Dynamic Trade, Education and Intergenerational Inequality*

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Abstract

In this paper, I develop a dynamic multicountry general equilibrium model to investigate channels influencing the transitional paths of trade-induced inequality. This framework incorporates human capital accumulation, capital accumulation, and capital-skill complementarity. The exact transitional path following trade liberalization is computed by applying the model to 40 countries and 6 sectors using the World Input-Output Database. In the steady state, trade liberalization increases the skill premium, skill share and real wages for both skilled and unskilled workers in all countries in the sample. The inequality consequences of trade liberalization are more severe in the short run along the transitional path. The decomposition implies that (i) the dynamics of trade-induced inequality can be explained by the flexibility to adjust the factor supply at different stages of the transition and (ii) in the long run, education eliminates 65% of trade-induced inequality on average. These results explain the observed transitional path of the skill premium in recent trade liberalization episodes in Mexico, China and Korea. This paper also argues that globalization can cause greater intergenerational inequality.

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1 Introduction

Studies on recent trade liberalization episodes in Mexico, Korea, and China find that trade liberalization results in a rapid increase in the skill premium in the early stage of the transition, followed by a prolonged decline after the skill premium reaches the peak.[1] What forces drive this particular pattern during the transition?

Answering this question requires a dynamic framework to incorporate multiple characteristics across countries and sectors. Some sectors are more skill intensive, and some countries have more robust institutions or larger comparative advantages in skill-intensive sectors. The sectoral and country-level differences are transmitted via international trade, affecting the income inequality across countries.

I extend a multisector Eaton and Kortum (2002) model to a dynamic framework, accommodating sectoral and country-level heterogeneity and geography. To emphasize the sectoral heterogeneity in the production technology, economic activity is divided into agricultural and food production, machinery, high-skilled manufacturing, low-skilled manufacturing, low-skilled services and professional services. The framework incorporates capital accumulation, human capital accumulation and capital-skill complementarity, as in Parro (2013). Capital and human capital investment are chosen optimally in each country. By quantifying this framework, the model is used to evaluate the contribution of different mechanisms to the transitional dynamics of the skill premium following trade liberalization.

The model is parameterized to data from 2001 for 40 countries and 6 sectors using the World Input-Output Database. The educational institution for each country is calibrated so that the steady-state skill premium implied by the model matches the observed skill premium for each country in the sample. I then conduct a counterfactual in which there is an unanticipated, universal 25% reduction in bilateral trade costs for all country pairs and all sectors, and the exact transitional paths are computed for analysis.

The transitional dynamics of the skill premium implied by the counterfactual exercise match the pattern observed in recent trade liberalization episodes. Following unexpected trade liberalization, the skill premium of all countries in the sample

[1] Robertson (2007), Campos-Vázquez (2013) and Atolia and Kurokawa (2016) study the changes in the college premium in Mexico after trade liberalization in the 1980s. Kim and Topel (2007) studies the Korean labor market in the 1970s. Bai et al. (2019) investigate the income inequality in China between 2000 and 2012.

increases rapidly in the early stage of the transition and then exhibits a prolonged and slow decline after reaching the peak. What are the mechanisms that drive this particular pattern? Where do these mechanisms originate?

To understand the forces acting on different stages of the transition, various scenarios are considered by activating and deactivating capital and human capital accumulation. The exact transitional path for each scenario is also calculated. By means of this decomposition exercise, the model indicates that trade liberalization impacts the dynamics of skill premium via three channels, (i) comparative advantage, (ii) capital accumulation, and (iii) education channels, which correspond to short-, medium- and long-run effects. This framework explains the empirical observations of the response of the skill premium to recent trade liberalization episodes. The model suggests that the drastic increase in the skill premium upon trade liberalization is driven by capital accumulation, and the following prolonged decline in the skill premium is connected to the adjustment of education in the longer term.

These outcomes are closely related to the flexibility to adjust the factor supply at different stages of the transition. In the short run, the economy is unable to adjust the factor supply promptly upon trade liberalization; hence, the short-run effect is driven mainly by comparative-advantage-induced reallocation of resources. In the medium run, since capital adjusts faster than human capital, the effects of this stage result from capital accumulation. Trade liberalization lowers the price of capital goods; as a result, the economy starts to accumulate more capital. By means of the capital-skill complementarity, the relative productivity of skilled workers also rises, thereby increasing the skill premium. In the long run, all factors adjust freely, and the adjustment in human capital shifts the relative skill supply and neutralizes the impacts of comparative advantage and capital accumulation.

Rising income inequality associated with globalization in many countries over the past two decades has become a growing concern for policymakers around the world (OECD. 2008 and Dabla-Norris et al. 2015). Education is often regarded as a crucial instrument to combat inequality (see Corak 2013 and Gregorio and Lee 2002); therefore, quantifying the effectiveness of education in alleviating trade-induced inequality is an important objective of this paper. The framework is applied to examine to what extent education alleviates trade-induced inequality. By comparing the transitional paths with and without human capital accumulation, the quantitative experiment illustrates that education eliminates 65% of trade-induced inequality among skilled and unskilled labor.

Finally, I ask how gains from trade are distributed across generations and educational categories. By comparing the percentage gain in discounted lifetime wealth for each group, I find that the older, more educated groups gain the most from globalization, while older, less educated groups gain the least. This finding shows that globalization can be a source of increasing intergenerational inequality, leading to an expanding understanding of the recent heated discussion on the wealth distribution across generations[2].

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the theoretical model and derives the equilibrium conditions for the model. Section 4 demonstrates the intuition and mechanisms of the model using a simplified two-country and two-sector economy. Section 5 explains the parameterization and calibration procedure. Section 6 presents the counterfactual, which illustrates the dynamic effects and mechanism of trade liberalization on education, inequality and gains from trade. Finally, Section 7 concludes this paper.

2 Related Literature

Conventional Heckscher-Ohlin trade models suggest that globalization can reduce the skill premium in developing countries and raise the skill premium in developed countries through the reallocation of labor across sectors (i.e., the Stolper-Samuelson theorem). However, the predictions of the Heckscher-Ohlin model are inconsistent with empirical evidence. As discussed in Goldberg and Pavcnik (2007), globalization raises the skill premium for both developing and developed countries.

The existing theoretical and quantitative works examine the interaction between the skill premium and trade from a wide range of perspectives, including skill-biased technology (Burstein and Vogel 2016, Parro 2013 and Yeaple 2005), structural change (Cravino and Sotelo 2016 and Xu 2016), and global value chain (Costinot et al. 2012). These papers study inequality and international trade in static settings and assume the skill supply is exogenously determined.

The assumption of inelastic skill supply excludes the potential impact of endogenous human capital adjustment on the skill premium. As a result, trade patterns and inequality are determined mainly by cross-country differences in the abundance

[2]See Erikson and Goldthorpe (2002) and Bowles and Gintis (2002)

of skill and productivity and cross-sector differences in skill intensity. Exogenous shocks in these models affect only relative skill demand: the quantitative results depict movement along a vertical skill supply curve. Thus, the ensuing analysis can potentially exaggerate changes in the skill premium. The model in this paper includes an endogenous adjustment of skill, and a quantitative comparison of the exact transitional paths is conducted. To be qualitatively consistent with empirical evidence presented in Goldberg and Pavcnik (2007), the model also accommodates capital-skill complementarity, as in Parro (2013) and Krusell et al. (2000).

This paper is not the first to study the interaction between international trade and educational choice. Recent empirical studies offer compelling evidence that an individual's educational decisions are influenced by globalization. Hickman and Olney (2011) study the U.S. economy and find that globalization increases the educational attainment of workers in the U.S. Atkin (2016) studies Mexico in the period between 1986 and 2000 and finds that export expansion in the manufacturing sector is associated with an increased high school dropout rate. Blanchard and Olney (2017) use a panel of 102 countries over 45 years to investigate the relationship between export composition and educational attainment. By implementing a gravity regression to eliminate endogeneity, Blanchard and Olney (2017) find that an expansion in less skill-intensive exports depresses educational attainment, while an expansion in skill-intensive exports increases educational attainment. These studies suggest that the demand-side comparative advantage mechanism is empirically important in determining aggregate educational attainment across countries.

From a theoretical and quantitative perspective, Findlay and Kierzkowski (1983) build a two-country, two-sector Heckscher-Ohlin model with endogenous educational choice. In their model, the Stolper-Samuelson effect drives the relative return between skilled and unskilled labor; they show that if a country with a comparative advantage in the skill-intensive sector opens up to trade, the relative reward to skill rises and the country becomes more skill abundant. Danziger (2017) studies a dynamic model of educational choice and trade of a small open economy. Blanchard and Willmann (2016) utilize a two-country general equilibrium model to show that the curvature of the education cost function can determine trade patterns, demonstrating how globalization induces the polarization of skills. The model in this paper considers a multicountry framework in which the skill premium and educational choice are driven by both comparative advantages and the quality of educational institutions. The model addresses effects for developed and developing countries simultaneously, which offers quantitative and theoretical foundations for educational choice and international trade studied by Atkin (2016), Hickman and Olney (2011) and Blanchard and Olney (2017).

This paper complements previous work in many aspects. The framework adapts the procedure of Alvarez and Lucas (2007) to a dynamic setting and contributes to the recently growing literature on dynamic trade in the multicountry world. Eaton et al. (2016) quantify shocks between the year 2000 and 2011 and examine the potential cause of trade collapse during the 2008 recession. Anderson et al. (2015) build a model in which the investment rate is independent of trade cost and compute the exact transitional dynamics of the model. Alvarez (2017) linearizes the model around the steady state to approximate the dynamics. Caliendo et al. (2019) study trade shocks on the reallocation of workers by implementing dynamic hat algebra. Ravikumar et al. (2019) compute the exact transitional path of capital accumulation by reformulating a finite horizon problem. I provide a flexible and fast algorithm for solving the dynamic multicountry model, which uses market-clearing condition to iterate prices and utilizes the solutions of the optimization problems to update the factor supply. The solution method computes the exact transitional path for 40 countries and 300 periods within 1 minute on a regular laptop.

Similar to **?**, this paper quantifies the educational institution across countries and evaluates the implications on the comparative advantage and aggregate economic outcomes. Hence, it also contributes to the literature on economic institutions, e.g., Nunn and Trefler (2014) and Acemoglu et al. (2001).

3 Model

Consider an economy of N countries and J sectors, where countries are indexed by i and n and sectors are indexed by j. Within each sector j, there is a continuum of intermediates $\omega \in [0, 1]$. The international trade setting for each industry follows Eaton and Kortum (2002). A final goods producer in each country buys sector-j goods domestically and combines them to produce final goods. All markets are competitive, including factor markets and goods markets.

3.1 Workers

The economy is populated by infinitely lived individuals who face constant probability of death ζ in each period (as in Blanchard 1985). At each time period t, there is a population of mass L_i born in country i. Assume that there is no population growth; hence, newly born individuals exactly replenish the perished population in each period.

Upon birth, each worker draws idiosyncratic innate ability a from a Pareto distribution $G(x) = 1 - x^{-1}$, $x \in [1, \infty)$. The realization of innate ability is directly linked to the cost of education. Each worker decides whether to obtain higher education in his first period; if he chooses to pursue higher education, he becomes a skilled worker throughout his entire lifetime. Similarly, if he chooses not to pursue higher education, he becomes an unskilled worker throughout his entire lifetime. A worker is endowed with one unit of time in each period. A high-skilled individual must spend $a^{-\gamma_i}$ of his time in each period to maintain his educational status and spends his remaining time earning wages as a skilled worker. An unskilled individual uses the entirety of his time to earn wages as an unskilled worker. To be consistent with the definition from the World-Input Database, a skilled worker is defined as a worker with at least a tertiary degree.

The time cost of education is determined by the innate ability of each individual and a country-specific parameter γ_i. The cost is inversely related to innate ability a, i.e., the smarter an individual is, the lower the time cost to maintain his status as a skilled worker in each period. Parameter γ_i captures the quality of educational institutions in country i. Given the same level of innate ability, the larger γ_i is, the less time required in each period to maintain educational status. Countries with larger γ_i provide better environments for workers to pursue an education.

At time $t + s$, a skilled worker in country i receives a wage of $w^H_{i,t+s}$, while an unskilled worker receives $w^L_{i,t+s}$. Workers' instantaneous utility function is logarithmic, with future consumption discounted at a rate of $\beta \in [0, 1]$. Since individuals face a constant chance of death ζ in each period, the effective discount factor is $\nu = (1-\zeta)\beta$. Each worker has perfect foresight about the aggregate economy and evaluates the benefits of being a skilled versus unskilled worker in deciding whether to pursue higher education. Assume individuals cannot save their income; the optimization problem for a worker with innate ability a born in country i at time t is given by:

$$\max\left\{\sum_{s=0}^{\infty}\nu^s\log\Big(\big[1-\frac{1}{a^{\gamma_i}}\big]\times\frac{w^H_{i,t+s}}{P_{i,t+s}}\Big),\sum_{s=0}^{\infty}\nu^s\log\Big(\frac{w^L_{i,t+s}}{P_{i,t+s}}\Big)\right\}. \tag{1}$$

By equating the benefit of being a skilled worker versus an unskilled worker, we derive the threshold innate ability $\bar{a}_{i,t}$. A worker with innate ability$\bar{a}_{i,t}$ in country i born at time t is indifferent to being a skilled or unskilled worker. This threshold ability is denoted by:

$$\bar{a}_{i,t}=\left[1-\Big(\prod_{s=0}^{\infty}\big(\frac{w^L_{i,t+s}}{w^H_{i,t+s}}\big)^{\nu^s}\Big)^{\frac{1}{\sum_{s=0}^{\infty}\nu^s}}\right]^{-\frac{1}{\gamma_i}}. \tag{2}$$

For a worker born at time t in country i, if his innate ability is larger than $\bar{a}_{i,t}$, the benefit of being a skilled worker outweighs that of being an unskilled worker; hence, he pursues higher education. In all other instances, he does not pursue higher education. Equation (2) denotes a key equilibrium condition, which implies that a more efficient educational institution and higher skill premium in the subsequent periods are associated with higher educational attainment.

