCT approach, the change in the skill premium in countries 1 and 3 is 0.4% and -1.7%, respectively. With skill-biased technology, the FCT approach predicts a change in the skill premium that is very different from the actual change in the skill premium implied by the model. It predicts the change in the skill premium with the incorrect sign in skill-scarce countries, and underestimates by an order of magnitude the change in the skill premium in skill-abundant countries.

The FCT does well with Hicks-neutral technology and poorly with skill-biased technology because the assumptions underlying the approach are reasonable in the prior case—in which all producers in a sector share the same skill intensity—but not the latter case—in which the skill intensity of a typical exporting producer is relatively high compared to the skill intensity of a typical producer that is replaced by imports.

Factor reallocation: The strength of the between effect can be inferred from the amount of between-sector (and within-sector) factor reallocation, as in, for example, Berman et. al. (1994). Intuitively, if international trade causes a substantial increase in the relative demand for skill via the between effect, then—given the elasticity of substitution between skill groups—it must also generate substantial shifts in the sectoral distribution of employment towards skill-intensive sectors. At fixed factor supplies, this requires within-sector reductions in skill intensities in all sectors. However, empirical studies document both within-industry increases in the share of skilled workers—see e.g. Berman et. al. (1994) for the U.S.—and relatively little between-sector labor reallocation—see e.g. Currie and Harrison (1997) for Morocco, Hanson and Harrison (1999) for Mexico, and Attanasio et. al. (2004) for Colombia. These findings have been interpreted as evidence that globalization is not responsible for much of the rise in inequality.

Instead, we interpret these empirical results as evidence that the between effect is not responsible for much of the rise in the skill premium, but not as evidence against the combined impact of the between and within effects. In our model, a rise in the skill premium can accompany small changes in the sectoral allocation of factors. To see this, note that under Assumptions GEN and SB we proved in Proposition 3 that reductions in trade costs increase the skill premium in a one-sector model in which, by construction, there is no between-sector factor reallocation. In our baseline parameterization with trade and MP, moving from autarky to 2006 levels of globalization we obtain a 4.8% increase in the skill premium in country 1 while the increase in the share of manufacturing labor employed in the 50% most skill intensive sectors that results from this liberalization is 3% in country 1.

Sectoral prices and the mandated wage approach: The basic mandated wage approach takes changes in observed sectoral prices, which are often assumed to result from international trade, and attempts to identify the mandated change in factor prices that are consistent with maintaining zero profits, given factor intensities; see, e.g., Sachs and Shatz (1994). Using this approach, the observation that large increases in the skill premium in the U.S. have not been accompanied by large increases in the relative price of skill-intensive sectors has been interpreted as evidence that globalization is not responsible for much of the rise in inequality; see e.g. Lawrence and Slaughter (1993). This conclusion follows from the following logic. Globalization raises the skill premium if and only if globalization raises the relative price of skill-intensive sectors, all else equal.

All else, however, is not equal. For example, skill-biased technological change changes relative goods prices for given factor prices. A similar mechanism to skill-biased technological change is at work in our model with skill-biased technology. Globalization affects sectoral absorption prices, $P_i(j)$, through two channels. First, it increases the relative price of sectors intensive in the locally abundant factor, as in the Heckscher-Ohlin model. Second, in our parameterization with skill-biased technology, globalization leads to a greater increase in trade volumes in skill-intensive sectors.[33] This decreases the relative price of skill-intensive goods, similar to skill-biased technological change. These two channels push relative sectoral prices in opposite directions in a skill-abundant country (such as the U.S.). Figure 7 displays the percentage change in sectoral absorption prices of tradeable sectors in country 1 that results from moving from autarky to our baseline level of trade and MP. Note that the relative price of skill-intensive sectors falls because the within effect is more powerful than the between effect.

Our model, therefore, provides a mechanism by which globalization can jointly increase the skill premium and decrease the relative price of skill-intensive goods. The mandated wage approach, however, would not attribute the rise in the skill premium generated by this mechanism to globalization.[34]

8 Conclusions

We have constructed a quantitative model of international trade and multinational production to study the impact of globalization on the skill premium in skill-abundant and skill-scarce countries. The key mechanisms in our framework arise from the interaction between three elements: asymmetric countries, technological heterogeneity across producers within sectors, and skill-biased technology. By combining these three elements, our model includes both the between effect and the within effect of globalization on the skill premium. We have shown that within-sector heterogeneity can (*i*) rationalize the finding—in previous empirical studies—that the between effect is weak, and (*ii*) generate a stronger within effect, which can lead to a rise in the skill premium in both skill-abundant and skill-scarce countries. We have also shown that multinational production strengthens both the between and within effects of globalization on the skill premium. We used our framework to investigate the impact on the skill premium of changes in the extent (the share of trade and MP in output), the geographical composition (the relative importance of skill-abundant and skill-scarce countries in the world economy), and the type (international trade and MP) of globalization.

[33] That reductions in trade costs increase trade more in skill-intensive sectors is not an unambiguous prediction of the model. Indeed, one can show that the growth of trade in skill-intensive sectors is higher (lower) at high (low) trade costs.

[34] Feenstra and Hanson (1999) provide a richer version of the mandated wage approach that controls for technological change. Their approach provides an estimate of the impact of globalization, through the between effect, on the skill premium, but misses the impact of the within effect on the skill premium.

We have shown that a reduction in trade and MP costs starting in autarky to our baseline parameterization of 2006—holding fixed all other parameters at our baseline level—increases the skill premium by roughly 5% in skill-abundant countries and 6% in skill-scarce countries. One way to interpret this counterfactual is that it answers the question: But for international trade and MP, by how much would the skill premium change? We then showed that globalization accounts for between $1/9^{\text{th}}$ and $1/6^{\text{th}}$ of the 24% rise in the U.S. skill premium between 1966 and 2006. Multinational production is at least as important as international trade in generating this rise in the skill premium.

While our framework captures two important forces in the debate on globalization and the skill premium, the between and within effects, and incorporates both trade and MP, it abstracts from other interesting and potentially important considerations. For example, our model abstracts from additional factors of production and does not incorporate endogenous changes in the supply of skilled and unskilled labor, endogenous skill-biased technical change, process and product innovation, and capital accumulation with capital-skill complementarity. Our analysis also abstracts from considerations of unemployment and within-group inequality. Extending our model along these directions is a fruitful area for future research to fully assess the quantitative effects of globalization on inequality.

Finally, the mechanisms studied in this paper apply equally well to intra-national integration as to international integration. The effects of intra-national integration on the skill premium could prove quantitatively large given the high volumes of intra-national trade relative to international trade in the United States.

A Proofs

Lemma 1 *In any equilibrium, the $\pi_{ni}(j)$'s and relative national expenditure, Q_1P_1/Q_2P_2, are uniquely determined by α_x, α_y, Δ_1, Δ_2, and Δ_3.*

Proof of Lemma 1. Trade balance, $\Delta_1 Q_1 P_1 = \Delta_2 Q_2 P_2$, implies $Q_1P_1/Q_2P_2 = \Delta_2/\Delta_1$. Moreover, using the definitions of Δ_1 and Δ_3, we have $\pi_{12}(x) = \Delta_1 - \frac{1}{2}\Delta_3$, $\pi_{12}(y) = \Delta_1 + \frac{1}{2}\Delta_3$, $\pi_{11}(x) = 1 - \pi_{12}(x)$, and $\pi_{11}(y) = 1 - \pi_{12}(y)$. It remains only to solve for the $\pi_{2i}(j)$ terms.

