Global Sourcing and Domestic Value-added in Exports*

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Abstract

This paper employs data from the World Input-Output Database to document the evolution of the domestic content in exports, as measured by the domestic value added to gross exports ratio (DVAR), across countries and sectors, over the period 1995-2008. We develop a multiple-sector general equilibrium model with domestic and global input-output linkages following Eaton and Kortum (2002) and Caliendo and Parro (2015) to provide structural interpretations of individual countries' DVAR. We use the calibrated version of the model to fully decompose the time-series changes of the global DVAR and selected countries' DVAR into parts that are due to global changes in technology, international trade costs, domestic trade costs, factor endowments and trade balances. Regarding global DVAR, we find that while the stand-alone effects of technology, domestic trade costs and international trade costs are negative, the interactive effects among them sum up to be significantly positive. We find that the total effect of technology, which has been either overlooked or misinterpreted in the existing literature, is significantly positive. The total effect of total trade costs, though negative, can explain only about 50% of the changes in global DVAR over the sample period. Taking into account the interactive effects, the total effect of domestic trade costs is significantly positive as well.

JEL Classification codes: F10, F11, F14, F17

Keyword: fragmentation, global value chains, domestic value-added ratio

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1 Introduction

Improvements in information and communication technologies and declining trade barriers have facilitated not only the rapid growth but a structural change of world trade in the past few decades. Firms source more inputs from suppliers located further away, both foreign and domestic. Due to the increase in global fragmentation of production, a country's exports may contain a significant amount of content from foreign countries, implying that gross trade statistics have become increasingly misleading in representing the actual value-added of a country in its exports. According to Kee and Tang (2016), only 53% of the exports of electronics from China in 2007 was value-added attributable to Chinese factors of production. The phenomenon is not specific to electronic products. As documented by Koopman, Wang, and Wei (2014) and Johnson and Noguera (2017), among others, the share of domestic value-added in gross exports is significantly lower than 1 for most countries, especially in manufacturing sectors, and has been decreasing for decades.[1]

While there is an extensive literature about the structure and evolution of global supply chains, research on understanding the determinants of a country's domestic value-added (DVA) in exports receives relatively scant attention, despite paramount policy implications. For instance, how may different levels and sectoral patterns of DVA in exports affect optimal trade policy? Do industrial developments contribute to certain countries' moving up the value chains, as measured by the increases in DVA in exports over time? Are recent protectionist policies responsible for the observed global trade slowdown? To answer these questions, one needs first to have some basic understanding of the DVA of a country's exports.

In this paper, we employ data from the multi-country, multi-sector, input-output tables from the World Input-Output Database (WIOD) to document and provide a quantitative and structural explanation for the evolution of the DVA in exports, as measured by the ratio of domestic value-added to gross exports (DVAR) across countries and sectors over the period 1995-2008. To guide our quantitative analysis of the evolution of the DVARs in exports, we develop a multi-country, multi-sector, quantitative trade model with inter-sectoral input-output linkages, based on Eaton and Kortum (2002) and Caliendo and Parro (2015), to provide structural interpretations of the DVAR at the country-sector level for each year.

After documenting the patterns of DVAR across time and countries, we examine the determinants of a country's DVAR. To this end, we use the calibrated version of the model to fully decompose the time-series changes of the global and selected countries' DVAR into parts that are due to (exogenous) *global changes* in three sets of factors, namely (i) technology,

[1] The value-added ratio in global exports was about 75% in 2008, down from about 85% in the 1970-1980s (Johnson, 2014). Also see Timmer et al. (2014) for a review of the studies on the measurement of domestic value added in trade and other global value chains.

(ii) trade costs (both domestic and international), and (iii) other exogenous factors such as factor endowments and trade balances.[2]

Regarding global DVAR, we have the following findings. First, the total effect of technology on global DVAR, an overlooked or misinterpreted aspect in existing analyses of the determinants of DVAR, is significantly positive, and even larger in magnitude than the negative total effect of total trade costs, which has been the focus of most analyses in the literature. Second, the total effect of domestic trade costs, another overlooked effect in the literature, is also significantly positive. Third, the total effect of total trade costs, though negative, can explain only about 50% of the changes in global DVAR over the sample period. In other words, the total effect of global changes in total trade costs is far from being able to explain the decline in global DVAR, contrasting with the literature. For developing countries, the total effect of total trade costs is significantly negative. By contrast, for developed countries, the total effect of total trade costs is minor. This distinction between the developing countries and developed countries has not been reported in the literature before and it deserves further investigation. Fourth, the total effect of other factors (i.e., factor endowments and trade balances) are quantitatively very small.

