# What Determined the Evolution of Globalization During 1995-2017?*

Haichao FAN† Edwin L.-C. LAI‡ Han (Steffan) QI§

This draft: March 12, 2025

**Abstract**

We adapt the Eaton and Kortum (2002) model to a multi-sector general equilibrium Ricardian model with input-output linkages, and then carry out counterfactual exercises to quantify the impacts of the changes in technology stocks, trade costs and net exports on the degree of globalization of nations. We treat the gains from trade as an indicator of the degree of globalization of a country. We find that global changes in trade costs and technology stocks explain 97% of the variance of change in the degree of globalization across countries. Thus, the evolution of globalization during 1995-2017 was mainly driven by increases in technology stocks and reduction of trade costs of countries around the world. Changes in developing countries had significantly larger impacts on this evolution than those in developed countries. We found that foreign changes contributed to an average of 65 percent of the increase in the degree of globalization of countries, while domestic changes accounted for only 35 percent. We also estimate bilateral contributions across all country pairs in our sample. We are able to identify "friends" and "foes" in trade relationship among countries, in the spirit of Kleinman, Liu and Redding (2023). China's contribution to foreign countries, which amounted to 31% of the world's total contribution from domestic country to foreign countries, was by far the largest among all countries.

JEL Classification codes: F10, F14, F15, F62

Keywords: globalization, gains from trade, fragmentation, global value chains

*We would like to thank Samuel Kortum, Jonathan Eaton, Fernando Parro, Costas Arkolakis, Zhi Wang, Davin Chor and Lorenzo Caliendo for their helpful comments on an earlier version of this paper. The research in the paper has been partially supported by General Research Funds of the Research Grants Council of Hong Kong (Project No. 16506820).

†Institute of World Economy, School of Economics, Fudan University, Shanghai, China. Email: FAN_HAICHAO@FUDAN.EDU.CN

‡Corresponding author. CESifo Research Network Fellow. Department of Economics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong. Phone: (852) 2358-7611; Fax: (852) 2358-2084; Email: ELAI@UST.HK, EDWIN.L.LAI@GMAIL.COM

§Shenzhen Audencia Business School, WeBank Institute of Fintech, Shenzhen University, Shenzhen, China. Email: STEFFAN@SZU.EDU.CN, STEFFANCHI@GMAIL.COM

# 1 Introduction

The period 1995-2017 is widely recognized as a period of "hyperglobalization" in the sense of deepening trade relationship among countries. We ask, What determined the evolution of globalization during this period? We measure the change in the degree of globalization of a country by the change in gains from trade (GFT). We aim to (i) quantitatively account for the contributions of global changes in factors such as trade costs, technology stocks and net exports, to the change in GFT of each country; (ii) calculate a matrix of the contribution of changes in each country to the GFT of foreign countries through trade; (iii) estimate the contribution of changes in China to the rest of the world through trade; and (iv) find out whether changes in developing countries or developed countries were more important drivers of the evolution of globalization during 1995-2007.

To achieve the above tasks, we construct a general-equilibrium multi-sector Eaton-Kortum-type Ricardian model with input-output linkages. We distinguish between production functions and trade flows of intermediate goods and those of final goods. We run gravity regressions, making use of the data of trade flows in intermediate and final goods/services. This allows us to estimate the trade elasticities as well as changes in technology, trade costs and GFT of each country in intermediate and final goods/services. After calibrating the model, we carry out two sets of counterfactual exercises. In the first set of exercises, we estimate the impact of *global changes* in each exogenous variable on the domestic GFT of each country. In the second set of exercises, we estimate the impact of the change of each exogenous variable *in each country* on *its own domestic GFT*. Thus, we are able to compute the contribution of changes in the rest of the world to the change in domestic GFT of each country.

We make a few contributions to the literature. First, as far as we know, our paper is the first in the literature to carry out variance decomposition to account for the contribution of various exogenous factors to the changes in GFT of nations. We overcome the difficulty of estimating the contribution of each factor to the GFT of a country due to the existence of interactive effects among the various factors. It turns out that the average of the pure effect and total effect of each factor is a good proxy for the contribution of that factor. So, we use this average as the estimate of the contribution of the factor, then carry out variance decomposition accordingly. The second contribution of this paper is that we compute a matrix of the contribution of the changes in the technology stocks and trade costs of each country (e.g. China) to the GFT of foreign countries. Thus, we identify "friends" and "foes" in trade relationship among countries (Kleinman, Liu and Redding 2022).

Here is the preview of the results. (i) There is convergence in the technology stocks and trade costs across countries for intermediate goods/services and final goods/services. (ii) Global changes in trade costs contribute most to the changes in the degree of globalization of countries, but changes in technology stocks also play an important role. Yet the previous literature tends to overlook the latter aspect.

Specifically, global changes in trade costs and technology stocks together explain 97% of the variance of changes in GFT of nations; global reduction in trade costs contribute positively to domestic change in GFT (117.6%); global increases in technology stocks contribute negatively to domestic change in GFT (-21.1%). (iii) The above decomposition result is driven mainly by developing countries, reflecting the faster rates of changes of technology stocks and trade costs in the developing countries during the sample period 1995-2017 (due to convergence). (iv) A model that does not distinguish between the production functions and trade flows of intermediate and those of final goods underestimates the change in GFT of countries by 53% on average. (v) Changes in technology stocks and trade costs of foreign countries contribute to 65% of the change in domestic GFT on average. Specifically, foreign technological changes contribute to 48% of the change in domestic GFT on average, while foreign changes in trade costs contribute to 17% of the change in domestic GFT. (vi) China's contribution to the change in welfare of foreign countries through trade, being 31% of world total contribution of domestic countries to foreign countries, was by far larger than that of any other country. (vii) Domestic changes in technology and trade costs pertaining to intermediate goods trade are more important to domestic GFT than those pertaining to final goods trade. (Elasticities of GFT w.r.t. intermediate goods technology and trade cost are 2 to 3 times those of final goods.)

In section 2, we derive a general equilibrium trade model, which we use to carry out our empirical work later in the paper. In section 3, we describe the procedure of the empirical estimation based on the theoretical model. We find that there is convergence in the technology stocks and trade costs across countries for intermediate goods and services as well as final goods and services. In section 4, we estimate the change in GFT in each country based on our baseline model. We find that the model's fit is very good for both the changes in GFT in intermediate and final goods. It demonstrates that the Ricardian model is very powerful in explaining the data. Furthermore, we find that the average change in GFT are larger for intermediate goods than for final goods. Then, we estimate the change in GFT of countries based on the roundabout production (RP) model, and compare the result with that from our baseline model. We find that the estimated GFT from our baseline model, which distinguishes between production functions and trade flows of intermediate goods and those of final goods, is 53% higher than that estimated by the RP model. This demonstrates the need for distinguishing between intermediate goods and final goods in the empirical analysis. Our result echoes the finding of Antras and de Gortari (2020), who find that the version of their model with vertical specialization yields 60% higher GFT than the version without vertical specialization.

In Section 5, we carry out counterfactual analyses, followed by variance decomposition, to estimate the contribution of the global change in each exogenous factor to the cross-country variance in the changes in GFT. Specifically, we find that global increases in technology stocks and reduction in trade costs contribute on average to -21.1% and 117.6%, respectively, of the change in domestic GFT.

In section 6, we carry out counterfactual exercises to estimate the impacts of domestic country's technological improvement and trade costs reduction on domestic GFT. We find that the magnitude of the average elasticity of domestic GFT with respect to domestic technology stock (as well as trade cost) for intermediate goods is distinctly larger than that for final goods. We attribute this to the multiplier effects of trade cost reduction and technological change in the intermediate goods sector.[1] This result implies that trade liberalization policies pertaining to intermediate goods and services are more important to GFT than those pertaining to final goods and services. This echoes the finding of Antras, Fort, Gutiérrez and Tintelnot (2022) that it is optimal for tariffs to be lower for intermediate goods than for final goods. Finally, the counterfactual exercises reveal the extents of impacts on domestic GFT of foreign technological changes and trade costs reduction. We found that changes in foreign countries contributed to an average of 65% of the changes in domestic GFT of countries. Additional counterfactual exercises allow us to estimate the contribution of individual countries to the rest of the world through trade. We find, for example, that China accounted for 31 percent of the world's total contribution from domestic country to foreign countries. In addition, we estimate bilateral contributions between country pairs, and construct a bilateral contribution heat map. From it, we are able to identify "friends" (positive contribution) and "foes" (negative contribution) in trade relationship among countries, in the spirit of Kleinman, Liu and Redding (2022). Finally, section 7 concludes.

**Related Literature**

Our paper is related to the literature on GVCs, vertical specialization, global sourcing, fragmentation and multi-stage production, which includes the notable work of Hummels, Ishii and Yi (2001), Yi (2003), Grossman and Rossi-Hansberg (2008), Johnson and Noguera (2012), Baldwin and Venables (2013), Costinot, Vogel and Wang (2013), Antras and Chor (2013), Koopman, Wang & Wei (2014), Kee and Tang (2016), Fally and Hillberry (2018), and Antras and de Gortari (2020), Johnson and Moxnes (2019). The approach we take is to distinguish between trade in intermediate goods and that in final goods in calculating the changes in GFT of countries resulting from global changes in trade costs and technology stocks.

Our work is also related to the literature that employs quantitative trade models to calculate the gains from trade. Examples are Arkolakis, Costinot, and Rodriguez-Clare (2012) [hereinafter ACR], Costinot and Rodriguez-Clare (2014), Antras and de Gortari (2020), Antras and Chor (2013), Melitz and Redding (2015), Ossa (2015), Donaldson (2018), Caliendo and Parro (2015), Alexander (2021). ACR develop a sufficient statistic approach for calculating the GFT for a class of quantitative trade models. Costinot and Rodriguez-Clare (2014) extend ACR's framework and quantify gains from globalization in several

[1] The multiplier effect can roughly be stated as follows. Trade cost reduction (or technological improvement) in intermediate goods leads to the reduction of the price of the composite intermediate good, which in turn lowers the prices of intermediate goods, which in turn lowers the price of the composite intermediate good, and so on.

settings. Melitz and Redding (2015), on the other hand, show that trade elasticity is no longer a sufficient statistic for GFT when it is variable across markets and levels of trade costs. Ossa (2015) points out the dominant role of some critical sectors in determining the GFT when the elasticities of trade are different across sectors. While most papers in the literature focus on the effects of trade cost reduction on GFT, we quantitatively decompose the change in GFT into the effects of not just trade costs but also technology stocks and net exports. We emphasize a comprehensive understanding of the contributions of global and domestic changes in various factors to the changes in GFT of countries by distinguishing between trade in intermediate goods and that in final goods.

In our baseline model, we distinguish between the production functions and trade flows of intermediate goods and those of final goods. We assume that intermediate and final goods in the same sector $i$ are produced from the same input bundle but the production functions of the two goods are governed by different Frechet distributions that have different technology stocks $T_i$ and shape parameters $\theta_i$ (using EK's notations). Thus, our baseline model still carries the feature that each intermediate or final good is produced by an infinite loop of intermediate goods, like in the RP model. This distinguishes ours from the truly multi-stage production model of GVCs, a notable example of which is Antras and de Gortari (2020). Their goal is to adapt the EK model to a multi-stage production environment so as to predict the average participation of countries in different segments of GVCs. Their theory predicts that more centrally located countries tend to produce more downstream goods. They also find that a one-stage production process is sufficient for an excellent fit of the model for final goods, and a two-stage production process is sufficient to produce an excellent fit for intermediate goods.

What is common between our baseline model and that of Antras and de Gortari (2020) is that both of our models yield different equilibrium home sourcing shares in intermediate and final goods, and both of our models yield substantially higher GFT (or change in GFT) than does the RP model (60% in their model and 53% in our model). In an independent work, Alexander (2021) constructs a model of vertical specialization similar to ours. Unlike our model, the only difference between the production functions of intermediate and final goods in Alexander (2021) is that they have different technology stocks $T$ but the same shape parameter $\theta$. Unlike us, Alexander's (2021) main focus is on comparing the calculated GFT based on the RP model and that based on his model, and there is no general equilibrium analysis. In contrast to our result, he finds that discarding the RP assumption does not yield significantly higher GFT. An important feature of our paper is that we carry out counterfactual analyses based on a fully specified general equilibrium model that extends the EK model.

Our paper is also related to the literature that seeks to quantify the effects of productivity growth (or trade liberalization) of China on the rest of the world through trade. Notable works include Hsieh and Ossa (2016), Di Giovanni, Levchenko and Zhang (2014), Bloom, Draca and van Reenen (2016), Caliendo, Dvorkin and Parro (2019), and Autor, Dorn and Hanson (2011). Distinct from the literature, we calculate

the impacts of China through trade from a unique angle — by estimating the contribution of changes in China's technology stocks and reduction of trade costs to the change in GFT of its trading partners. We show that China stands out as the country that has by far the largest contribution to the welfare change of foreign countries through trade. This was resulted from the large changes of its technology stocks and trade costs. We found that China accounted for 31% of the world's total contribution from domestic country to foreign countries through trade during 1995-2017.

Our paper is methodologically related to the literature on decomposition of the change of a variable into the contributions of a number of exogenous factors. For example, Tombe and Zhu (2019) and Swiecki (2017) try to allocate the contributions of different factors while taking into account interactive effects among them. Notable examples of papers that carry out variance decomposition are Eaton, Kortum and Kramarz (2004) and Hottman, Redding and Weinstein (2016). Our approach of calculating the contributions of different factors is distinct from those of other papers in the literature in that we use the mean of the pure and total effects to proxy for the contribution of a factor. By doing that, we take into account the interactive effects among multiple factors, and allocate them to each factor. We demonstrate that the sum of the contributions of all the factors give a good fit to the data, which verifies that our proxy is a reasonable one.

## 2 The Model

In this section, we describe a general equilibrium multi-sector model of production and trade of intermediate goods and final goods by extending the Ricardian model of EK. We use this model to derive and estimate two sets of gravity equations. Our model has some similarities with but is distinct from that of Caliendo and Parro (2015). The distinctions are that they assume (i) roundabout production, and (ii) that services are non-tradable.

**The General Setting.** There are $N$ countries in the world, indexed by $n = 1, 2..., N$. Country $n$ has labor endowment $L_n$, which serves as the only primary input in production of all kinds of goods and services. There are $K$ sectors of goods and services, indexed by $i = 1, 2, ...K$. To simplify writing, hereinafter, we shall use the terms "good(s)" and "good(s) or service(s)" interchangeably unless there is ambiguity. Labor is fully mobile across sectors within the same country, but not mobile across countries. Labor wage in country $n$ is denoted by $w_n$. The production of an intermediate or final good requires the conversion from a composite input called an input bundle, which is a combination of labor and the entire set of intermediate goods from all sectors (called a composite intermediate good). For each sector, there are multiple varieties of final goods and multiple varieties of intermediate goods. We assume that all countries have the capability to produce all varieties of intermediate goods and all varieties of final goods for all sectors. All goods are tradeable but there are trade costs.

A typical country imports intermediate goods from all over the world (including itself), then combines the entire set of intermediate goods with domestic labor to form input bundles, and then produces intermediate goods or final goods from the input bundles. The goods are then exported to destinations all over the world. In equilibrium, all countries export some intermediate goods and some final goods to all other countries and to themselves. Markets for both intermediate and final goods are assumed to be perfectly competitive.

Regarding notation, any variable with a tilde pertains to final goods only. Whenever an intermediate (or final) good in sector $i$ is shipped from country $n$ to country $m$, an iceberg trade cost $\tau_{mn}^{i}$ (or $\widetilde{\tau_{mn}^{i}}$) is incurred. That is, $\tau_{mn}^{i} > 1$ (or $\widetilde{\tau_{mn}^{i}} > 1$) units of intermediate (or final) good are shipped from the origin for one unit to arrive at the destination. We assume $\tau_{nn}^{i} = \widetilde{\tau_{nn}^{i}} = 1$ for all $n$ and $i$.

**Preferences.** In each country a representative household maximizes utility by choosing a consumption bundle of final goods of varieties $\omega \in [0,1]$ in each sector $i = 1, ..., K$, subject to the budget constraint. The utility function of the representative household in country $n$ is given by

$$U_n = \prod_{i=1}^{K} \left\{ \left[ \int_0^1 \left( \widetilde{Q_n^i}(\omega) \right)^{\frac{\widetilde{\sigma}_n^i - 1}{\widetilde{\sigma}_n^i}} d\omega \right]^{\frac{\widetilde{\sigma}_n^i}{\widetilde{\sigma}_n^i - 1}} \right\}^{\alpha_n^i} \quad \text{for } n = 1, 2, ..., N \tag{1}$$

where $\alpha_n^i$ is the expenditure share on sector $i$ (with $\sum_{i=1}^{K} \alpha_n^i = 1$), and $\widetilde{Q_n^i}(\omega)$ is the consumption of variety $\omega$ of sector-$i$ final good by the representative household in country $n$. Within each sector $i$, $\widetilde{\sigma}_n^i > 1$ is the elasticity of substitution between any two varieties.