Equation (12) and $\pi_{12}(x) = \Delta_1 - \frac{1}{2}\Delta_3$ yield

$$\left[\left(\frac{s_2}{s_1}\right)^{\alpha_x}\left(\frac{w_2}{w_1}\right)^{1-\alpha_x}\right]^{1/\theta} = \left[\frac{1}{\tau}\frac{A_2(x)}{A_1(x)}\right]^{1/\theta}\left(\frac{1}{\Delta_1 - \frac{1}{2}\Delta_3} - 1\right). \tag{19}$$

Similarly, Equation (12) and $\pi_{12}(y) = \Delta_1 + \frac{1}{2}\Delta_3$ yield

$$\left[\left(\frac{s_2}{s_1}\right)^{\alpha_y}\left(\frac{w_2}{w_1}\right)^{1-\alpha_y}\right]^{1/\theta} = \left[\frac{1}{\tau}\frac{A_2(y)}{A_1(y)}\right]^{1/\theta}\left(\frac{1}{\Delta_1 + \frac{1}{2}\Delta_3} - 1\right). \tag{20}$$

Equation (12) and Equation (19) yield

$$\pi_{21}(x) = \left[\tau^{2/\theta}\left(\frac{1}{\Delta_1 - \frac{1}{2}\Delta_3} - 1\right)^{-1} + 1\right]^{-1} \tag{21}$$

Similarly, Equation (12) and Equation (20) yield

$$\pi_{21}(y) = \left[\tau^{2/\theta}\left(\frac{1}{\Delta_1 + \frac{1}{2}\Delta_3} - 1\right)^{-1} + 1\right]^{-1} \tag{22}$$

Equation (21), Equation (22), and $\Delta_2 \equiv \frac{1}{2}[\pi_{21}(x) + \pi_{21}(y)]$ provide an implicit solution for τ as a function of Δ_1, Δ_2, and Δ_3 alone. Thus, $\pi_{21}(x)$ and $\pi_{21}(y)$ are pinned down by α_x, α_y, Δ_1, Δ_2, and Δ_3. Finally, $\pi_{22}(x) = 1 - \pi_{21}(x)$ and $\pi_{22}(y) = 1 - \pi_{21}(y)$. **QED.** ■

Proof of Proposition 1. We focus on proving Proposition 1 for country 1 in the case in which $\Delta_3 > 0$. In particular, we prove that $\left.\frac{s_1}{w_1}\right|_{\Delta_1=\Delta_2=\Delta_3=0} < \left.\frac{s_1}{w_1}\right|_{\Delta_1,\Delta_2,\Delta_3>0}$ for arbitrary $\Delta_1, \Delta_2, \Delta_3 > 0$. The proof for country 2 in the case in which $\Delta_3 > 0$, and the proof for countries 1 and 2 in the case in which $\Delta_3 < 0$ are similar. The proof requires a preliminary Lemma.

Lemma 2 If τ, τ', a, a', θ, and θ' are chosen such that $\Delta_3 > \Delta_3' \geq 0$, $\Delta_1 = \Delta_1' > 0$, and $\Delta_2 = \Delta_2' > 0$, then $\left.\frac{s_1}{w_1}\right|_{\Delta_3'} < \left.\frac{s_1}{w_1}\right|_{\Delta_3}$.

Proof of Lemma 2. We first show that if $\Delta_3 > \Delta_3' \geq 0$, $\Delta_1 = \Delta_1' > 0$, and $\Delta_2 = \Delta_2' > 0$, then $\pi_{21}(y) < \pi_{21}'(y)$ and $\pi_{21}(x) > \pi_{21}'(x)$. We have

$$\pi_{12}(x) = \Delta_1 - \frac{1}{2}\Delta_3 < \Delta_1 - \frac{1}{2}\Delta_3' = \pi_{12}'(x) \tag{23}$$

and

$$\pi_{12}(y) = \Delta_1 + \frac{1}{2}\Delta_3 > \Delta_1 + \frac{1}{2}\Delta_3' = \pi_{12}'(y). \tag{24}$$

Equations (12), (23), and (24) imply

$$\left(\frac{v_2(x)}{v_1(x)}\right)^{-1/\theta}\left(\frac{v_1'(x)}{v_2'(x)}\right)^{-1/\theta'} < \frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}} < \left(\frac{v_2(y)}{v_1(y)}\right)^{-1/\theta}\left(\frac{v_1'(y)}{v_2'(y)}\right)^{-1/\theta'}. \tag{25}$$

Equation (12) and $\Delta_2 = \Delta_2'$ imply

$$\gamma_1\left[1 - \frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}}\left(\frac{v_2(x)}{v_1(x)}\right)^{-1/\theta}\left(\frac{v_1'(x)}{v_2'(x)}\right)^{-1/\theta'}\right] = \gamma_2\left[\frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}}\left(\frac{v_2(y)}{v_1(y)}\right)^{-1/\theta}\left(\frac{v_1'(y)}{v_2'(y)}\right)^{-1/\theta'} - 1\right] \tag{26}$$

where $\gamma_1 > 0$ and $\gamma_2 > 0$ are functions of τ, τ', and $v_i(j)$ for $i = 1, 2$ and $j = x, y$. Equations (25) and (26) imply

$$\gamma_1\left[1 - \frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}}\left(\frac{v_2(y)}{v_1(y)}\right)^{-1/\theta}\left(\frac{v_1'(y)}{v_2'(y)}\right)^{-1/\theta'}\right] < -\gamma_2\left[1 - \frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}}\left(\frac{v_2(y)}{v_1(y)}\right)^{-1/\theta}\left(\frac{v_1'(y)}{v_2'(y)}\right)^{-1/\theta'}\right]$$

which implies

$$\frac{(\tau')^{-1/\theta'}}{\tau^{-1/\theta}} > \left(\frac{v_1(y)}{v_2(y)}\right)^{-1/\theta} \left(\frac{v_2'(y)}{v_1'(y)}\right)^{-1/\theta'}. \tag{27}$$

Equations (12) and (27) imply $\pi_{21}(y) < \pi'_{21}(y)$, which, in turn, implies $\pi_{21}(x) > \pi'_{21}(x)$. Hence, we have proven that if $\Delta_3 > \Delta'_3 \geq 0$, $\Delta_1 = \Delta'_1 > 0$, and $\Delta_2 = \Delta'_2 > 0$, then $\pi_{21}(y) < \pi'_{21}(y)$ and $\pi_{21}(x) > \pi'_{21}(x)$.

To conclude the proof of Lemma 2, denote by

$$\gamma(\Delta_3) = \left(\frac{s_1}{w_1}\right) = \frac{L_1}{H_1} \frac{\alpha_x R_1(x) + \alpha_y R_1(y)}{(1-\alpha_x) R_1(x) + (1-\alpha_y) R_1(y)}$$

where $R_i(j)$ is country i's revenue in sector j. Hence, $\gamma(\Delta_3) > \gamma(\Delta'_3)$ if and only if $R_1(x) R'_1(y) > R'_1(x) R_1(y)$. $\Delta_1 = \Delta'_1$ and $\Delta_2 = \Delta'_2$ imply $Q_1P_1/Q_2P_2 = Q'_1P'_1/Q'_2P'_2 = \Delta_2/\Delta_1$ for $i = 1, 2$. Therefore, $R_1(j) = Q_2P_2[\pi_{21}(j) + \pi_{11}(j)\Delta_2/\Delta_1]$ and $R'_1(j) = Q'_2P'_2[\pi'_{21}(j) + \pi'_{11}(j)\Delta_2/\Delta_1]$. We have (i) $\pi'_{21}(x) < \pi_{21}(x)$ from above and we have (ii) $\pi'_{11}(x) < \pi_{11}(x)$ from $\pi'_{12}(x) > \pi_{12}(x)$; similarly, we have (iii) $\pi'_{21}(y) > \pi_{21}(y)$ from above and we have (iv) $\pi'_{11}(y) > \pi_{11}(y)$ from $\pi'_{12}(y) < \pi_{12}(y)$. Together with the definition of $R_1(j)$ and $R'_1(j)$, Conditions (i), (ii), (iii), and (iv) imply $R_1(x) R'_1(y) > R'_1(x) R_1(y)$, concluding the proof of Lemma 2. **QED.** ■

Proof of Proposition 1. When $\Delta_1, \Delta_2, \Delta_3 = 0$, we have

$$\left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2,\Delta_3=0} = \frac{L_i}{H_i} \frac{\alpha_x + \alpha_y}{2 - (\alpha_x + \alpha_y)}.$$

If $\Delta_1, \Delta_2 \geq 0$ and $\Delta_3 = 0$, we have $\pi_{12}(x) = \pi_{12}(y) = \Delta_1$, $\pi_{21}(x) = \pi_{21}(y) = \Delta_2$, $\pi_{11}(x) = \pi_{11}(y) = 1 - \Delta_1$, and $\pi_{22}(x) = \pi_{22}(y) = 1 - \Delta_2$, so that

$$\left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2\geq 0,\Delta_3=0} = \frac{L_i}{H_i} \frac{\alpha_x + \alpha_y}{2 - (\alpha_x + \alpha_y)}.$$

Hence,

$$\left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2,\Delta_3=0} = \left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2\geq 0,\Delta_3=0}. \tag{28}$$