Table 1 summarizes the calibrated decomposition of the decline in the world's, developed countries', and developing countries' DVAR during the sample period. It reports the total effect of each factor. We find that for the developed countries, developing countries or the world as a whole, the total effects of global changes in technology and domestic trade costs are both positive and significant. By contrast, the total effect of global changes in total trade costs is significantly negative for developing countries but insignificant for developed countries. In fact, a fast-growing economy like China can have its DVAR increasing over time, despite having falling total trade costs, due to the dominant effect of its continuous improvement in technology and reduction in domestic trade barriers.

< Table 1 about here >

It is worth noting that the sum of the total effects of technology, total trade costs and other factors is far from being equal to the data, as each total effect is equal to the sum of its "pure effect" and its "interactive effects" with other factors.[3] The potentially large

[2] Two definitions are in order. First, "total trade costs" is defined as the combination of domestic trade costs and international trade costs. Total trade costs are incurred whenever two entities trade with each other. If the two entities belong to the same country, the international trade costs are equal to zero, and only domestic trade costs are incurred. Otherwise, both domestic trade costs and international trade costs are incurred. Second, the "total effect" of a factor is defined as the impact lost (compared with the case when all factors are turned on) when the factor is shut down while all other factors are turned on. The "pure effect" (stand-alone effect) of a factor, on the other hand, is the impact when it is turned on while all other factors are shut down.

[3] Mathematically, in a Taylor series expansion up to the second order derivatives, the pure effect of a factor

	World	Developed	Developing
Data	-4.36	-4.42	-4.29
Total effect of global changes in			
(i) Technology	3.92	3.18	5.27
(ii) Total Trade Costs	-2.26	-0.65	-5.31
(Combination of Domestic and International)			
(iii) Other Factors	0.18	-0.54	1.57

Table 1: Percentage-point Changes in DVAR (1995-2008)

interactive effects are the outcome of the non-linearity in the structural gravity equations derived from a large class of quantitative trade models, to which Eaton and Kortum (2002) belongs, together with the correlation between the changes of the determinants. For example, there was a negative correlation between changes in technology and changes in domestic trade cost across countries, as well as positive correlation between changes in international trade cost and changes in domestic trade cost across countries. Because of the existence of the potentially large interactive effects, the total effect of the change in technology on a country's DVAR cannot be isolated from that of domestic and international trade costs, or vice versa. The total effect of each factor depends on the underlying empirical joint distribution of the changes in technology, international trade costs and domestic trade costs across time and sectors within a country. Since international and domestic trade costs act in conjunction with technology to shape a country's trade pattern, ignoring such interactive effects may result in biased estimates of the contribution of any single determinant of the DVAR and other global value chain (GVC) measures.

Note that behind the aggregate effects reported in Table 1, there is a large variation in the changes in DVARs across countries. Our decomposition exercise in fact explains the annual change in DVAR for each country and that for each country-cum-sector-pair in the sample over the period 1995-2008. We find that the total effect of the combination of all the factors in our model fits the data very well. On the other hand, as expected, the pure effect of any individual factor does not explain the data well. Specifically, the pure effects of total trade costs and domestic trade costs under-predict the DVARs for almost all countries, while the pure effects of technology and other factors over-predict the DVARs of countries on average.

Regarding the two largest economies in the world, the US and China, we have the following findings. The total effect of technology on China's DVAR is much greater than that on the

is the sum of the first and second derivatives with respect to (w.r.t.) the factor while the interactive effect between two factors is the cross-derivative w.r.t. the two factors.

average developing country, reflecting China's fast technological progress. Moreover, the total effect of "other factors" on China's DVAR is also much larger than that on the average developing country, reflecting the fast capital accumulation and large average trade surplus of China during the sample period. For the US, the total effect of "other factors" is much larger than that on the average developed country, possibly due to the large average trade deficit of the US during the sample period.

We also use our calibrated model to conduct a series of counterfactual exercises. As a first pass, we study quantitatively how shutting down China's technological progress, total trade costs and domestic trade costs (i.e., setting the three estimated parameters to their 1995 levels) will affect the DVAR of China's, US's, and the world's exports. We find that the total effect of China's technological progress and reduction of domestic trade costs on its own DVAR are both significantly positive. Importantly, the reduction of total trade costs of China has strong and positive total effect on China's DVAR, contrasting the conventional view that lower import barriers will induce more global sourcing and result in a reduction in a country's DVAR. It is also worth noting that while the total effects of China's technological progress, changes in domestic trade costs or changes in total trade costs on the DVAR of the rest of the world are all positive, their effects on the DVAR of the US are negative.

Finally, we investigate the relationship between the reduction in DVAR and welfare change across countries. We find that there is no relationship between the change in DVAR and welfare change across countries in our sample. However, if we allow only the international trade cost of each country to change, then the change in welfare is negatively correlated with the change in DVAR across countries. This makes sense since, in that case, the welfare change of each country arises only from the change in gains from trade, and, according to Arkolakis, Costinot and Rodriguez-Clare (2012), there is a negative relationship between domestic sourcing share (which correlates positively with DVAR) and gains from trade. In reality, it is possible that welfare increases but gains from trade decreases (because of an increase in DVAR due to, for instance, an increase in aggregate productivity).