**Technology and Market Structure.** For each country**,** each final good or intermediate good is converted from the input bundle, but the efficiency of conversion for each variety of good is stochastic. Denote the efficiency of country $l$ in converting the sector-$i$ input bundle into a variety $\omega \in [0,1]$ of sector-$i$ final good by $\widetilde{Z_l^i}(\omega)$, and denote the efficiency for converting a sector-$i$ input bundle into a variety $\omega \in [0,1]$ of sector-$i$ intermediate good by $Z_l^i(\omega)$. The production function of an input bundle in country $n$ is given by:

$$y_n^i = \left(M_n^i\right)^{1-\beta_n^i} \left(l_n^i\right)^{\beta_n^i}, \text{ with } 0 < \beta_n^i < 1, \tag{2}$$

where $y_n^i$ is the quantity of sector-$i$ input bundle produced in country $n$; $M_n^i$ is the corresponding quantity of the sector-$i$ composite intermediate good (which is defined in equation (3) below); $l_n^i$ is the corresponding labor input; $\beta_n^i$ is called the value-added share in the production of an input bundle.[2]

Due to perfect competition, firms in country $n$ will import any variety of any intermediate good from

[2] It is also equal to the value-added share in the production of an intermediate or a final good.

the source country that sells at the lowest competitive price in $n$. The quantity of sector-$i$ composite intermediate good produced by $n$ is determined by the following production function:

$$M_n^i = \prod_{h=1}^{K} \left\{ \left[ \int_0^1 \left( Q_n^{ih}(\omega) \right)^{\frac{\sigma_n^h - 1}{\sigma_n^h}} d\omega \right]^{\frac{\sigma_n^h}{\sigma_n^h - 1}} \right\}^{\gamma_n^{ih}}, \tag{3}$$

where $Q_n^{ih}(\omega)$ is the quantity of variety $\omega$ of sector-$h$ intermediate good used by country $n$ in the production of the sector-$i$ composite intermediate good, $\gamma_n^{ih}$ is the cost share of intermediate goods from sector $h$ used to produce the sector-$i$ composite intermediate good in country $n$. Thus, $\sum_{h=1}^{K} \gamma_n^{ih} = 1$ for all $i$. Within sector $h$, $\sigma_n^h > 1$ is the elasticity of substitution between any pair of varieties.

We follow EK by assuming that $Z_l^i(\omega)$ is drawn from a Fréchet distribution, with the cumulative density function given by

$$\Pr[Z_l^i(\omega) < z] = e^{-[T_l^i] z^{-\theta_i}} \quad \forall \omega \in [0,1] \text{ for } i = 1, ..., K$$

where $T_l^i$ is country $l$'s technology stock for producing sector-$i$ intermediate goods and $1/\theta_i$ is positively related to the variance of the distribution of $Z_l^i(\omega)$ $\forall \omega \in [0,1]$. When $\theta_i$ is smaller, there is more room for GFT due to differences in comparative advantage across varieties of each intermediate good among countries. The parameter $T_l$ reflects country $l$'s absolute advantage in producing intermediate goods, which can be viewed as a summary measure of the (broadly defined) technology stock of country $l$ for the production of intermediate goods, e.g. technology embodied in machines, human capital, infrastructure, how well-developed is the domestic supply network, etc.

Following the above assumptions, the competitive price of variety $\omega$ of sector-$i$ intermediate good that can potentially be exported from $l$ to $n$ is given by

$$p_{nl}^i(\omega) = \frac{c_l^i}{Z_l(\omega)} \tau_{nl}^i$$

where

$$c_n^i = \left[ \frac{\prod_{j=1}^{K} \left( \frac{P_n^j}{\gamma_n^{ij}} \right)^{\gamma_n^{ij}}}{1 - \beta_n^i} \right]^{1-\beta_n^i} \left( \frac{w_n}{\beta_n^i} \right)^{\beta_n^i} \tag{4}$$

is the unit cost of a sector-$i$ input bundle corresponding to equation (2), with $P_n^i$ being the unit cost of the sector-$i$ composite intermediate good in $n$, the production function of which is given by equation (3). Perfect competition in the market of each variety of a sector implies that the home country will only buy from the source country offering the lowest price for that variety in the home country. Consequently, it can be easily shown that

$$P_n^i = \Omega_n^i \left( \Phi_n^i \right)^{-\frac{1}{\theta_i}}, \tag{5}$$

where $\Omega_n^i$ is a constant for given $i$ and $n$,[3] and

$$\Phi_n^i \equiv \sum_{m=1}^{N} T_m^i \left(c_m^i \tau_{nm}^i\right)^{-\theta_i}$$

is defined as country $n$'s "global access" to intermediate goods.

It is straightforward to show that the market share of sector-$i$ intermediate goods imported from $l$ in $n$'s market is given by

$$\pi_{nl}^i = \frac{T_l^i \left(c_l^i \tau_{nl}^i\right)^{-\theta_i}}{\Phi_n^i} \tag{6}$$

We define $D_l^i \equiv T_l^i \left(c_l^i\right)^{-\theta_i}$ as country $l$'s competitiveness in supplying sector-i intermediate goods. Thus, the competitiveness of a country in intermediate goods can be high in a sector because of three factors: low wage, large technology stock for the production of intermediate goods in that sector, or favorable access to foreign intermediate goods of that sector. Note that the set of unit costs of input bundles $\{c_l^i\}$ and set of unit prices of composite intermediate goods $\{P_l^i\}$ for $l = 1, 2, ...N$ are interrelated through sets of equations (4) and (5). When the set of trade-costs-adjusted technology stocks $\{T_m \left(\tau_{lm}\right)^{-\theta_i} \Big| \; l, m = 1, ..., N\}$ and set of labor costs $\{w_m |\; m = 1, ..., N\}$ are known, we can solve for the $\{c_l |\; l = 1, ..., N\}$ and $\{P_l |\; l = 1, ..., N\}$ from the sets of equations given by (4) and (5).

For the final goods, we assume that $\widetilde{Z_l^i}(\omega)$ is drawn from a Fréchet distribution, with the cumulative density function given by

$$\Pr[\widetilde{Z_l^i}(\omega) < z] = e^{-\left[\widetilde{T_l^i}\right] z^{-\widetilde{\theta_i}}} \quad \forall \omega \in [0,1] \;\; \text{for } i = 1, ..., K$$

where $\widetilde{T_l^i}$ is country $l$'s technology stock for producing sector-$i$ final goods and $1/\widetilde{\theta_i}$ is positively related to the variance of the distribution of $\widetilde{Z_l^i}(\omega) \;\; \forall \omega \in [0,1]$.

The competitive price of variety $\omega$ of sector-$i$ final good that can potentially be exported from $l$ to $n$ is given by

$$\widetilde{p_{nl}^i}(\omega) = \frac{c_l^i}{\widetilde{Z_l^i}(\omega)} \widetilde{\tau_{nl}^i},$$

where $c_l^i$ is given in (4).

Similar to (6), the market share of sector-$i$ final goods imported from $l$ in $n$'s market is given by

$$\widetilde{\pi}_{nl}^i = \frac{\widetilde{T_l^i} \left(c_l^i \widetilde{\tau_{nl}^i}\right)^{-\widetilde{\theta}_i}}{\widetilde{\Phi_n^i}} \tag{7}$$

where $\widetilde{\Phi_n^i} \equiv \sum_{m=1}^{N} \widetilde{T_m^i} \left(c_m^i \cdot \widetilde{\tau_{nm}^i}\right)^{-\widetilde{\theta}_i}$ is defined as country n's global access to sector-$i$ final goods, and $\widetilde{D_l^i} \equiv \widetilde{T_l^i} \left(c_l^i\right)^{-\widetilde{\theta}_i}$ is defined as the competitiveness of country $l$ in supplying sector-$i$ final goods.

[3] $\Omega_n^i = \left[\Gamma\left(\frac{\theta_i + 1 - \sigma_n^i}{\theta_i}\right)\right]^{\frac{1}{1-\sigma_n^i}}$, where $\Gamma(\cdot)$ is the Gamma function.

It can be easily shown that the exact price index of the entire set of final goods as indicated in the utility function (1) is given by

$$\widetilde{P_n^i} = \widetilde{\Omega_n^i} \left( \widetilde{\Phi_n^i} \right)^{-1/\widetilde{\theta}_i} \tag{8}$$

where $\widetilde{\Omega_n^i}$ is a constant for given $i$ and $n$.[4]

**Market Clearing**

Define the total value of the outputs of sector-$i$ intermediate and final goods produced by $n$ as $Y_n^i$; define $n$'s total expenditure on sector-$i$ intermediate and final goods as $X_n^i$; and define $NX_n$ as the net exports of country $n$. To close the model, we need three more conditions, viz. (9), (10) and (11) given below:

$$Y_n^i = \sum_{l=1}^{N} \pi_{ln}^i \sum_{j=1}^{K} \gamma_l^{ji} Y_l^j \left(1 - \beta_l^j\right) + \sum_{l=1}^{N} \widetilde{\pi_{ln}^i} \alpha_l^i \left(w_l L_l - NX_l\right) \tag{9}$$

which says that the supply of sector-$i$ goods produced by country $n$ is equal to the demand for sector-$i$ intermediate goods produced by country $n$ plus the demand for sector-$i$ final goods produced by country $n$;

$$X_n^i = \alpha_n^i \left(w_n L_n - NX_n\right) + \sum_{j=1}^{K} \gamma_n^{ji} \left(1 - \beta_n^j\right) Y_n^j \tag{10}$$

which says that country $n$'s expenditure on sector-i goods is equal to country $n$'s expenditure on sector-$i$ final goods, plus country $n$'s expenditure on sector-$i$ intermediate goods; and

$$NX_n = \sum_{i=1}^{K} Y_n^i - \sum_{i=1}^{K} X_n^i \tag{11}$$

which says that net exports of a country is equal to output minus expenditure.

The "exact hat algebra" version of the general equilibrium model is given in Appendix A. It is the exact hat algebra version that we use to carry out most of our empirical work. Note that, throughout the paper, change of $x$ is defined as $\ln \widehat{x}$ where $\widehat{x} \equiv x'/x$ with $x'$ = new value of $x$, unless otherwise stated.

# 3 Empirical Estimation

This section describes how we estimate the trade elasticities, technology stocks and trade barriers.

[4] $\widetilde{\Omega_n^i} = \left[\Gamma\left(\frac{\widetilde{\theta_i}+1-\widetilde{\sigma_n^i}}{\widetilde{\theta_i}}\right)\right]^{\frac{1}{1-\widetilde{\sigma_n^i}}}$, where $\Gamma(\cdot)$ is the Gamma function.

### 3.1 Data

Bilateral values of trade in intermediate goods and final goods are obtained from the underlying inter-country input-output (ICIO) tables of the 2021 edition of the Measuring Trade in Value Added (**TiVA**) data set, a product of an OECD-WTO joint project. The data set contains the estimated value-added of any origin country in its exports of any good or service to any destination country. The project also yields a data set on the bilateral values of trade in intermediate goods and final goods between countries. It is the subset of this data set that we use in this paper. We aggregate the trade flows into 50 countries plus the rest of the world (ROW) (indexed by $j$) and 12 sectors (indexed by $s$) for the years 1995, 2000, 2005, 2010, 2015 and 2017.[5] The data for bilateral trade costs come from the GeoDist dataset of CEPII, which is also used by Head, Mayer and Ries (2010). Data on tariffs are obtained from the WTO. The data for labor supply of countries are from the World Bank.

### 3.2 Estimation strategy

To solve the system given in Appendix A, we first calculate $\alpha_l^i$, $\beta_n^i$, $\gamma_n^{ij}$, $\widetilde{\pi_{ln}^i}$, $\pi_{ln}^i$ and $NX_l$ based on the inter-country input-output tables. Then, we estimate the trade elasticity, $\theta_i$, based on the gravity equation. Finally, we estimate the exogenous variables, namely, technology $T_n^i$ and trade costs $\tau_{ln}^i$. Table A3 in the Appendix reports the statistics of the estimated variables.

The variables $\alpha_l^i$, $\beta_n^i$, $\gamma_n^{ij}$, $\widetilde{\pi_{ln}^i}$, $\pi_{ln}^i$ and $NX_l$ are calculated based on the inter-country input-output table, as explained below.

- $\alpha_l^i$ represents the share of sector-$i$ final goods in country $l$'s final consumption expenditure. Based on the input-output table, we calculate $\alpha_l^i$ according to the following equation

$$\alpha_l^i = \frac{\sum_{n=1}^{N} \widetilde{X_{ln}^i}}{\sum_{i=1}^{K}\sum_{n=1}^{N} \widetilde{X_{ln}^i}},$$

  where $\widetilde{X_{ln}^j}$ is the value of sector-$i$ final goods purchased by the households in country $l$ from country $n$.

- From the inter-country input-output table, we obtain the value of output in sector-$i$ of country $n$:

$$y_n^i = \sum_{j=1}^{K}\sum_{l=1}^{N} z^{(n,i),(l,j)} + VA_n^i,$$

  where $z^{(n,i),(l,j)}$ represents the value of the sector-$j$ intermediate goods from country $l$ used in the production of sector-$i$ goods in country $n$, and $VA_n^i$ is the sector-$i$ value-added of country

[5] There are 22 developed countries and 28 developing countries, which are listed in Online Appendix G.

$n$. Therefore, the share of value-added in the production of sector-$i$ goods in country $n$ can be expressed as $\beta_n^i = \frac{VA_n^i}{y_n^i}$; and the cost share of sector-$j$ goods used in the production of sector-$i$ goods in country $n$ is given by $\gamma_n^{ij} = \frac{\sum_{l=1}^{N} z^{(n,i),(l,j)}}{\sum_{j=1}^{2}\sum_{l=1}^{N} z^{(n,i),(l,j)}}$.

- $\pi_{\ln}^i$ denotes the market share of sector-$i$ intermediate goods imported from $n$ in $l$'s market, given by $\pi_{ln}^i = \frac{X_{ln}^i}{\sum_{n=1}^{N} X_{ln}^i}$ where $X_{ln}^i$ is the value of sector-i intermediate goods purchased by $l$ from $n$.
- $\widetilde{\pi_{ln}^i}$ denotes the market share of sector-$i$ final goods imported from $n$ in $l$'s market, given by $\widetilde{\pi_{ln}^i} = \frac{\widetilde{X_{ln}^i}}{\sum_{n=1}^{N} \widetilde{X_{ln}^i}}$ where $\widetilde{X_{ln}^i}$ is the value of sector-$i$ final goods purchased by the households in $l$ from $n$.
- Net exports in $l$ is given by: $NX_l = \sum_{i=1}^{K}\sum_{n=1}^{N}\left(X_{nl}^i + \widetilde{X_{nl}^i}\right) - \sum_{i=1}^{K}\sum_{n=1}^{N}\left(X_{ln}^i + \widetilde{X_{ln}^i}\right)$

### 3.3 Estimating Trade Elasticities

From now on, we specialize into $K = 12$, where $i = 1$ stands for the primary sector, $i = 2, ..., 11$ stand for ten manufacturing sectors and $i = 12$ stands for services. We use the gravity equation for trade in intermediate goods in the primary and manufacturing sectors (i.e. for $i = 1, ..., 11$) to estimate the trade elasticity $\theta_i$ for each intermediate good. Following Caliendo and Parro (2015), we use the mean elasticity across the intermediate goods in the non-service sectors $i = 1, ..., 11$ to proxy for the elasticity for the intermediate services sector (i.e. for $i = 12$) as there is no tariff for services and so we cannot estimate trade elasticity as a coefficient of tariff in the services sector regression.Equation (6) implies that

$$\ln\left(\frac{X_{nlt}^i}{X_{nnt}^i}\right) = \ln D_{lt}^i - \ln D_{nt}^i - \theta_i \tau_{nlt}^i \tag{12}$$

for $t = 1995, 2000, 2005, 2010, 2015, 2017$ with $\tau_{nlt}^i = d_{nlt} + b_{nlt} + lang_{nlt} + legal_{nlt} + colonial_{nlt} + RTA_{nlt} + im_{nt}^i + Tariff_{nlt}^i + v_{nlt}^i$, where $\tau_{nlt}^i$ = trade barriers of $n$ on $l$ on intermediate goods for sector i, $d_{nlt}$ = bilateral distance bins following Eaton and Kortum (2002),[6] $b_{nlt}$ = common border, $lang_{nlt}$ = common language, $legal_{nlt}$ = common legal system, $colonial_{nlt}$ = colonial or dependency relationship, $RTA_{nlt}$ = regional trade agreement, $im_{nt}^i$ = (extra) importer fixed effect (to improve the fit of the regression), $Tariff_{nlt}^i$ = intermediate goods tariff of $n$ on $l$ for sector i, and $v_{nlt}^i$ = residual. The variables $d$, $b$, $lang$, $legal$, $colonial$, $RTA$ are dummy variables.[7] In order to capture their different impacts at different years, we interact each dummy variable with year dummies $\delta_t$. We can rewrite equation (12) as

$$\ln\left(\frac{X_{nlt}^i}{X_{nnt}^i}\right) = \underbrace{\ln D_{lt}^i}_{\text{Exporter Fixed Effect}} - \underbrace{\left(\ln D_{nt}^i + im_{nt}^i\right)}_{\text{Importer Fixed Effect}} - \underbrace{\theta_i \cdot Tariff_{nlt}^i}_{\text{Tariff Effect}} - bilateral\ controls - \underbrace{\theta_i v_{nlt}^i}_{\text{Error Term}}$$

[6] The distance bins are: $d_{nlt}$ is equal to $k$ when the distance between $n$ and $l$ lies in the $k$th interval of the following six intervals: [0, 375); [375, 750); [750, 1500); [1500 3000); [3000, 6000); and [6000, maximum) miles.

[7] Following Eaton and Kortum (2002), we add an extra importer fixed effect to improve the fit of the regression.

where

$$\begin{aligned} bilateral\ controls &= \sum_t \big(\theta^i_{1,t} d_{nlt} \times \delta_t + \theta^i_{2,t} b_{nlt} \times \delta_t + \theta^i_{3,t} lang_{nlt} \times \delta_t + \theta^i_{4,t} legal_{nlt} \times \delta_t \\ &\quad + \theta^i_{5,t} \mathrm{col}\, onial_{nlt} \times \delta_t + \theta^i_{6,t} RTA_{nlt} \times \delta_t \big) \end{aligned}$$

and $\theta^i_{k,t}$ (for $k = 1, ..., 6$ and $t = 1995$, 2000, 2005, 2010, 2015, 2017) are to be estimated.