Combining Lemma 2 and Equation (28) yields

$$\left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2,\Delta_3=0} < \left.\frac{s_i}{w_i}\right|_{\Delta_1,\Delta_2,\Delta_3>0}$$

which concludes the proof of Proposition 1. **QED.** ■

Proof of Proposition 2. If country 1 has a comparative advantage in sector x and $\Delta_1, \Delta_2 > 0$, then $\Delta_3 > 0$. We first show that if $\Delta_3 \geq \Delta'_3 > 0$, $\Delta_1 = \Delta'_1 > 0$, and $\Delta_2 = \Delta'_2 > 0$ then the following condition holds:

$$\left(\frac{1}{a'} \times \left(\frac{s'_1/w'_1}{s'_2/w'_2}\right)^{(\alpha_x-\alpha_y)}\right)^{1/\theta'} \geq \left(\frac{1}{a} \times \left(\frac{s_1/w_1}{s_2/w_2}\right)^{(\alpha_x-\alpha_y)}\right)^{1/\theta}. \tag{29}$$

Lemma 2 implies

$$\pi_{12}(x) \leq \pi'_{12}(x) \quad (30)$$
$$\pi_{12}(y) \geq \pi'_{12}(y) \quad (31)$$
$$\pi_{21}(x) \geq \pi'_{21}(x) \quad (32)$$
$$\pi_{21}(y) \leq \pi'_{21}(y) \quad (33)$$

Equations (30) – (33) and Equation (12) imply

$$\left(\frac{v_2(y)}{v_1(y)}\right)^{1/\theta} \leq \left(\frac{v'_2(y)}{v'_1(y)}\right)^{1/\theta'} \quad (34)$$
$$\left(\frac{v_2(x)}{v_1(x)}\right)^{1/\theta} \geq \left(\frac{v'_2(x)}{v'_1(x)}\right)^{1/\theta'}. \quad (35)$$

Equations (34) and (35) imply Equation (29).

Second, note that $\Delta_3 > 0$ and $\Delta'_3 > 0$ imply, respectively,

$$\frac{1}{a} \times \left(\frac{s_1/w_1}{s_2/w_2}\right)^{(\alpha_x - \alpha_y)} < 1 \quad (36)$$

and

$$\frac{1}{a'} \times \left(\frac{s'_1/w'_1}{s'_2/w'_2}\right)^{(\alpha_x - \alpha_y)} < 1. \quad (37)$$

Third, note that Lemma 2 implies

$$s_1/w_1 \geq s'_1/w'_1 \quad (38)$$
$$s_2/w_2 \leq s'_2/w'_2. \quad (39)$$

We now use Equation (29) and Equations (36)-(39) to prove Proposition 2.

We first prove the comparative static result for θ. To obtain a contradiction, suppose that $\theta > \theta'$, $a = a'$, and that $\Delta_3 \geq \Delta'_3 > 0$. Then

$$\left(\frac{1}{a'}\left(\frac{s'_1/w'_1}{s'_2/w'_2}\right)^{(\alpha_x - \alpha_y)}\right)^{\theta/\theta'} \geq \frac{1}{a'}\left(\frac{s_1/w_1}{s_2/w_2}\right)^{(\alpha_x - \alpha_y)} \geq \frac{1}{a'}\left(\frac{s'_1/w'_1}{s'_2/w'_2}\right)^{(\alpha_x - \alpha_y)} \quad (40)$$

where the first weak inequality follows from Equation (29) and $a = a'$ while the second weak inequality follows from Equations (38) and (39). Equation (40) and $\theta > \theta'$ contradict Equation (37). Thus, if $a = a'$, $\theta > \theta'$, and country 1 has a comparative advantage in sector x, then $\Delta_3 < \Delta'_3$. Combined with Lemma 2, this yields the desired comparative static result for θ.

Next, we prove the comparative static result for a. To obtain a contradiction suppose that $\theta = \theta'$, $a < a'$, and $\Delta_3 \geq \Delta'_3 > 0$. Then Equation (29) yields

$$\frac{1}{a'} \times \left(\frac{s'_1/w'_1}{s'_2/w'_2}\right)^{(\alpha_x - \alpha_y)} \geq \frac{1}{a} \times \left(\frac{s_1/w_1}{s_2/w_2}\right)^{(\alpha_x - \alpha_y)} \quad (41)$$

With $a < a'$, Equation (41) requires $\frac{s_1'/w_1'}{s_2'/w_2'} > \frac{s_1/w_1}{s_2/w_2}$, which contradicts Equations (38) and (39). Thus, if $\theta = \theta'$, $a < a'$, and country 1 has a comparative advantage in sector x, then $\Delta_3 < \Delta_3'$. Combined with Lemma 2, this yields the desired comparative static result for a. **QED.** ■

Proof of Proposition 3. Here we prove that if $\tau < \tau'$, then $\frac{s(\tau')}{w(\tau')} < \frac{s(\tau)}{w(\tau)}$. After setting out the necessary notation we proceed in three steps: Steps 1 and 2 are preliminary while Step 3 completes the proof of Proposition 3. In what follows we impose Assumptions GEN and SB.

Notation and factor market clearing: Denote by $\chi_{in}(z;\tau) / \int_0^\infty \chi_{in}(z';\tau)\, dz'$ the density of country n subsectors with productivity z supplying country i, written explicitly as a function of the trade cost τ. Define $\Delta\chi_{ii}(z) \equiv \chi_{ii}(z;\tau') - \chi_{ii}(z;\tau)$ and $\Delta\chi_{-ii}(z) \equiv \chi_{-ii}(z;\tau') - \chi_{-ii}(z;\tau)$. Denote by $\Omega_{ii}(\tau)$ the set of subsectors in which country i producers supply their domestic market; similarly denote by $\Omega_{-ii}(\tau)$ the set of subsectors in which country i producers supply the foreign country.

Under Assumptions GEN and SB, we can write the factor market clearing conditions as

$$\begin{aligned} wL &= \textstyle\sum_{j=x,y} \int_0^\infty f\left(\frac{w}{s}, z, j\right) \left[\chi_{ii}(z,j) + \chi_{-ii}(z,j)\right] dz \\ sH &= \textstyle\sum_{j=x,y} \int_0^\infty g\left(\frac{w}{s}, z, j\right) \left[\chi_{ii}(z,j) + \chi_{-ii}(z,j)\right] dz \end{aligned} \tag{42}$$

where f and g are as defined in Equations (**??**) and (**??**), however with $\eta = 1$.

Step 1: *If $\tau < \tau'$ and $\frac{w(\tau)}{s(\tau)} \geq \frac{w(\tau')}{s(\tau')}$, then $\omega \in \Omega_{ii}(\tau)$ implies $\omega \in \Omega_{ii}(\tau')$.*

Let $\tau < \tau'$ and $\frac{w(\tau)}{s(\tau)} \geq \frac{w(\tau')}{s(\tau')}$ and suppose that $\omega \in \Omega_{ii}(\tau)$, which is equivalent to $\frac{c_{ii}(\omega;\tau)}{c_{i-i}(\omega;\tau)} \leq 1$, where $c_{in}(\omega,\tau)$ is the unit cost of country n supplying country i in subsector ω at trade cost τ. There are two possible cases to consider: (i) $z_{-i}(\omega) \geq z_i(\omega)$ and (ii) $z_{-i}(\omega) < z_i(\omega)$. In case ($i$) we have $\frac{c_{ii}(\omega;\tau')}{c_{i-i}(\omega;\tau')} < \frac{c_{ii}(\omega;\tau)}{c_{i-i}(\omega;\tau)} \leq 1$, since $\frac{c_{ii}(\omega;\tau)}{c_{i-i}(\omega;\tau)}$ is weakly increasing in w/s if $z_{-i}(\omega) \geq z_i(\omega)$ and is strictly decreasing in τ. Hence, in case (i) we have $\omega \in \Omega_{ii}(\tau')$. In case ($ii$), we have $\omega \in \Omega_{ii}(\tau'')$ for any $\tau'' \geq 1$; and in particular, $\omega \in \Omega_{ii}(\tau')$. Thus, if $\tau < \tau'$ and $\frac{w(\tau)}{s(\tau)} \geq \frac{w(\tau')}{s(\tau')}$, then $\omega \in \Omega_{ii}(\tau)$ implies $\omega \in \Omega_{ii}(\tau')$, concluding the proof of Step 1.