This paper relates to various strands of literature on GVC. First, it contributes to the literature of the modeling of fragmentation (Baldwin, 2013, Baldwin and Venables, 2013; Eaton and Kortum, 2002; Alvarez and Lucas, 2007; Yi, 2003; 2010; Costinot et al., 2013; Antras and Chor, 2018, 2022).[4] Second, our paper contributes to the literature that provides methods to measure various aspects of GVC (e.g., domestic value-added, upstreamness, length of production chains). This literature starts with Hummels, Ishii and Yi (2001), who use industry input-output (IO) tables to calculate the value-added to exports ratios for many countries. Recent related work includes De la Cruz, Koopman, Wang and Wei (2011), Antràs, Fally

[4]See Feenstra (1998) for a review of the early literature on foreign outsourcing.

and Hillberry (2012), Antràs and Chor (2013), Johnson and Noguera (2012, 2017), Koopman, Wang and Wei (2012, 2014), and Johnson (2014).

The third strand of studies bridges the first largely theoretical literature and the second literature on measurement by calibrating quantifiable models of GVC (Antras and Chor, 2018; Antras and de Gortari, 2020; Johnson and Noguera, 2017; Fally and Hillberry, 2018; de Gortari, forthcoming). Our paper belongs to this frontier of research, by linking the literature that documents the domestic content in countries' exports (e.g. Hummels, Ishii and Yi, 2001 and Koopman, Wang, and Wei, 2014, among others) and the one that develops quantitative trade models to estimate the gains from trade and answer other macroeconomic questions (e.g., Arkolakis, Costinot, and Rodriguez-Clare, 2012).

The paper is organized as follows. Section 2 introduces the theoretical model we use to quantify the determinants of countries' and sectors' DVAR. Section 3 describes how to bring our model to the data. Section 4 presents the quantitative results based on our calibrated model, including the decomposition and counterfactual exercises. Section 5 investigates the relationship between the change in welfare and the change in DVAR. Section 6 concludes.

2 A Model of production fragmentation

2.1 Setup

Our model is built on Eaton and Kortum (2002). The assumptions are: (1) All countries have the capability to produce all intermediate and final goods; (2) international trade and domestic trade are both costly; and (3) all markets are perfectly competitive.

There are N countries in the world, indexed by $n = 1, ..., N$. Each country has (time-varying) labor (L_n) and capital (K_n) endowments. Labor and capital are fully mobile across sectors within a country, but not mobile across countries. There are J goods (indexed by $i = 1, ..., J$) which can be used for consumption or as intermediate inputs in production.

In each country there is a representative household, who uses labor and capital income to purchase an optimal bundle of final good varieties from all sectors to maximize utility as follows:

$$U = \prod_{i=1}^{J} \left\{ \left[\int_0^1 \left(q^i(\omega) \right)^{\frac{\sigma^i - 1}{\sigma^i}} d\omega \right]^{\frac{\sigma^i}{\sigma^i - 1}} \right\}^{\alpha^i}, \text{ with } \sum_{i=1}^{J} \alpha^i = 1. \tag{1}$$

where $q^i(\omega)$ is the consumption of variety ω in sector i. Within each sector i, $\sigma^i > 1$ is the elasticity of substitution between any two varieties. Across sectors, for simplicity, we assume a Cobb-Douglas aggregator over the J final goods, with α^i being the share of expenditure on final good sector i.

The production function of variety ω of sector i in country n is given by

$$y_n^i(\omega) = z_n^i(\omega)\left[M_n^i(\omega)\right]^{1-\beta_n^i}\left[l_n^i(\omega)\right]^{\beta_n^i\mu^i}\left[k_n^i(\omega)\right]^{\beta_n^i(1-\mu^i)}, \quad \omega \in [0,1] \tag{2}$$

where $y_n^i(\omega)$ is the quantity of variety ω of sector i being produced; $z_n^i(\omega)$ is the total factor productivity (TFP) of country n in producing variety ω of sector i; $M_n^i(\omega)$ is the quantity of corresponding intermediate composite (to be defined later) employed; $l_n^i(\omega)$ and $k_n^i(\omega)$ are the corresponding labor and capital inputs, respectively. The good produced according to this production function can be either consumed as final good, contributing to utility, or used as intermediate input, contributing to the production of an intermediate composite.