We estimate the trade elasticity $\theta_i$ as the coefficient of the average bilateral tariff in the sector-i intermediate goods. (See, for example, Fontagne, Guimbard & Orefice 2022, who use a similar method to estimate trade elasticity.) We also obtain the sector-i intermediate goods competitiveness of country $l$, $\ln D^i_{lt}$, as the exporter fixed effect.

Similarly, we use the gravity equation for trade in final goods in each of the primary and manufacturing goods sectors (i.e. for $i = 1, ..., 11$) to estimate the trade elasticity $\widetilde{\theta}_i$ for each final good. Again, following Caliendo and Parro (2015), we use the mean elasticity across the final goods sectors $i = 1, ..., 11$ to proxy for the elasticity for the final services sector ($i = 12$), for the same reason as stated above for intermediate services. Equation (7) implies that

$$\ln\left(\frac{\widetilde{X^i_{nlt}}}{\widetilde{X^i_{nnt}}}\right) = \ln \widetilde{D^i_{lt}} - \ln \widetilde{D^i_{nt}} - \widetilde{\theta}_i \cdot \widetilde{\tau^i_{nlt}} \tag{13}$$

with $\widetilde{\tau^i_{nlt}} \equiv d_{nlt} + b_{nlt} + lang_{nlt} + legal_{nlt} + colonial_{nlt} + RTA_{nlt} + \widetilde{im}^i_{nt} + \widetilde{Tariff}^i_{nlt} + \widetilde{v}^i_{nlt}$, where $\widetilde{\tau^i_{nlt}}$ = trade barriers of $n$ on $l$ on final goods for sector i; $\widetilde{im}^i_{nt}$ = (extra) importer fixed effect, $\widetilde{Tariff}^i_{nlt}$ = tariffs of $n$ on $l$ on final goods for sector i, $\widetilde{v}^i_{nlt}$= residual. We rewrite equation (13) as

$$\ln\left(\frac{\widetilde{X^i_{nlt}}}{\widetilde{X^i_{nnt}}}\right) = \underbrace{\ln \widetilde{D^i_{lt}}}_{\text{Exporter Fixed Effect}} - \underbrace{\left(\ln \widetilde{D^i_{nt}} + \widetilde{im}^i_{nt}\right)}_{\text{Importer Fixed Effect}} - \underbrace{\widetilde{\theta}_i \cdot \widetilde{Tariff}^i_{nlt}}_{\text{Tariff Effect}} - bilateral\ controls - \underbrace{\widetilde{\theta}_i \widetilde{v}^i_{nlt}}_{\text{Error Term}}$$

where the *bilateral controls* term is exactly the same as above. We estimate the trade elasticity $\widetilde{\theta}_i$ as the coefficient of bilateral tariff in sector-i final goods. We also obtain the sector-i final goods competitiveness of country $l$, $\ln \widetilde{D^i_l}$, as the exporter fixed effect.

The coefficients on tariff obtained by estimating equations (12) and (13) via OLS are shown in Table 1. As shown in the table, our mean estimates of $\theta_i = 4.430$ and $\widetilde{\theta}_i = 3.430$ fall in the usual range obtained from gravity equations in the literature (see, for example, Simonovska and Waugh 2014 and Head and Mayer 2014).

When $i = 12$, i.e. for the services sector, there are no tariffs. In that case, we run a regression similar to (12) and (13) without the tariff term in order to estimate the competitiveness of intermediate and final services of countries.

Table 1: Trade Elasticities in different sectors

| | **TRADE ELASTICITIES BY SECTOR** | Interm. | Final |
|---|---|---|---|
| Sector no. | **Sector name** | good | good |
| 1 | Primary sector | 2.318 | 1.505 |
| 2 | Food products, beverages and tobacco[ISIC 10-12] | 1.159 | 1.015 |
| 3 | Textiles, textile products, leather and footwear[ISIC 13-15] | 5.057 | 3.139 |
| 4 | Wood and products of wood and cork[ISIC 16] | 5.325 | 3.034 |
| 5 | Paper products and printing[ISIC 17-18] | 5.314 | 4.143 |
| 6 | Chemical products & Pharmaceuticals [ISIC 20-21] | 6.618 | 6.538 |
| 7 | non-metallic mineral products [ISIC 22-23] | 4.055 | 3.432 |
| 8 | Basic metals & Fabricated metal products [ISIC 24-25] | 8.650 | 4.784 |
| 9 | Machinery and equipment [ISIC 26-28] | 6.254 | 5.442 |
| 10 | Transport equipment [ISIC 29-30] | 2.203 | 2.470 |
| 11 | Other manufacturing [ISIC 31-33] | 1.778 | 2.229 |
| | Mean | 4.430 | 3.430 |

Note: The trade elasticity for the services sector is assumed to be the average elasticity of the non-services sectors.

### 3.4 Estimating Technology Stocks

In order to estimate the technology stocks, we need to first estimate the wages. We solve for the wages of countries $\{w_l\}$ and the estimated values of sectoral outputs of countries $\left\{Y_n^i\right\}$ from the following two sets of equations:

(1) Goods market clearing condition

$$Y_n^i = \sum_{l=1}^{N} \pi_{ln}^i \sum_{j=1}^{K} \gamma_l^{ji} Y_l^j \left(1 - \beta_l^j\right) + \sum_{l=1}^{N} \widetilde{\pi_{ln}^i} \alpha_l^i \left(w_l L_l - NX_l\right)$$

(2) Total value-added is equal to wage payment to labor

$$\sum_{j=1}^{K} Y_l^j \beta_l^j = w_l L_l \ ,$$

given $\gamma_n^{ji}$, $\pi_{ln}^j$, $\widetilde{\pi_{ln}^i}$, $\alpha_l^i$, $NX_l$ and $L_l$. During the estimation process, we set US wage in each year as the numeraire and calculate the relative wage of each country year by year based on the model. Then, we make use of the data of the actual change in the wage of the US, $\widehat{w_{US}}$, in each period obtained from the World Bank, and calculate the change in the absolute wage for other countries based on the relative wages calculated from our model explained above. Figure A1 in the Appendix shows the fit of our model

to the data. As shown in this figure, the logarithm of the wage of a country relative to that of the US implied by the model closely approximates the logarithm of the GDP per capita of the country relative to that of the US. This verifies that our estimates of the wages are reasonable.

We estimated intermediate goods competitiveness $D_n^j$ from subsection 3.3, and calculate $w_n$ from the last paragraph and $\pi_{nn}^j$ from the data. After that, we compute $\Phi_n^j = \frac{D_n^j}{\pi_{nn}^j}$. Then, intermediate goods technology stock $T_n^i$ is implicitly determined by the following equation:

$$D_n^i \equiv T_n^i \left(c_n^i\right)^{-\theta_i} = T_n^i \left(w_n\right)^{-\beta_n^i \theta_i} \left[\left[1-\beta_n^i\right]^{1-\beta_n^i} \left(\beta_n^i\right)^{\beta_n^i}\right]^{\theta_i} \prod_{j=1}^{K} \left[\frac{\Phi_n^j}{\left(\gamma_n^{ij}\right)^{-\theta_i}}\right]^{\gamma_n^{ij}\left(1-\beta_n^i\right)} \tag{14}$$

Hence, the change of $T_n^i$ can be obtained from

$$\widehat{T_n^i} = \frac{\widehat{D_n^i}}{\left(\widehat{w_n}\right)^{-\beta_n^i \theta_i} \prod_{j=1}^{K} \left(\widehat{\Phi_n^j}\right)^{\gamma_n^{ij}\left(1-\beta_n^i\right)}} \tag{15}$$

Similarly, we have

$$\widetilde{D_n^i} \equiv \widetilde{T_n^i} \left(c_n^i\right)^{-\widetilde{\theta_i}} = \widetilde{T_n^i} \left(w_n\right)^{-\beta_n^i \widetilde{\theta_i}} \left[\left[1-\beta_n^i\right]^{1-\beta_n^i} \left(\beta_n^i\right)^{\beta_n^i}\right]^{\widetilde{\theta_i}} \prod_{j=1}^{K} \left[\frac{\Phi_n^j}{\left(\gamma_n^{ij}\right)^{-\widetilde{\theta_i}}}\right]^{\gamma_n^{ij}\left(1-\beta_n^i\right)} \tag{16}$$

and

$$\widehat{\widetilde{T_n^i}} = \frac{\widehat{\widetilde{D_n^i}}}{\left(\widehat{w}_n\right)^{-\beta_n^i \widetilde{\theta_i}} \prod_{j=1}^{K} \left(\widehat{\Phi_n^j}\right)^{\gamma_n^{ij}\left(1-\beta_n^i\right)}} \tag{17}$$

Given parameters $\beta_n^i$, $\gamma_n^{ij}$, and $\theta_i$, we can solve for the technology stocks for intermediate/final goods based on equations (14) and (16), and calculate their changes based on equations (15) and (17). Consistent with the literature (e.g. Levchenko and Zhang (2016), and Rodrik (2013), both of whom show convergence in productivities), our estimation shows convergence of technology stocks across countries. Our estimated technology stocks (which can proxy for average productivities) grew systematically faster in countries whose technology stocks were initially relatively lower. This is shown in Figure 1. This is an important result. What distinguishes our result from that of Levchenko and Zhang (2016) is that we show convergence not only in the technology stock when intermediate and final goods are lumped together, but in the technology stocks of intermediate goods, intermediate services, final goods and final services separately and also sector by sector.

### 3.5 Estimating Trade Barriers

Bilateral trade costs for intermediate/final goods/services are estimated from

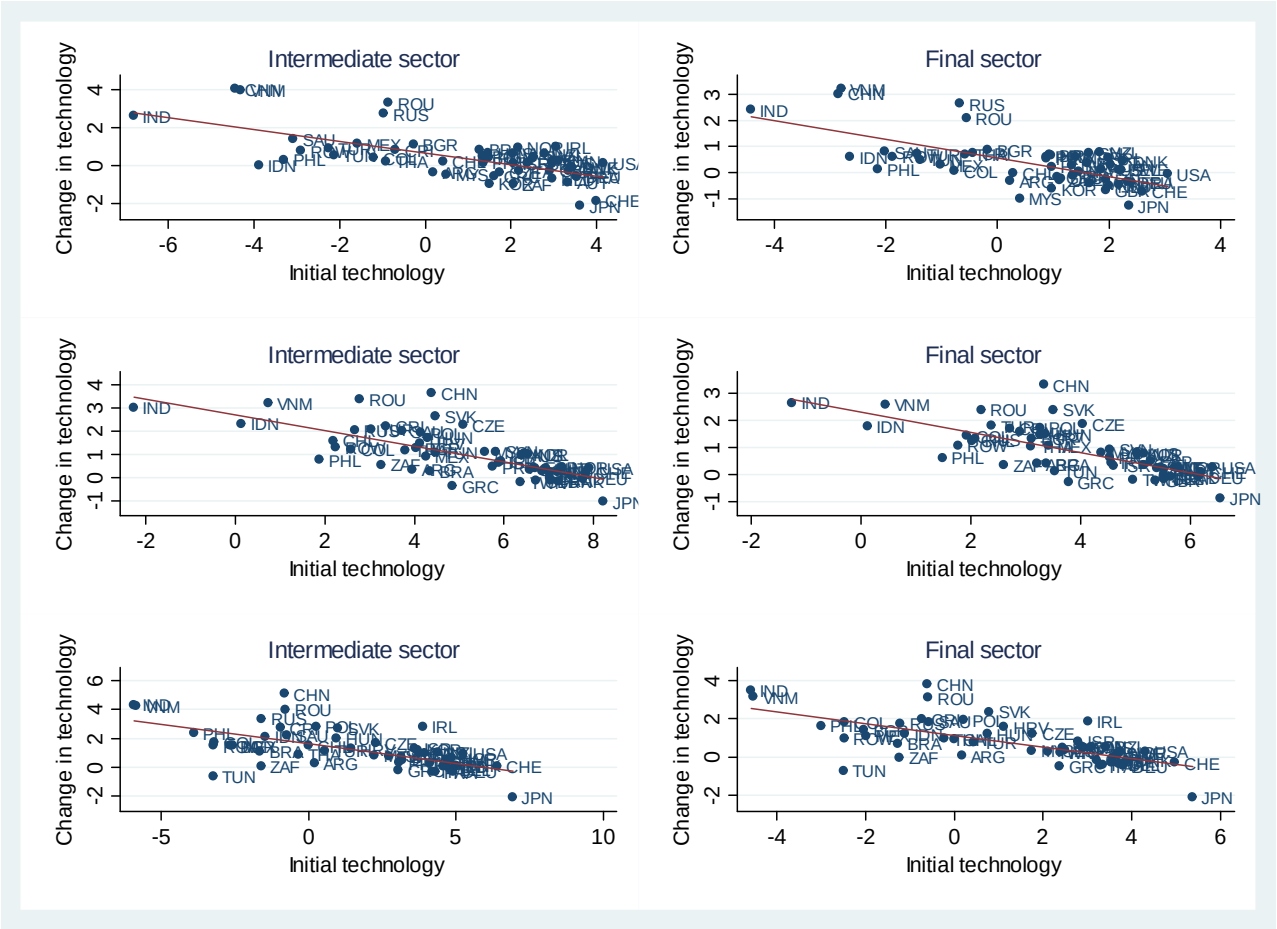



Figure 1: Convergence in Technology Stocks. The first row is for primary goods. The second row is for manufactured goods. The third row is for services.

$$\tau_{nl}^{i} = \frac{-1}{\theta_i}\left[\ln\left(\frac{X_{nl}^{i}}{X_{nn}^{i}}\right) - \ln D_{l}^{i} + \ln D_{n}^{i}\right]$$

and

$$\widetilde{\tau_{nl}^{i}} = \frac{-1}{\widetilde{\theta_i}}\left[\ln\left(\frac{\widetilde{X_{nl}^{i}}}{\widetilde{X_{nn}^{i}}}\right) - \ln \widetilde{D_{l}^{i}} + \ln \widetilde{D_{n}^{i}}\right]$$

where $\ln D_{l}^{i}$, $\ln D_{n}^{i}$, $\ln \widetilde{D_{l}^{i}}$, $\ln \widetilde{D_{n}^{i}}$ are estimated in subsection 3.3.

To further check the model's fit for the solution to our model, we binscatter the estimated trade cost against the physical distance between each country-pair in Figure A2 in the Appendix. We find a very strong positive correlation. This verifies that our estimates of trade costs are reasonable. More importantly, there is convergence in trade costs across countries, a pattern similar to the convergence in technology stocks. As shown in Figure 2, our estimated trade costs decline faster in regions with initially relatively higher trade costs. What is interesting is that this convergence result applies to trade costs in intermediate goods, intermediate services, final goods and final services separately and also sector by sector.

Thus, we have

**Result 1** *(Convergence in technology stocks and trade costs) Technology stocks grew systematically faster in countries whose technology stocks were initially relatively lower. Furthermore, trade costs decline faster in countries with initially relatively higher trade costs. These result applies to the technology stocks and trade costs in intermediate goods, intermediate services, final goods and final services separately.*

Table A2 in the appendix shows that the average percentage increase in technology stock and average percentage decrease in trade costs are both distinctly higher in developing countries.[8] This is consistent with Result 1, as developing countries tend to have lower initial technology stocks and higher initial trade costs.

# 4 Calculating change in GFT

In this section, we explain how we estimate the change in GFT of each country from our baseline model as well as the RP model and compare them. The changes in technology stocks and trade costs are estimated according to the procedure given in section 3.

[8] Table A2 shows that, for the period 1995-2017, on average, developing countries' intermediate (final) goods technology stock increases by a factor which is 39.6 (12.6) times that of developed countries. On average, developing countries' intermediate (final) goods trade cost decreases by a factor which is 0.82 (0.87) times that of developed countries.