Step 2: *If $\tau < \tau'$ and $\frac{w(\tau)}{s(\tau)} \geq \frac{w(\tau')}{s(\tau')}$, then $-\int_0^z \Delta\chi_{-ii}(v)\, dv < \int_0^z \Delta\chi_{ii}(v)\, dv$ for all $z > 0$, $j = x, y$, and $i = 1, 2$.*

Let $\tau < \tau'$ and $\frac{w(\tau)}{s(\tau)} \geq \frac{w(\tau')}{s(\tau')}$ and suppose that $\omega \notin \Omega_{ii}(\tau)$. Then $\frac{c_{ii}(\omega;\tau)}{c_{i-i}(\omega;\tau)} > 1$, which requires $z_{-i}(\omega) > z_i(\omega)$. Hence, $\frac{c_{ii}(\omega;\tau)}{c_{i-i}(\omega;\tau)} > \frac{c_{ii}(\omega;\tau')}{c_{i-i}(\omega;\tau')}$. Thus, there must exist a positive mass of ω for which $\omega \notin \Omega_{ii}(\tau)$ and $\omega \in \Omega_{ii}(\tau')$ for $i = 1, 2$.[35] Choose an arbitrary ω such that $\omega \notin \Omega_{ii}(\tau)$ and $\omega \in \Omega_{ii}(\tau')$. Then $\omega \in \Omega_{i-i}(\tau)$, $\omega \notin \Omega_{i-i}(\tau')$, and $z_{-i}(\omega) > z_i(\omega)$. Moreover, for any ω there is a positive probability that $\omega \notin \Omega_{ii}(\tau)$ and $\omega \in \Omega_{ii}(\tau')$ (so that $\omega \in \Omega_{i-i}(\tau)$ and $\omega \notin \Omega_{i-i}(\tau')$). Hence,

$$\Pr\left[z_{-i}(\omega) < z \mid \omega \in \Omega_{i-i}(\tau) \backslash \Omega_{i-i}(\tau')\right] < \Pr\left[z_i(\omega) < z \mid \omega \in \Omega_{ii}(\tau') \backslash \Omega_{ii}(\tau)\right]$$

or, equivalently,

$$\frac{\int_0^z \left[-\Delta\chi_{i-i}(v)\right] dv}{\int_0^\infty \left[-\Delta\chi_{i-i}(v)\right] dv} < \frac{\int_0^z \Delta\chi_{ii}(v)\, dv}{\int_0^\infty \Delta\chi_{ii}(v)\, dv}, \text{ for all } z > 0 \tag{43}$$

[35] This requires that the density of subsectors drawing a productivity z must be positive for all z, but is otherwise independent of our choice of exponential distribution.

By symmetry: (i) $\chi_{i-i}(z) = \chi_{-ii}(z)$ for almost all z, and (ii) $\int_0^\infty -\Delta\chi_{i-i}(v)\,dv = \int_0^\infty \Delta\chi_{ii}(v)\,dv$. Thus, according to Equation (43), we have $\int_0^z \left[-\Delta\chi_{-ii}(v)\right] dv < \int_0^z \Delta\chi_{ii}(v)\,dv$ for all $z > 0$, $j = x, y$, and $i = 1, 2$, concluding the proof of Step 2.

Step 3: *The skill premium s/w is strictly decreasing in τ.*

Consider an arbitrary pair of trade costs $1 \le \tau < \tau'$, and to obtain a contradiction, suppose that $\frac{w(\tau)}{s(\tau)} \ge \frac{w(\tau')}{s(\tau')}$. According to Equation (11), and our normalization $w(\tau)L + s(\tau)H = 1$, this implies $w(\tau) \ge w(\tau')$ and $s(\tau) \le s(\tau')$. Equation (42), the condition that $w(\tau) \ge w(\tau')$, and the fact that $\frac{d}{d(w/s)} f\left(\frac{w}{s}, z, j\right) < 0$ together imply

$$\sum_{j=x,y} \int_0^\infty f\left(\frac{w(\tau)}{s(\tau)}, z, j\right) \Delta\chi_{ii}(z)\,dz \le \sum_{j=x,y} \int_0^\infty f\left(\frac{w(\tau)}{s(\tau)}, z, j\right) \left[-\Delta\chi_{-ii}(z)\right] dz. \tag{44}$$

Finally, (i) $\frac{d}{dz} f\left(\frac{w(\tau)}{s(\tau)}, z, j\right) < 0$ with $\varphi > 0$, (ii) and Step 2 imply[36]

$$\int_0^\infty f\left(\frac{w(\tau)}{s(\tau)}, z, j\right) \Delta\chi_{ii}(z)\,dz > \int_0^\infty f\left(\frac{w(\tau)}{s(\tau)}, z, j\right) \left[-\Delta\chi_{-ii}(z)\right] dz. \tag{45}$$

Equation (44) contradicts Equation (45). Therefore, if $\tau < \tau'$, then $\frac{w(\tau)}{s(\tau)} < \frac{w(\tau')}{s(\tau')}$. **QED.** ■

Proof of Proposition 4. We prove Part 1 and Part 2 separately.

Part 1. From Equations (13) and (14), we have $\lim_{\tau\to\infty} H_1 s_1 = \frac{1}{2} Q_1 P_1 (\alpha_x + \alpha_y)$ and $\lim_{\tau\to\infty} L_1 w_1 = \frac{1}{2} Q_1 P_1 (2 - \alpha_x - \alpha_y)$, since $\lim_{\tau\to\infty} \pi_{11}(j) = 1$ and $\lim_{\tau\to\infty} \pi_{21}(j) = 0$ for $j = x, y$. Hence, $\lim_{\tau\to\infty}(s_1/w_1) = (\alpha_x + \alpha_y)/(2 - \alpha_x - \alpha_y)$, so that $\frac{d}{d\mu} \lim_{\tau\to\infty}(s_1/w_1) = 0$. Similarly, we have $\frac{d}{d\mu} \lim_{\tau\to\infty}(s_2/w_2) = 0$, concluding the proof of Part 1 of Proposition 4.

Part 2. The cost of MP and θ affect the equations determining wages, Equations (13) and (14), through the $\pi_{ni}(j)$ terms. Here we show that in the limit as MP becomes costless, the $\pi_{ni}(j)$ terms have the same solution as in the limit as the dispersion of idiosyncratic productivity goes to zero. We focus here on $\pi_{12}(j)$, but the proof for all other $\pi_{ni}(j)$ terms is similar.

Consider $\pi_{12}(j)$ with MP:

$$\begin{aligned}
\pi_{12}(j) &= \Pr\left[v_2(j)\,\tau_{12} \min\left\{\frac{1}{z_2(\omega, j)}, \frac{\mu m_{12}(\omega, j)}{z_1(\omega, j)}\right\} \le v_1(j) \min\left\{\frac{\mu m_{21}(\omega, j)}{z_2(\omega, j)}, \frac{1}{z_1(\omega, j)}\right\}\right] \\
&= \Pr\left[v_2(j)\,\tau_{12} \frac{\min\left\{\frac{1}{z_2(\omega,j)}, \frac{\mu m_{12}(\omega,j)}{z_1(\omega,j)}\right\}}{\min\left\{\frac{\mu m_{21}(\omega,j)}{z_2(\omega,j)}, \frac{1}{z_1(\omega,j)}\right\}} \le v_1(j)\right]
\end{aligned}$$

If $\lim_{\mu m_{ki}(\omega,j)\to 1 \forall(\omega,j),k,i}$ $\forall(\omega, j), k, i$, then $\frac{\min\left\{\frac{1}{z_2(\omega,j)}, \frac{\mu m_{12}(\omega,j)}{z_1(\omega,j)}\right\}}{\min\left\{\frac{\mu m_{21}(\omega,j)}{z_2(\omega,j)}, \frac{1}{z_1(\omega,j)}\right\}} \to 1$, and $\lim_{\mu m_{ki}(\omega,j)\to 1 \forall(\omega,j),k,i} \pi_{12}(j) = \Pr\left[v_2(j)\,\tau_{12} \le v_1(j)\right]$.

[36] This follows from the fact that if $\int_0^z f(v)\,dv < \int_0^z g(v)\,dv$ for any $z > 0$, and $h'(z) < 0$, then $\int_0^\infty f(v)\,h(v)\,dv < \int_0^\infty g(v)\,h(v)\,dv$.