3.2 Labor Supply Dynamic

The computation of the skilled and unskilled labor supply of country i at time t requires information about the skill supply from the previous period as well as the ability threshold of the current generation. Given $\bar{a}_{i,t}$, the average skilled labor hours of country i and generation t are given by:

$$\int_{\bar{a}_{i,t}}^{\infty}(1-\frac{1}{x^{\gamma_i}})dG(x)=\bar{a}_{i,t}^{-1}-\frac{1}{(1+\gamma_i)}\bar{a}_{i,t}^{-(\gamma_i+1)}=\mu_{i,t}. \tag{3}$$

Similarly, given $\bar{a}_{i,t}$, the average unskilled labor hours of country i and generation t are given by:

$$\int_{1}^{\bar{a}_{i,t}}dG(x)=G(\bar{a}_{i,t}). \tag{4}$$

Letting $L^H_{i,t}$ and $L^L_{i,t}$ be the total skilled and unskilled labor supply of country i at time t, the transitions of skilled and unskilled labor supply can be characterized by:

$$L^H_{i,t}=(1-\zeta)L^H_{i,t-1}+\mu_{i,t}L_i \tag{5}$$

$$L^L_{i,t}=(1-\zeta)L^L_{i,t-1}+G(\bar{a}_{i,t})L_i. \tag{6}$$

The first term on the right-hand side of equations (5) and (6) captures the remaining population from the existing labor force pool. Adding the supply of skilled and unskilled labor from newly born individuals, we arrive at the total labor supply at time t. The evolution of the skilled and unskilled labor supply can be fully characterized by their corresponding initial values and the paths of ability thresholds.

3.3 Production

I introduce capital-skill complementarity into the production function for each sector-j intermediate ω. Capital, skilled workers, and unskilled workers are used to produce intermediates. The production of sector-j intermediate ω follows a technology:

$$M_{i,t}^{j}(\omega) = \left([\delta_i^j]^{1/\rho}[L_{i,t}^{H,j}(\omega)]^{\frac{\rho-1}{\rho}} + [1-\delta_i^j]^{1/\rho}[K_{i,t}^{j}(\omega)]^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}} \tag{7}$$

$$y_{i,t}^{j}(\omega) = A_{i,t}^{j}(\omega)B_i^j[L_{i,t}^{L}(\omega)]^{\alpha_i^j}[M_{i,t}^{j}(\omega)]^{1-\alpha_i^j} \tag{8}$$

where $K_{i,t}^{j}(\omega)$, $L_{i,t}^{H}(\omega)$ and $L_{i,t}^{L}(\omega)$ are the amounts of capital, skilled, and unskilled workers, respectively, used by producer of intermediate ω. Specifically, capital and skilled workers are combined in a CES function with an elasticity of substitution ρ to produce $M_{i,t}^{j}(\omega)$. The intermediate production follows Cobb-Douglas technology combining unskilled labor and $M_{i,t}^{j}(\omega)$. The input share of unskilled labor is represented by α_i^j, with lower values of α_i^j resulting in a more skill-intensive sector j. Skill intensities are heterogeneous across sectors. Additionally, the productivity of intermediate ω of sector j in country i at time t is drawn from a Fréchet distribution $F_{i,t}^{j}(z) = e^{-T_{i,t}^{j}z^{-\theta}}$, where $T_{i,t}^{j}$ is associated with the country-sector-specific total factor productivity and θ determines the dispersion of the distribution. Lastly, $B_i^j = (\alpha_i^j)^{-\alpha_i^j}(1-\alpha_i^j)^{-(1-\alpha_i^j)}$ is a normalizing parameter. Letting $r_{i,t}$, $w_{i,t}^{H}$ and $w_{i,t}^{L}$ be the capital rent and the wages of skilled and unskilled workers in country i at time t, the unit cost to produce intermediate ω of sector j in country i at time t is given by:

$$c_{i,t}^{j}(\omega) = \frac{c_{i,t}^{j}}{A_{i,t}^{j}(\omega)}, \tag{9}$$

with

$$c_{i,t}^{j} = (w_{i,t}^{L})^{\alpha_i^j}(P_{i,t}^{M,j})^{1-\alpha_i^j} \tag{10}$$

$$p_{i,t}^{M,j} = \left[\delta_i^j(w_{i,t}^{H})^{1-\rho} + (1-\delta_i^j)(r_{i,t})^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{11}$$

Sector-j goods in country i are produced using intermediates $\omega \in [0, 1]$ priced at $p^j_{i,t}(\omega)$. Intermediates ω are either from a domestic market or foreign countries. Letting $Y^j_{i,t}$ be the total quantity of sector-j goods in country i produced at time t and $q^j_{i,t}(\omega)$ be the total quantity of intermediate ω used by sector j in country i at time t, the production of sector-j goods follows a CES technology:

$$Y^j_{i,t} = \Big(\int_0^1 [q^j_{i,t}(\omega)]^{\frac{\eta-1}{\eta}} d\omega\Big)^{\frac{\eta}{\eta-1}}, \tag{12}$$

where η is the elasticity of substitution within a sector. Sector-j price index in country i at time t is given by:

$$P^j_{i,t} = \left(\int_0^1 [p^j_{i,t}(\omega)]^{1-\eta} d\omega\right)^{\frac{1}{1-\eta}}. \tag{13}$$

The final goods producer in country i combines sectoral goods from the domestic market priced at $P^j_{i,t}$. Letting $Y_{i,t}$ be the total output of final goods in country i at time t and $q^j_{i,t}$ be the amount of sectoral goods used by the final good production, the production of the final good follows a CES technology:

$$Y_{i,t} = \left(\sum_{j=1}^{J} [q^j_{i,t}]^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{1-\sigma}}, \tag{14}$$

where ρ is the elasticity of substitution across sectors. The price index in country i at time t is given by:

$$P_{i,t} = \left[\sum_{j=1}^{J} (P^j_{i,t})^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{15}$$

The total expenditure on the sector-j good in the production of the final good in country i at time t is given by:

$$E^j_{i,t} = \left(\frac{P^j_{i,t}}{P_{i,t}}\right)^{\frac{1}{1-\sigma}} \times P_{i,t} Y_{i,t} \tag{16}$$

3.4 Capital Supply

For simplicity, assume a representative household in each country dictates the decision of capital investment: individuals do not make the decision regarding investment. Instead, the head of household in country i maximizes the following lifetime welfare function:

$$U_i = \sum_{t=0}^{\infty} \nu^t \log(C_{i,t}), \tag{17}$$

with resource constraints:

$$W_{i,t} = w_{i,t}^H L_{i,t}^H + w_{i,t}^L L_{i,t}^L + r_{i,t} K_{i,t} \tag{18}$$

$$\frac{W_{i,t}}{P_{i,t}} = C_{i,t} + I_{i,t} \tag{19}$$

$$K_{i,t+1} = (1-\delta) K_{i,t} + I_{i,t}, \tag{20}$$

where $C_{i,t}$ and $I_{i,t}$ are the real consumption and real investment, respectively, of country i at time t, and δ is the depreciation rate of capital. The representative household in each country collects all nominal income from workers and capital and then allocates resources between real consumption $C_{i,t}$ and capital investment $I_{i,t}$ by solving the optimization problem. Equation (20) captures the law of motion of capital stock in country i.

As stated previously, the representative household has perfect foresight. Solving the maximization problem, the Euler's equations are given by:

$$\lambda_{i,t} = \frac{1}{C_{i,t}} \tag{21}$$

$$-\lambda_{i,t} + \nu \lambda_{i,t+1} \left[\frac{r_{i,t+1}}{P_{i,t+1}} + (1-\delta) \right] = 0 \tag{22}$$

$$\frac{W_{i,t}}{P_{i,t}} = C_{i,t} + K_{i,t+1} - (1-\delta) K_{i,t}. \tag{23}$$

The dynamics of capital are governed by the Euler's equations. These conditions pin down the transition of capital supply for each country. Combining this information with the transition of skill supply, we can solve the factor supply for every country at each time period.

3.5 International Trade

The iceberg trade cost of delivering one unit of a sector-j intermediate from country i to n is denoted by $d_{i,n}^j \geq 1$. Hence, the unit cost of producing sector-j intermediate ω in country i after delivering to country n is given by $c_{i,n,t}^j(\omega) = c_{i,t}^j(\omega) d_{i,n}^j$. Since the market is competitive, the sector-j good producer in country n buys each intermediate ω from the cheapest source, and the price of intermediate ω is given by:

$$p^j_{i,n,t}(\omega) = \min_i \left\{ c^j_{i,n,t}(\omega) \right\}. \tag{24}$$

Following Eaton and Kortum (2002) to solve trade share and sectoral price indices, the probability of country n buying sector-j intermediates from country i at time t is

$$\pi^j_{i,n,t} = \frac{T^j_{i,t}(d^j_{i,n}c^j_{i,t})^{-\theta}}{\sum_{i'=1}^{N} T^j_{k,t}(d^j_{i',n}c^j_{i',t}c^j_{i',t})^{-\theta}} = \frac{T^j_{i,t}(d^j_{i,n}c^j_{i,t})^{-\theta}}{\Phi^j_{n,t}}. \tag{25}$$

$\pi^j_{i,n,t}$ is also n's expenditure share on i in sector j. Let $E^j_{i,n,t}$ be the total sector-j intermediate export from country i to country n at time t, given by

$$E^j_{i,n,t} = \pi^j_{i,n,t} E^j_{n,t} = \frac{T^j_{i,t}(d^j_{i,n}c^j_{i,t})^{-\theta}}{\Phi^j_{n,t}} E^j_{n,t}. \tag{26}$$

Equation (26) is the gravity equation, where θ is trade elasticity, i.e., the elasticity of export with respect to trade costs. A smaller dispersion of productivity across countries corresponds to higher trade elasticity since trade flows are more responsive to trade costs when countries are more similar in the distribution of productivity.

The price index for sector j in country n at time t is given by:

$$\begin{aligned} P^j_{n,t} =& \left[\int_0^1 p^j_{n,t}(\omega)^{1-\eta} d\omega \right]^{\frac{1}{1-\eta}} \\ =& \Gamma\left(\frac{\theta - 1 + \eta}{\theta}\right) \times [\Phi^j_{n,t}]^{-\frac{1}{\theta}}, \end{aligned} \tag{27}$$

where $\Gamma(\cdot)$ is a gamma function.

3.6 General Equilibrium

Assuming trade is balanced for simplicity, the goods markets and all factor markets clear for every country and all time periods in the general equilibrium. The sectoral goods are cleared if the following condition holds for each i, j, and t:

$$E^j_{i,t} = P^j_{i,t} Y^j_{i,t} = \sum_{n=1}^{N} \pi^j_{i,n,t} E^j_{n,t}, \tag{28}$$

where $E^j_{i,t}$ is the value of gross output of sector j in country i at time t. Equilibrium also requires total spending to equal total income for each country and each time period,

$$P_{i,t}Y_{i,t} = w^H_{i,t}L^H_{i,t} + w^L_{i,t}L^L_{i,t} + r_{i,t}K_{i,t}. \tag{29}$$

Since factors can freely move across sectors but are unable to move across countries, factor prices are equalized across sectors within each country. The market clearing conditions for capital, skilled, and unskilled labor in country i at time t is

$$r_{i,t}K_{i,t} = \sum_{j=1}^{J}\left[(1-\alpha^j_i)(1-\delta^j_i)\left(\frac{r_{i,t}}{P^{M,j}_{i,t}}\right)^{1-\rho}\sum_{n=1}^{N}\pi^j_{i,n,t}X^j_{n,t}\right] \tag{30}$$

$$w^H_{i,t}L^H_{i,t} = \sum_{j=1}^{J}\left[(1-\alpha^j_i)\delta^j_i\left(\frac{w^H_{i,t}}{P^{M,j}_{i,t}}\right)^{1-\rho}\sum_{n=1}^{N}\pi^j_{i,n,t}X^j_{n,t}\right] \tag{31}$$

$$w^L_{i,t}L^L_{i,t} = \sum_{j=1}^{J}\left[\alpha^j_i\sum_{n=1}^{N}\pi^j_{i,n,t}X^j_{n,t}\right]. \tag{32}$$

The left-hand side of equations (30) to (32) is the total income of each factor in country i at time t, and the right-hand side is the total payment to each factor. In equilibrium, these market clearing conditions hold across all i and all t.

Given all equilibrium conditions, including the solutions to maximization problems, trade shares, and price indices, the equilibrium is defined in the following manner. Denoting economic fundamentals at time t as Ψ_t, which includes bilateral trade cost $d^j_{i,n,t}, \forall i, n \in N, j \in J$, and productivity $T^j_{i,t}, \forall i \in N, j \in J$, these variables can potentially be time-varying but are deterministic and converge at some constants. The initial condition, denoted as Θ_0, includes initial factor supply $K_{i,0}$, $L^H_{i,0}$ and $L^L_{i,0}$ $\forall i$. Given Θ_0 and $\{\Psi_t\}^\infty_{t=0}$, an equilibrium is composed of sequences of factor prices and factor supply $\{r_{i,t}, w^H_{i,t}, w^L_{i,t}, K_{i,t}, L^H_{i,t}, L^L_{i,t}\}^\infty_{t=0}, \forall i \in N$ such that all equilibrium conditions and market clearing conditions are satisfied.

Steady-state equilibrium can be defined similarly. Given steady-state fundamental Ψ^*, which includes trade cost $d^j_{i,n}, \forall i, n \in N, j \in J$ and $T^j_i, \forall i \in N, j \in J$, a steady-state equilibrium is $\{r_i, w^H_i, w^L_i, K_i, L^H_i, L^L_i\}, \forall i \in N$ such that all equilibrium conditions and market clearing conditions are satisfied.[3]

[3]See Appendix (C) for the equilibrium conditions of the steady state and the algorithm to compute both the steady state and transitional path.

Parameters		Value
Elasticity of substitution across sectors:	σ	2.2
Elasticity of substitution within sectors:	η	2.7
Elasticity of substitution between skilled labor and capital:	ρ	1
Productivity dispersion:	θ	4
Unskilled labor intensity in manufacturing:	α^M	0.7
Unskilled labor intensity in service:	α^S	0.3
Skill share relative to capital:	δ^j	0.7
Population:	L_i	1

Table 1: Baseline parameters used in the simplified cases.

4 Special Cases

To demonstrate important channels driving this model, this section implements a simplified and numerical version for a world with two countries, North and South, and with two sectors, service and manufacturing. This numerical model allows me to quantitatively study the implications of the model with respect to the skill premium, skill share, relative export share, and real income. In this section, I focus on these economic variables that vary in the steady state as the economic environment changes.