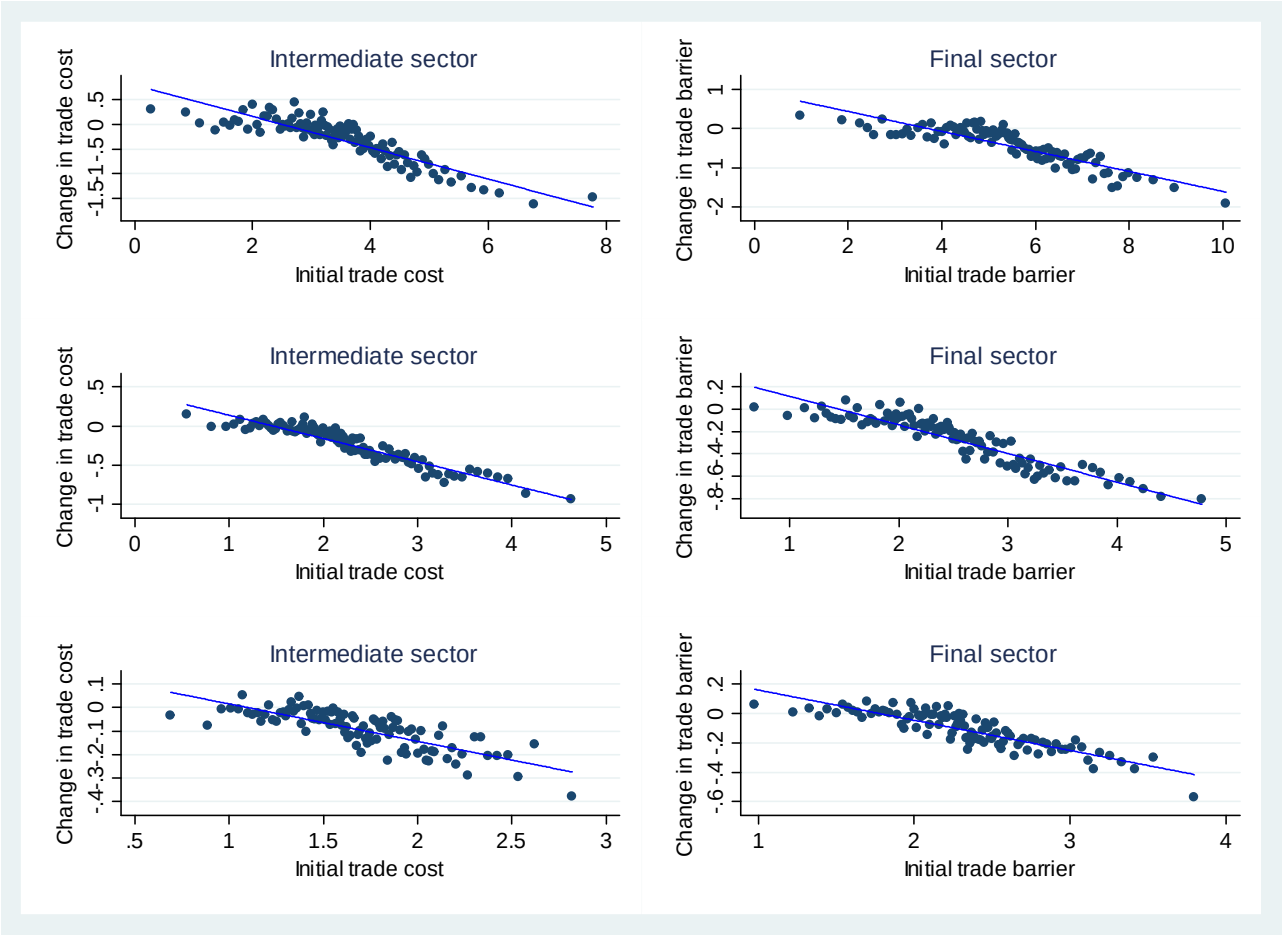



Figure 2: Convergence in Trade Costs. The first row is for primary goods. The second row is for manufactured goods. The third row is for services.

### 4.1 The fit of the baseline model

In Appendix B, we prove that the change in GFT of country $n$ resulting from changes in the domestic sourcing shares, $\left\{\widehat{\widetilde{\pi^i_{nn}}}\right\}_{i=1,...,K}$ and $\left\{\pi^j_{nn}\right\}_{j=1,...,K}$, is given by

$$\Delta GFT_n = \underbrace{\ln\left\{\prod_{i=1}^{K}\left(\widehat{\widetilde{\pi^i_{nn}}}\right)^{-\alpha^i_n/\widetilde{\theta}_i}\right\}}_{\text{Change in GFT in final goods}} + \underbrace{\ln\left\{\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\widehat{\pi^j_{nn}}\right)^{-\left(\alpha^i_n\cdot\delta^{ij}_n\right)/\theta_i}\right\}}_{\text{Change in GFT in intermediate goods}} \tag{18}$$

where $\delta^{ij}_n$ is a parameter related to the row $i$ column $j$ element of the Leontief inverse matrix defined in Appendix B. The first term represents the change in GFT in final goods, while the second term represents the change in GFT in intermediate goods. This equation is a modification of the formula for GFT by ACR, who do not distinguish between the domestic sourcing shares in intermediate and final goods/services.

We calculate the actual and estimated values of $\Delta GFT_n$. The actual value of $\Delta GFT_n$ is calculated from (18) using the values of $\left\{\widehat{\widetilde{\pi^i_{nn}}}\right\}_{i=1,...,K}$ and $\left\{\widehat{\pi^j_{nn}}\right\}_{j=1,...,K}$ in the beginning year (1995) and end year (2017) that are calculated directly based on the data in the Trade in Value-added (TiVA) data base. The estimated value of $\Delta GFT_n$ is calculated from (18) using the estimated values of $\left\{\widehat{\widetilde{\pi^i_{nn}}}\right\}_{i=1,...,K}$ and $\left\{\widehat{\pi^j_{nn}}\right\}_{j=1,...,K}$ based on the model, i.e. the system of equations stated in Appendix A by allowing all exogenous factors (including technology stocks, trade costs, and net exports) in the intermediate and final goods/services sectors in all countries to change.

Table 2 reports the actual (data-generated) and estimated (model-generated) change in GFT.[9] As shown in the table, the fit of our model is very good for both developed countries and developing countries.In Table 2, we also show a breakdown of the average change in GFT into those due to final goods and intermediate goods for the period 1995-2017. In Figure 3, we plot the estimated change in GFT against the actual one for intermediate goods and final goods, respectivly, for each country. Our model can explain 99.1% of the variance of the actual change in GFT in final goods and 81.6% of the variance of the actual change in GFT in intermediate goods (this value is lower than that for final goods because of an outlier Vietnam). This demonstrates that the Ricardian model with fragmentation and I-O linkages is very powerful in explaining the data, in particular the domestic sourcing shares of countries.

Table A2 shows that developing countries had faster increases in technology stocks and faster decreases in trade costs, while Table 2 shows that the average increase in GFT is smaller for developing countries than for developed countries. In fact, these two facts are related. Later in the paper, in Table 3, we

[9] The average change in domestic GFT due to the global changes in each exogenous factor are reported in Table A1 in the Appendix.

Table 2: Model Fit concerning the average change in GFT in intermediate goods and final goods

| **Change in GFT** | All Countries | | Developed Countries | | Developing Countries | |
|---|---|---|---|---|---|---|
| | Actual | Estimated | Actual | Estimated | Actual | Estimated |
| Total | 6.047% | 6.065% | 7.044% | 6.874% | 5.291% | 5.520% |
| Intermediate Goods | 3.667% | 3.802% | 3.845% | 3.719% | 3.532% | 3.864% |
| Final Goods | 2.379% | 2.263% | 3.200% | 3.065% | 1.757% | 1.656% |

Note: Odd columns report actual average change in GFT calculated based on the actual domestic sourcing shares of countries; even columns report estimated average change in GFT calculated based on the estimated domestic sourcing shares of countries.

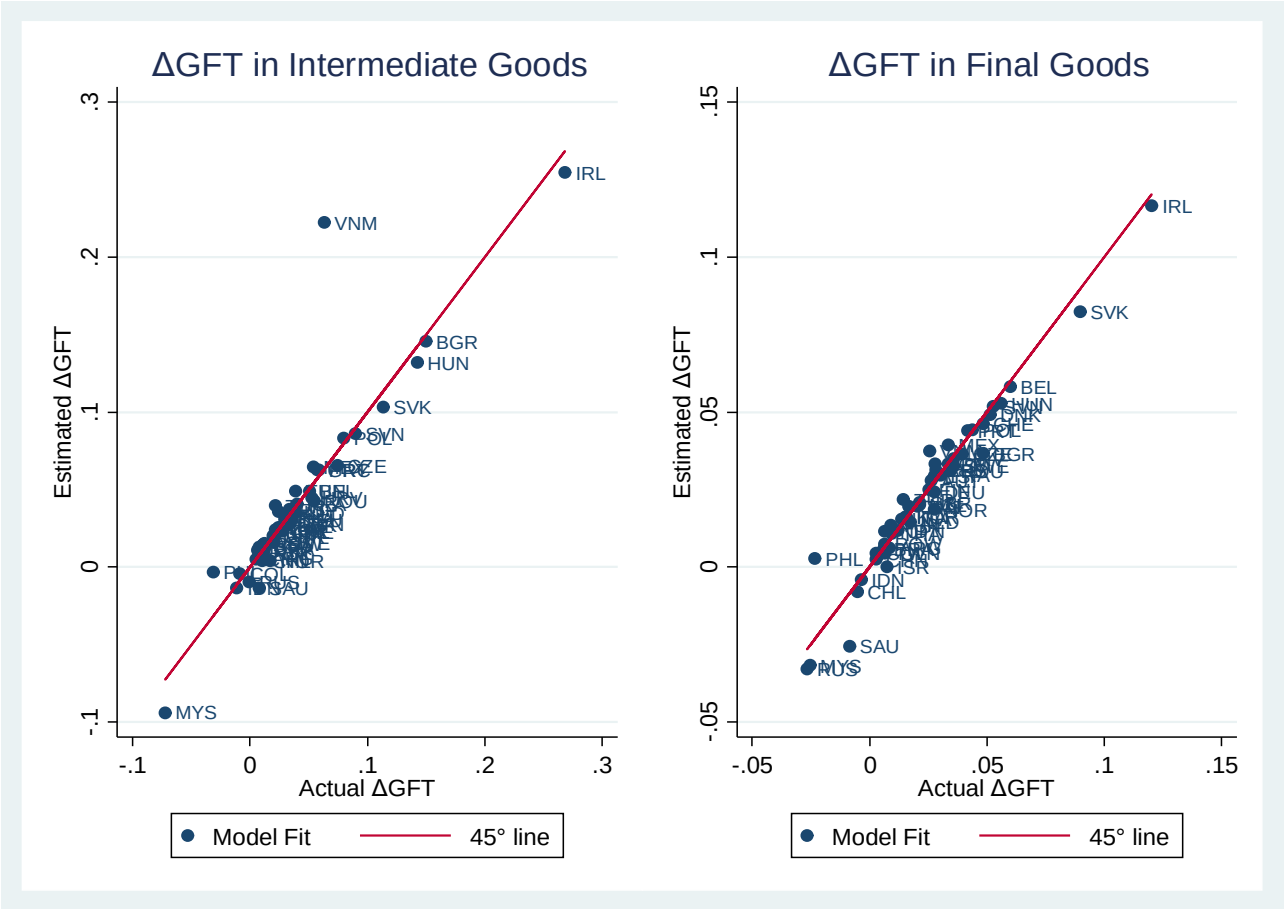



Figure 3: Model Fit for Intermediate Goods and Final Goods

show that increases (decreases) in technology stocks (trade costs) tended to reduce (increase) the GFT in developing countries. Thus, the increase in GFT in developing countries is smaller mainly because the pace of increase in technology stocks in developing countries is faster.

### 4.2 The RP model

In Appendix C, we describe the calculation of the GFT under a roundabout production (RP) model. We obtain the following result:

**Result 2** *(Underestimation of GFT by the RP model) The change in GFT estimated by our baseline model, which distinguishes between intermediate and final goods, is 53% higher than that estimated by the RP model, which does not distinguish between intermediate and final goods.*

## 5 Variance Decomposition — Global Changes on Domestic GFT

In this section, we shall quantify the contributions of the global changes in the technology stocks, trade costs and net exports, to domestic GFT of countries. The system of equations shown in Appendix A shows that the domestic sourcing share for intermediate goods (and final goods) in each sector of each country is affected by the technology stocks and trade costs in the intermediate and final goods in all sectors in all countries. The domestic sourcing shares in intermediate and final goods will in turn determine the domestic GFT in these sectors. In this section, we carry out an accounting exercise of decomposing the contributions of global changes of these exogenous factors in all sectors to the variation of changes in GFT across countries. Specifically, the exogenous factors are: (a) intermediate and final goods technology stocks in each sector, (b) intermediate and final goods trade costs in each sector, (c) net exports. The unexplained part is the residual. To carry out this exercise, we follow Eaton, Kortum, and Kramarz's (2004) variance decomposition method commonly used in the international trade literature. In particular, we regress the value of the contribution of each of the above factors to the change in GFT of countries on the estimated total change in GFT of countries based on our model. For each country, the contribution of an exogenous factor to the change in domestic GFT is calculated as the average of its "pure effect" and "total effect", which are obtained from counterfactual exercises.[10] The *pure effect* of an exogenous factor is obtained by allowing only that factor (in all countries) to change while shutting down all other exogenous factors (in all countries). The *total effect* of an exogenous factor is equal to the following first effect minus second effect: 1. The first effect is obtained from allowing all factors (in all countries) to

[10] We can show that the sum over all factors of the average of the pure effect and the total effect of each factor is equal to the model prediction plus some higher-order ($\geq 3$) interactive terms, which are very small in the current setting. In other words, the contribution of the residual is of second order importance. Refer to Online Appendix H for a proof.

change. 2. The second effect is obtained from shutting down that factor (in all countries) while allowing all other factors (in all countries) to change.

We find that, for each country, calculating the average of the pure effect and the total effect of each factor and then adding these averages up over all factors delivers a very good fit of the model for the change of GFT of the country. The fits are distinctly better than using the pure effect or total effect alone. The reason is that it takes into account the interactive effects among factors, which can be quite substantial. In fact, the use of the average of the pure effect and total effect to proxy for the contribution of a factor is a novel technique of this paper. This method can possibly be applied to many other contexts where the higher-order (i.e. higher than second-order) interactive terms are very small. It is the use of this proxy that allows us to carry out variance decomposition with the confidence that the contribution of each factor calculated by us is reasonable.

The average change in domestic GFT due to the global changes in each exogenous factor are reported in Table A1 in the Appendix. The variance decomposition results for the change in GFT across all countries are reported in Row A of Table 3. The variance is mostly explained by global changes in trade costs ($0.705 + 0.471 = 1.176 = 117.6\%$ for intermediate goods trade costs and final goods trade costs together), followed by global increases in the technology stocks, which contribute negatively ($-0.241 + 0.03 = -0.211 = -21.1\%$ for intermediate and final goods together). So, global changes in trade costs and technology stocks together explain $117.6\% - 21.1\% = 96.5\%$ of the variance in changes in GFT. The intuition is that domestic and foreign reduction of trade costs tend to reduce the domestic sourcing share, increasing GFT. On the other hand, when domestic technological improvement is faster than the global average (which is true for developing countries, which dominate the effect of the global changes in technology), it tends to increase the domestic sourcing share, reducing GFT. Note that focusing on reduction of trade costs would have over-estimated the change in GFT of nations. The changes in technology stocks play a non-trivial role in mitigating the effects of trade cost reduction. This is a direct consequence of the Ricardian model. But the previous literature tends to overlook this aspect.

We also carry out the variance decomposition for the developed and developing countries separately, as shown in Rows B and C of Table 3. Comparing the two rows, it can be seen that the magnitudes of the effects are stronger in developing countries. This is due to the distinctly faster rates of change of both the technology stocks and trade costs in the developing countries during the sample period 1995-2017 due to convergence of both variables.

Thus, we have

**Result 3** *Global reduction in trade costs, which impacted average GFT positively, and global increases in technology stocks, which impacted average GFT negatively, together explain 97% of the variance of changes in GFT of countries. These effects are stronger in developing countries because of the convergence*

Table 3: Variance decomposition of the contribution of global changes to the variance of domestic changes in GFT

| **Contribution to Variance of Changes in GFT** | $T_{int}$ | $T_{fnl}$ | $\tau_{int}$ | $\tau_{fnl}$ | $NX$ | Residual |
|---|---|---|---|---|---|---|
| Row A: All Countries | -0.241 | 0.030 | 0.705 | 0.471 | 0.008 | 0.028 |
| Row B: Developed Countries | -0.047 | 0.060 | 0.578 | 0.396 | -0.048 | 0.062 |
| Row C: Developing Countries | -0.435 | -0.001 | 0.832 | 0.546 | 0.063 | -0.006 |

Note: Rows A, B and C report the contribution of global changes in each factor to the variance of the changes in GFT across all countries, developed countries and developing countries, respectively. $T_{int}$ ($\tau_{int}$) is technology (trade costs) in intermediate goods; $T_{fnl}$ ($\tau_{fnl}$) is technology (trade costs) in final goods; NX is net exports.

*phenomenon.*

# 6 Impacts on Foreign Countries and Policy Implications

## 6.1 Impacts on Foreign Countries

In the previous sections, we have carried out counterfactual exercises to understand the impacts of global changes in each exogenous factor on the GFT of the home country. In this section, we compute the impact of the foreign changes in each exogenous factor on the home country's GFT.

First, we compute the impact of each of the following domestic exogenous factors on the domestic GFT: the domestic (a) intermediate goods technology stocks of all sectors; (b) final goods technology stocks of all sectors; (c) intermediate goods trade costs in all sectors; (d) final goods trade costs in all sectors. ; (e) domestic net exports. We carry out counterfactuals to estimate the contribution of each of the above factors to the domestic change in GFT. As before, the contribution of an exogenous factor is calculated as the average of its pure effect and total effect. The pure effect of an exogenous factor of a country is obtained by allowing only that factor in that country to change while shutting down all other exogenous factors in that country and all exogenous factors in other countries. The total effect of an exogenous factor of a country is equal to the following first effect minus the second effect. 1. Allowing all factors in all countries to change. 2. Shutting down that factor in that country while allowing all other exogenous factors in that country and all exogenous factors in other countries to change.

Row A of Table 4 shows the average contribution of each domestic factor to the change in domestic GFT. We see that reduction of domestic trade costs accounts for $3.87\% + 2.74\% = 6.61\%$ of the change in domestic GFT. The positive impact makes sense, as decreases of trade costs lower domestic sourcing

shares. On the other hand, increases in domestic technology stocks account for $-4.39\%+0.16\% = -4.23\%$ of the change in domestic GFT. The negative impact makes sense as increases in domestic technology stocks raise domestic sourcing shares.