With only trade we have:

$$\begin{aligned}\pi_{12}(j) &= \Pr\left[\frac{v_2(j)\,\tau_{12}}{z_2(\omega,j)} \leq v_1(j)\,\frac{1}{z_1(\omega,j)}\right] \\ &= \Pr\left[v_2(j)\,\tau_{12} \leq v_1(j)\,\frac{z_2(\omega,j)}{z_1(\omega,j)}\right]\end{aligned}$$

where $\lim_{\theta\to 0}\frac{z_2(\omega,j)}{z_1(\omega,j)} = 1$, so $\lim_{\theta\to 0}\pi_{12}(j) = \Pr[v_2(j)\,\tau_{12} \leq v_1(j)]$. Hence, $\lim_{\mu m_{ki}(\omega,j)\to 1\forall(\omega,j),k,i}\pi_{12}(j)$ $= \lim_{\theta\to 0}\pi_{12}(j)$. Given that the same applies for all $\pi_{ni}(j)$, we must have $\lim_{\mu m_{ki}(\omega,j)\to 1\forall(\omega,j),k,i}\frac{s_l}{w_l} = \lim_{\theta\to 0}\frac{s_l}{w_l}$ for $l = 1, 2$. **QED.** ■

Proof of Proposition 5. The proof of Proposition 5 follows very closely the proof of Proposition 3: Under Assumptions GEN and SB, we can write the factor market clearing conditions as:

$$\begin{aligned}wL &= \sum_{j=x,y}\int_0^\infty f\left(\frac{w}{s},z,j\right)\left[\chi_{ii}^{i}(z;\mu) + \chi_{-ii}^{i}(z;\mu) + \chi_{ii}^{-i}(z;\mu)\right]dz \qquad (46)\\ sH &= \sum_{j=x,y}\int_0^\infty g\left(\frac{w}{s},z,j\right)\left[\chi_{ii}^{i}(z;\mu) + \chi_{-ii}^{i}(z;\mu) + \chi_{ii}^{-i}(z;\mu)\right]dz.\end{aligned}$$

We define $\chi_{in}^{k}(z;\mu)/\int_0^\infty \chi_{in}^{k}(z;\mu)\,dz$ as the density of productivities of subsectors in country n that supply market i using productivity from country k, written explicitly as a function of the MP cost μ. Note that with symmetric countries we have $\chi_{-ii}^{-i}(z;\mu) = 0$ because $c_{-ii}^{-i}(\omega) > c_{-i-i}^{-i}(\omega)$. We let $\Delta\chi_{in}^{k}(z) \equiv \chi_{in}^{k}(z;\mu') - \chi_{in}^{k}(z;\mu)$. Finally, we denote by $\Omega_{in}^{k}(\mu)$ the set of subsectors in which country n producers supply country i using country k's productivity.

We proceed in two steps. The first step is a preliminary step and the second step concludes the proof of Proposition 5.

Step 1: *If* $1 < \mu < \min\{\mu',\tau\}$, *and* $\frac{w(\mu)}{s(\mu)} \geq \frac{w(\mu')}{s(\mu')}$, *then*

$$-\int_0^z \Delta\chi_{ii}^{-i}(z)\,dv < \int_0^z \left[\Delta\chi_{ii}^{i}(z) + \Delta\chi_{-ii}^{i}(z)\right]dv$$

for all $z > 0$ *and* $i = 1, 2$.

Let $1 < \mu < \min\{\mu',\tau\}$ and $\frac{w(\mu)}{s(\mu)} \geq \frac{w(\mu')}{s(\mu')}$ and suppose that $\omega \in \Omega_{ii}^{i}(\mu)$. As in the proof of Proposition 3, it is easy to show that if $\mu < \min\{\mu',\tau\}$ and $\frac{w(\mu)}{s(\mu)} \geq \frac{w(\mu')}{s(\mu')}$, then (*i*) $\omega \in \Omega_{ii}^{i}(\mu)$ implies $\omega \in \Omega_{ii}^{i}(\mu')$; (*ii*) $\omega \in \Omega_{-ii}^{i}(\mu)$ implies $\omega \in \Omega_{-ii}^{i}(\mu')$; (*iii*) there exist a positive mass of ω for which $\omega \notin \Omega_{ii}^{i}(\mu)$ and $\omega \in \Omega_{ii}^{i}(\mu')$; (*iv*) there exist a positive mass of ω for which $\omega \notin \Omega_{-ii}^{i}(\mu)$ and $\omega \in \Omega_{-ii}^{i}(\mu')$; and (*v*) there exist a positive mass of $\omega \in \Omega_{ii}^{-i}(\mu)$ for which $\omega \notin \Omega_{ii}^{-i}(\mu)$.[37]

Choose an arbitrary $\omega \notin \Omega_{ii}^{i}(\mu) \cup \Omega_{i-i}^{-i}(\mu)$ and $\omega \in \Omega_{ii}^{i}(\mu') \cup \Omega_{i-i}^{-i}(\mu')$. Then $\omega \in \Omega_{ii}^{-i}(\mu)$, $\omega \notin \Omega_{ii}^{-i}(\mu')$, and $z_{-i}(\omega) > z_i(\omega)$; we have $z_{-i}(\omega) > z_i(\omega)$, because, if $z_{-i}(\omega) \leq z_i(\omega)$ then no MP would take place for any $\mu > 1$, contradicting $\omega \in \Omega_{ii}^{-i}(\mu)$. Of course, if $\omega \notin \Omega_{i-i}^{-i}(\mu)$ and $\omega \in \Omega_{i-i}^{-i}(\mu')$, then the efficiency of production in subsector ω is unaffected, since country $-i$'s productivity is used under either μ or μ'. Nevertheless, for any ω there is a positive probability that $\omega \notin \Omega_{ii}^{i}(\mu)$, $\omega \in \Omega_{ii}^{i}(\mu')$, $\omega \notin \Omega_{i-i}^{-i}(\mu)$ and

[37] If $\mu \geq \tau$, then no offshoring takes place, so that decreasing μ' to μ has no impact on the equilibrium.

$\omega \in \Omega_{i-i}^{-i}(\mu')$. Hence,

$$\Pr\left[z_{-i}(\omega) < z \mid \omega \in \Omega_{ii}^{-i}(\mu) - \Omega_{ii}^{-i}(\mu')\right] < \Pr\left[z_i(\omega) < z \mid \omega \in \Omega_{ii}^{i}(\mu') \cup \Omega_{i-i}^{-i}(\mu') - \Omega_{ii}^{i}(\mu) \cup \Omega_{i-i}^{-i}(\mu)\right]$$

or, equivalently,

$$\frac{\int_0^z \left[-\Delta\chi_{ii}^{-i}(v)\right] dv}{\int_0^\infty \left[-\Delta\chi_{ii}^{-i}(v)\right] dv} < \frac{\int_0^z \left[\Delta\chi_{ii}^{i}(v) + \Delta\chi_{i-i}^{-i}(v)\right] dv}{\int_0^\infty \left[\Delta\chi_{ii}^{i}(v) + \Delta\chi_{i-i}^{-i}(v)\right] dv}, \text{ for all } z > 0 \tag{47}$$

By symmetry

$$\chi_{i-i}^{-i}(z) = \chi_{-ii}^{i}(z) \text{ for almost all } z,$$

and

$$\int_0^\infty \left[-\Delta\chi_{ii}^{-i}(v)\right] dv = \int_0^\infty \left[\Delta\chi_{ii}^{i}(v) + \Delta\chi_{i-i}^{-i}(v)\right] dv.$$

Thus, according to Equation (47), we have

$$\int_0^z \left[-\Delta\chi_{ii}^{-i}(v)\right] dv < \int_0^z \left[\Delta\chi_{ii}^{i}(v) + \Delta\chi_{-ii}^{i}(v)\right] dv, \forall z > 0, i = 1, 2$$

completing Step 1.

Step 2: Consider an arbitrary pair of MP costs satisfying $1 < \mu < \min\{\mu', \tau\}$. To obtain a contradiction, suppose that $\frac{w(\mu)}{s(\mu)} \geq \frac{w(\mu')}{s(\mu')}$. According to Condition (11), and our normalization $w(\mu)L + s(\mu)H = 1$, this implies $w(\mu) \geq w(\mu')$ and $s(\mu) \leq s(\mu')$. Equation (42), the condition that $w(\mu) \geq w(\mu')$, and the fact that $\frac{d}{dw/s} f(w/s, z, j) < 0$ together imply

$$\int_0^\infty f\left(\frac{w(\mu)}{s(\mu)}, z, j\right)\left[\Delta\chi_{ii}^{i}(z) + \Delta\chi_{-ii}^{i}(z)\right] dz \leq -\int_0^\infty f\left(\frac{w(\mu)}{s(\mu)}, z, j\right)\Delta\chi_{ii}^{-i}(z)\, dz \tag{48}$$

Finally, $\frac{d}{dz} f\left(\frac{w(\mu)}{s(\mu)}, z, z\right) < 0$ and Step 1 imply

$$\int_0^\infty f\left(\frac{w(\mu)}{s(\mu)}, z, j\right)\left[\Delta\chi_{ii}^{i}(z) + \Delta\chi_{-ii}^{i}(z)\right] dz > -\int_0^\infty f\left(\frac{w(\mu)}{s(\mu)}, z, j\right)\Delta\chi_{ii}^{-i}(z)\, dz. \tag{49}$$

Equation (48) contradicts Equation (49). Thus, if $\mu < \min\{\mu', \tau\}$, then $\frac{w(\mu)}{s(\mu)} < \frac{w(\mu')}{s(\mu')}$. **QED.** ■

Proposition 6 *If Assumptions GEN and SB' hold (where SB' is a two-sector version of SB in which $\alpha_x > \alpha_y$), then normalized trade in each country is greater in the skill-intensive sector.*

Proof of Proposition 6. The proof is in two steps. The first step is a preliminary step and the second step concludes the proof of Proposition 6.