Table (1) presents my baseline values for parameters that are used for the quantitative experiments in the simplified environment. When possible, the parameter values chosen are common in the literature. The elasticity of substitution between skilled labor and capital is set to $\rho = 1$ to eliminate capital-skill complementarity in order to emphasize other mechanisms. The payment shares to unskilled labor in manufacturing and service are set to 0.7 and 0.3, respectively. Hence, the manufacturing sector is more unskilled-labor intensive.

4.1 The Comparative Advantage Mechanism

In the first numerical experiment, I give the North a comparative advantage in the service sector by imposing $T_i^j = 1$ for all i and j, except for $T_{North}^{service} = 2$. To eliminate heterogeneity for educational institution, I set educational efficiencies to $\gamma_i = 1$ for

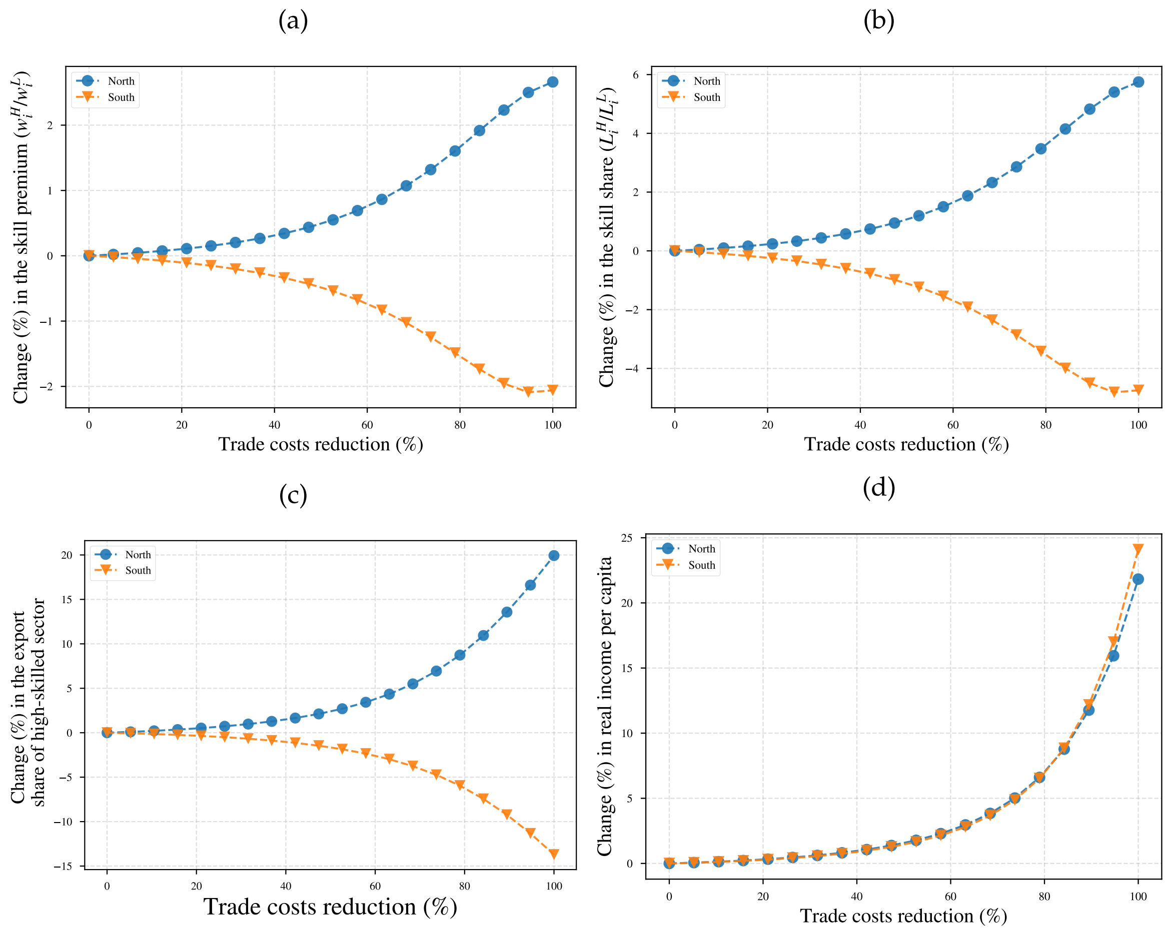

Figure 1: The steady-state effects of trade cost removal. (1a) Changes (%) in skill premium. (1b) Changes (%) in skill share. (1c) Changes (%) in exports of the high-skilled sector relative to low-skilled sector. (1d) Changes (%) in real income per capita.

both the North and the South. Iceberg costs are set to $d^j_{i,n} = 3$ for $i \neq n$ so that the numerical model features trade friction. As a result, the North has a comparative advantage in the high-skilled sector, while the South has a comparative advantage in the low-skilled sector. The quantitative experiment gradually reduces the trade cost until trade barriers are completely eliminated.The changes in skill premium and skill share relative to the baseline equilibrium are recorded.

Panels (1a) and (1b) in Figure (1) present the changes in skill premium and skill share for this experiment. As predicted by Stolper-Samuelson theorem, the reduction in trade costs causes the factors to be allocated toward the sector having a comparative advantage in each country. Since the North has a comparative advantage in the high-skilled sector, its export share in the high-skilled sector starts to climb, and the between-sector reallocation induced by the trade costs reduction increases the skill premium in the North. In response to the higher skill premium, workers in the North seek more education, so educational attainment also rises. These changes in educational outcomes reflect the outward shift of relative skill demand along a positively sloped skill supply. As a result, the relative price rises, and the relative quantity falls. The opposite occurs in the South since it has a comparative advantage in the low-skilled sector.

The result of this quantitative experiment echoes the prediction of Findlay and Kierzkowski (1983) that trade liberalization induces skill upgrading and downgrading according to a country's comparative advantage. The results are also consistent with the empirical findings of Blanchard and Olney (2017) that export expansions in high-skilled sectors are associated with an increase in educational attainment.

4.2 The Educational Institution Mechanism

In this subsection, the educational institution mechanism is studied. To emphasize the effect of educational institution, the comparative advantage channel is eliminated by assuming that the productivities across countries and sectors are the same, $T_i^j = 1$ for all i, j. Additionally, $d_{i,n}^j = 1$ for all j, i, n is imposed to remove trade friction. The goal of these assumptions is to isolate the effect of educational institutions on the economy. The values of educational efficiency γ_i are set to 1 for both countries in the baseline. The quantitative experiment entails gradually increasing the North's educational efficiency until it reaches 2 while holding everything else unchanged and recording the changes in economic outcomes.

Panels (2a) and (2b) in Figure (2) show that as the North's educational institutions become more efficient, the skill premium in the North falls and the educational attainment in the North rises. However, an improvement in the North's educational institutions does not have a significant impact on the South's labor market, as it slightly reduces the skill premium and the skill share in the South.

Even though improvement in the North's educational efficiency has only a minimal impact on the South's labor market, it has a significant impact on the pattern of specialization. Panel (2c) in Figure (2) shows that as the North's educational institution improves, the North exports relatively more high-skilled goods, while the

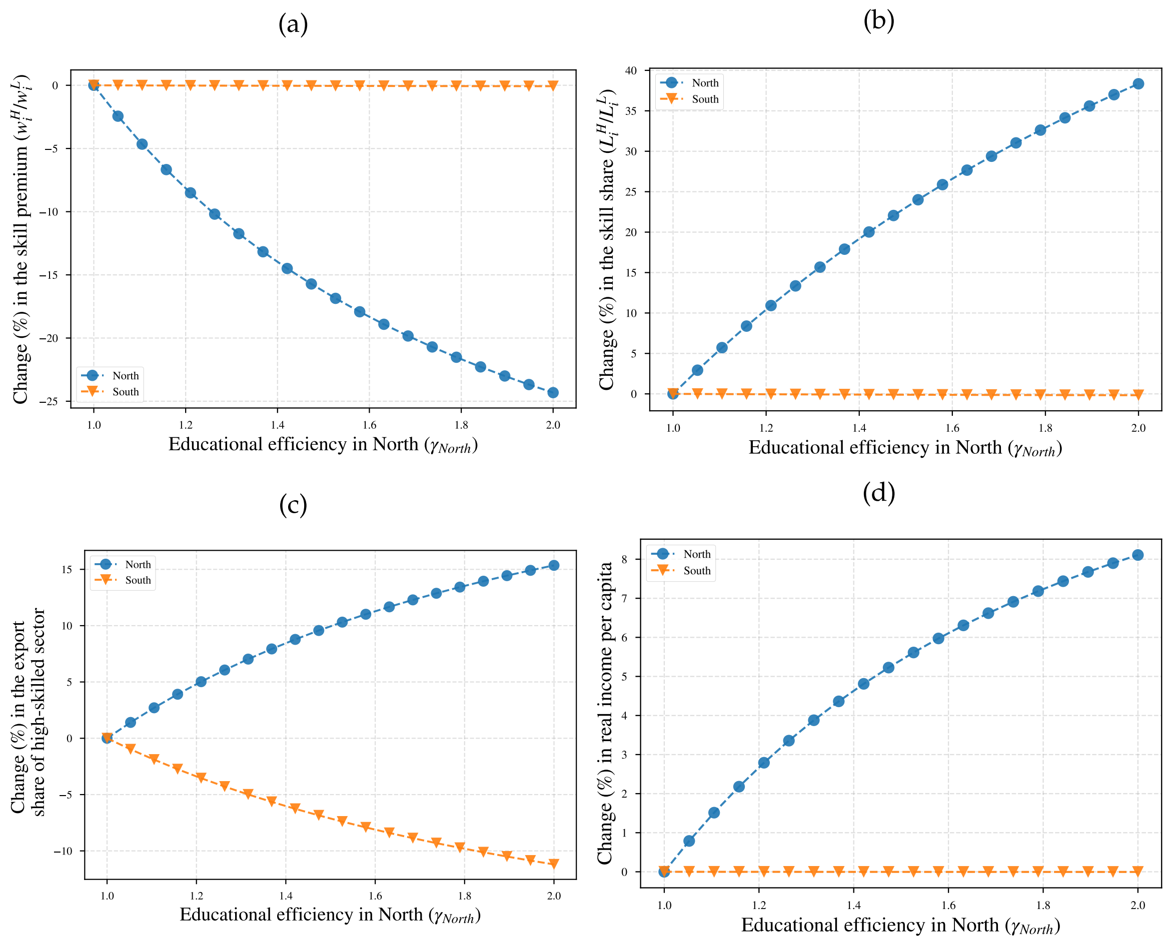

Figure 2: The steady-state effects of increasing educational efficiency in the North. (2a) Changes (%) in skill premium. (2b) Changes (%) in skill share. (2c) Changes (%) in exports of the high-skilled sector relative to the low-skilled sector. (2d) Changes (%) in real income per capita.

South exports relatively more low-skilled goods. That is, the North starts to specialize in high-skilled sectors, and the South specializes in low-skilled sectors.

This example demonstrates that differences in educational institutions across countries can be a source of comparative advantage. Countries with more robust educational institutions are more capable of providing skilled labor; hence, they are also more likely to specialize in high-skilled sectors. This characteristic suggests that educational policies can be used as instruments in determining patterns of international trade and specialization.

5 Parameterization

Model parameters are either taken from the literature, estimated, or calibrated. Using data from the World Input-Output Database (WIOD), as discussed in Timmer et al. (2015), I calibrate the parameters of my model to match observations in the year 2001. Assuming the world is in a steady state in 2001, the model is parameterized to 40 countries and 6 sectors aggregated from 33 industries[4] using bilateral trade data from the World Input-Output Table (WIOT) and production data from the Socio-economic Accounts (SEA). Table (5) and (6) in Appendix (A) list the countries and industries included in my sample.

5.1 Common Parameters

The following parameters are assumed to be shared across countries and invariant overtime: elasticities, factor shares for each industry, constant probability of death, discount factor, and the rate of capital depreciation.

According to the estimation of Simonovska and Waugh (2014), trade elasticity is set to $\theta = 4$. To match the median 5-digit SITC and 3-digit elasticity of substitution between 1990 and 2001 estimated by Broda and Weinstein (2006), I set elasticity of substitution within sector to $\eta = 2.7$ and that across sector to $\sigma = 2.2$. The estimation of Krusell et al. (2000) is adopted to set the elasticity of substitution between skilled labor and capital to $\rho = 0.67$. I set the constant probability of death $\zeta = 0.025$; hence, on average, workers stay in the labor force for 40 years. Finally, the capital depreciation rate is set to $\delta = 0.05$, and the discount factor is set to $\beta = 0.98$.

For factor shares, I assume α_i^j and δ_i^j are the same across all countries but differ across industries. On the basis of U.S. data in 2001 from the SEA as the baseline, the values of α_i^j are set to match the expenditure share on unskilled labor and the values of δ_i^j are set to match the expenditure share on skilled labor relative to capital for each industry. See Table (8) in Appendix (A) for the values of factor shares for each industry.

[4] See Table (7) for details of the aggregation.

Parameters		Value
Elasticity of substitution across sectors:	σ	2.2
Elasticity of substitution within sectors:	η	2.7
Elasticity of substitution between skilled labor and capital:	ρ	0.67
Trade elasticity:	θ	4
Rate of capital depreciation:	δ	0.05
Probability of death:	ζ	0.025
Discount factor:	β	0.98
Factor shares:	α^j and δ^j	U.S. data

Table 2: Common parameters

5.2 Country-specific Parameters and Trade Costs

The total labor force L_i in each country is set to match the total number of employees in the SEA. The SEA dataset also enables me to compute the skill share, the skill premium, and nominal wages for skilled and unskilled labor. See Appendix (B) for further details.