Next, we compare the effects of global changes and domestic changes on domestic GFT. Row B of Table 4 shows the average contribution of the global changes of each factor to the change in domestic GFT. It is taken from the the first line of Table A1 in the appendix,which is the outcome of the previous counterfactual exercise. Row C shows the average contribution of the foreign changes of each factor to the change in domestic GFT. By definition, Row C is equal to Row B minus Row A. Comparing Row A with Row B, we see that, averaging over all countries, the contribution of domestic changes to domestic GFT (2.126%) is significantly smaller than the contribution of global changes to domestic GFT (6.065%). Let us define "foreign contribution" to a country as the contribution of changes in foreign factors to the increase in domestic GFT of the country, as shown in Row C. From Row C, one can see that foreign contribution on average account for 3.939% or 65 percent (= 3.939/6.065) of the changes in domestic GFT of countries. Furthermore, most of the foreign contribution comes from technological improvement (the contribution of foreign technological changes is equal to $2.678\% + 0.223\% = 2.901\%$) rather than trade costs reduction (the contribution of foreign changes in trade costs is equal to $0.764\%+0.145\% = 0.909\%$). The contribution of foreign changes in NX, net exports, is merely equal to 0.130%. Thus, international technological changes accounts for 74 percent (=2.901/3.939) of the total international contribution. This makes sense since technological improvements in foreign countries have a positive and first order effect on domestic GFT through lowering the domestic sourcing share (refer to equations (6) and (7)). On the other hand, foreign countries' importing trade costs (i.e. domestic exporting trade costs) only have effects on domestic GFT through domestic wage, and the effects are more nuanced. In the context of the EK model, the contribution of technological changes here corresponds to "export-biased technological change", as the domestic country obtains higher GFT from the increases in technology stocks of foreign countries through importing their goods. (See, for example, Hsieh and Ossa 2016, who also express the view that technological changes are export-biased in nature in the EK model.) Thus, export-biased technological changes accounted for 48% ($= 0.65 \times 0.74$) of the increases in domestic GFT of countries during the sample period.

Table 4: Effects of Domestic, Global and Foreign Changes in Each factor on Change in Domestic GFT

| **Effects on Domestic GFT** | $T_{int}$ | $T_{fnl}$ | $\tau_{int}$ | $\tau_{fnl}$ | $NX$ | Total Effect |
|---|---|---|---|---|---|---|
| **Row A: Domestic Changes** | -4.393% | 0.159% | 3.866% | 2.744% | -0.251% | 2.126% |
| **Row B: Global Changes** | -1.715% | 0.382% | 4.630% | 2.889% | -0.121% | 6.065% |
| **Row C: Foreign Changes** | 2.678% | 0.223% | 0.764% | 0.145% | 0.130% | 3.939% |

Note: 1. The Effects of Foreign Changes on Domestic GFT are also referred to as "Foreign Contribution" in this paper.

2. Row C is equal to Row B minus Row A.

In fact, we can carry out counterfactuals to compute the bilateral contribution of each country's change in technology and trade costs on each of the other countries in the rest of the world. The result is a matrix of the bilateral contribution from the origin to the receiver country for all country pairs. Figure 4 and 5 show the result of such an exercise by way of a heat map. Red indicates positive contribution while blue indicates negative contribution. The darker the color the larger is the magnitude of the impact. From it, we are able to identify "friends" (positive contribution) and "foes" (negative contribution) in trade relationship among countries, in the spirit of Kleinman, Liu and Redding (2022). We see that China stands out as the country that has large and positive contribution to almost all other countries due to large changes of its technology stocks and trade costs. Thus, it has many "good friends" in trading relationship. By contrast, the US has mostly positive technology contribution but mostly negative trade cost contribution to other countries, while Japan has mostly negative technology contribution and trade cost contribution to other countries. Thus, the US has a mix bag of "friends" and "foes", while Japan has mostly "foes". This is because a country with larger increases (decreases) in technology stocks or larger reduction (increase) in importing trade costs will have greater positive (negative) contribution to the rest of the world. The fact is that China had large increases in technology stocks and large reduction in trade costs, while the US had moderate increases in technology stocks but increases in importing trade costs, and Japan had large decreases in technology stocks and also increases in importing trade costs.

The patterns in Figure 4 and 5 are perfectly consistent with those in Figure A4, in the appendix, which indicates that the sign and magnitude of the average contribution to the rest of the world of each country's change in technology stocks and importing trade costs, as well as the average total contribution. Here, we see more clearly that China has by far the largest contribution to the rest of the world. In the right hand panel, we see that, on average, trading with China increases a country's GFT by 1.221% during the period 1995-2017. Thus, noting that the average foreign contribution is equal to 3.939% (from Table 4), we can calculate that China is responsible for 1.221/3.939=31% of total foreign contribution from all countries. This is about 4 times the contribution of the second highest country (Russia) and larger than the sum of the contributions of the four highest countries below China. Last but not least, the right panel of Figure A4 shows that the countries contributing most to the rest of the world through trade were all developing countries (e.g. the top five are China, Russsia, India, Poland and South Korea). Thus, developing countries accounted for the lion's share of the evolution of globalization during 1995-2017.

So, we have

**Result 4** *1. Foreign contribution accounts for 65% of the increase in domestic GFT of countries. 2. Technological change accounts for 74% of foreign contribution. 3. China's contribution to the rest of the world accounts for 31% of total foreign contribution from all countries. 4. Export-biased technological change account for 48% of the increases in domestic GFT of countries. 5. Changes in developing countries account for the lion's share of the evolution of globalization.*

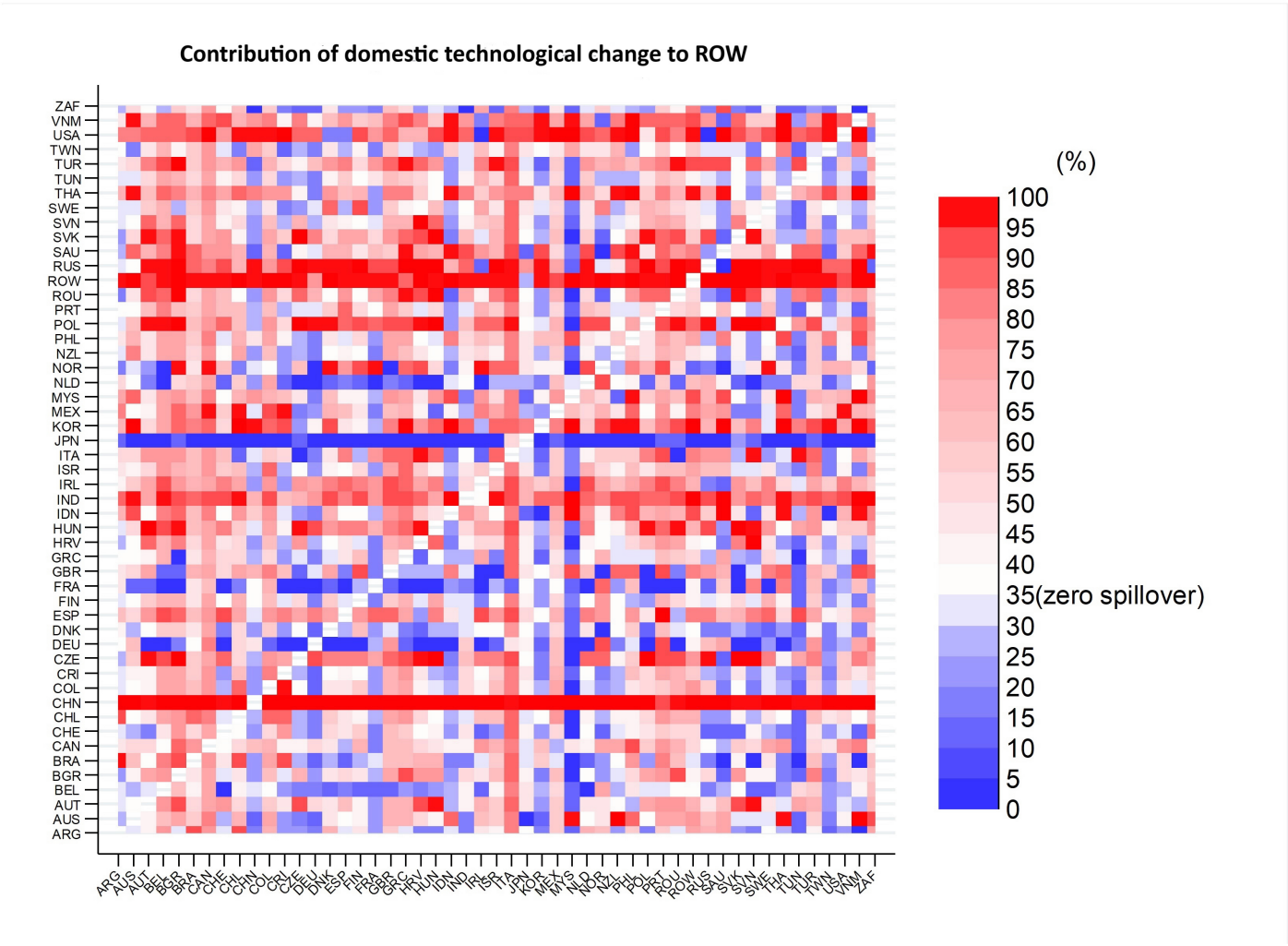



Figure 4: Contribution of change in technology stock of each country to the gains from trade of foreign countries.

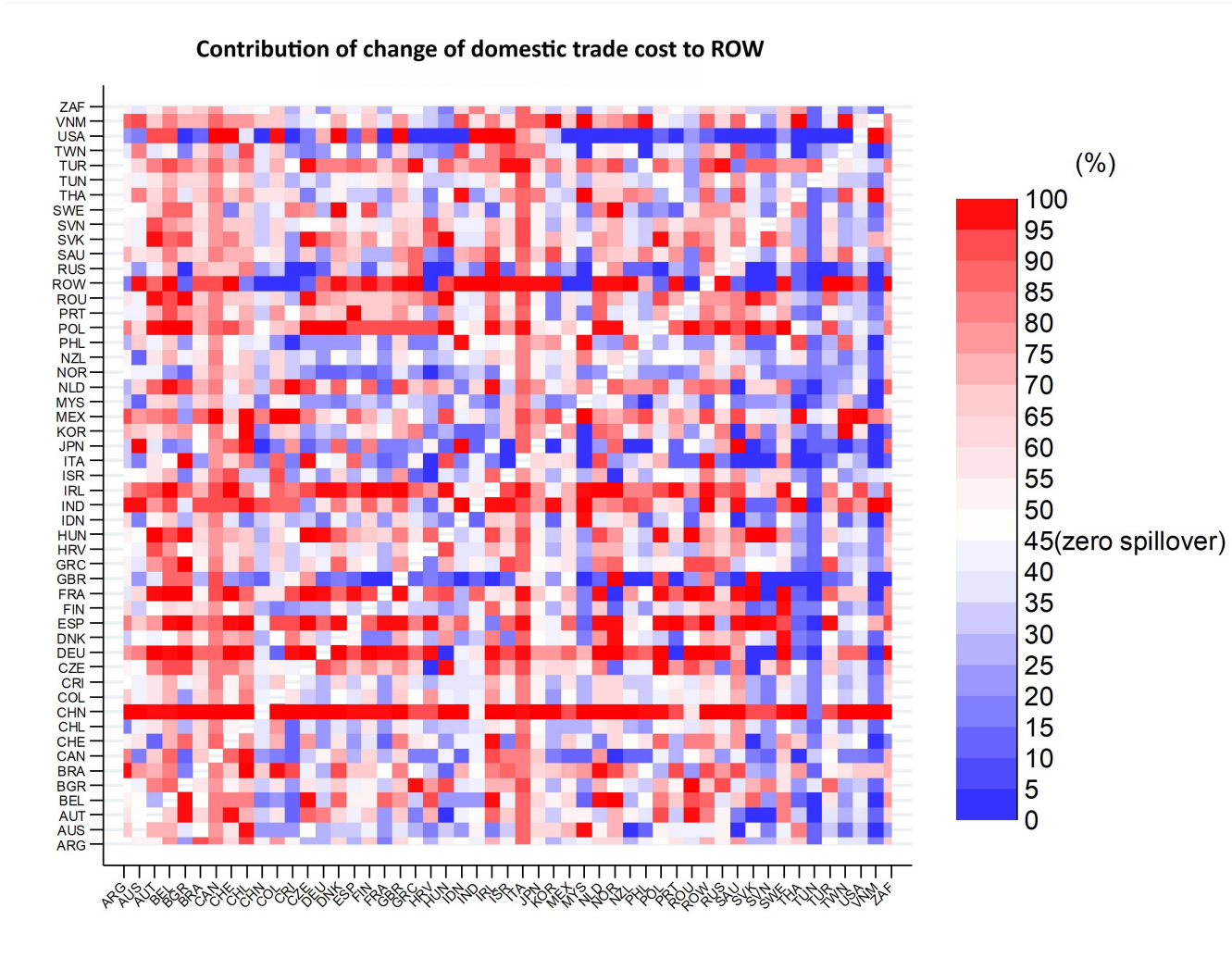



Figure 5: Contribution of change in importing trade cost of each country to the gains from trade of foreign countries.

### 6.2 Policy Implications: Elasticities of Domestic GFT w.r.t. Domestic Changes

To see more clearly the policy implications, in this subsection we calculate the impact of the domestic change in each exogenous factor on the home country's GFT. In Appendix D, we compute the elasticity of domestic GFT with respect to domestic change in each factor, and the result is shown in Table 5 in the appendix.

We conclude with the following result:

**Result 5** *The fact that (i) elasticities of domestic GFT w.r.t. domestic factors in the intermediate-goods sector are larger than elasticities w.r.t. domestic factors in the final-goods sector and (ii) that there are more trade in intermediate goods than in final goods, imply that policy measures pertaining to the intermediate goods sectors have higher impacts on the GFT than those pertaining to the final goods sectors.*

This result echoes the finding of Antras, Fort, Gutierrez and Tintelnot (2022), who argue that tariff escalation is an optimal policy, as reduction of tariffs on intermediate goods has larger GFT impacts than those on final goods.

## 7 Conclusion

Using a multi-sector general equilibrium Ricardian model with input-output linkages, we carry out counterfactual exercises to quantify the impacts of the global changes in technology stocks, trade costs and net exports on GFT of individual nations. We find that global changes in trade costs and technology stocks explain 97% of the variance of change in the degree of globalization across countries. Thus, the evolution of globalization during 1995-2017 was mainly driven by increases in technology stocks and reduction of trade costs of countries around the world. Changes in developing countries accounted for the lion's share of the deepening of globalization around the world. We also found that foreign changes contributed to an average of 65 percent of the increase in the degree of globalization of countries while domestic changes accounted for only 35 percent. China's contribution to the rest of the world through trade, which amounts to 31% of the world's total, is by far the largest among all countries.

In a more general model, it is conceivable that as a country trades more, it may lead to faster technological change in the country. For example, reduction of trade costs leads to more imports and exports, which can induce firms in the country to invest in improving productivity so as to capture more profits from exporting, or improving productivity so as to compete with foreign firms in the domestic market. In that case, reduction in trade costs and increases in technology stocks are not independent of

each other but linked. Consequently, we have to modify our model and our empirical analysis as well. This can be a topic for future research.

## References


[1] Alexander, Patrick. 2021. "Vertical Specialisation and Gains from Trade." *The World Economy*, **44(4)**, 1110-1140.

[2] Antras, Pol, and Davin Chor. 2013. "Organizing the Global Value Chain." *Econometrica* **81(6)**, 2127–2204.

[3] Antras, Pol, and Davin Chor. 2021. "Global Value Chains." in *Handbook of International Economics, vol. 5.*

[4] Antras, Pol and Alonso de Gortari. 2020. "On the Geography of Global Value Chains," *Econometrica*, **88(4)**, 1553-1598.

[5] Antras, Pol; Teresa Fort, Augustín Gutiérrez, and Felix Tintelnot. 2022. "Trade Policy and Global Sourcing: A Rationale for Tariff Escalation".Working Paper.

[6] Arkolakis, Costas; Arnaud Costinot, and Andres Rodriguez-Clare. 2012. "New Trade Models, Same Old Gains?." *American Economic Review*, **102(1)**, 94–130.

[7] Autor, David H., David Dorn, and Gordon H. Hanson. 2011. "The China Syndrome: Local Labor Market Effects of Import Competition in the United States." American Economic Review.

[8] Baldwin, Richard E., and Anthony Venables. 2013. "Spiders and Snakes: Offshoring and Agglomeration in the Global Economy." *Journal of International Economics* **90(2)**, 245–254.

[9] Bloom, Nicholas, Mirko Draca, and John Van Reenen. 2016. "Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity." *The Review Of Economic Studies* 83, no. 1: pp.87-117.

[10] Caliendo, L., M. Dvorkin, and F. Parro. 2019. "Trade and Labor Market Dynamics: General Equilibrium Analysis of the China Trade Shock." Econometrica, 87, pp.741–835.

[11] Caliendo, Lorenzo and Fernando Parro. 2015. "Estimates of the Trade and Welfare Effects of NAFTA." *Review of Economic Studies*. **82(1)**, 1-44.

[12] Costinot, Arnaud; Jonathan Vogel, and Su Wang. 2013. "An Elementary Theory of Global Supply Chains." *Review of Economic Studies* **80**, 109–144.

[13] Costinot, Arnaud and Andres Rodriguez-Clare. 2014. "Trade Theory with Numbers: Quantifying the Consequences of Globalization." *Handbook of International Economics Vol. 4*, Elsevier Publisher, 197-261.

[14] Dekle, Robert; Jonathan Eaton and Samuel Kortum. 2008. "Global Rebalancing with Gravity: Measuring the Burden of Adjustment." *IMF Economic Review* **55**, 511–540.