Step 1: *Suppose Assumptions GEN and SB' hold and fix an arbitrary pair of productivities $z_i \equiv z_i(\omega, y) = z_i(\omega, x)$ and $z_{-i} \equiv z_{-i}(\omega, y) = z_{-i}(\omega, x)$. Then $z_i > z_{-i}$ implies $\frac{c_{ni}(\omega,x)}{c_{n-i}(\omega,x)} < \frac{c_{ni}(\omega,y)}{c_{n-i}(\omega,y)}$ for $n = i, -i$.*

To obtain a contradiction, suppose that $z_i > z_{-i}$ and

$$\frac{c_{ni}(\omega, y)}{c_{n-i}(\omega, y)} \leq \frac{c_{ni}(\omega, x)}{c_{n-i}(\omega, x)} \quad \text{for } n = i \text{ or } n = -i. \tag{50}$$

Equation (50) is equivalent to

$$z_i^{\varphi} \leq z_{-i}^{\varphi}. \tag{51}$$

With $\varphi > 0$ Condition (51) is equivalent to

$$z_i \leq z_{-i},$$

a contradiction that concludes the proof of Step 1.

Step 2: According to Step 1, the mass of subsectors that export from country i in the skill-intensive x sector is strictly greater than the mass that export from the unskill-intensive y sector, for all i. With $\eta = 1$, this implies that the value of a country's exports plus its imports is greater in the x sector than in the y sector. Finally, with $\eta = 1$, the value of a country's consumption is equal in the x and y sectors. Hence, normalized trade is strictly greater in the skill-intensive sector, concluding the proof of Proposition 6. **QED.** ■

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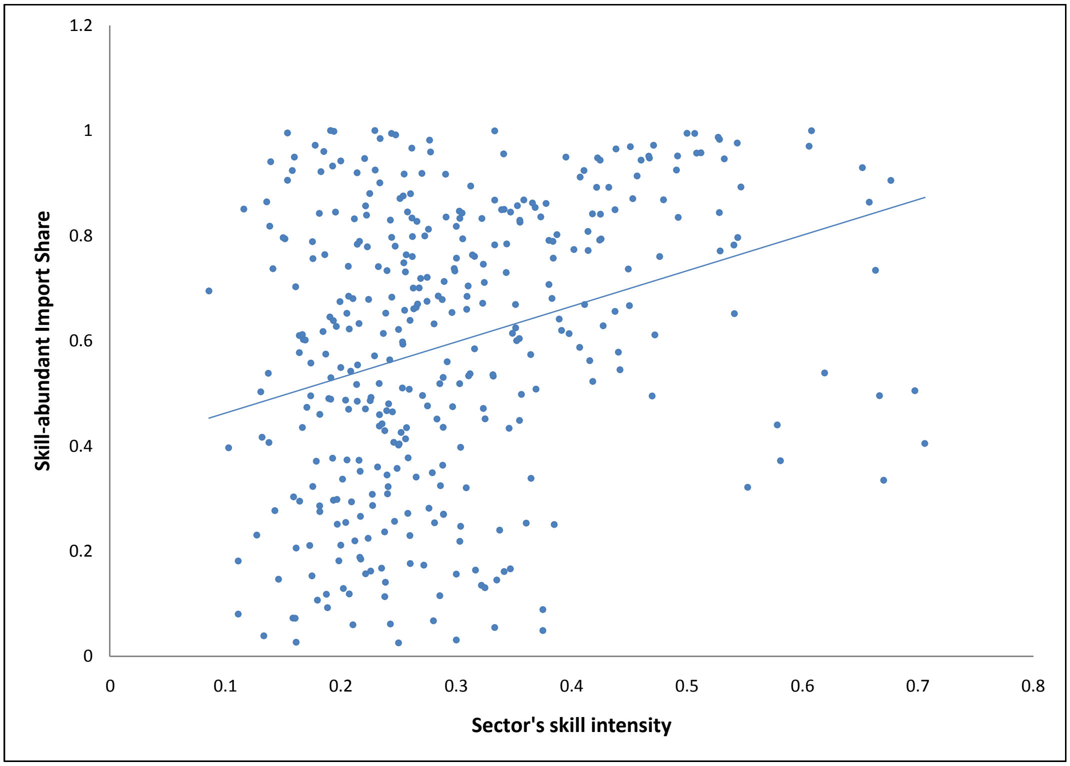
Figure 1: U.S imports from skill abundant countries by sector: Data and Model