To estimate bilateral trade costs, I assume that trade costs take the form

$$d_{i,n}^{j} = (Dist_{i,n})^{b_1^j} \times \exp(b_2^j \times border_{i,n} + b_3^j \times language_{i,n} + b_4^j \times colony_{i,n}). \tag{33}$$

This specification captures geographical barriers across countries, where $Dist_{i,n}$ is the distance between i and n and $border_{i,n} = 1$ if i and n do not share border. Similarly, $language_{i,n}$ and $colony_{i,n}$ refer, respectively, to whether i and n share a common official language and whether they share colonial history. The data on the geography for each country pair are from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). Combining the specification of trade costs with the gravity structure, the empirical specification is given by:

$$\begin{aligned} \log E_{i,n}^{j} =& b_1'^{j} \log D_{i,n} + b_2'^{j} \times border_{i,n} + b_3'^{j} \times language_{i,n} + b_4'^{j} \times colony_{i,n} \\ &+ Exporter_i^j + Importer_n^j + \varepsilon_{i,n}^{j}, \end{aligned} \tag{34}$$

where $Exporter_i^j$ and $Importer_n^j$ are exporter and importer dummies, respectively. By means of the data for 2001, equation (34) is estimated industry-by-industry via ordinary least squares. Given the value of trade elasticity θ, the parameters of iceberg trade costs for each industry can be recovered by $b^j = -\theta \hat{b}'^{j}$. See Table (10) in Appendix (B) for the estimated parameters for trade costs in each industry. The productivity for each (i,j) is calculated by $\hat{T}_i^j = \exp(\hat{Exporter}_i^j)(c_{i,t}^j)^\theta$, where $c_{i,t}^j$ is computed using the factor prices and shares from the WIOD.

5.3 Calibrating the Educational Efficiency

The only remaining unspecified parameter is the educational efficiency γ_i for each country. The educational efficiency γ_i is calibrated such that the steady-state skill premium in the model matches the skill premium in the data. Details of the calibration procedure can be found in Appendix (D).

Figure (3) illustrates the calibrated value of educational efficiency for each country. In general, more developed countries have more efficient educational systems, while less developed countries have less efficient educational systems. Countries with the most efficient educational systems are welfare states such as Denmark, Sweden, and Finland. Larger developing countries, such as Indonesia and India, have the least efficient educational systems.

The quality of educational institutions across countries is difficult to evaluate. Recently, the Program for International Student Assessment (PISA) has gained considerable attention as a measure for cross-country comparison of educational systems. The PISA score has become the most commonly used measure for global educational rankings, although this approach is not without criticism[5].

To check whether the educational efficiency derived from the model resonates with real-world measures, the calibrated educational parameters γ_i are compared against year 2003 PISA scores in both math and reading. The results are summarized in Figure (4), which shows that calibrated educational efficiency is positively and strongly correlated with PISA scores. The correlation coefficients are 0.74 and 0.75 for PISA scores in math and reading, respectively, and the rank correlation coefficients are 0.79 and 0.80 (see Table (9)).

? also use a general equilibrium framework and trade data to quantify the quality of educational systems across countries, and they emphasize the educational quality in the dimensions of cognitive and noncognitive skills. Similarly, my structure provides a cross-country comparison of educational institutions using publicly available data and does not rely on direct measures of the educational system in

[5] See Hanushek and Woessmann (2011) and **?**

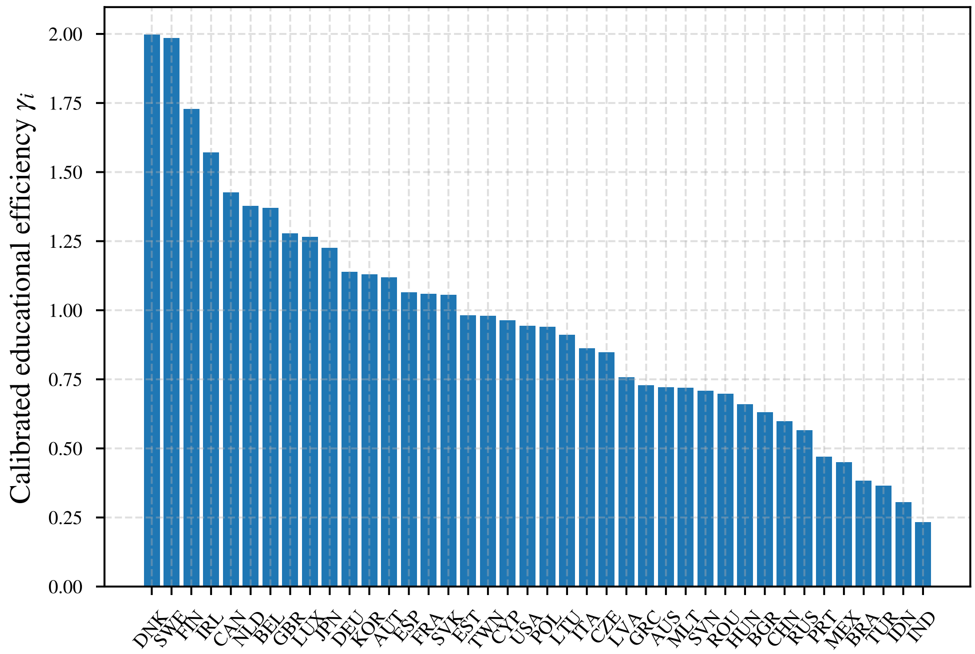

Figure 3: Calibrated educational institution parameter γ_i.

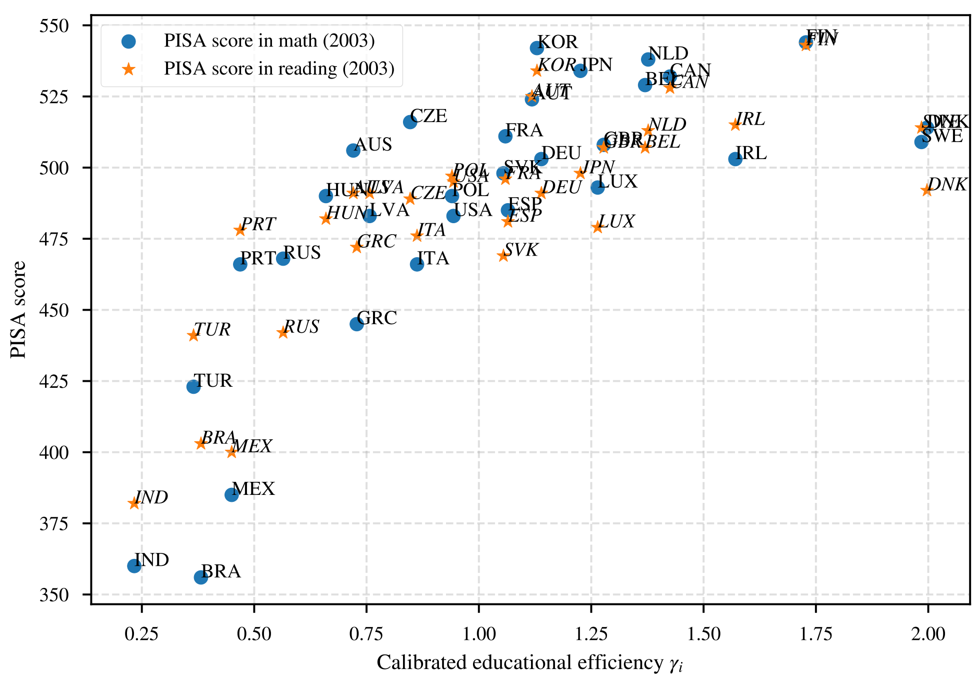

Figure 4: Calibrated educational institution parameter γ_i and PISA scores.

each country. The calibrated educational efficiency across countries exhibits a pattern similar to that of the most commonly used measure for global ranking of educational systems. This result is useful for the evaluation of educational quality in countries or regions that lack detailed information about their educational system: evaluations can be conducted using only the structure of this model and publicly available data.

5.4 Model Fit

The calibrated parameters are used to compute the steady state of the model. Figure (5) plots the skill premium and skill share in the data and in the steady state of the calibrated model. The skill premium is the targeted moment, and the model matches the data almost perfectly, with a correlation coefficient of 1. For skill share, the correlation coefficient between the data and the model is 0.6, even though the skill share is not the targeted moment. Figure (5) shows a negative relationship between skill premium and skill share in the data, with a correlation coefficient of -0.59. The model preserves this negative relationship, with a correlation coefficient of -0.83. In summary, the model matches the skill premium perfectly and preserves the negative relationship between the skill premium and the skill share observed in the data.

6 Counterfactual: Trade Liberalization

In this section, I study the effect of unanticipated permanent trade liberalization. The trade liberalization corresponds to a uniform reduction in iceberg trade costs. At period $t = 0$, the economy begins in a calibrated steady state. At period $t = 1$, iceberg trade costs fall by 25% unexpectedly for each country pair and each sector.

Then, I compute the corresponding exact transitional paths for all countries and quantify the impacts on educational outcome, labor market, and international trade. Solving the transitional path for all 40 countries simultaneously is a daunting task since it involves finding solutions in a vast state space. I adapt the algorithm of Alvarez and Lucas (2007) to this dynamic framework by incorporating perfect foresight. The method I use is efficient, as the computation of the full transitional paths for 300 periods and 40 countries takes less than 1 minute. See Appendix (C) for

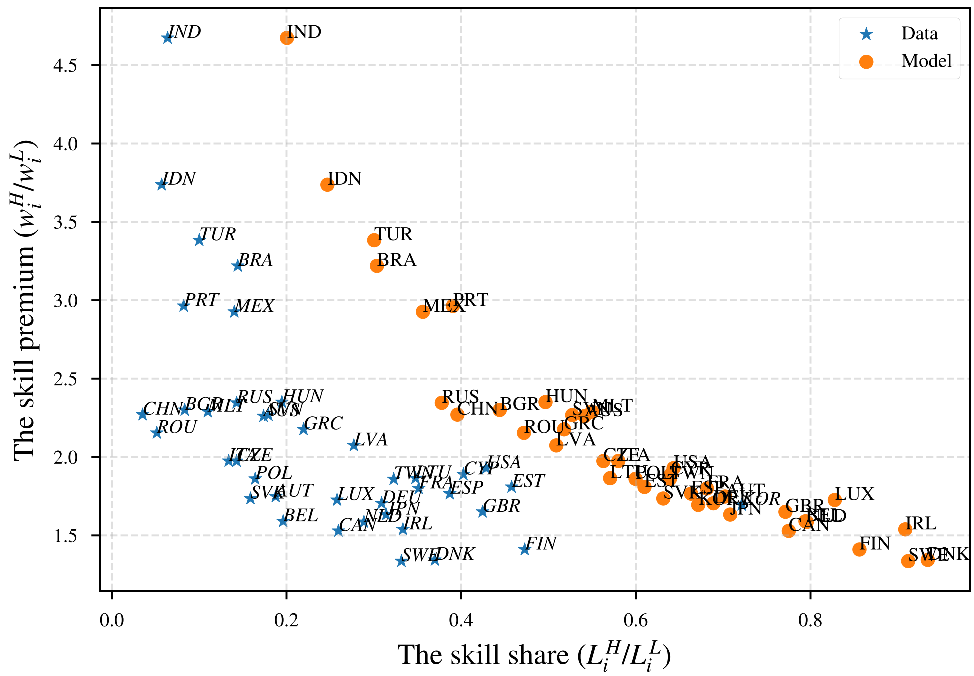

Figure 5: Model fit for the educational outcomes in the baseline steady-state equilibrium and the data. Horizontal axis for the skill share, and vertical axis for the skill premium.

details of the algorithm.

6.1 Changes in the Skill Premium and Skill Share

Figure (6) plots the percentage changes in the skill share and skill premium relative to the baseline steady-state equilibrium for each country. The skill premium and skill share rise by 0.93% and 1.71% on average, respectively, but vary widely across countries. The skill premium rises as much as 1.32% in Brazil, 1.35% in India, and 1.40% in Indonesia and as little as 0.37% in Canada and 0.35% in Belgium. Skill share rises as much as 2.02% in Russia, 1.96% in India, and 1.89% in China and as little as 0.87% in Taiwan, 0.85% in Japan, and 0.73% in Belgium. The changes in the steady state for economic variables across countries are summarized in Table (3). Note that contrary to the prediction of the Stolper-Samuelson theorem, the skill premium increases in all countries. For both developed and developing countries, workers with higher education gain more from trade, resulting in growing inequality between educational categories. This result suggests that capital-skill comple-

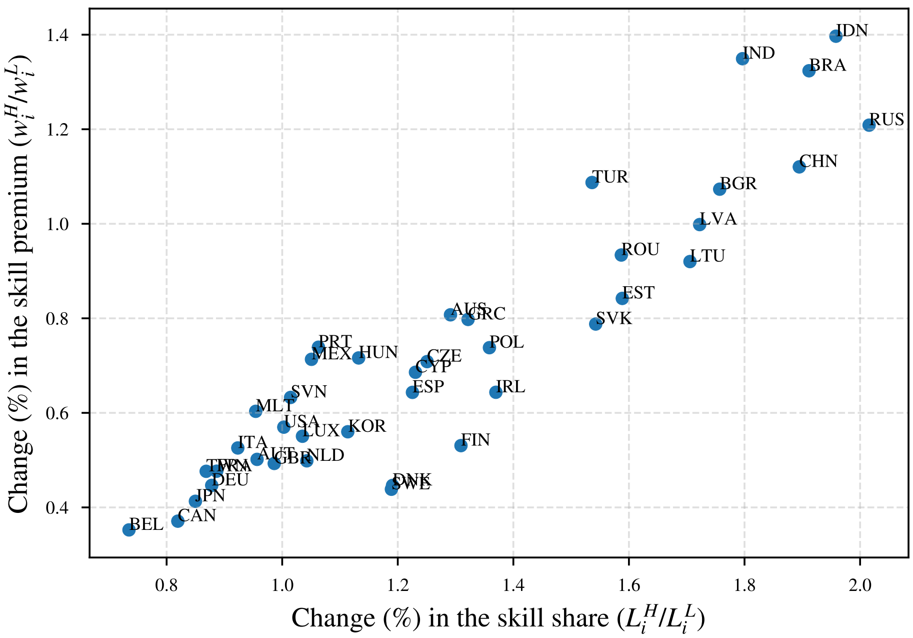

Figure 6: Steady-state changes (%) in the skill premium and skill share resulting from an unanticipated 25% trade cost reduction.