The production function of an intermediate composite M_n^i in country n is given by:

$$M_n^i = \prod_{k=1}^{J}\left\{\left[\int_0^1\left(q^k(\omega)\right)^{\frac{\sigma^k-1}{\sigma^k}}d\omega\right]^{\frac{\sigma^k}{\sigma^k-1}}\right\}^{\gamma_n^{ik}}, \text{ with } \sum_{k=1}^{J}\gamma_n^{ik} = 1. \tag{3}$$

where $q^k(\omega)$ is the quantity of input variety ω from sector k. Within sector k, $\sigma^k > 1$ is the elasticity of substitution between any pair of varieties. Across sectors, we assume a Cobb-Douglas aggregator of intermediates over the J sectors, with γ_n^{ik} being the cost share of (upstream) input k in the total cost of producing (downstream) input composite i in country n. Production of intermediate composite i does not necessarily need input varieties from all J sectors. If inputs from a particular sector k are not needed, $\gamma_n^{ik} = 0$.

Both international and intra-national trade are costly. Whenever an intermediate or final good variety from sector i is shipped from country n to country m to be used as input in sector j (or consumed), an iceberg trade cost τ_{mn}^{ji} is incurred ($j = F$ if it is used as a final good), implying that τ_{mn}^{ji} units of the good are needed to be shipped from the origin for only one unit to arrive at the destination. We follow Caliendo, Parro and Tsyvinski (forthcoming) and assume that the country-pair-sector-pair total trade cost is expressed as

$$\tau_{nl}^{ji} = \kappa_{nl}^{ji}\tau_{nn}^{ji}$$

where τ_{nl}^{ji} is called "total trade cost", τ_{nn}^{ji} is called "domestic trade cost" of the destination country and κ_{nl}^{ji} (where $n \neq l$) is called "international trade cost". Note that $\kappa_{nl}^{ji} > 1$ when $n \neq l$, and $\kappa_{nn}^{ji} = 1$ by definition; and we assume that $\tau_{nn}^{ji} > 1$ when $j \neq F$, and $\tau_{nn}^{ji} = 1$ when $j = F$ as normalization.[5]

[5] In other words, foreign firms need to overcome both the international trade costs and domestic trade costs in order to trade with domestic firms, whereas domestic firms only need to overcome the domestic trade costs in order to trade with domestic firms.

As such, the competitive price of a variety ω in sector i shipped from country l to country n to be used as input in sector j ($j = F$ if it is used as a final good) takes the following form:

$$p_{nl}^{ji}(\omega) = \frac{\tau_{nl}^{ji} c_l^i}{z_l^i(\omega)} \qquad \text{for all } \omega \in [0,1],$$

where

$$c_l^i = \left(\frac{P_l^i}{1-\beta_l^i}\right)^{1-\beta_l^i} \left(\frac{w_l}{\beta_l^i \mu_l^i}\right)^{\beta_l^i \mu_l^i} \left[\frac{r_l}{\beta_l^i\left(1-\mu_l^i\right)}\right]^{\beta_l^i\left(1-\mu_l^i\right)}$$

where P_l^i is the price index of the intermediate composite used in sector i and country l, while w_l and r_l are the equilibrium wage rate and rental cost of capital in country l, respectively.

A final remark about the supply side is about the country-sector-specific productivity. We assume that country l possesses a technology stock of T_l^i to produce sector-i varieties, which reflects country l's absolute advantage in producing sector-i goods. Following Eaton and Kortum (2002), we treat $z_l^i(\omega)$, the efficiency (or TFP) of country l in producing variety $\omega \in [0,1]$ in sector i, as the realization of an extreme value distribution. Specifically, a variety ω producer of good i in country l draws $z_l^i(\omega)$ independently from the Fréchet distribution:

$$\Pr\left(z_l^i(\omega) < z\right) = e^{-T_l^i z^{-\theta}} \quad \text{with } T_l^i > 0,\ \forall\, \omega \in [0,1]$$

where θ is a parameter governing the (inverse) dispersion of productivity draw $z_l^i(\omega)$ from the distribution; and T_l^i governs the state of technology of country l in sector i. For simplicity, we assume that θ is identical for all countries and sectors.

2.2 Price indices and sourcing shares

Perfect competition implies that a variety producer in sector j and country n will purchase each variety of its sector-i intermediates from the source country that offers the lowest price. Let the price index of the entire range of variety $\omega \in [0,1]$ of sector-i intermediates employed by n for the production of a sector-j good be denoted by p_n^{ji}. The Fréchet distribution of the efficiency of source country m, $z_m^i(\omega)$, implies that

$$p_n^{ji} = \tau_{nn}^{ji}\left(\Phi_n^{ji}\right)^{-\frac{1}{\theta}}$$

where

$$\Phi_n^{ji} = \sum\nolimits_m T_m^i \left(c_m^i \kappa_{nm}^{ji}\right)^{-\theta}.$$

Therefore, the price index of the intermediate composite for sector j in country n is given by

$$P_n^j = \Upsilon_n \prod_{i=1}^{J} \left(p_n^{ji}\right)^{\gamma_n^{ji}} = \Upsilon_n \delta_n^j \prod_{i=1}^{J} \left(\Phi_n^{ji}\right)^{-\frac{\gamma_n^{ji}}{\theta}},$$

where $\Upsilon_n = \prod_{i=1}^{J} \left(\gamma_n^{ii}\right)^{-\gamma_n^{ii}}$ is a constant, $\delta_n^j = \prod_{i=1}^{J} \left(\tau_{nn}^{ji}\right)^{\gamma_n^{ji}}$ is the sector-specific domestic trade cost.