Panel A: U.S. Data 2006



Panel B: Model

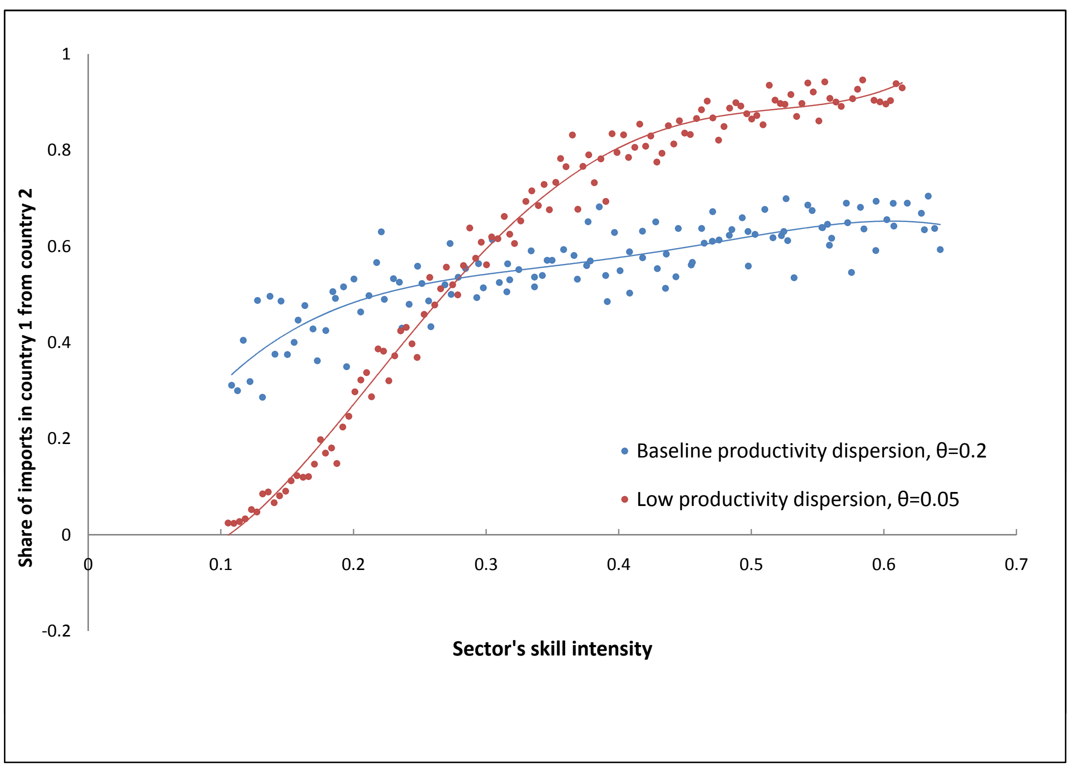


Figure 2: Normalized trade by sector in model

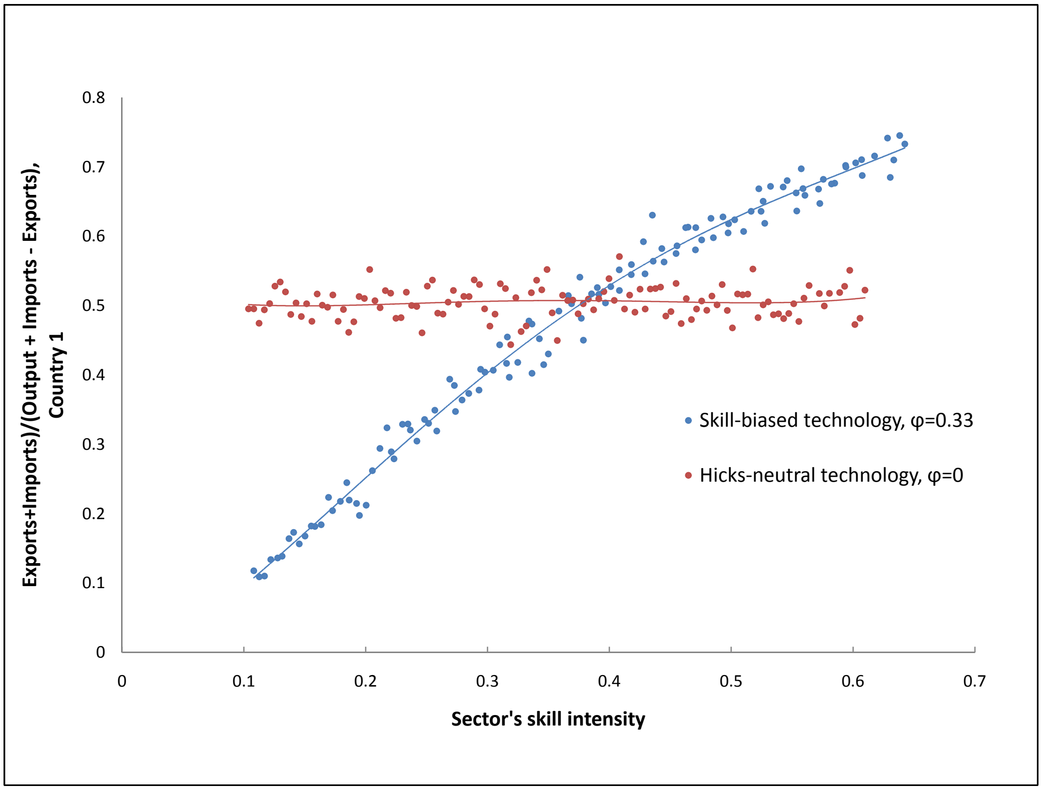


Figure 3: Skill premium and productivity dispersion, Hicks neutral technology

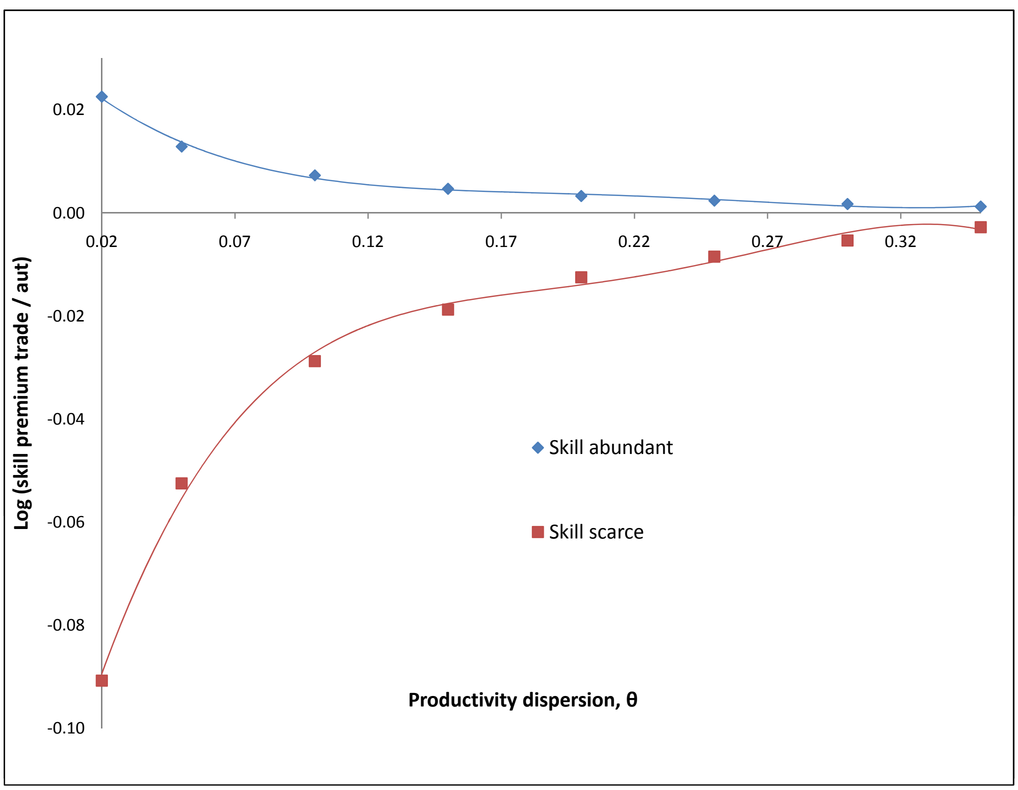
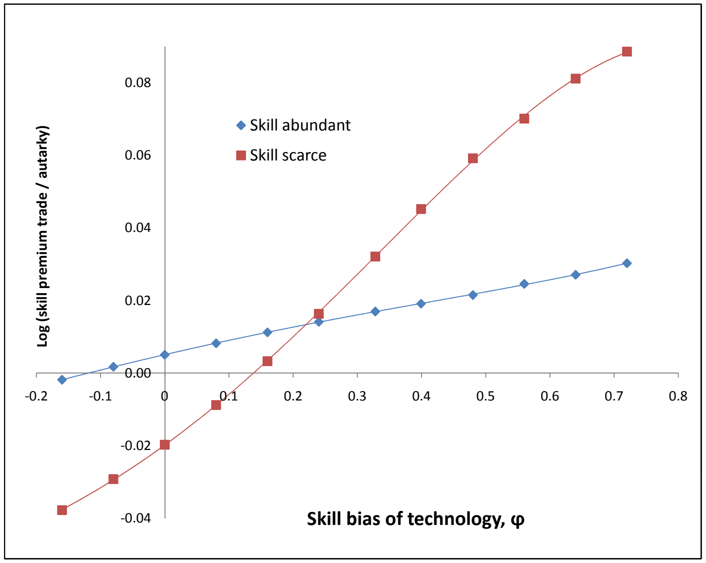


Figure 4: Skill premium and skill-bias of technology

Panel A: Skill premium



Panel B: Skill intensity exporters relative to non-exporters, skill scarce country

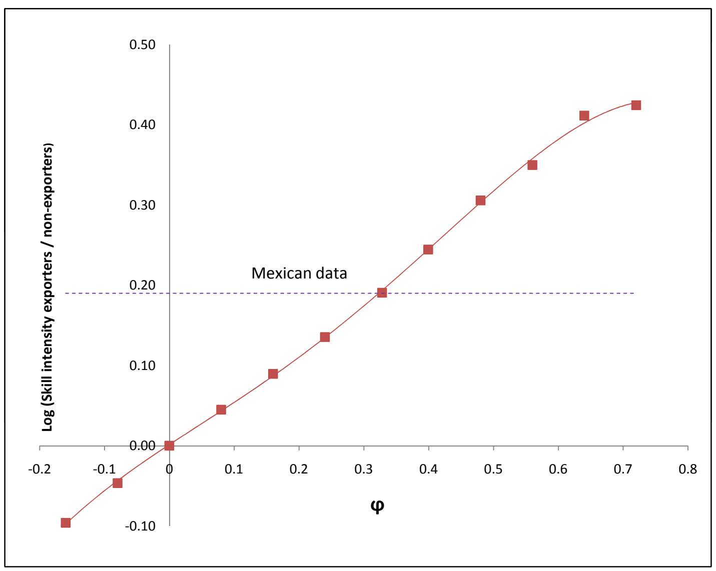
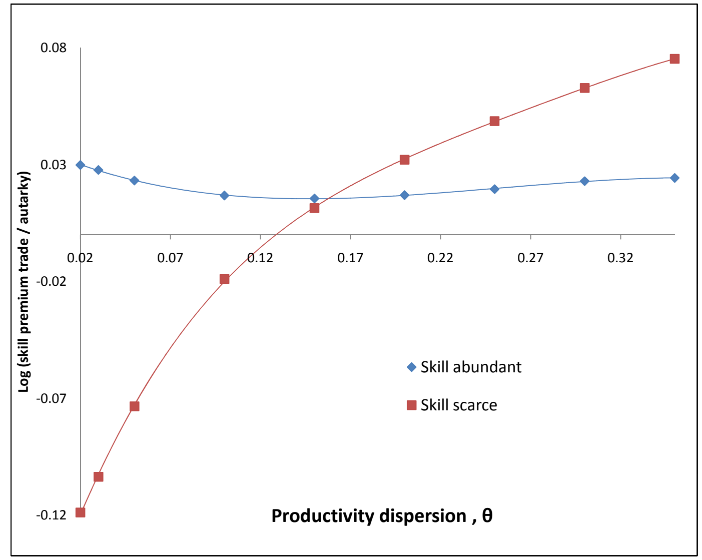