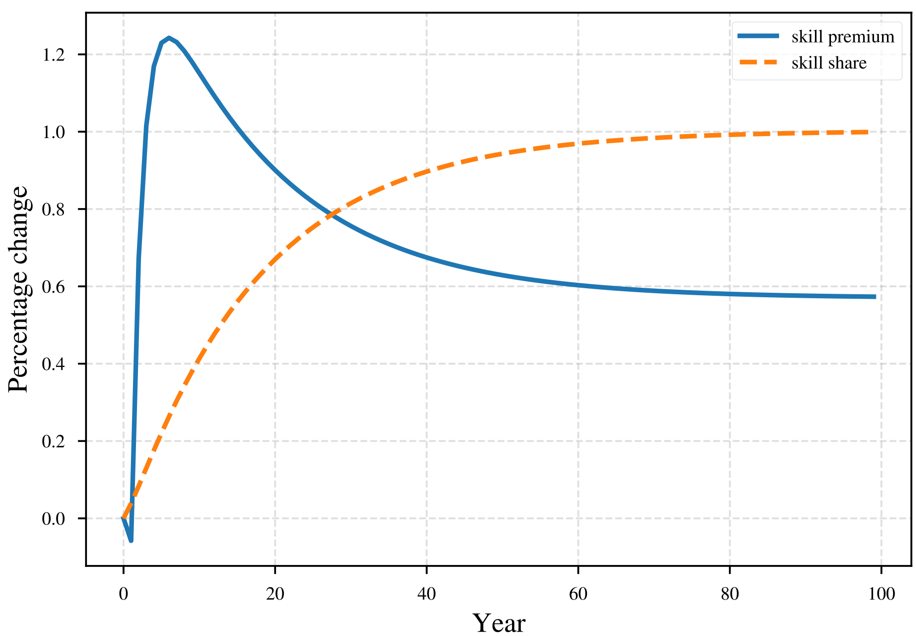

Figure 7: Transitional paths for the changes (%) in the skill premium and skill share in the U.S. resulting from an unanticipated 25% trade cost reduction.

Country	Skill Premium (w_i^H/w_i^L)	Skill Share (L_i^H/L_i^L)	Capital Supply (K_i)	Real Wage for Skilled (w_i^H/P_i)	Real Wage for Unskilled (w_i^L/P_i)	Average Real Wage (w_i/P_i)	Real Income per Capita (Y_i/P_i)
AUS	0.81	1.29	23.53	30.45	29.40	29.98	28.85
AUT	0.50	0.96	14.92	20.75	20.15	20.48	19.74
BEL	0.35	0.73	8.63	13.26	12.86	13.08	12.47
BGR	1.07	1.76	23.57	28.90	27.54	28.23	27.03
BRA	1.32	1.91	28.70	34.39	32.63	33.51	32.27
CAN	0.37	0.82	9.19	13.46	13.04	13.26	12.57
CHN	1.12	1.89	26.32	32.78	31.31	32.01	30.41
CYP	0.69	1.23	19.88	26.73	25.86	26.34	25.33
CZE	0.71	1.25	18.99	24.61	23.73	24.20	23.23
DEU	0.45	0.88	15.74	21.24	20.70	20.99	20.25
DNK	0.45	1.19	19.21	24.73	24.17	24.48	23.63
ESP	0.64	1.23	20.32	26.27	25.47	25.90	24.96
EST	0.84	1.59	21.31	27.00	25.94	26.50	25.34
FIN	0.53	1.31	14.87	21.64	21.00	21.35	20.41
FRA	0.48	0.89	17.03	22.29	21.71	22.03	21.30
GBR	0.49	0.99	17.29	22.96	22.35	22.69	21.91
GRC	0.80	1.32	20.88	27.35	26.34	26.88	25.78
HUN	0.72	1.13	20.99	26.69	25.79	26.28	25.28
IDN	1.40	1.96	29.14	35.38	33.51	34.41	32.93
IND	1.35	1.80	26.75	32.54	30.77	31.63	30.25
IRL	0.64	1.37	11.61	18.45	17.69	18.13	17.19
ITA	0.53	0.92	18.35	25.00	24.35	24.70	23.81
JPN	0.41	0.85	16.32	23.70	23.19	23.46	22.50
KOR	0.56	1.11	17.71	24.92	24.23	24.60	23.47
LTU	0.92	1.71	21.87	27.69	26.52	27.12	25.89
LUX	0.55	1.04	8.96	14.78	14.15	14.52	13.88
LVA	1.00	1.72	22.19	28.23	26.96	27.61	26.38
MEX	0.71	1.05	22.09	27.89	26.98	27.45	26.43
MLT	0.60	0.95	19.37	25.64	24.89	25.31	24.42
NLD	0.50	1.04	15.01	20.27	19.68	20.01	19.20
POL	0.74	1.36	20.16	25.40	24.48	24.97	24.01
PRT	0.74	1.06	19.65	26.33	25.40	25.90	24.91
ROU	0.93	1.59	24.31	30.30	29.10	29.71	28.47
RUS	1.21	2.02	26.95	31.96	30.38	31.13	29.97
SVK	0.79	1.54	18.50	24.54	23.56	24.07	22.91
SVN	0.63	1.01	17.55	23.91	23.13	23.55	22.63
SWE	0.44	1.19	17.99	24.76	24.21	24.51	23.61
TUR	1.09	1.54	23.98	29.53	28.14	28.84	27.73
TWN	0.48	0.87	17.29	24.30	23.71	24.03	23.01
USA	0.57	1.00	18.70	25.60	24.88	25.28	24.37
Average	0.73	1.28	19.40	25.41	24.50	24.98	23.97

Table 3: Steady-state changes (%) resulting from an unanticipated 25% trade cost reduction.

mentarity is the dominant force in shaping educational outcomes and inequality. Skill share changes in the same direction as skill premium, since the changes in the educational outcome in a steady state reflect movements along positively sloped relative skill supply curves.

Figure (7) illustrates the transitional paths of skill premium and relative skill supply in the U.S. The skill premium rises rapidly after trade liberalization, and peaks at $t = 6$. As shown in Figure (7), the skill premium increases by 1.25% at the peak. In the early stage of the transition, older generations are unable to adjust their educational status, resulting in a slow adjustment of human capital. Relative skill supply climbs slowly along the transitional path after trade liberalization. As demonstrated in Figure (7), this leads to an eventual 1.26% increase in relative skill supply. In the long run, the adjustment of human capital affects the skill premium; as more people become skilled workers, the skill premium falls and converges to the new steady state following the trade liberalization. In the new steady state, the skill premium rises by 0.57%, and human capital accumulation eliminates 54% of the increased skill premium from the peak in the U.S. The transitional paths of other countries are similar to that of the U.S.

In summary, trade liberalization raises the skill premium and educational attainment in all countries in the new steady state. On the transitional path, inequality resulting from trade liberalization is more severe in the early stage of the transition than in the long term. Moreover, inequality decreases as future generations gradually accumulate more human capital. The adjustment of education alleviates approximately half of the transitory inequality.

6.2 Channels Affecting the Transition Paths

Two main components are included in the model: physical capital accumulation and human capital accumulation. The interaction between these two components drives the transitional behavior of the economic outcomes in each country. By turning each component on and off, various channels can be isolated and studied.

First, I compute the baseline steady-state equilibrium using the calibrated parameters and store the steady-state level of capital supply and human capital supply. To deactivate capital accumulation under trade shocks, I force capital supply to be at the baseline steady-state level while computing the full transitional path.

Cases	Factor Supply		Active Channel		
	Skill	Capital	Comparative Advantage	Skill-Biased Technology	Education
(1) Short run	✗	✗	✓	✗	✗
(2) Medium run	✗	✓	✓	✓	✗
(3) Long run	✓	✓	✓	✓	✓

Table 4: Different scenarios and the corresponding active components and mechanisms.

Human capital accumulation is deactivated in a similar manner.

In the short term, all factors are unable to adjust promptly. Deactivating both capital and human capital accumulation illustrates the economic consequences in the short run. At this stage, the outcome is driven by the comparative advantage channel. The skill premium rises in countries with a comparative advantage in high-skilled sectors and falls in countries with a comparative advantage in low-skilled sectors. Since physical capital adjusts faster than human capital, activating only capital accumulation accentuates the economic impacts in the medium run. In the medium run, active channels include the comparative advantage effect and the skill-biased technology effect induced by capital accumulation. Lastly, in the long run, all factors can freely adjust, and all components are active; hence, the full model corresponds to the long-run case. The long-run case features all channels, including all channels mentioned above and educational effects. These different scenarios and the corresponding mechanisms are summarized in Table (4).

The exact transitional paths are calculated for all cases and all countries. Figure (8) shows the evolution of the Mexican skill premium following a 25% reduction in bilateral trade costs in each case. When all components are inactive (short-run case), the skill premium in Mexico drops immediately after the trade liberalization and reaches the steady state after one period. The decline in Mexican skill premium suggests that Mexico has a comparative advantage in low-skilled sectors.

When only capital accumulation is active (medium-run case), the immediate decline in skill premium is preserved, followed by drastic increases in skill premium in the early stage of transition. Then, the skill premium reaches the peak and plateaus.

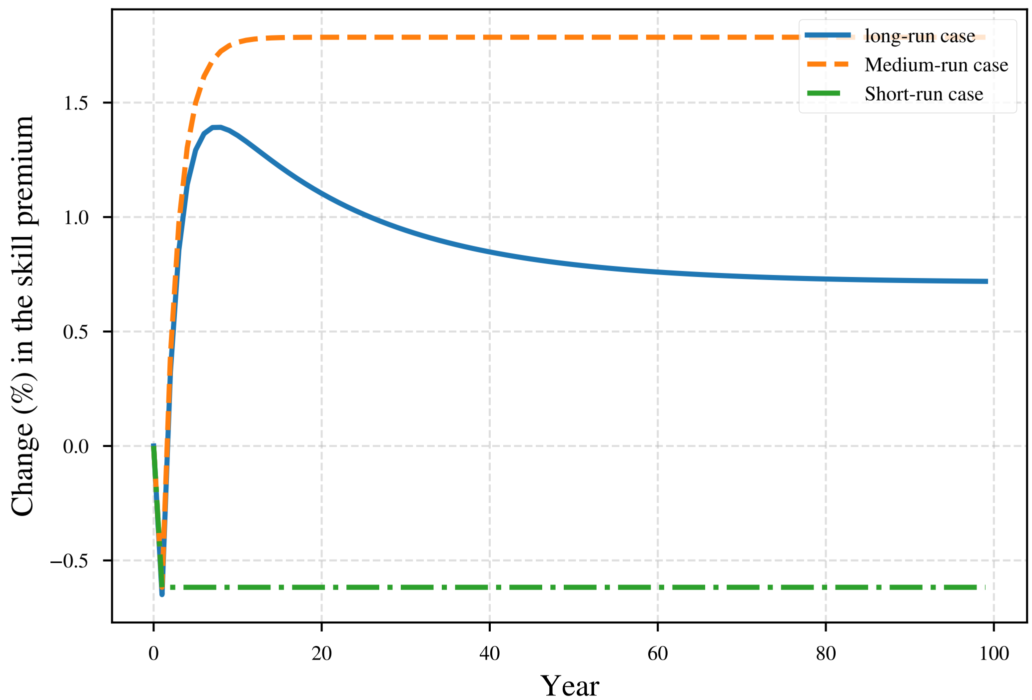

Figure 8: Transitional paths of the changes (%) in the Mexican skill premium for different cases resulting from an unanticipated 25% trade cost reduction.

This outcome reflects the fact that capital becomes cheaper after trade liberalization; hence, a household head invests more intensively in physical capital. The rapid accumulation of capital, along with the capital-skill complementarity, boosts the productivity and the demand of skilled workers. As a result, the skill premium rises rapidly. In this particular case, the absence of educational choice pushes the steady-state skill premium higher than the peak level on the transitional path of the full model.

As all components are active (long-run case), future generations can choose their educational status freely. Since younger generations know that the skill premium will become higher in the future, more people choose to pursue higher education. This adjustment in human capital counteracts the effect of capital accumulation on the skill premium. As a result, the skill premium falls gradually along the transitional path and converges to a level higher than that in the baseline equilibrium. Since the capital-skill complementarity is the dominant force in all countries, the transitional paths for the medium- and long-run cases across countries are similar.

The immediate reaction in each country is determined by whether the country has a comparative advantage in low-skilled or high-skilled sectors.

A similar pattern of the skill premium, as implied by the full model, has been observed in recent trade liberalization episodes. Mexico joined the General Agreement on Tariff and Trade (GATT) in 1986, and trade barriers in Mexico were substantially reduced. Atolia and Kurokawa (2016) show that although the skill premium in Mexico increased rapidly between 1986 to 1994, it subsequently declined in the long term. Bai et al. (2019) record a continuous rise in the Chinese skill premium after China's accession to the World Trade Organization (WTO) in 2002. The Chinese skill premium peaked in 2009 and has since exhibited a non-temporary declining trend. Kim and Topel (2007) document a similar pattern in Korea after the Korean government implemented a series of trade liberalization policies in the 1970s. The real-world transitional behavior of the skill premium resulting from globalization can be explained by the flexibility to adjust the factor supply. The faster adjustment of physical capital, together with the capital-skill complementarity, explain the dramatic increase in skill premium in the early stage of the transition. Young generations make their educational choice accordingly, but it takes a long time for future generations to populate the labor force fully. Hence, the human capital accumulation only starts to neutralize the impact of trade liberalization until later stages. This quantitative experiment suggests that physical capital and human capital accumulation are crucial elements in shaping the evolution of income inequality between educational categories.