To produce sector-j goods in country n, the cost share of intermediates from sector-i imported from country l in the total expenditure on intermediates from sector-i is given by

$$\pi_{nl}^{ji} = \frac{T_l^i \left(c_l^i \tau_{nl}^{ji}\right)^{-\theta}}{\sum_m T_m^i \left(c_m^i \tau_{nm}^{ji}\right)^{-\theta}} = \frac{T_l^i \left(c_l^i \kappa_{nl}^{ji}\right)^{-\theta}}{\Phi_n^{ji}}. \tag{4}$$

where $T_l^i \left(c_l^i\right)^{-\theta}$ is defined as the competitiveness of Country l in sector i. Note that if good i is used as a final good then $j = F$ for all the variables in this subsection.

2.3 Expressions of DVAR

Now let us derive the accounting expressions of the DVAR in sales (domestic or exports) at the country-sector level. Let us denote the value-added ratio (VAR) of country n embodied in country m's production of sector-i goods by r_{mn}^i. (In other words, $\sum_{n=1}^{N} r_{mn}^i = 1$.)

A complete accounting of a country-sector's DVAR should incorporate (1) domestic value-added (DVA) embodied in imported intermediates from foreign countries; (2) DVA embodied in domestically produced intermediates; (3) The costs of primary factors (i.e. capital and labor) employed directly (direct DVA). Formally, country n's DVAR in sector i, which is equal to country n's value-added ratio embodied in its own sector-i output, can be expressed as

$$r_{nn}^i = \beta_n^i + (1 - \beta_n^i) \sum_{h=1}^{N} \sum_{k=1}^{J} \pi_{nh}^{ik} \gamma_n^{ik} r_{hn}^k, \tag{5}$$

while country n's VAR in country m's sector-i output, which is equal to country n's value-added ratio embodied in country m's sector-i output, is given by

$$r_{mn}^i = (1 - \beta_m^i) \sum_{h=1}^{N} \sum_{k=1}^{J} \pi_{mh}^{ik} \gamma_m^{ik} r_{hn}^k \quad \text{for } m \neq n. \tag{6}$$

Two remarks are in order. First, the main difference between r_{nn}^i and r_{mn}^i is that β_n^i appears in the former but not in the latter, as domestic content in a country's exports obviously includes direct value-added generated by domestic primary factors, including labor and physical capital.

Second, both (5) and (6) feature the recursive nature of a country's own sector-specific DVAR, as the domestic value-added of a country's sectoral exports will be used as intermediates by other countries' production, which can be exported back to the source country, thus becoming part of its domestic value-added. To more systematically analyze the recursive nature of VAR, we express the VAR as a matrix $\mathbf{r}$ for all country-sector pairs as follows:

$$\underbrace{\mathbf{r}}_{NJ\times N} = \underbrace{\boldsymbol{\beta}}_{NJ\times N} + \underbrace{(\mathbf{I}-\mathbf{B})}_{NJ\times NJ} \underbrace{\mathbf{G}}_{NJ\times NJ} \underbrace{\mathbf{r}}_{NJ\times N}$$

where $\mathbf{r}$ is a $NJ \times N$ matrix whose $\{(i-1)\,N+m,\ n\}$ entry is r^i_{mn}. The matrix $\mathbf{B}$ is the $NJ \times NJ$ square matrix with all off-diagonal elements equal to 0 and the $[(i-1)\,N+n]$-th diagonal element equal to β^i_n. The matrix $\mathbf{G}$ is the $NJ \times NJ$ global intermediate goods cost share matrix, whose $\{(i-1)N+m,\ (k-1)N+n\}$ entry is equal to $\pi^{ik}_{mn}\gamma^{ik}_m$. Finally, $\boldsymbol{\beta}$ is a $NJ \times N$ matrix, formed by stacking up J number $N \times N$ matrixes, each containing 0 off-diagonal elements; in addition, the $\{(i-1)\,N+n,\ n\}$ entry of the $\boldsymbol{\beta}$ is equal to β^i_n.