[15] Di Giovanni, J., Andrei Levchenko, and Jing Zhang. 2014. The global welfare impact of China: trade integration and technological change. Am. Econ. J. Macroecon. 6 (3), pp.153–183.

[16] Eaton, Jonathan and Samuel Kortum. 2002. "Technology, Geography and Trade." *Econometrica* **70(5)**, 1741–1779.

[17] Eaton, Jonathan, Samuel Kortum, and Francis Kramarz. 2004. "Dissecting Trade: Firms, Industries, and Export Destinations." AEA Papers and Proceedings, 94, pp.150–154.

[18] Fally, Thibault and Russell Hillberry. 2018. "A Coasian model of international production chains." *Journal of International Economics*, **114**, 299-315.

[19] Fontagné, Lionel, Houssein Guimbard, and Gianluca Orefice. "Tariff-based product-level trade elasticities." Journal of International Economics 137 (2022): 103593.

[20] Grossman, Gene M., and Esteban Rossi-Hansberg. 2008. "Trading Tasks: A Simple Theory of Offshoring." *American Economic Review* **98(5)**: 1978-1997.

[21] Head, Keith and Thierry Mayer. 2014. "Gravity Equations: Workhorse, Toolkit, Cookbook." *Handbook of International Economics Vol. 4*, Elsevier Publisher, 131-195.

[22] Head, Keith, Thierry Mayer, and John Ries. 2010. "The erosion of colonial trade linkages after independence." *Journal of International Economics.* **81(1)**, 1-14.

[23] Hottman, Colin J., Stephen J. Redding, and David E. Weinstein. 2016. "Quantifying The Sources Of Firm Heterogeneity." The Quarterly Journal of Economics (2016), pp.1–74.

[24] Hsieh, Chang-Tai, and Ralph Ossa. 2016. "A global view of productivity growth in China." *Journal of International Economics*, Volume 102, Pages 209-224.

[25] Hummels, D., J. Ishii, and Kei-Mu Yi. 2001. "The nature and growth of vertical specialization in world trade." *Journal of International Economics* **54**, 75–96.

[26] Johnson, Robert and Andreas Moxnes. 2019. "GVCs and Trade Elasticities with Multistage Production." NBER working paper. Conditional acceptance by Journal of International Economics.

[27] Johnson, R.C. and G. Noguera. 2012. "Accounting for intermediates: Production sharing and trade in value added." *Journal of International Economics* **86,** 224–236.

[28] Kee, Hiau Looi, and Heiwai Tang. 2016. "Domestic value-added in exports: Theory and firm evidence from China." *American Economic Review*, **106(6)**, 1402-1436.

[29] Kleinman, Benny, Ernest Liu, and Stephen J. Redding. 2022. "International Friends and Enemies." Working paper.

[30] Koopman, R., Zhi Wang, and Shang-Jin Wei. 2014 "Tracing Value-added and Double Counting in Gross Exports." *American Economic Review* **104(2)**: 459-494.

[31] Levchenko, Andrei A. and Jing Zhang. 2016. "The Evolution of Comparative Advantage: Measurement and Welfare Implications." *Journal of Monetary Economics* 78: 96–111

[32] Melitz, Marc J. and Redding, Stephen J., 2014. "Missing gains from trade?" *American Economic Review*, **104(5)**, 317-21.

[33] Ossa, Ralph. 2015. "Why Trade Matters after All." *Journal of International Economics*, **97(2)**, pp.266-277.

[34] Rodrik, Dani. 2013. "Unconditional Convergence in Manufacturing." *The Quarterly Journal of Economics* **128**, 165–204.

[35] Simonovska, Ina, and Michael E. Waugh. "The elasticity of trade: Estimates and evidence." Journal of international Economics 92, no. 1 (2014): 34-50.

[36] Swiecki, Tomasz. 2017. "Determinants of structural change." Review of Economic Dynamics 24, pp.95-131.

[37] Tombe, Trevor and Xiaodong Zhu. 2019. "Trade, Migration, and Productivity: A Quantitative Analysis of China." *American Economic Review* 109(5): pp.1843–1872. https://doi.org/10.1257/aer.20150811

[38] Yi, Kei-Mu. 2003. "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy*, **111(1)**, 52-102..

# Online Appendix

## A The System of Equations for Estimation: our baseline model

Following Dekle, Eaton, and Kortum (2008), we use exact hat algebra to characterize the equilibrium changes: $\widehat{x} = x'/x$. We solve for the following system of equations, which is the hat algebra form of equations (4), (5), (6), (7), (8), (9), (10) and (11).

$$
\begin{aligned}
\widehat{c_n^i} &= \left(\widehat{w_n}\right)^{\beta_n^i} \left[\prod_{j=1}^{K} \left(\widehat{P_n^j}\right)^{\gamma_n^{ij}}\right]^{1-\beta_n^i} \\
\widehat{P_n^i} &= \left[\sum_{m=1}^{N} \pi_{nm}^i \widehat{T_m^i} \left(\widehat{c_m^i} \cdot \widehat{\tau_{nm}^i}\right)^{-\theta_i}\right]^{-1/\theta_i} \\
\widehat{\widetilde{P_n^i}} &= \left[\sum_{m=1}^{N} \widetilde{\pi_{nm}^i} \cdot \widehat{\widetilde{T_m^i}} \left(\widehat{c_m^i} \cdot \widehat{\widetilde{\tau_{nm}^i}}\right)^{-\widetilde{\theta}_i}\right]^{-1/\widetilde{\theta}_i} \\
\widehat{\pi_{nl}^i} &= \widehat{T_l^i} \left(\frac{\widehat{c_l^i} \cdot \widehat{\tau_{nl}^i}}{\widehat{P_n^i}}\right)^{-\theta_i} \\
\widehat{\widetilde{\pi_{nl}^i}} &= \widehat{\widetilde{T_l^i}} \left(\frac{\widehat{c_l^i} \cdot \widehat{\widetilde{\tau_{nl}^i}}}{\widehat{\widetilde{P_n^i}}}\right)^{-\widetilde{\theta}_i} \\
\widehat{Y_n^i} &= \sum_{l=1}^{N} \widehat{\pi_{ln}^i} \pi_{ln}^i \sum_{j=1}^{K} \gamma_l^{ji} \cdot \widehat{Y_l^j} \cdot \frac{\left(1-\beta_l^j\right) Y_l^j}{Y_n^j} + \sum_{l=1}^{N} \widehat{\widetilde{\pi_{ln}^i}} \cdot \widetilde{\pi_{ln}^i} \cdot \alpha_l^i \cdot \frac{\widehat{w_l} \cdot w_l L_l - \widehat{NX_l} \cdot NX_l}{Y_n^i} \\
\widehat{X_n^i} &= \alpha_n^i \cdot \frac{w_n L_n \widehat{w_n} - NX_n \cdot \widehat{NX_n}}{X_n^i} + \sum_{j=1}^{K} \widehat{Y_n^j} \cdot \frac{\gamma_n^{ji} \left(1-\beta_n^j\right) Y_n^j}{X_n^i} \\
\sum_{i=1}^{K} \frac{Y_n^i}{\sum_{i=1}^{K} Y_n^i} \cdot \widehat{Y_n^i} &= \sum_{i=1}^{K} \frac{X_n^i}{\sum_{i=1}^{K} Y_n^i} \cdot \widehat{X_n^i} + \frac{NX_n}{\sum_{i=1}^{K} Y_n^i} \cdot \widehat{NX_n}
\end{aligned}
$$

## B Derivation of Equation (18)

Recall equations (7) and (8). Welfare of country $n$, $W_n$, is defined as the real wage of $n$. The percentage change in real wage in country $n$ is given by

$$\begin{aligned} d\ln W_n &= d\ln w_n - \sum_{i=1}^{K} \alpha_n^i d\ln \widetilde{P_n^i} \\ &= \sum_{i=1}^{K} \alpha_n^i \left( d\ln w_n + \frac{1}{\widetilde{\theta_i}} d\ln \widetilde{\Phi_n^i} \right) \qquad \text{from (8)} \\ &= \sum_{i=1}^{K} \alpha_n^i \left( d\ln w_n - d\ln c_n^i + \frac{d\ln \widetilde{T_n^i}}{\widetilde{\theta_i}} - \frac{d\ln \widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}} \right) \end{aligned} \tag{19}$$

where the last equality follows from $\frac{d\ln \widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}} = \frac{d\ln \widetilde{T_n^i}}{\widetilde{\theta_i}} - d\ln c_n^i - \frac{1}{\widetilde{\theta_i}} d\ln \widetilde{\Phi_n^i}$ (from (7)).

According to (4) and (5),

$$\begin{aligned} d\ln c_n^i &= \beta_n^i d\ln w_n + \left(1-\beta_n^i\right) \sum_{j=1}^{K} \gamma_n^{ij} d\ln P_n^j \qquad \text{for } i = 1, ..., K \\ &= \beta_n^i d\ln w_n - \left(1-\beta_n^i\right) \sum_{j=1}^{K} \gamma_n^{ij} \frac{d\ln \Phi_n^j}{\theta_i} \quad \text{(Note that } d\ln \Omega_n^i = 0 \text{ as } \Omega_n^i \text{ is constant.)} \end{aligned}$$

$$\begin{aligned} \Rightarrow \quad d\ln w_n - d\ln c_n^i &= \left(1-\beta_n^i\right) \sum_{j=1}^{K} \gamma_n^{ij} \left( d\ln w_n + \frac{d\ln \Phi_n^j}{\theta_i} \right) \qquad \text{for } i = 1, ..., K \\ &= \left(1-\beta_n^i\right) \sum_{j=1}^{K} \gamma_n^{ij} \left[ \left( d\ln w_n - d\ln c_n^j \right) + \frac{d\ln T_n^j}{\theta_i} - \frac{d\ln \pi_{nn}^j}{\theta_i} \right] \end{aligned} \tag{20}$$

where the last equality follows from $d\ln \pi_{nn}^j = d\ln T_n^j - \theta_i d\ln c_n^j - d\ln \Phi_n^j$ (from (6)).

For country $n$, define $\mathbf{c}_n \equiv \{\mathbf{d\ln w_n - d\ln c_n^j}\}$, which is a $K \times 1$ vector; define $\boldsymbol{\pi}_n \equiv \{\frac{d\ln T_n^j}{\theta_i} - \frac{d\ln \pi_{nn}^j}{\theta_i}\}$, which is also a $K \times 1$ vector; define $\mathbf{B}_n$ as a $K \times K$ diagonal matrix with the $j$th diagonal element being $\beta_n^j$; define $\boldsymbol{\Gamma}_n \equiv \{\gamma_n^{ij}\}$ as the $K \times K$ input-output matrix of country $n$ with $\gamma_n^{ij}$ being the element at the $i$th row and $j$th column. Thus, (20) can be rewritten as

$$\begin{aligned} \mathbf{c}_n &= \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n \left(\mathbf{c}_n + \boldsymbol{\pi}_n\right) \\ \Rightarrow \quad \mathbf{c}_n &= \left[\mathbf{I} - \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n\right]^{-1} \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n \boldsymbol{\pi}_n \\ &= \left\{\left[\mathbf{I} - \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n\right]^{-1} - \mathbf{I}\right\} \boldsymbol{\pi}_n \end{aligned}$$

where $\left[\mathbf{I} - \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n\right]^{-1}$ is a typical Leontief inverse matrix. Define $\delta_n^{ij}$ as the row $i$ column $j$ element of $\left[\mathbf{I} - \left(\mathbf{I} - \mathbf{B}_n\right) \boldsymbol{\Gamma}_n\right]^{-1} - \mathbf{I}$, the last line of the above equation becomes

$$d\ln w_n - d\ln c_n^i = \sum_{j=1}^{K} \delta_n^{ij} \left( \frac{d\ln \pi_{nn}^j}{\theta_i} - \frac{d\ln T_n^j}{\theta_i} \right) \quad \text{for } i, j = 1, ..., K. \tag{21}$$

Substituting (21) into (19), we obtain

$$\begin{aligned} d\ln W_n &= -\sum_{i=1}^{K}\alpha_n^i\left[\frac{d\ln\widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}}-\frac{d\ln\widetilde{T_n^i}}{\widetilde{\theta_i}}+\sum_{j=1}^{K}\delta_n^{ij}\left(\frac{d\ln\pi_{nn}^j}{\theta_i}-\frac{d\ln T_n^j}{\theta_i}\right)\right] \\ &= -\sum_{i=1}^{K}\alpha_n^i\left(\frac{d\ln\widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}}-\frac{d\ln\widetilde{T_n^i}}{\widetilde{\theta_i}}\right)-\sum_{i=1}^{K}\sum_{j=1}^{K}\alpha_n^i\delta_n^{ij}\left(\frac{d\ln\pi_{nn}^j}{\theta_i}-\frac{d\ln T_n^j}{\theta_i}\right) \end{aligned}$$

Under autarky, $\widetilde{\pi_{nn}^i}=\pi_{nn}^j=1$ for all i and j. So, $d\ln\widetilde{\pi_{nn}^i}=d\ln\pi_{nn}^j=0$. Define the autarky welfare as $W_n^A$. Then

$$d\ln W_n^A=-\sum_{i=1}^{K}\alpha_n^i\left(-\frac{d\ln\widetilde{T_n^i}}{\widetilde{\theta_i}}\right)-\sum_{i=1}^{K}\sum_{j=1}^{K}\alpha_n^i\delta_n^{ij}\left(-\frac{d\ln T_n^j}{\theta_i}\right)$$

$$\begin{aligned} \text{Define}\quad GFT_n &= \ln\left(W_n/W_n^A\right). \\ \text{Then,}\quad dGFT_n &= d\ln W_n-d\ln W_n^A \\ &= -\sum_{i=1}^{K}\alpha_n^i\left(\frac{d\ln\widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}}\right)-\sum_{i=1}^{K}\sum_{j=1}^{K}\alpha_n^i\delta_n^{ij}\left(\frac{d\ln\pi_{nn}^j}{\theta_i}\right) \end{aligned}$$

Therefore,

$$\begin{aligned} GFT_n &= -\sum_{i=1}^{K}\alpha_n^i\left(\frac{\ln\widetilde{\pi_{nn}^i}}{\widetilde{\theta_i}}\right)-\sum_{i=1}^{K}\sum_{j=1}^{K}\alpha_n^i\delta_n^{ij}\left(\frac{\ln\pi_{nn}^j}{\theta_i}\right)+C_1 \qquad \text{where } C_1 \text{ is a constant} \\ &= \ln\left\{\prod_{i=1}^{K}\left(\widetilde{\pi_{nn}^i}\right)^{-\alpha_n^i/\widetilde{\theta_i}}\right\}+\ln\left\{\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\pi_{nn}^j\right)^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\}+\ln C_2 \qquad \text{where } C_2 \text{ is a constant} \\ &= \ln\left\{C_2\cdot\prod_{i=1}^{K}\left(\widetilde{\pi_{nn}^i}\right)^{-\alpha_n^i/\widetilde{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\pi_{nn}^j\right)^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\} \end{aligned}$$

$$\text{New value of GFT}\qquad (GFT_n)'=\ln\left\{C_2\cdot\prod_{i=1}^{K}\left[\left(\widetilde{\pi_{nn}^i}\right)'\right]^{-\alpha_n^i/\widetilde{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left[\left(\pi_{nn}^j\right)'\right]^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\}$$

$$\begin{aligned} \text{Change in GFT}\quad \Delta GFT_n &= (GFT_n)'-GFT_n=\ln\left\{C_2\cdot\prod_{i=1}^{K}\left[\left(\widetilde{\pi_{nn}^i}\right)'\right]^{-\alpha_n^i/\widetilde{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left[\left(\pi_{nn}^j\right)'\right]^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\} \\ &\quad -\ln\left\{C_2\cdot\prod_{i=1}^{K}\left(\widetilde{\pi_{nn}^i}\right)^{-\alpha_n^i/\widetilde{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\pi_{nn}^j\right)^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\} \\ &= \ln\left\{\prod_{i=1}^{K}\left(\widehat{\widetilde{\pi_{nn}^i}}\right)^{-\alpha_n^i/\widetilde{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\widehat{\pi_{nn}^j}\right)^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\theta_i}\right\} \end{aligned}$$

from which we obtain equation (18).