6.3 Education and Trade-Induced Inequality

Table (13) records the percentage change in skill premium for all countries for short-, medium- and long-run cases in the steady states. When only the comparative advantage channel is active, the skill premium drops in 32 of 40 countries. The capital-skill complementarity dominates in all countries, resulting in an eventual increase in the skill premium for all countries. To investigate to what extent education eliminates inequality engendered by trade liberalization, I compare the percentage changes in the steady state for cases with and without the educational effect, which corresponds to the medium-run and long-run cases. The difference in skill premium between these two cases is the proportion of globalization-induced inequality elim-

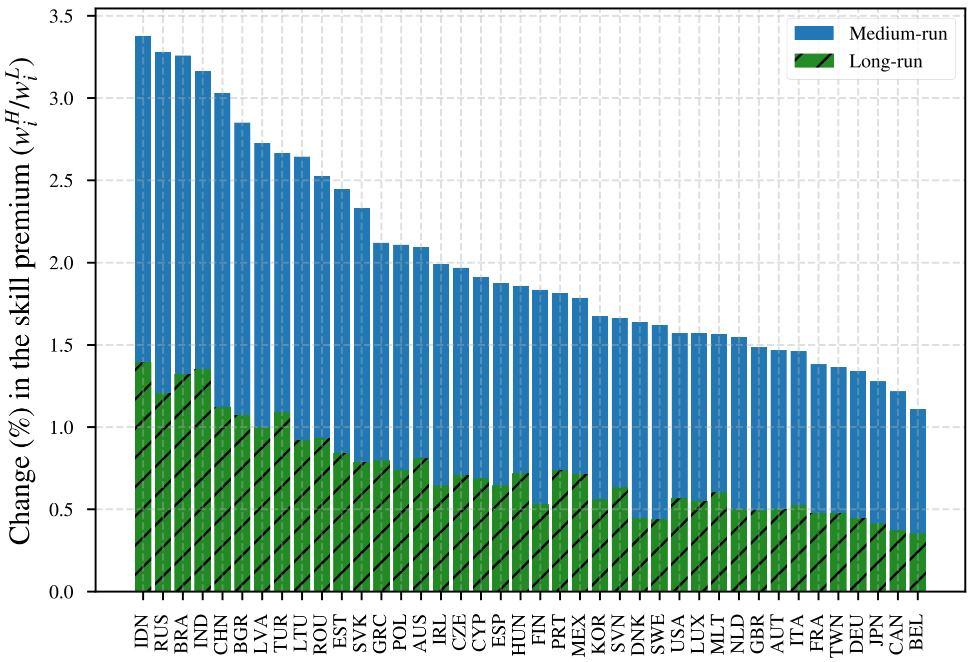

Figure 9: Changes(%) in the skill premium resulting from an unanticipated 25% trade cost reduction for both the long-run case and the medium-run case.

inated by education. The results are summarized in Figure (9) and Table (13). I find that education eliminates 57.37% to 72.96% of trade-induced inequality, with an average rate of 64.51%. This quantitative analysis suggests that education is a very effective instrument in combating trade-induced inequality.

6.4 Intergenerational Distribution of Gains from Trade

Table (3) shows the percentage change in terms of real wages for all educational categories and all countries relative to the baseline steady state. In all countries, both skilled and unskilled workers gain from trade liberalization. Average real wages rise as much as 34.41% in Indonesia, 33.51% in Brazil, and 32.01% in China and as little as 13.08% in Belgium, 13.26% in Canada, and 14.52% in Luxembourg. The average increase in real wages is 24.98%.

The dynamic structure of my framework allows me to further explore the distribution of gains from trade not only across educational categories but also across generations. Let $W^e_{i,t}$ be the lifetime earnings for the group born at time t in country

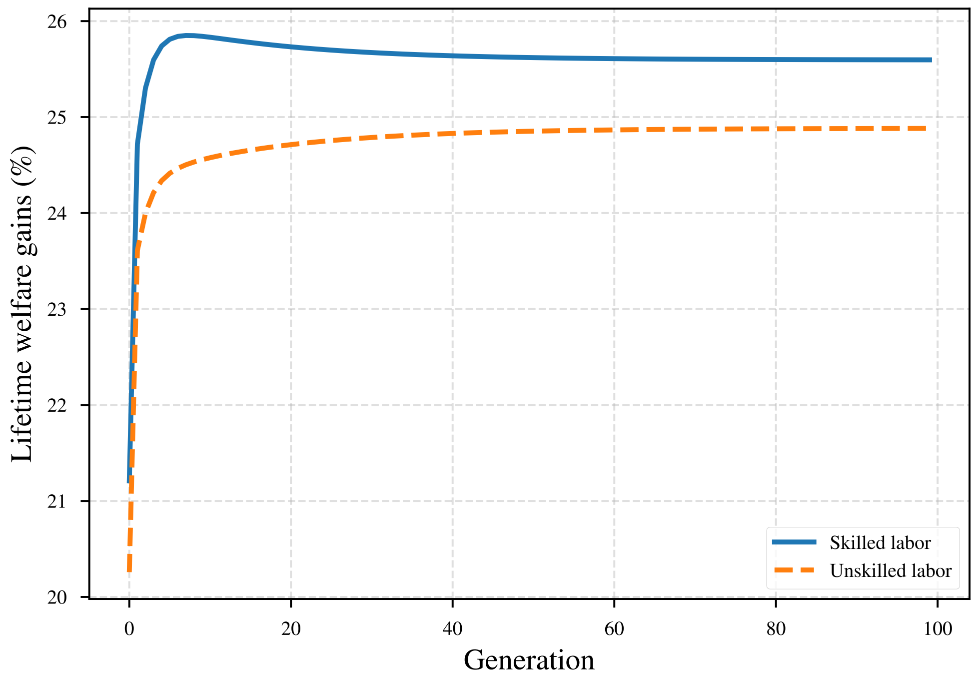

Figure 10: Changes in lifetime earnings (%) for each generation and each educational category in the U.S. resulting from trade liberalization.

i with educational category e, where $e \in \{skilled, unskilled\}$. $W^e_{i,t}$ follows

$$W^e_{i,t} = \sum_{s=0}^{\infty} \nu^s \left(\frac{w^e_{i,t+s}}{P_{i,t+s}} \right), \tag{35}$$

which is a measure of welfare for people who born at time t in country i with educational status e along the transitional path. I calculate the lifetime earnings for each group under the baseline equilibrium path and the transitional path under trade liberalization. The percentage difference in $W^e_{i,t}$ relative to the baseline equilibrium captures the welfare gains for each generation and each group.[6]

Figure (10) depicts the percentage change in the lifetime earnings relative to the baseline for each generation and educational category in the U.S. For any generations, skilled workers gain more from trade than do unskilled workers because capital-skill complementarity is the dominant force: trade liberalization favors skilled workers over unskilled workers. By comparing the distribution of gains from trade

[6] Ravikumar et al. (2019) use consumption-equivalent units to define the dynamic gains from trade.

among skilled workers, following Figure (10), we can observe that older skilled workers benefit relatively more from globalization because they enjoy a path of skill premium that is higher than the new steady state and can reap the benefit from the drastic transitory inequality. Future generations of skilled workers still gain substantially from trade liberalization but not as much as their older counterparts. The reason is that as the economy progresses, it also becomes more stable; hence, there is less room for future skilled workers to exploit.

The distribution of gains from trade among unskilled workers shows that the oldest group gains the least. Subsequent generations of unskilled workers gain relatively more but never attain the same gains as their skilled counterparts. Old and unskilled workers gain the least from international trade; they are the losers of globalization because they suffer from two hits. The first is that globalization tends to favor skilled workers; hence, unskilled workers generally gain less from trade. The second reason is that, for old and unskilled workers, in the early stage of their life, they face the widest income gap between skilled and unskilled workers; hence, they suffer even more from the transitory inequality. Other countries show similar patterns in the distribution of welfare to that of the U.S.

In summary, trade liberalization favors older and more educated generations the most, and subsequent generations do not gain as much. The group that gains the least is the oldest and uneducated generation. These results show that the distribution of gains from trade is not only unequal across educational categories but also unequal across generations, which suggests that globalization is a potential cause of rising intergenerational inequality. The results from my analysis echo the sentiments of recent antiglobalization movements, for example, Occupy Wall Street in the U.S., the Five Stars Movement in Italy, and the Yellow Vests Movement in France. The results also provide new perspectives to consider the potential consequences of globalization so that we can think about policies to remedy these consequences.

7 Conclusion

This paper construct a dynamic multicountry trade model incorporating both human capital accumulation and physical capital accumulation to study the dynamics of trade-induced inequality. Via a quantitative exercise, the transitional dynamics of trade-induced inequality are shown to be closely related to adjustments in factor supply. Upon an unanticipated trade liberalization, both capital and skill supply do not respond to the shock immediately. In the short run, comparative advantage is the main driving force that shifts relative demand to skilled labor, resulting in changes in the skill premium. Adjustment of physical capital is more flexible than education; the drastic increase in the skill premium in the early stage of the transition reflects the rapid capital accumulation and the capital-skill complementarity. In the long run, future generations make educational decisions based on prospects of the economy, and they gradually succeed older generations in the existing population. The slow adjustment in the skill supply shapes the eventual outcome of trade-induced inequality. This quantitative result is consistent with observations from recent trade liberalization episodes in Mexico, Korea, and China.

The analysis of the dynamics also indicates that education is an effective means for combating inequality associated with globalization. The adjustment in human capital reduces transitory inequality by 65%. Furthermore, the educational institution is a source of comparative advantage. A country with a more robust educational institution is more likely to specialize in skill-intensive sectors.

This framework has implications for the intergenerational distribution of gains from trade. Older educated generations benefit the most from globalization, as they can take full advantage of the transitory inequality to accumulate more wealth in the early stage of the transition. Old uneducated groups are the relative losers from globalization. Recently, there has been considerable discussion in policy and press circles about rising intergenerational inequality. This paper offers a theoretical foundation to view this issue — it suggests that globalization is a potential source of the rising intergenerational inequality.

This tractable framework can be used to address broader questions about both trade and educational policies. Many developing countries have implemented policies aiming to promote higher educational attainment and increased exports at the same time. The model indicates that improving the quality of educational institutions in countries with a comparative advantage in low-skilled sectors may reduce total exports, which could result in trade-offs between education and exports. This framework offers a tool for policymakers to carefully design and examine possible interactions among trade and educational policies and, in turn, make more informed decisions.

In future research, this framework can be extended and applied to different economic issues. By applying the model to province- or state-level data, researchers would be able to compare educational institutions across locations within a country and study the implications on migration and trade. This type of comparison is vital for the educational administration for allocating limited resources across locations efficiently. Retraining programs such as Trade Adjustment Assistance (TAA) in the U.S. provide opportunities for workers who are impacted by trade to retrain and gain additional work-related skills. Introducing a retraining program into this model can help in analyzing economic benefits and costs of such programs and also the relevant effects on trade patterns and transitory costs of inequality.

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A Tables

ISO Code	Country Name	ISO Code	Country Name
AUS	Australia	JPN	Japan
AUT	Austria	KOR	Republic of Korea
BEL	Belgium	LVA	Latvia
BRA	Brazil	LTU	Lithuania
BGR	Bulgaria	LUX	Luxembourg
CAN	Canada	MLT	Malta
CHN	China	MEX	Mexico
CYP	Cyprus	NLD	Netherlands
CZE	Czech Republic	POL	Poland
DNK	Denmark	PRT	Portugal
EST	Estonia	ROU	Romania
FIN	Finland	RUS	Russia
FRA	France	SVK	Slovak Republic
DEU	Germany	SVN	Slovenia
GRC	Greece	ESP	Spain
HUN	Hungary	SWE	Sweden
IND	India	TWN	Taiwan
IDN	Indonesia	TUR	Turkey
IRL	Ireland	GBR	United Kingdom
ITA	Italy	USA	United States

Table 5: List of countries

Industry code	Description
AtB	Agriculture, Hunting, Forestry and Fishing
C	Mining and Quarrying
15t16	Food, Beverages and Tobacco
17t18	Textiles and Textile Products
19	Leather, Leather and Footwear
20	Wood and Products of Wood and Cork
21t22	Pulp, Paper, Paper, Printing and Publishing
23	Coke, Refined Petroleum and Nuclear Fuel
24	Chemicals and Chemical Products
25	Rubber and Plastics
26	Other Non-Metallic Mineral
27t28	Basic Metals and Fabricated Metal
29	Machinery, Nec
30t33	Electrical and Optical Equipment
34t35	Transport equipment
36t37	Manufacturing, Nec; Recycling
E	Electricity, Gas and Water Supply
F	Construction
50	Sale, Maintenance and Repair of Motor Vehicles, Retail Sale of Fuel
51	Wholesale Trade and Commission Trade, Except of Motor Vehicles
52	Retail Trade, Except of Motor Vehicles; Repair of Household Goods
H	Hotels and Restaurants
60	Inland Transport
61	Water Transport
62	Air Transport
63	Other Supporting and Auxiliary Transport Activities;
	Activities of Travel Agencies
64	Post and Telecommunications
J	Financial Intermediation
70	Real Estate Activities
71t74	Renting of M& Eq and Other Business Activities
L	Public Admin and Defence; Compulsory Social Security
M	Education
N	Health and Social Work

Table 6: Sector codes in the World Input-Output Database

Category	Industry Description
Agriculture, food and mining	AtB, 15t16, C
Machinery	29, 36t37, 34t35
High-skilled manufacturing	24, 30t33
Low-skilled manufacturing	21t22, 23, 25, 17t18, 19, 20, 26, 27t28
Low-skilled services	50, 51, 52, 60, 61, 62, 63, 64, H, F
Professional services	J, 70, 71t74, L, M, N

Table 7: Industry aggregation

Sector	Share on L^L (α^j)	Share on L^H relative to K (δ^j)
Agriculture, food and mining	0.32	0.19
High-skilled manufacturing	0.32	0.49
Low-skilled manufacturing	0.43	0.33
Low-skilled service	0.51	0.34
Machinery	0.47	0.39
Professional Service	0.27	0.44

Table 8: Factor shares for each sector

Note: The U.S. data in 2001 are used as the baseline.

	PISA score in math (2003)		PISA score in reading (2003)	
	Correlation Coef.	Rank Corr.	Correlation Coef.	Rank Corr.
Calibrated γ_i	0.74	0.79	0.75	0.80

Table 9: Correlations between calibrated educational institution and PISA scores

Note: The correlation coef. is the Pearson correlation coefficient, and the rank corr. is Spearman's rank correlation coefficient.

Industry	Agriculture, Food and Mining	High-skilled Manufacturing	Low-skilled Manufacturing	Low-skilled Service	Machinery	Professional Service
	(1)	(2)	(3)	(4)	(5)	(6)
Distance (logarithm)	-0.737*	-0.511*	-0.654*	-0.79*	-0.553*	-0.772*
	(-24.32)	(-16.73)	(-20.79)	(-23.27)	(-18.28)	(-22.06)
Contiguity	0.786*	0.817*	1.004*	-0.097	0.721*	-0.556*
	(3.68)	(3.78)	(4.5)	(-0.41)	(3.34)	(-2.14)
Common language	0.778*	0.585*	0.83*	0.924*	0.736*	1.278*
	(3.19)	(2.44)	(3.31)	(3.41)	(3.03)	(4.42)
Common colonizer	0.674*	0.453	0.521	0.513	0.476	-0.186
	(2.58)	(1.72)	(1.91)	(1.76)	(1.81)	(-0.59)
Origin fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Destination fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1296	1364	1392	1156	1327	1039
R^2	0.51	0.5	0.46	0.45	0.53	0.46

Table 10: Gravity model estimates (ordinary least squares)

The dependent variable is the logarithm of a destination country's import from an origin country.