The recursive relationship in VAR through global IO linkages allows us to solve for $\mathbf{r}$ in the above equation by collecting $\mathbf{r}$ on the left hand side:

$$\mathbf{r} = [\mathbf{I} - (\mathbf{I}-\mathbf{B})\,\mathbf{G}]^{-1}\,\boldsymbol{\beta}. \tag{7}$$

Totally differentiating $\mathbf{r}$ gives us the following expression

$$d\mathbf{r} = \underbrace{[\mathbf{I} - (\mathbf{I}-\mathbf{B})\,\mathbf{G}]^{-1}\,[d\boldsymbol{\beta} - (d\mathbf{B})\,\mathbf{G}\mathbf{r}]}_{\text{pure effects of changing } \beta^i_n} + \underbrace{[\mathbf{I} - (\mathbf{I}-\mathbf{B})\,\mathbf{G}]^{-1}\,(\mathbf{I}-\mathbf{B})\,(d\mathbf{G})\,\mathbf{r}}_{\text{pure effects of changing } \pi^{ik}_{nm} \text{ and } \gamma^{ik}_n} \tag{8}$$

The first term on the right hand side captures the pure effect of changes in β^i_n. The second term captures the effect of the changes in intermediate goods shares π^{ik}_{nm} and the input-output coefficients γ^{ik}_n. In the structural estimation exercises below, we shall quantify the magnitude of each effect.

2.4 A simplified illustrative model

The model so far in matrix form may hide a lot of insights that are essential for understanding our quantitative and counterfactual results below. This being the case, we develop a simple two-country ($m \in \{1,2\}$), one-factor, one-sector model with inter-country IO linkages to obtain some insights about both the stand-alone and interactive effects of the changes in technology and international trade costs on country 1's DVAR. Let us denote the relative technology stock between the two countries by $t = T_1/T_2$ and the relative factor cost by $c = c_1/c_2$. As there are only two countries, we can simplify the international trade costs as $\kappa_1 \equiv \kappa_{12}$ (international importing trade costs of country 1) and $\kappa_2 \equiv \kappa_{21}$ (international importing trade costs of country 2). Furthermore, define $\delta \equiv \tau_{11}$ (domestic trade costs of country 1) and normalize by setting $\tau_{22} = 1$ (domestic trade costs of country 2). Thus, $\tau_1 \equiv \tau_{12} = \kappa_1 \delta$ (total importing trade costs of country 1) and $\tau_2 \equiv \tau_{21} = \kappa_2$ (total importing trade costs of country 2).

Using the sourcing share equation (4) derived in the general model, we can express the sourcing share from country n in country m's total expenditure (π_{mn}) as

$$\begin{aligned} \pi_{11} &= \frac{tc^{-\theta}}{tc^{-\theta} + \kappa_1^{-\theta}}, \qquad \pi_{12} = \frac{\kappa_1^{-\theta}}{tc^{-\theta} + \kappa_1^{-\theta}}, \\ \pi_{22} &= \frac{1}{1 + tc^{-\theta}\kappa_2^{-\theta}}, \qquad \pi_{21} = \frac{tc^{-\theta}\kappa_2^{-\theta}}{1 + tc^{-\theta}\kappa_2^{-\theta}}. \end{aligned}$$

Using the accounting identities of DVAR (5) and (6), we can express the VAR of country 1's firms in country 1's exports and country 2's exports respectively as

$$\begin{aligned} r_{11} &= \beta + (1-\beta)(\pi_{11} r_{11} + \pi_{12} r_{21}); \\ r_{21} &= (1-\beta)(\pi_{21} r_{11} + \pi_{22} r_{21}). \end{aligned}$$

Note that

$$\pi_{11} = 1 - \pi_{12}\ ; \qquad \pi_{22} = 1 - \pi_{21}\ ; \qquad r_{11} = 1 - r_{12}\ ; \qquad r_{22} = 1 - r_{21}\ .$$

Totally differentiating this system of two equations yields

$$\begin{aligned} dr_{11} &= (1-\beta)(\pi_{11} dr_{11} + \pi_{12} dr_{21}) + (1-\beta)(r_{11} - r_{21}) d\pi_{11} \\ dr_{21} &= (1-\beta)(\pi_{21} dr_{11} + \pi_{22} dr_{21}) - (1-\beta)(r_{11} - r_{21}) d\pi_{22} \end{aligned}$$

which leads to

$$dr_{11} = A d\pi_{11} - B d\pi_{22}$$

where A and B are some constants, with $A > B > 0$.[6]

Taylor series expansion of $d\pi_{11}$ and $d\pi_{22}$ up to the second order derivatives gives the decomposition of the effects of different forces on country 1's DVAR (See the appendix for details). Specifically, the pure effect of a factor is the sum of the first and second derivatives with respect to (w.r.t.) the factor while the interactive effect between two factors is the cross-derivative w.r.t. the two factors. Rearranging the terms and ignoring the second order effects on the relative factor cost c, the effect on r_{11} can be decomposed into

[6] $A = \{(1-\beta)(r_{11} - r_{21})[1 - (1-\beta)\pi_{22}]\} / \left[(2\beta - \beta^2) - \beta(1-\beta)(\pi_{11} + \pi_{22})\right]$ and $B = \left[(1-\beta)^2 (r_{11} - r_{21}) \pi_{12}\right] / \left[(2\beta - \beta^2) - \beta(1-\beta)(\pi_{11} + \pi_{22})\right]$

- The pure effect of technology

$$(C + D)\frac{dt}{t} - [C\pi_{11} + D\pi_{21}]\left(\frac{dt}{t}\right)^2 \tag{9}$$

where $C = A\pi_{11}(1 - \pi_{11}) > 0$ and $D = B\pi_{22}(1 - \pi_{22}) > 0$.