Figure 5: Skill premium and productivity dispersion, skill-biased technology

Panel A: Skill premium



Panel B: Sales exporters relative to non-exporters, skill-abundant country

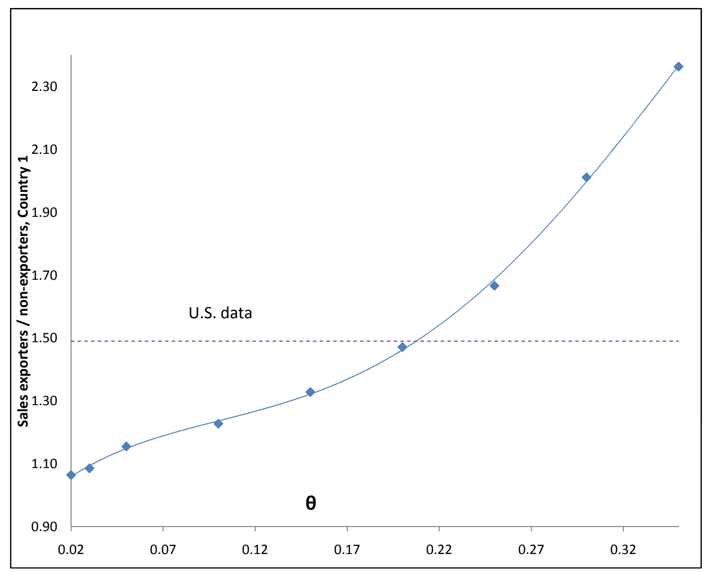
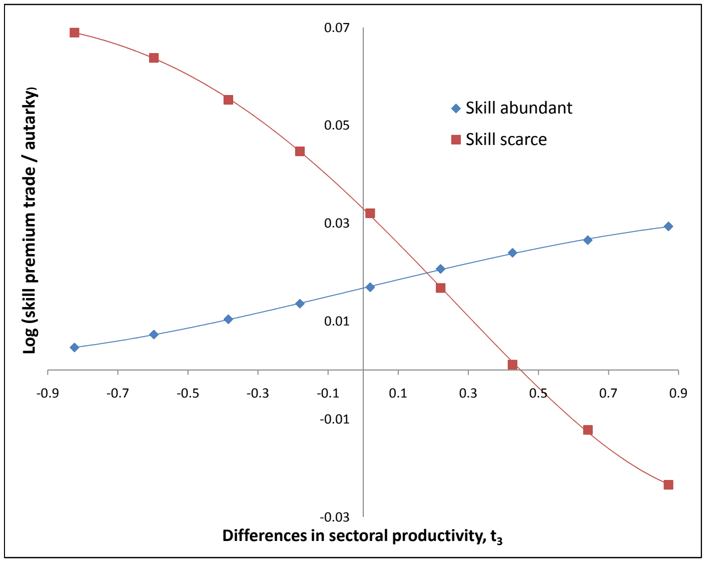


Figure 6: Skill premium and differences in sectoral productivity
Skill-biased technology

Panel A: Skill premium



Panel B: Between-sector trade

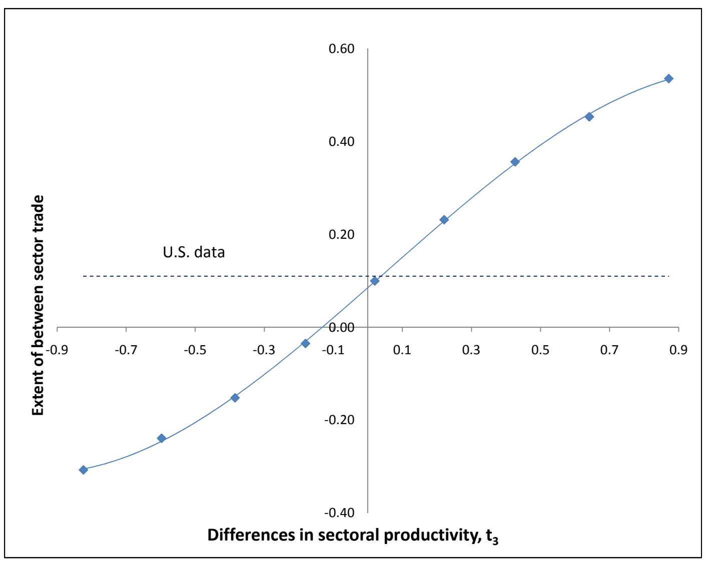


Figure 7: Change in sectoral prices by sector, from autarky to 2006 Trade and MP

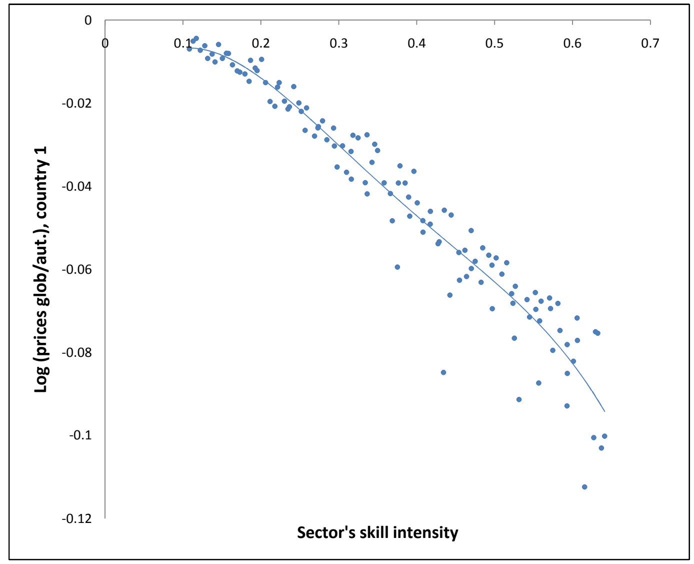


Table 1: Baseline parameterization

		1	2
		Trade only	**Trade and MP**
Production parameters			
1	Skill-bias of technology, φ	0.33	0.33
2	Dispersion of productivities, θ	0.2	0.2
3	Demand elasticity across sub-sectors and sectors, $\eta=\eta'$	2.7	2.7
4	Elasticity of substitution skilled-unskilled labor, ρ	1.2	1.2
5	Share of tradeables in final output, γ	0.26	0.26
Endowments			
6	Skill-unskill endowment ratio country 1, H_1/L_1	0.71	0.71
7	Skill-unskill endowment ratio country 3, H_3/L_3	0.35	0.35
8	Aggregate total factor productivity country 3, T_3	0.29	0.29
9	Sectoral productivity differences, t_3	0.02	0.08
Trade costs			
11	Between countries 1 and 2, τ_{12}	1.295	1.220
12	Between countries 1 and 3, τ_{13}	1.305	1.295
13	Between countries 3 and 4, τ_{34}	1.230	1.225
Multinational Production			
14	Dispersion of idisoyncratic MP costs, θ_m	0.1	0.1
15	Country-level MP cost between Countries 1 and 2, μ_{12}	1000	4.684
16	Country-level MP cost between Countries 1 and 3, μ_{13}	100	100
Other Parameters			
17	Sectoral skill intensities	α~U(0.1,0.6)	
18	Endowment of unskill labor country 1	1	
19	Endowment of unskill labor country 3	1	
20	Total factor productivity country 1, T_1	1	

Table 2: Baseline results

		1	2	3
		Trade only	**Trade and MP**	**Target**
Calibration Targets				
1	1/2*(Exports+Imports)/ Tradeable Output, country 1	0.252	0.254	0.253
	1/2*(Exports+Imports)/ Tradeable Output, country 3	0.509	0.509	Not a target
	1/2*(Exports+Imports)/Total Output, Country 1	0.066	0.066	Not a target
2	1/2*(Exports+Imports)/Total Output, Country 3	0.133	0.133	0.133
	Share of imports in country 1 from country 2			
3	Level	0.59	0.59	0.59
4	Difference Top 1/2 Skilled - Bottom 1/2 Skilled Sectors	0.10	0.10	0.11
5	Share of imports in country 3 from country 4, Level	0.21	0.21	0.21
6	Ratio of sales of exporters / non-exporters, country 1	1.47	1.50	1.49
7	Skill intensitity of exporters relative to non-exporters (log difference), country 3	0.19	0.19	0.19
8	Effective elasticity of substitution between skills, country 1	1.35	1.35	1.4
9	Share of tradeables in gross output	0.26	0.26	0.26
10	Outward MP / Exports, country 1	-	2.48	2.45
11	Share of Country 1's outward MP to country 2	-	0.84	0.85
Counterfactuals				
Skill Premium, log baseline/autarky				
12	Country 1 and Country 2	0.017	0.048	
13	Country 3 and Country 4	0.032	0.059	