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Country	Skill Premium (w_i^H/w_i^L)	Relative Skill Supply (L_i^H/L_i^L)	Labor Force (millions)	Educational Institution (γ_i)
AUS	2.26	0.17	9.13	0.72
AUT	1.75	0.19	3.96	1.12
BEL	1.59	0.20	4.16	1.37
BGR	2.30	0.08	3.22	0.63
BRA	3.22	0.14	79.54	0.38
CAN	1.53	0.26	15.20	1.43
CHN	2.27	0.04	730.25	0.60
CYP	1.89	0.40	0.32	0.96
CZE	1.97	0.14	4.96	0.85
DEU	1.71	0.31	39.32	1.14
DNK	1.34	0.37	2.74	2.00
ESP	1.77	0.39	16.93	1.06
EST	1.81	0.46	0.58	0.98
FIN	1.41	0.47	2.32	1.73
FRA	1.80	0.35	24.76	1.06
GBR	1.65	0.42	29.92	1.28
GRC	2.18	0.22	4.26	0.73
HUN	2.35	0.19	4.23	0.66
IDN	3.74	0.06	93.44	0.30
IND	4.67	0.06	432.38	0.23
IRL	1.54	0.33	1.75	1.57
ITA	1.97	0.13	23.39	0.86
JPN	1.63	0.31	64.76	1.23
KOR	1.69	0.72	21.56	1.13
LTU	1.87	0.35	1.35	0.91
LUX	1.73	0.26	0.28	1.26
LVA	2.07	0.28	0.95	0.76
MEX	2.93	0.14	40.10	0.45
MLT	2.29	0.11	0.15	0.72
NLD	1.59	0.29	8.28	1.38
POL	1.86	0.16	14.20	0.94
PRT	2.96	0.08	5.12	0.47
ROU	2.15	0.05	10.66	0.70
RUS	2.35	0.14	74.73	0.56
SVK	1.74	0.16	2.04	1.05
SVN	2.27	0.18	0.91	0.71
SWE	1.34	0.33	4.39	1.98
TUR	3.38	0.10	21.52	0.37
TWN	1.86	0.32	9.38	0.98
USA	1.93	0.43	146.82	0.94
Average	2.11	0.25	48.85	0.95

Table 11: Country characteristics calculated using the year 2001 data

Note: See Appendix (B) for the details of the calculation.

	Skill	Skill	Real Wages Relative to real wage of USA		
	Premium	Share	Skilled	Unskilled	Avg
Country	w_i^H/w_i^L	L_i^H/L_i^L	w_i^H/P_i	w_i^L/P_i	w_i/P_i
AUS	2.26	0.54	133.03	58.84	72.65
AUT	1.75	0.70	229.80	131.46	155.76
BEL	1.59	0.79	359.35	226.00	263.38
BGR	2.30	0.44	27.66	12.03	14.47
BRA	3.22	0.30	22.29	6.92	8.52
CAN	1.53	0.78	244.53	159.95	183.55
CHN	2.27	0.40	6.56	2.89	3.41
CYP	1.89	0.64	220.57	116.74	140.02
CZE	1.97	0.56	69.81	35.36	42.22
DEU	1.71	0.69	174.29	102.21	119.89
DNK	1.34	0.93	195.81	145.72	162.59
ESP	1.77	0.66	114.46	64.80	76.49
EST	1.81	0.61	63.92	35.33	41.57
FIN	1.41	0.86	185.66	131.66	148.40
FRA	1.80	0.68	186.15	103.43	123.21
GBR	1.65	0.77	179.16	108.54	127.66
GRC	2.18	0.52	102.19	46.95	56.95
HUN	2.35	0.50	72.55	30.87	38.02
IDN	3.74	0.25	10.38	2.78	3.42
IND	4.67	0.20	8.99	1.92	2.40
IRL	1.54	0.91	269.57	175.20	204.76
ITA	1.97	0.58	166.41	84.26	101.04
JPN	1.63	0.71	141.71	86.78	100.74
KOR	1.69	0.67	86.26	50.90	59.41
LTU	1.87	0.57	48.72	26.12	30.75
LUX	1.73	0.83	562.73	326.02	392.65
LVA	2.07	0.51	51.36	24.76	29.56
MEX	2.93	0.36	52.56	17.96	22.20
MLT	2.29	0.55	226.66	99.00	123.01
NLD	1.59	0.80	212.55	134.04	156.10
POL	1.86	0.60	67.28	36.15	42.80
PRT	2.96	0.39	141.74	47.82	60.28
ROU	2.15	0.47	25.60	11.89	14.19
RUS	2.35	0.38	17.56	7.49	8.85
SVK	1.74	0.63	57.19	32.95	38.46
SVN	2.27	0.53	153.04	67.49	83.06
SWE	1.34	0.91	159.92	119.69	133.04
TUR	3.38	0.30	39.18	11.58	14.41
TWN	1.86	0.64	123.49	66.43	79.26
USA	1.93	0.64	159.69	82.79	100.00
Average	2.11	0.59	134.26	75.84	89.48

Table 12: The baseline equilibrium in the steady state

Note: All real wages are relative to the U.S. average real wage; hence, the U.S. average real wage is normalized to 100.

	Changes in Skill Premium (%)			
	(1)	(2)	(3)	(4)
Country	Short-run	Medium-run	Long-run	$\lvert\frac{(2)-(3)}{(2)}\rvert \times 100$
AUS	-0.15	2.09	0.81	61.44
AUT	0.15	1.47	0.50	65.79
BEL	0.25	1.11	0.35	68.24
BGR	-0.11	2.85	1.07	62.36
BRA	-0.27	3.26	1.32	59.36
CAN	0.14	1.22	0.37	69.50
CHN	-0.51	3.03	1.12	63.01
CYP	0.01	1.91	0.69	64.12
CZE	-0.10	1.97	0.71	64.02
DEU	-0.12	1.34	0.45	66.73
DNK	-0.18	1.64	0.45	72.74
ESP	-0.14	1.87	0.64	65.66
EST	-0.11	2.45	0.84	65.59
FIN	0.44	1.83	0.53	71.07
FRA	-0.17	1.38	0.48	65.49
GBR	-0.04	1.49	0.49	66.83
GRC	-0.11	2.12	0.80	62.37
HUN	-0.26	1.86	0.72	61.49
IDN	-0.32	3.38	1.40	58.63
IND	-0.28	3.16	1.35	57.37
IRL	0.85	1.99	0.64	67.68
ITA	-0.21	1.47	0.53	64.11
JPN	-0.20	1.28	0.41	67.72
KOR	-0.13	1.68	0.56	66.62
LTU	-0.07	2.64	0.92	65.21
LUX	0.79	1.57	0.55	65.00
LVA	-0.04	2.73	1.00	63.38
MEX	-0.62	1.79	0.71	60.06
MLT	-0.16	1.57	0.60	61.53
NLD	0.03	1.55	0.50	67.84
POL	-0.13	2.11	0.74	65.00
PRT	-0.09	1.81	0.74	59.23
ROU	-0.36	2.53	0.93	63.02
RUS	-0.56	3.28	1.21	63.14
SVK	0.15	2.33	0.79	66.21
SVN	-0.02	1.66	0.63	61.89
SWE	0.05	1.62	0.44	72.96
TUR	-0.27	2.66	1.09	59.19
TWN	-0.27	1.37	0.48	65.17
USA	-0.02	1.57	0.57	63.81
Average	-0.08	2.02	0.73	64.51

Table 13: Decomposition of changes in the skill premium(%) resulting from an unanticipated 25% trade cost reduction

B Data

The skill share and the skill premium in each country are calculated using the Social Economic Account (SEA) from the World Input-Output Database (WIOD).

The Skill Share

SEA records the share of total hours worked by high-skilled, medium-skilled and low-skilled workers over 15 years old (H_HS, H_MS, and H_LS in the database, respectively) to calculate skill share, which is given by

$$\text{Skill Share}_i^{data} = \frac{H\_HS_i}{H\_MS_i + H\_LS_i}$$

The Skill Premium

I combine additional data on the share of total labor compensation to high-skilled, medium-skilled and low-skilled workers over 15 years old ($LABHS$, $LABMS$ and $LABLS$ in the database, respectively) to compute skill premium, which is given by

$$\text{Skill Premium}_i^{data} = \frac{LABHS_i / H\_HS_i}{(LABMS_i + LABLS_i)/(H\_MS_i + H\_LS_i)}$$

Labor Force

I use the number of persons engaged (EMP in the database) as the total labor force in each country.

Nominal Wages

SEA records total labor compensation (LAB in the database) for each country. The nominal wage for each country is calculated by LAB/EMP (in the national currency). I use the average exchange rate in the year 2001[7] to convert nominal income to US dollars.

Wages for skilled and unskilled workers are computed by combining information on nominal wage, the skill premium and the skill share in each country, which

[7]Source: https://openexchangerates.org

are given by

$$w_i^{L,data} = \left[\frac{\text{skill premium}_i^{data}}{1 + (\text{relative skill supply}_i^{data})^{-1}} + (1 + \text{relative skill supply}_i^{data})^{-1}\right]^{-1} \times w_i^{data}$$
$$w_i^{H,data} = w_i^{L,data} \times \text{skill premium}_i^{data}.$$

C Solution Algorithms

In this section, I describe the algorithm for computing both the steady state and the transitional path. The technique used to solve the model is built upon Alvarez and Lucas (2007). The goal is to find a sequence of factor prices such that the resulting educational choice is optimal, the Euler equations are satisfied and the factor markets are cleared.

C.1 Computing the Steady State

Let $x(\tau)$ be the τ^{th} round of iteration of variable x. First, start with initial guess of steady state wages such that $w_i^H(0) > w_i^L(0)$ for all i and an initial guess of capital rent $r_i(0) > 0$ and capital stock $K_i(0) > 0$. Then, follow the below procedure:

1. **Update Skill Supply**

   Use $w_i^H(\tau)$ and $w_i^L(\tau)$ to find the ability threshold[8]:

   $$\bar{a}_i(\tau) = \left[1 - \left(\frac{w_i^L(\tau)}{w_i^H(\tau)}\right)\right]^{-1/\gamma_i}, \quad \forall i$$

   Use $\bar{a}_i(\tau)$ to obtain skilled and unskilled labor supply[9]

   $$L_i^H(\tau) = \frac{\mu(\bar{a}_i(\tau), \gamma_i)}{\zeta} \times L_i, \quad \forall i$$
   $$L_i^L(\tau) = \frac{G(\bar{a}_i(\tau)}{\zeta} \times L_i, \quad \forall i.$$

2. **Update Trade Share and the Price Indices**

[8]The ability threshold in the steady state is derived by dropping all time subscripts t in equation (2).

[9]$\mu(\bar{a}, \gamma) = \int_{\bar{a}}^{\infty} [1 - 1/x^{\gamma}] dG(x)$ is used to simplify the notation.

Scale factor prices such that:

$$\sum_{i=1}^{N}\left[w_i^H(\tau)L_i^H(\tau)+w_i^L(\tau)L_i^L(\tau)+r_i(\tau)K_i(\tau)\right]=1$$

Compute the unit cost for each i and each j:

$$p_i^{j,M}(\tau)=\left[\delta_i^j(w_i^H(\tau))^{1-\rho}+(1-\delta_i^j)(r_i(\tau))^{1-\rho}\right]^{\frac{1}{1-\rho}}$$
$$c_i^j(\tau)=[w_i^L(\tau)]^{\alpha_i^j}[p_i^{M,j}(\tau)]^{1-\alpha_i^j}$$

Compute the bilateral trade share:

$$\begin{aligned}\pi_{i,n}^j(\tau)=&\frac{T_i^j[d_{n,i}^j c_i^j(\tau)]^{-\theta}}{\sum_{k=1}^N T_k^j[d_{n,k}^j c_k^j(\tau)]^{-\theta}}\\ =&\frac{T_i^j[d_{n,i}^j c_i^j(\tau)]^{-\theta}}{\Phi_n^j(\tau)}\end{aligned}$$

Compute the sectoral price indices:

$$p_n^j(\tau)=C[\Phi_n^j(\tau)]^{-\frac{1}{\theta}}$$

where $C=\Gamma\left(\frac{\theta+1-\eta}{\theta}\right)^{\frac{1}{1-\eta}}$.