- The pure effect of international trade costs

$$-C\left\{\frac{d\left(\kappa_1^{-\theta}\right)}{\kappa_1^{-\theta}} - \pi_{12}\left[\frac{d\left(\kappa_1^{-\theta}\right)}{\kappa_1^{-\theta}}\right]^2\right\} + D\left\{\frac{d\left(\kappa_2^{-\theta}\right)}{\kappa_2^{-\theta}} - \pi_{21}\left[\frac{d\left(\kappa_2^{-\theta}\right)}{\kappa_2^{-\theta}}\right]^2\right\} \tag{10}$$

- The pure effect of domestic trade costs

$$(C + D)\left[\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right] - [C\pi_{11} + D\pi_{21}]\left[\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right]^2 \tag{11}$$

- The interactive effects among technology, international trade costs and domestic trade costs. They are discussed in Appendix B.

Comparing (9) and (11), we can see that the pure effects of $\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}$ and $\frac{dt}{t}$ are isomorphic.

The pure effect of technology. Suppose $\left|\frac{dt}{t}\right| > \left(\frac{dt}{t}\right)^2$, which is likely to be the case as $\frac{dt}{t}$ is normally less than one for annual change. Thus, if $dt > 0$ ($dt < 0$), then the effect is positive (negative). The intuition is that when a country's productivity increases, the prices of its output will decline, raising the country's competitiveness relative to the foreign country's. As a result, the domestic content in exports will increase. In a multi-country setting, if larger countries tend to have $dt < 0$, then it is likely that the effect on global DVAR is negative.

The pure effect of international trade costs. Suppose (a) $d\kappa_1 < 0$ and $d\kappa_2 < 0$ so that $d\kappa_1^{-\theta} > 0$ and $d\kappa_2^{-\theta} > 0$, which is the likely scenario empirically during our sample period of 1995-2008, and (b) $\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}} > \left(\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}}\right)^2$, which is likely to be the case as $\left|\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}}\right|$ is normally less than one for annual change. Then, $\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}} - (1 - \pi_{ii})\left(\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}}\right)^2 > 0$ for $i = 1, 2$. Base on this, we can conclude that the term is negative when 1. under the symmetric case, or 2. Country 1 reduces international trade costs unilaterally.[7] In sum, the pure effect of global changes in international trade costs on global DVAR is likely to be negative.

[7] 1. In the symmetric case where $\kappa_1 = \kappa_2$, $\pi_{11} = \pi_{22}$ and $d\kappa_1 = d\kappa_2 < 0$ (which implies that $d\kappa_1^{-\theta} > 0$ and $d\kappa_2^{-\theta} > 0$ and $\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}} > \left(\frac{d\kappa_i^{-\theta}}{\kappa_i^{-\theta}}\right)^2$ for $i = 1, 2$), the term is negative as $C > D$ under symmetry. 2. If country 1 reduces international trade costs unilaterally (i.e., $\frac{d\left(\kappa_1^{-\theta}\right)}{\kappa_1^{-\theta}} > 0$ and $\frac{d\left(\kappa_2^{-\theta}\right)}{\kappa_2^{-\theta}} = 0$), the term is clearly negative.

The pure effect of domestic trade costs. Suppose $\left|\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right| > \left[\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right]^2$, which is likely to be the case, as $\left|\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right|$ is normally less than one. Note that $\frac{d\left(c^{-\theta}\right)}{d\delta} < 0$.[8] Thus, if $d\delta < 0$ ($d\delta > 0$), then the term is positive (negative). The intuition is that when a country's domestic trade cost falls (rises), the prices of input will decline (rise), which leads the prices of its output to decrease (increase), raising (lowering) the country's competitiveness relative to the foreign country's. Thus, the domestic content in exports will increase (decrease). Thus, in a multi-country setting, if larger countries tend to have $d\delta > 0$ ($d\delta < 0$), then the pure effect of domestic trade costs on global DVAR is likely to be negative (positive). Empirical facts seem to indicate that $d\delta > 0$ tends to be true for larger countries, which means that the pure effect of global changes in domestic trade costs on global DVAR is likely to be negative.