# C The RP Model

## C.1 The System of Equations under RP:

If we do not distinguish between the production functions and trade flows of intermediate goods and those of final goods, our baseline model will be reduced to the multi-sector EK model with roundabout production, which we call the "RP model". The general equilibrium under the RP model is defined by the following system of equations:

$$
\begin{aligned}
c_n^i &= \left[\frac{\prod_{j=1}^K \left(\frac{P_n^j}{\gamma_n^{ij}}\right)^{\gamma_n^{ij}}}{1-\beta_n^i}\right]^{1-\beta_n^i} \left(\frac{w_n}{\beta_n^i}\right)^{\beta_n^i} && \text{Cost of an input bundle} \\
P_n^i &= \left[\sum_{m=1}^N T_m^i \left(c_m^i \tau_{nm}^i\right)^{-\overline{\theta_i}}\right]^{-1/\overline{\theta_i}} && \text{Unit price of a sector-i good} \\
\pi_{nl}^i &= \frac{T_l^i \left(c_l^i \tau_{nl}^i\right)^{-\overline{\theta_i}}}{\sum_{m=1}^N T_m^i \left(c_m^i \tau_{nm}^i\right)^{-\overline{\theta_i}}} && \text{Sector-}i\text{ good trade share of } l \text{ in } n \\
Y_n^i &= \sum_{l=1}^N \pi_{ln}^i \sum_{j=1}^K \gamma_l^{ji} Y_l^j \left(1-\beta_l^j\right) + \sum_{l=1}^N \pi_{ln}^i \alpha_l^i \left(w_l L_l - NX_l\right) && \text{Goods market clearing condition} \\
X_n^i &= \alpha_n^i \left(w_n L_n - NX_n\right) + \sum_{j=1}^K \gamma_n^{ji} \left(1-\beta_n^j\right) Y_n^j && \text{Total expenditure on sector-i goods by } n \\
NX_n &= \sum_{i=1}^K Y_n^i - \sum_{i=1}^K X_n^i && \text{Net exports = output minus expenditure}
\end{aligned}
$$

Using the hat algebra form of the above equations, we estimate change in GFT for the RP model. The percentage change in GFT (i.e. real wage) of country $n$ under the RP model is given by:

$$
\begin{aligned}
d\ln W_n &= d\ln w_n - d\ln P_n \\
&= d\ln w_n - \sum_{i=1}^K \alpha_n^i d\ln P_n^i \\
&= \sum_{i=1}^K \alpha_n^i (d\ln w_n + \frac{1}{\overline{\theta}_i} d\ln \Phi_n^i) \\
&= -\sum_{i=1}^K \sum_{j=1}^K \alpha_n^i \lambda_n^{ij} \cdot \frac{d\ln \pi_{nn}^j}{\overline{\theta}_i}
\end{aligned}
$$

where $\lambda_n^{ij} = \delta_n^{ij} + \mathbf{1}^{ij}$ where $\mathbf{1}^{ij}$ is an indicator variable which is equal to 1 iff $i = j$ and 0 otherwise.

## C.2 Calculation of Change in GFT under RP:

If we do not distinguish between the production functions and trade flows of intermediate goods and those of final goods, the sector-$i$ market share of goods in $n$ imported from $l$ is given by

$$\overline{\pi_{nl}^i} = \frac{X_{nl}^i + \widetilde{X}_{nl}^i}{X_n^i},$$

and our baseline model is reduced to a multi-sector EK model with roundabout production. There are still input-output linkages.[11] We call this model the "RP model". Hereinafter, we use symbols with an upper bar to denote variables pertaining to the RP model. The system of equations that determine the general equilibrium is shown in Appendix C. We estimate the country changes in GFT under the RP model and compare them with those under our baseline model. Under the RP model, we re-estimate the trade elasticity and the changes of technology stocks and trade barriers without distinguishing between trade in intermediate goods and final goods. Denote the trade elasticity for the RP model in sector i by $\overline{\theta_i}$. The estimates of $\overline{\theta_i}$ are listed in Table A4. As in our baseline model, there is convergence in technology stocks in the sense that the estimated technology stocks grew faster in countries whose technology stocks were initially relatively low. There is also convergence in trade costs, as in the baseline model. The change in GFT of country $n$, $\Delta\overline{GFT}_n$, under the RP model is given by

$$\Delta\overline{GFT}_n = \ln\left\{\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\widehat{\overline{\pi_{nn}^j}}\right)^{-\left(\alpha_n^i\cdot\lambda_n^{ij}\right)/\overline{\theta_i}}\right\} \tag{22}$$

with $\lambda_n^{ij} = \delta_n^{ij} + \mathbf{1}^{ij}$ where $\mathbf{1}^{ij}$ is an indicator variable which is equal to 1 iff $i = j$ and 0 otherwise.[12]

In Figure 6, we plot the change in GFT under our baseline model against the change in GFT under the RP model (which is also called the standard model) for all countries for the period 1995-2017. It is quite clear that the RP model underestimates the changes in GFT of almost all countries compared to our baseline model. The slope of the fitted line is 1.53, which implies that the estimated change in GFT by our model is on average 53% higher than that estimated by the RP model. The previous literature, such

[11] The RP model here is similar to the model in Caliendo and Parro (2015). The difference is that we assume that services are tradable, while they assume that services are non-tradable.

[12] In the RP model, $\widehat{\overline{\pi_{nn}^i}} = \widehat{\pi_{nn}^i} = \widehat{\overline{\pi_{nn}^i}}$, and $\widehat{\overline{\theta_i}} = \widehat{\theta_i} = \widehat{\overline{\theta_i}}$. Thus, equation (18) becomes

$$\begin{aligned}\widehat{\overline{GFT}_n} &= \prod_{i=1}^{K}\left(\widehat{\overline{\pi_{nn}^i}}\right)^{-\alpha_n^i/\overline{\theta_i}}\cdot\prod_{i=1}^{K}\prod_{j=1}^{K}\left(\widehat{\overline{\pi_{nn}^j}}\right)^{-\left(\alpha_n^i\cdot\delta_n^{ij}\right)/\overline{\theta_i}} \\ &= \prod_{i=1}^{K}\prod_{j=1}^{K}\left(\widehat{\overline{\pi_{nn}^j}}\right)^{-\left(\alpha_n^i\cdot\lambda_n^{ij}\right)/\overline{\theta_i}}\end{aligned}$$

where $\lambda_n^{ij} = \delta_n^{ij} + \mathbf{1}^{ij}$, with $\mathbf{1}^{ij}$ being an indicator variable which is equal to 1 iff $i = j$ and 0 otherwise.

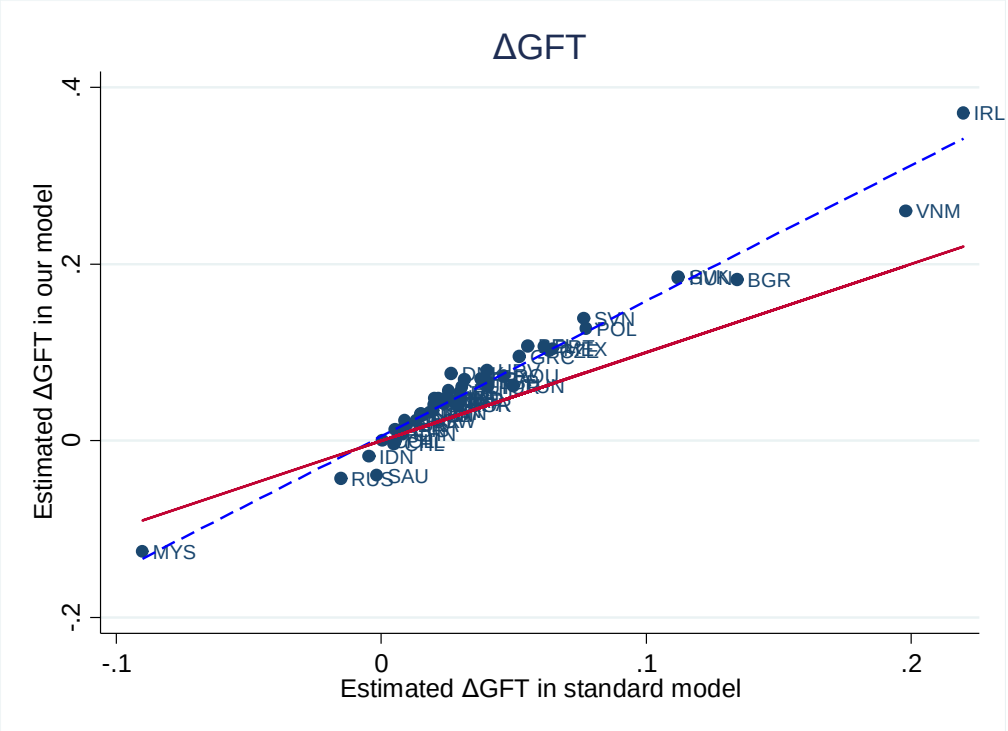



Figure 6: The Estimated Change in GFT in Our Baseline Model vs. the RP Model for All Countries. The red line is the 45 degree line.

as Antras and Chor (2021) and Antras and de Gortari (2020) already point out that the RP model can yield substantially lower predicted GFT than one that features fragmentation (multi-stage production in their cases). Although our baseline model is different from that of Antras and de Gortari (2020), it is interesting to see that their model yields 60% higher GFT than the version without multi-stage production, a number similar to ours. The similarity of the quantitative outcome of our paper with that of Antras and de Gortari (2020) is remarkable.

Thus, we have Result 2.

## D Elasticities of Domestic GFT w.r.t. Domestic Changes

To estimate the effect of domestic policies on domestic GFT, we compute the elasticity of domestic GFT with respect to (w.r.t.) domestic change in each exogenous factor by calculating the percentage change in domestic GFT caused by a 1% increase in the factor. In other words, we calculate the average of the pure effect of a 1% domestic increase of that factor and the total effect of 1% domestic increase of that

factor.[13] Then, we compute the average elasticity across countries. This exercise can inform domestic policy makers of the average impacts of changing the policy variables such as domestic technology stocks and domestic trade costs on the GFT of the home country.

Table 5 shows the mean elasticity across countries of domestic GFT w.r.t. domestic changes in technology stocks and importing trade costs.The mean elasticities across all countries of GFT w.r.t. intermediate and final technology stocks are negative, as expected. The mean elasticity of GFT w.r.t. intermediate goods technology is distinctly larger than that w.r.t. final goods technology (the former is about three times the latter). This is due to the multiplier effect to be explained below. Furthermore, the mean elasticities across all countries of GFT w.r.t. intermediate and final goods trade costs are both negative, as expected, as lower trade costs lead to larger GFT. In addition, the mean elasticity w.r.t. intermediate goods trade costs is distinctly larger than that w.r.t. final goods trade costs (the former is about twice the latter). As explained below, this is again due to the multiplier effect.

Table 5: Mean elasticity of domestic GFT with respect to domestic change in each factor

| **Elasticities of domestic GFT w.r.t. domestic factors** | All Countries | Developing Countries | Developed Countries |
|---|---|---|---|
| Intermediate goods technology | -0.032 | -0.034 | -0.031 |
| Final goods technology | -0.011 | -0.010 | -0.013 |
| Intermediate goods importing trade costs | -0.199 | -0.203 | -0.197 |
| Final goods importing trade costs | -0.101 | -0.099 | -0.107 |

Note: Trade cost of each country is average importing trade cost.

As mentioned above, there is a *multiplier effect* of reduction of trade costs (or changes in technology stocks) for intermediate goods on the GFT: The reduction of importing trade costs (or reduction of technology stocks) in intermediate goods lowers the domestic sourcing share $\pi^i_{nn}$ in sector i, increasing the GFT in intermediate goods in that sector. Due to input-output linkages, cheaper imported intermediate goods lower the domestic costs of production of all intermediate goods in all sectors, which lowers the domestic costs of production of all intermediate goods further, and so on. This amplifies the effect of a reduction in $\pi^i_{nn}$. By contrast, no such effect exists for final goods.[14] The multiplier effect, and the fact

[13] The pure effect is obtained by hypothetically increasing that factor in that country by 1% while shutting down all other exogenous factors in that country and all exogenous factors in other countries. The total effect is equal to the following first effect minus the second effect. 1. Allowing all factors in all countries to change. 2. Hypothetically reducing that factor in that country by 1% while allowing all other exogenous factors in that country and all exogenous factors in other countries to change.

[14] In the context of equation (18), this multiplier effect is reflected in a larger magnitude of the exponent for $\pi^i_{nn}$ than that for $\widetilde{\pi^i_{nn}}$ due to the parameter $\delta^{ij}_n$ (which is much greater than one), as well as the existence of two multiplication operators in the term "Change in GFT in intermediate goods" instead of one such operator in the term "Change in GFT in final goods". The fact that average value of the cost share of intermediate goods in production (1-$\beta^i_n$) is quite large (about 2/3)

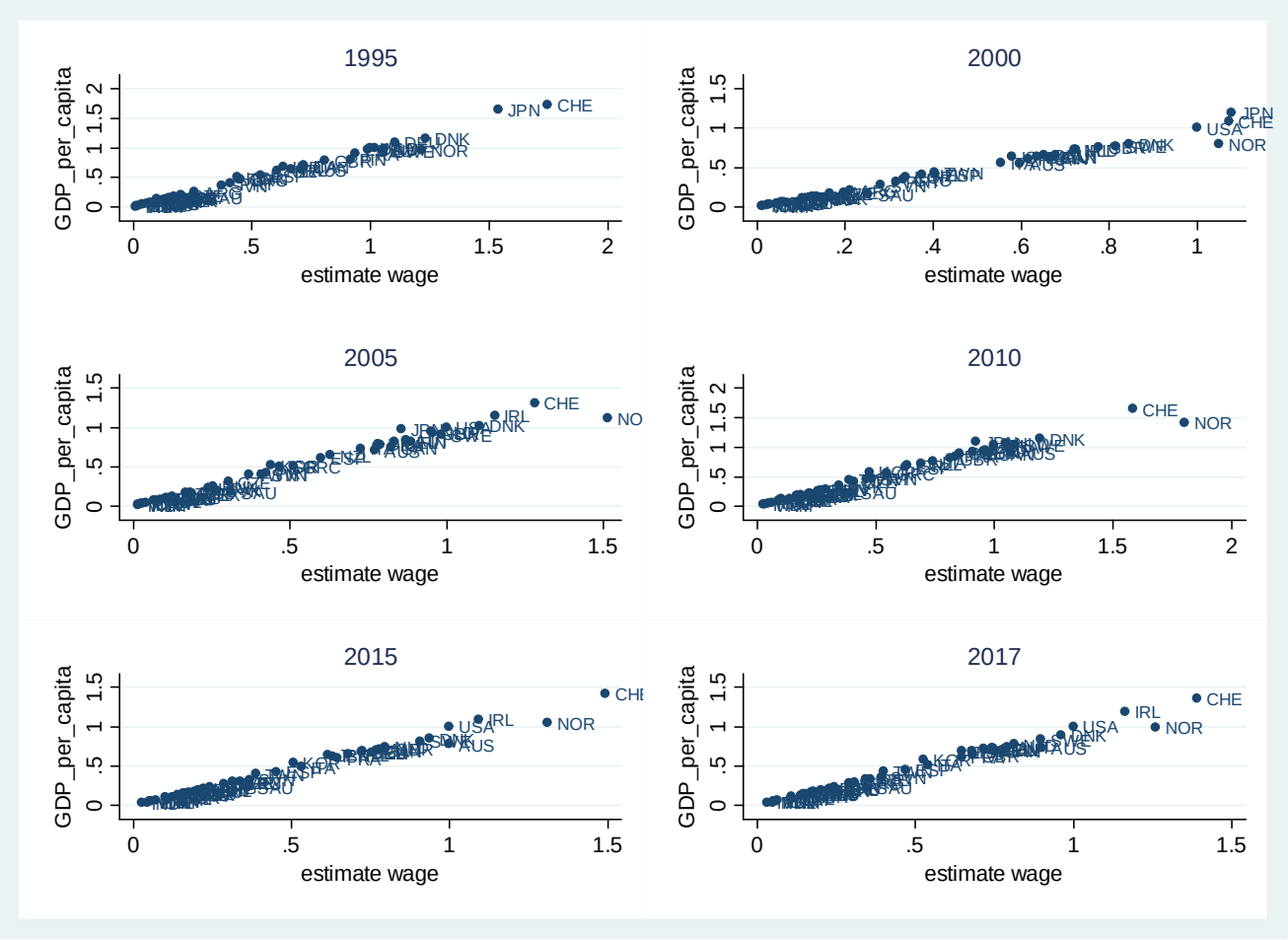



Figure A1: The Fit of the Model regarding Wage. The first row is for primary goods. The second row is for manufactured goods. The third row is for services.

that total trade flows of intermediate goods are larger than those of final goods, both lead to the policy implication that technological progress and trade liberalization in intermediate goods sectors have more impacts on the GFT than changes of the same magnitudes in the final goods sectors. Thus, we conclude with Result 5.

# E Additional Figures

contributes to the amplifying effect of $\delta_n^{ij}$, as it makes GFT in intermediate goods a large share of total GFT. Note also that $\theta_i$ and $\widetilde{\theta}_i$ do not differ much. Thus, for the same $\widehat{\pi_{nn}^i}$ and $\widehat{\widetilde{\pi_{nn}^i}}$, the change in GFT in intermediate goods is larger than the change in GFT in final goods as shown in equation (18).