Compute CPI:

$$P_n(\tau)=\left[\sum_{j=1}^{J}\left(p_n^j(\tau)\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

3. **Update Capital Supply**

In the steady state, nominal rent satisfies:

$$r_i=P_i\times[\nu^{-1}-(1-\delta)]$$

Denote the total nominal income by

$$W_n(\tau)=w_n^H(\tau)L_n^H(\tau)+w_n^L(\tau)L_n^L(\tau)+r_n(\tau)K_n(\tau)$$

Compute the total expenditure on sector j for each country:

$$X_n^j(\tau)=\left(\frac{p_n^j(\tau)}{P_n(\tau)}\right)^{1-\sigma}\times W_n(\tau).$$

Utilize this result to compute the average expenditure share on capital for each country:

$$\text{average capital share}'_i(\tau) = \frac{\sum_{j=1}^{J} \left[(1-\alpha_i^j)(1-\delta_i^j) \left(\frac{r_i(\tau)}{p_i^{j,M}(\tau)} \right)^{1-\rho} \sum_{n=1}^{N} \pi_{i,n}^j(\tau) X_n^j(\tau) \right]}{\sum_{j=1}^{J} \sum_{n=1}^{N} \pi_{i,n}^j(\tau) X_n^j(\tau)}$$

Use the average capital share and the condition for the nominal capital rent in the steady state to update capital stock:

$$K_i(\tau+1) = \frac{1}{\nu^{-1} - (1-\delta)} \times \frac{\text{average capital share}_i(\tau) \times W_i(\tau)}{P_i(\tau)}$$

4. **Compute Excess Demand for Factors**

   Scale factor prices again such that

$$\sum_{i=1}^{N} \left[w_i^H(\tau) L_i^H(\tau) + w_i^L(\tau) L_i^L(\tau) + r'_i(\tau) K_i(\tau+1) \right] = 1$$

   Compute total expenditure on sector j for each country:

$$X_n^j(\tau) = \left(\frac{p_n^j(\tau)}{P_n(\tau)} \right)^{1-\sigma} \times [w_i^H(\tau) L_i^H(\tau) + w_i^L(\tau) L_i^L(\tau) + r'_i(\tau) K_i(\tau+1)].$$

   Then, compute the excess demand function:

$$Z_i^L(\tau) = \frac{1}{w_i^L(\tau)} \left\{ \sum_{j=1}^{J} \left[\alpha_i^j \sum_{n=1}^{N} \pi_{i,n}^j(\tau) X_n^j(\tau) \right] - w_i^L(\tau) L_i^L(\tau) \right\}$$

$$Z_i^H(\tau) = \frac{1}{w_i^H(\tau)} \left\{ \sum_{j=1}^{J} \left[(1-\alpha_i^j)\delta_i^j \left(\frac{w_i^H(\tau)}{P_i^{M,j}(\tau)} \right)^{1-\rho} \sum_{n=1}^{N} \pi_{i,n}^j(\tau) X_n^j(\tau) \right] - w_i^H(\tau) L_i^H(\tau) \right\}$$

$$Z_i^K(\tau) = \frac{1}{r'_i(\tau)} \left\{ \sum_{j=1}^{J} \left[(1-\alpha_i^j)(1-\delta_i^j) \left(\frac{r'_i(\tau)}{P_i^{M,j}(\tau)} \right)^{1-\rho} \sum_{n=1}^{N} \pi_{i,n}^j(\tau) X_n^j(\tau) \right] - r'_i(\tau) K_i(\tau+1) \right\}$$

5. **Update Factor Prices**

   Update factor prices by:

$$w_i^H(\tau+1) = w_i^H(\tau) \Big[1 + \psi \frac{Z_i^H(\tau)}{L_i^H(\tau)} \Big], \quad \forall i$$

$$w_i^L(\tau+1) = w_i^L(\tau) \Big[1 + \psi \frac{Z_i^L(\tau)}{L_i^L(\tau)} \Big], \quad \forall i,$$

$$r_i(\tau+1) = r_i(\tau) \Big[1 + \psi \frac{Z_i^K(\tau)}{K_i(\tau+1)} \Big], \quad \forall i,$$

   where $\psi \in (0, 1]$.

6. **Check Convergence** Stop iteration if:
$$\max_i \left\{ \max \left\{ ||Z_i^H(\tau)||, ||Z_i^L(\tau)||, ||Z_i^K(\tau)|| \right\} \right\} < \text{tolerence}$$
Return to step 1 otherwise.

C.2 Computing the Transitional Path

Consider the transitional path from $t = 0, 1, \ldots, T + T^*$. The path is split into three phases: (1) $t = 0$, the economy is at the initial state; (2) the shock occurs place at $t = 1$, and let $t = 1, 2, \ldots, T$ be the transitional phase; (3) $t = T + 1, \ldots, T + T^*$, is the terminal phase, such that economy reaches a new steady state.

Equilibrium is a path of $\{w_{i,t}^H, w_{i,t}^L, r_{i,t}, L_{i,t}^H, L_{i,t}^L, K_{i,t}\}$ such that all equilibrium conditions are satisfied. Let x^{New} be the steady state of the variable x under the new economic environment. To solve the full transitional path, start with an initial guess of path on $\{w_{i,t}^H(0), w_{i,t}^L(0), r_{i,t}(0), L_{i,t}^H(0), L_{i,t}^L(0), K_{i,t}(0)\}_{t=1}^T$ such that:

$t = 0$: paths are set to the initial condition.

$t = 1, \ldots, T$: arbitrarily guess the factor supply and factor prices such that $w_{i,t}^H(0) > w_{i,t}^L(0)$.

$t = T, \ldots, T + T^*$: paths are set to the new steady state x^{New}.

Furthermore, assume the economy reaches a new steady state for any $t > T + T^*$.

Given the initial state, terminal state, and initial guess of prices, the procedure to solve the transitional path is as follows:

1. **Update Labor Supply**

   Use the current guess of factor prices to solve ability thresholds $\bar{a}_{i,t}(\tau)$ for $t = 1, \ldots, T + T^*$:
$$\begin{aligned}
\bar{a}_{i,t}(\tau) &= \left[1 - \left(\frac{\prod_{s=1}^{\infty} (w_{i,t+s}^L(\tau))^{\nu^s}}{\prod_{s=1}^{\infty} (w_{i,t+s}^H(\tau))^{\nu^s}} \right)^{\frac{1}{\sum_{s=0}^{\infty} \nu^s}} \right]^{-1/\gamma_i} \\
&= \left\{ 1 - \left[\prod_{s=0}^{T+T^*-t} \left(\frac{w_{i,t+s}^L(\tau)}{w_{i,t+s}^H(\tau)} \right)^{\nu^s} \prod_{s=T+T^*-t+1}^{\infty} \left(\frac{w_i^{L,New}}{w_i^{H,New}} \right)^{\nu^s} \right]^{1-\nu} \right\}^{-1/\gamma_i} \\
&= \left\{ 1 - \left[\prod_{s=0}^{T+T^*-t} \left(\frac{w_{i,t+s}^L(\tau)}{w_{i,t+s}^H(\tau)} \right)^{\beta^s} \left(\frac{w_i^{L,New}}{w_i^{H,New}} \right)^{\frac{\nu^{T+T^*-1+1}}{1-\nu}} \right]^{1-\nu} \right\}^{-1/\gamma_i}
\end{aligned}$$

Compute the skill supply sequentially for $t = 1, \ldots, T + T^*$:

$$\begin{aligned} L^H_{i,t}(\tau+1) =& (1-\zeta)L^H_{i,t-1}(\tau+1) + \nu(\bar{a}_{i,t}(\tau), \gamma_i)L_i \\ L^L_{i,t}(\tau+1) =& (1-\zeta)L^L_{i,t-1}(\tau+1) + G(\bar{a}_{i,t}(\tau))L_i \end{aligned}$$

2. **Update Trade Share and the Price Indices**

   Scale factor prices such that:

$$\sum_{i=1}^{N} \Big[w^H_{i,t}(\tau)L^H_{i,t}(\tau+1) + w^L_{i,t}(\tau)L^L_{i,t}(\tau+1) + r_{i,t}(\tau)K_{i,t}(\tau) \Big] = 1, \quad \forall t$$

   Compute the unit cost for all i, j, t:

$$\begin{aligned} p^{j,M}_{i,t}(\tau) &= \left[\delta^j_i (w^H_{i,t}(\tau))^{1-\rho} + (1-\delta^j_i)(r_{i,t}(\tau))^{1-\rho}\right]^{\frac{1}{1-\rho}} \\ c^j_{i,t}(\tau) &= [w^L_{i,t}(\tau)]^{\alpha^j_i}[p^{M,j}_{i,t}(\tau)]^{1-\alpha^j_i} \end{aligned}$$

   Compute the bilateral trade share:

$$\begin{aligned} \pi^j_{i,n,t}(\tau) =& \frac{T^j_{i,t}[d^j_{n,i,t}c^j_{i,t}(\tau)]^{-\theta}}{\sum_{k=1}^{N} T^j_{k,t}[d^j_{n,k,t}c^j_{k,t}(\tau)]^{-\theta}} \\ =& \frac{T^j_{i,t}[d^j_{n,i,t}c^j_{i,t}(\tau)]^{-\theta}}{\Phi^j_{n,t}(\tau)} \end{aligned}$$

   Compute the sectoral price indices:

$$p^j_{n,t}(\tau) = C[\Phi^j_{n,t}(\tau)]^{-\frac{1}{\theta}}$$

   where $C = \Gamma\left(\frac{\theta+1-\eta}{\theta}\right)^{\frac{1}{1-\eta}}$.

   Compute CPI:

$$P_{n,t}(\tau) = \Big[\sum_{j=1}^{J} \left(p^j_{n,t}(\tau)\right)^{1-\sigma}\Big]^{\frac{1}{1-\sigma}}$$

3. **Update Capital Supply**

   Compute real investment for all i, t using the current guess on the capital path

$$I_{i,t}(\tau) = K_{i,t+1}(\tau) - (1-\delta)K_{i,t}(\tau)$$

Use the result to construct the path of real consumption for a representative household

$$C_{i,t}(\tau) = \frac{w^H_{i,t}(\tau)L^H_{i,t}(\tau+1) + w^L_{i,t}(\tau)L^L_{i,t}(\tau+1) + r_{i,t}(\tau)K_{i,t}(\tau)}{P_{i,t}(\tau)} - I_{i,t}(\tau)$$

The shadow price of real consumption for a representative household is

$$\lambda_{i,t}(\tau) = \frac{1}{C^{i,t}(\tau)}$$

Compute average skill share$_{i,t}(\tau)$ similarly as in computing the steady state. Let $W_{i,t}(\tau) = w^H_{i,t}(\tau)L^H_{i,t}(\tau+1) + w^L_{i,t}(\tau)L^L_{i,t}(\tau+1) + r_{i,t}(\tau)K_{i,t}(\tau)$. Equation (22) can be rewritten as

$$-\lambda_{i,t-1}(\tau) + \nu\lambda_{i,t}(\tau)\Big[\frac{\text{average skill share}_{i,t}(\tau)W_{i,t}(\tau)/K_{i,t}(\tau+1)}{P_{i,t}(\tau)} + (1-\delta)\Big] = 0$$

Rearrange this equation. Update capital supply by:

$$K_{i,t}(\tau+1) = \left[\frac{\text{average skill share}_{i,t}(\tau)W_{i,t}(\tau)}{P_{i,t}(\tau)}\right]\left[\frac{\lambda_{i,t-1}(\tau)}{\nu\lambda_{i,t}(\tau)} - (1-\delta)\right]^{-1}, \quad t = 2, \ldots, T+T^*$$

4. **Compute Excess Demand for Factors**

Scale factor prices again such that:

$$\sum_{i=1}^{N}\Big[w^H_{i,t}(\tau)L^H_{i,t}(\tau+1) + w^L_{i,t}(\tau)L^L_{i,t}(\tau+1) + r_{i,t}(\tau)K_{i,t}(\tau+1)\Big] = 1, \quad \forall t$$

Then, compute sectoral total expenditure:

$$X^j_{n,t}(\tau) = \Big[\Big(\frac{p^j_{n,t}(\tau)}{P_{n,t}(\tau)}\Big)^{1-\sigma} \times \big(w^H_{i,t}(\tau)L^H_{i,t}(\tau+1) + w^L_{i,t}(\tau)L^L_{i,t}(\tau+1) + r_{i,t}(\tau)K_{i,t}(\tau+1)\big)\Big]$$

Then, compute the excess demand function:

$$Z^L_{i,t}(\tau) = \frac{1}{w^L_{i,t}(\tau)}\sum_{j=1}^{J}\left[\alpha^j_{i,t}\sum_{n=1}^{N}\pi^j_{i,n,t}(\tau)X^j_{n,t}(\tau) - w^L_{i,t}(\tau)L^L_{i,t}(\tau)\right]$$

$$Z^H_{i,t}(\tau) = \frac{1}{w^H_{i,t}(\tau)}\sum_{j=1}^{J}\left[(1-\alpha^j_i)\delta^j_i\left(\frac{w^H_{i,t}(\tau)}{P^{M,j}_{i,t}(\tau)}\right)^{1-\rho}\sum_{n=1}^{N}\pi^j_{i,n,t}(\tau)X^j_{n,t}(\tau) - w^H_{i,t}(\tau)L^H_{i,t}(\tau)\right]$$

$$Z^K_{i,t}(\tau) = \frac{1}{r_{i,t}(\tau)}\sum_{j=1}^{J}\left[(1-\alpha^j_i)(1-\delta^j_i)\left(\frac{r_{i,t}(\tau)}{P^{M,j}_{i,t}(\tau)}\right)^{1-\rho}\sum_{n=1}^{N}\pi^j_{i,n,t}(\tau)X^j_{n,t}(\tau) - r_{i,t}(\tau)K_{i,t}(\tau+1)\right]$$

5. **Update Factor Prices**

   Update factor prices for $t = 1, \ldots, T + T^*$:

$$w^H_{i,t}(\tau+1) = w^H_{i,t}(\tau)\Big[1 + \psi \frac{Z^H_{i,t}(\tau)}{L^H_{i,t}(\tau+1)}\Big]$$
$$w^L_{i,t}(\tau+1) = w^L_{i,t}(\tau)\Big[1 + \psi \frac{Z^L_{i,t}(\tau)}{L^L_{i,t}(\tau+1)}\Big]$$
$$r_{i,t}(\tau+1) = r_{i,t}(\tau)\Big[1 + \psi \frac{Z^K_{i,t}(\tau)}{K_{i,t}(\tau+1)}\Big]$$

   where $\psi \in (0, 1]$.

6. **Check Convergence**

   Stop iteration if:

$$\max_t \left\{ \max_i \left\{ \max \left\{ ||Z^H_{i,t}(\tau)||, ||Z^L_{i,t}(\tau)||, ||Z^K_{i,t}(\tau)|| \right\} \right\} \right\} < \text{tolerence}.$$

   Return to step 1 otherwise.

D Calibration of Educational Institution γ_i

This section discusses the calibration procedure of educational institution γ_i for each country. The calibration procedure involves two nested loops. In the outer loop, I compute the steady-state equilibrium given a guess of γ_i. The inner loop updates γ_i such that skill premium in the data is consistent with the ability threshold in the steady-state equilibrium. Let $x(\tau)$ be the variable of x at the τ^{th} iteration. Start with an arbitrary initial guess of education institution $\{\gamma_i(0)\}_{i=1}^N$, $\gamma_i(0) > 0\ \forall i$. The calibration procedure is conducted via the following steps.

1. Compute steady state equilibrium using $\{\gamma_i(\tau)\}_{i=1}^N$. Record the ability threshold in the steady state $\{\bar{a}_i(\tau)\}_{i=1}^N$.

2. Update the education institution for each country by solving:

$$\gamma_i(\tau+1) : \bar{a}_i(\tau) - \left[1 - \Big(\frac{w^{L,data}_{i,2001}}{w^{H,data}_{i,2001}}\Big)\right]^{-\frac{1}{\gamma_i(\tau+1)}} = 0.$$

3. Stop iteration if

$$\max_i \left\{ ||\gamma_i(\tau + 1) - \gamma_i(\tau)|| \right\} < \text{tolerence},$$

return to step 1 otherwise.