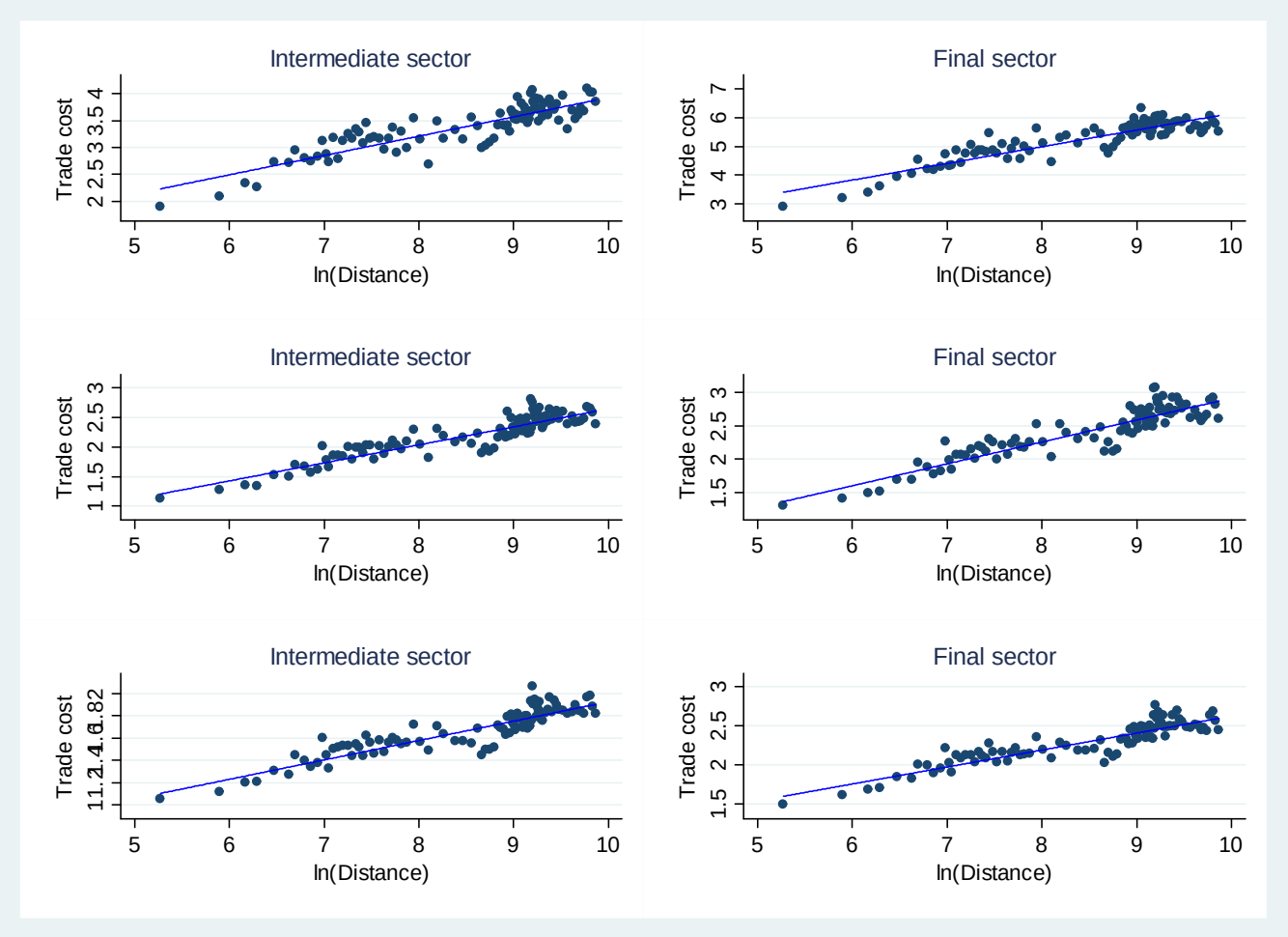



Figure A2: Estimated Bilateral Trade Cost vs. Distance. The first row is for primary goods. The second row is for manufactured goods. The third row is for services.

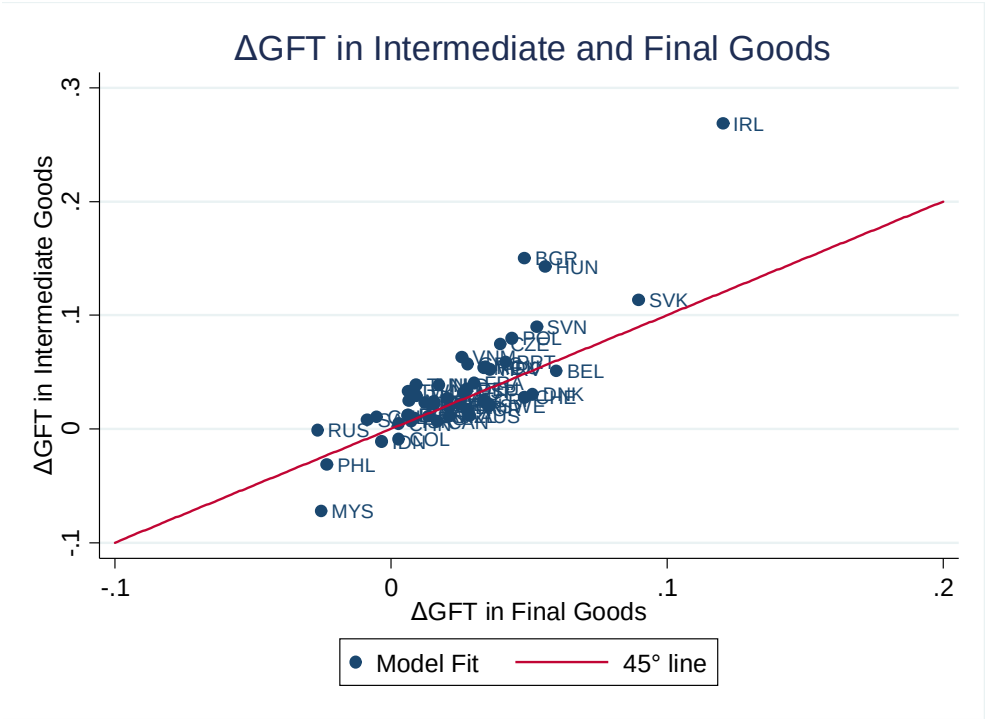



Figure A3: Change in GFT in Intermediate Goods vs. Final Goods for All Countries. Haichao: Something in the legend needs correcting: the dot should be "Data", not "Model Fit".

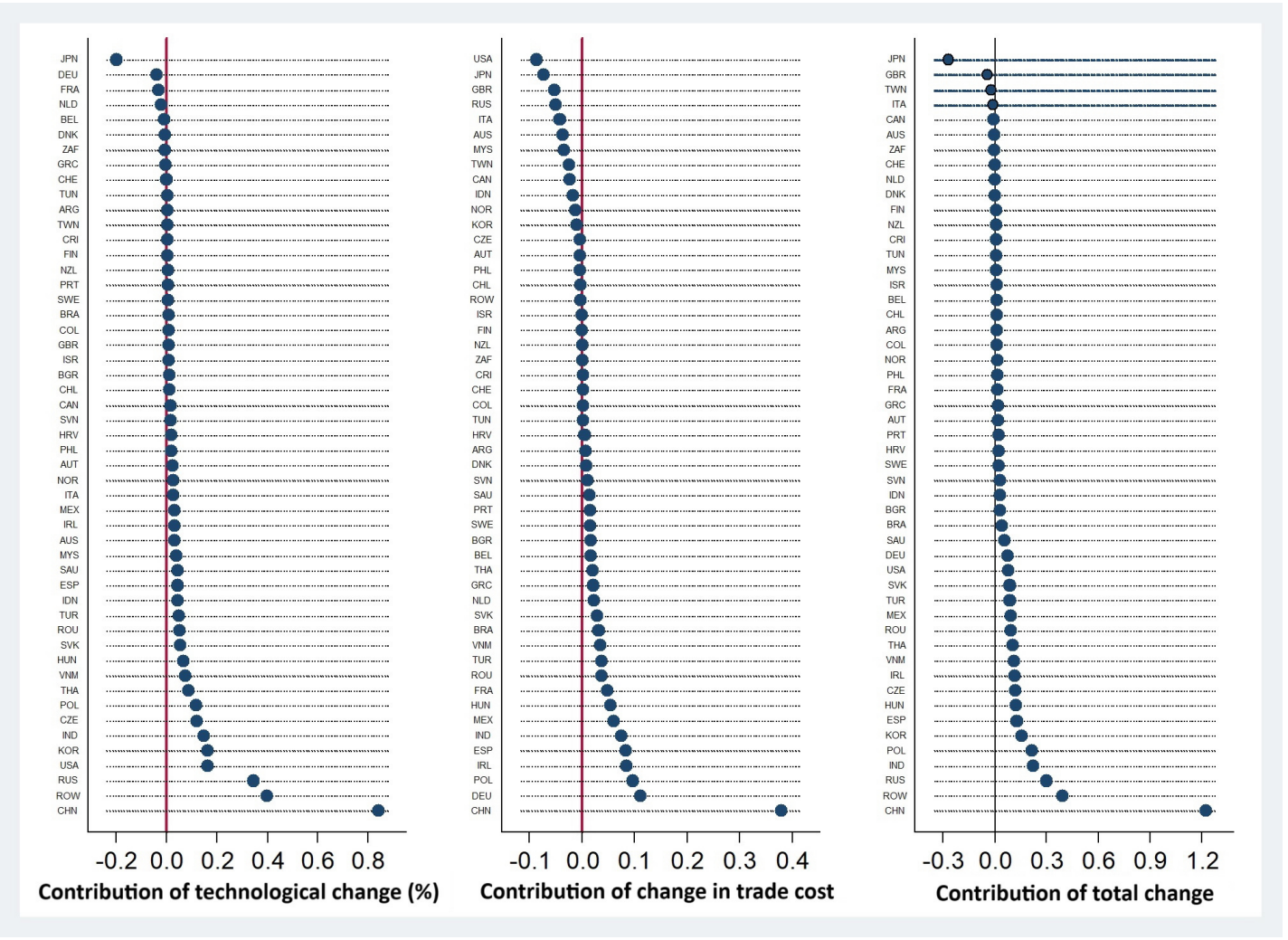



Figure A4: The average contribution (in terms of percentage point increase in GFT) to foreign countries of each country's change in technology stock (left panel), importing trade costs (middle panel) and the total change (right panel).

# F Additional Tables

Table A1: Estimated average contribution of global change in each factor to the change in domestic GFT

| **Contribution to ave. change in GFT** | $T_{int}$ | $T_{fnl}$ | $\tau_{int}$ | $\tau_{fnl}$ | $NX$ | Residual | Actual |
|---|---|---|---|---|---|---|---|
| Panel A: All Countries | | | | | | | |
| Total | -1.715% | 0.382% | 4.630% | 2.889% | -0.121% | -0.019% | 6.047% |
| Intermediate Goods | -2.113% | 1.404% | 5.204% | -0.676% | -0.017% | -0.135% | 3.668% |
| Final Goods | 0.398% | -1.021% | -0.574% | 3.565% | -0.104% | 0.116% | 2.379% |
| Panel B: Developed Countries | | | | | | | |
| Total | 0.899% | 0.640% | 3.043% | 2.280% | -0.079% | 0.261% | 7.044% |
| Intermediate Goods | 1.231% | -0.549% | 3.149% | -0.100% | -0.011% | 0.126% | 3.845% |
| Final Goods | -0.332% | 1.189% | -0.105% | 2.380% | -0.068% | 0.135% | 3.199% |
| Panel C: Developing Countries | | | | | | | |
| Total | -3.699% | 0.186% | 5.834% | 3.350% | -0.153% | -0.231% | 5.290% |
| Intermediate Goods | -4.650% | 2.885% | 6.764% | -1.113% | -0.021% | -0.332% | 3.533% |
| Final Goods | 0.951% | -2.698% | -0.929% | 4.463% | -0.132% | 0.101% | 1.757% |

Note: Panels A, B and C report the estimated average change in GFT due to the global changes in each factor, averaging over all countries, developed countries and developing countries, respectively. $T_{int}$ ($\tau_{int}$) is technology (trade costs) in intermediate goods; $T_{fnl}$ ($\tau_{fnl}$ ) is technology (trade costs) in final goods; NX is net exports.

Table A2: Statistics of the Changes of the Variables in Developed and Developing Countries from 1995 to 2017

| | **Global mean** | **LDCs mean** | **DCs mean** |
|---|---|---|---|
| $(\widehat{GFT_n})$ | 1.066 | 1.060 | 1.073 |
| $\widehat{T}_{int}$ | 2.684 | 4.896 | 1.216 |
| $\widehat{T}_{fnl}$ | 2.218 | 3.675 | 1.140 |
| $\widehat{\tau}_{int}$ | 0.794 | 0.714 | 0.913 |
| $\widehat{\tau}_{fnl}$ | 0.763 | 0.706 | 0.844 |
| $\widehat{\pi_{nn}}$ | 0.844 | 0.865 | 0.817 |
| $\widehat{\widetilde{\pi_{nn}}}$ | 0.825 | 0.890 | 0.747 |

Note: 1. LDCs = less developed countries; DCs = developed countries

2. $\widehat{x} = x'/x$, where $x$ is initial value and $x'$ is new value.

Table A3: Statistics of the variables calculated based on the actual domestic sourcing shares of countries

| **Statistics** | min | max | mean | SD |
|---|---|---|---|---|
| change in total GFT in interm. and final goods: $\Delta GFT_n$ | -0.1253 | 0.3563 | 0.0606 | 0.0752 |
| change in GFT in interm. goods: $(\Delta GFT_n)_{int}$ | -0.0937 | 0.2441 | 0.0380 | 0.0537 |
| change in GFT in final goods: $(\Delta GFT_n)_{fnl}$ | -0.0345 | 0.1123 | 0.0226 | 0.0255 |
| change of technology stock for interm. goods: $\ln \widehat{T}_{int}$ | -2.8087 | 5.8099 | 0.9874 | 1.3067 |
| change of technology stock for final goods: $\ln \widehat{T}_{fnl}$ | -2.1501 | 4.4757 | 0.7964 | 1.1265 |
| change of importing trade costs for interm. goods: $\ln \widehat{\tau}_{int}$ | -4.9783 | 4.1591 | -0.2307 | 0.6378 |
| change of importing trade costs for final goods: $\ln \widehat{\tau}_{fnl}$ | -5.3302 | 3.1805 | -0.2705 | 0.6378 |
| change in $NX$: $\widehat{NX}$ | -439.4187 | 59.75978 | -5.3764 | 62.9512 |
| change in $\pi_{nn}$ for interm. goods: $\ln \widehat{\pi_{nn}}$ | -2.3379 | 1.5949 | -0.1695 | 0.3204 |
| change in $\widetilde{\pi_{nn}}$ for final goods: $\ln \widehat{\widetilde{\pi_{nn}}}$ | -2.9644 | 1.2309 | -0.1921 | 0.4071 |

Table A4: Trade Elasticities for the RP Model

| **Sector** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trade Elasticity** | 2.16 | 1.05 | 3.85 | 4.45 | 4.88 | 6.59 | 3.86 | 8.33 | 5.78 | 2.35 | 1.94 |

Note: The trade elasticity for sector 12 (services) is assumed to be equal to the average of sectors 1 through 11, which is equal to 4.11.

# G List of Developing and Developed Countries

28 Developing countries (countries that were not members of the OECD as of January 1995):

Argentina, Brazil, Bulgaria, Chile, China, Columbia, Costa Rica, Croatia, Czech Republic, Hungary, India, Indonesia, Korea, Malaysia, Mexico, Philippines, Poland, Romania, Russia, Saudi Arabia, Slovak Republic, Slovenia, South Africa, Taiwan, Thailand, Tunisia, Turkey, Viet Nam

22 Developed countries (countries that were members of the OECD as of January 1995):

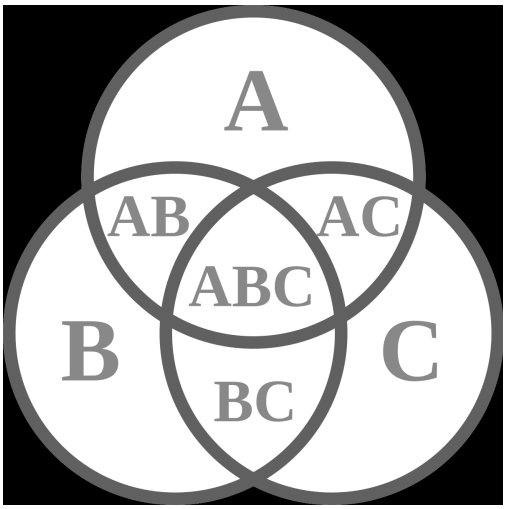
Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States

# H Proof that mean of pure and total effects of a factor is a good proxy for the contribution of a factor

**Proposition 1** *The sum over all factors of the mean of the pure effect and the total effect of each factor is equal to the model prediction plus some higher-order ($\geq 3$) interactive terms.*

Proof:

We start with the simple case of 3 exogenous factors, $\alpha$, $\beta$, $\gamma$, with their effects denoted by A, B and C respectively. In the following Venn diagram, the circles represent the total effects of factors $\alpha$, $\beta$, $\gamma$ respectively. The area with one letter represents the pure effect, while the area with more than one letters represent the interactive effect between the factors.



Then the pure effect and total effect of factor $\alpha$ are $A$ and $A + AB + AC + ABC$ respectively; the pure effect and total effect of factor $\beta$ are $B$ and $B + AB + BC + ABC$ respectively; the pure effect and total effect of factor $\gamma$ are $C$ and $C + AC + BC + ABC$ respectively.

Thus the sum of the pure effects is

$$A + B + C$$

and the sum of the total effects is

$$A + B + C + 2(AB + AC + BC) + 3ABC$$

As a result, the sum over all factors of the mean of the pure effect and the total effect of each factor is equal to the mean of the sum of the pure effects and the sum of the total effects, which is

$$\begin{aligned} & \frac{(A + B + C) + [A + B + C + 2(AB + AC + BC) + 3ABC]}{2} \\ = \; & A + B + C + AB + AC + BC + ABC + \frac{ABC}{2} \\ = \; & \text{Model Prediction} + \frac{ABC}{2} \end{aligned}$$

In a more general case, when there are N factors, the sum of the total effects = 1 × sum of first-order terms + 2 × second-order terms + ... + N × Nth-order terms. Thus the mean of the sum of the pure effects and the sum of the total effects equals to

$$\begin{aligned} & \text{sum of first-order terms} + \text{sum of second-order terms} \\ & + \frac{3}{2} \times \text{sum of third-order terms} + ... + \frac{N}{2} \times \text{sum of Nth-order terms} \\ = \; & \textit{Model Prediction} + \frac{1}{2} \times \text{sum of third-order terms} + ... + \frac{N-2}{2} \times \text{sum of Nth-order terms} \end{aligned}$$

which is the model prediction plus some higher-order ($\geq 3$) interactive terms.