Finally, it is worth noting that this theoretical exercise based on a simple model focuses on the comparative statics of the pure effects of changes in the key factors. While the sign of the pure effect of each factor is easier to figure out, the signs of the interactive effects among the factors are ambiguous, depending on the correlations among the changes of the factors across countries and sectors in the data. We discuss the details in Appendix B, and leave the quantitative analysis below to inform us about the total effects of the change in each factor.

3 Taking the model to the data

3.1 Main data sources

We use the 2013 edition of the World Input-Output Database (WIOD), which contains trade data for any sector-pair-country-pair combination for 40 countries plus the rest of the world (RoW) (indexed by j) and 35 sectors (indexed by s), over 14 years (indexed by t) from 1995 and 2008.[9] In particular, we use yearly changes in the $NJ \times NJ$ (2,059,225) sourcing shares (i.e., π_{nm}^{ik}) as targets for our calibration of the general-equilibrium model. We use the Socio-Economic Accounts (SEA) (2013 version) of the WIOD to obtain data on employment, capital stocks, intermediate inputs, and gross output at current and constant prices for the same set of countries and sectors.

[8]Note that $p_1(\omega) = \frac{\kappa_1 \delta c_1}{z_1(\omega)}$ and $c_1 = \left(\frac{P_1}{1-\beta_1}\right)^{1-\beta_1}\left(\frac{w_1}{\beta_1}\right)^{\beta_1}$. Ignoring the general equilibrium adjustments in w_1, we have $\frac{dP_1}{P_1} = \frac{d\delta}{\delta} + \frac{dc_1}{c_1}$ and $\frac{dc_1}{c_1} = (1-\beta_1)\frac{dP_1}{P_1}$. This leads to $\frac{dc_1}{c_1} = \frac{1-\beta_1}{\beta_1}\frac{d\delta}{\delta}$. Thus $\frac{\partial c_1}{\partial \delta} > 0$ and $\frac{d\left(c^{-\theta}\right)}{d\delta} < 0$.

[9]There is a 2016 version that covers more industries and more recent years but we chose to use the 2013 version to avoid dealing with the trade collapse during the 2008-2009 global financial crises.

3.2 Estimating trade costs and productivity

We calibrate the following set of parameters in the model: (i) parameters of the productivity distributions: T_n^i and θ; (ii) international trade costs κ_{nl}^{ji}; (iii) production function parameters β_n^i and γ_n^{ik}; (iv) preference parameters α^i; and (v) country factor endowments L_n and K_n. We shall discuss the calibration of each in turn, in particular which parameter we estimate, compute from the data, or take directly from existing studies.

The first step of our quantitative exercise is to estimate the change in technology stock of countries, $\left\{\widehat{T}_l^i\right\}$. Following equation (4) and the normalization $\tau_{ll}^{Fi} = 1$, we have

$$\pi_{ll}^{Fi} = T_l^i \left(\frac{c_l^i}{p_l^{Fi}}\right)^{-\theta}$$

where π_{ll}^{Fi} is the sector-i final goods domestic sourcing share and p_l^{Fi} is the price index of the entire range of variety $\omega \in [0,1]$ of final good i in country l. We denote the measured sectoral total factor productivity of sector i in country l as A_l^i. We express variables pertaining to the next period by a superscript "$\prime$". Following Dekle, Eaton, and Kortum (2008), we use exact hat algebra to characterize the equilibrium changes: $\widehat{x} = x'/x$. Following Caliendo, Parro, Rossi-Hansberg and Sarte (2018), we have[10]

$$\begin{aligned}
\ln \widehat{A}_l^i &= \ln \frac{\widehat{c}_l^i}{\widehat{p}_l^{Fi}}, \\
\ln \widehat{A}_l^i &= \frac{1}{\theta} \ln \frac{\widehat{T}_l^i}{\widehat{\pi}_{ll}^{Fi}} \qquad \text{(according to the previous equation)} \\
\Longrightarrow \qquad \ln \widehat{T}_l^i &= \ln \widehat{\pi}_{ll}^{Fi} + \theta \ln \widehat{A}_l^i. \qquad (12)
\end{aligned}$$

According to the production function (2),

$$\ln A_l^i = \ln \frac{X_l^i}{\mathcal{P}_l^i} - \left(1 - \beta_l^i\right) \ln M_l^i - \beta_l^i \mu^i L_l^i - \beta_l^i \left(1 - \mu^i\right) K_l^i$$

where the real gross output $\frac{X_l^i}{\mathcal{P}_l^i}$ (with X_l^i being the value of the sector-i gross output in country l and $\mathcal{P}_l^i$ being the producer price index of sector i in country l), quantity of intermediate inputs M_l^i, amounts of labor used L_l^i and real fixed capital stock K_l^i for each country and sector can all be directly obtained from the WIOD Socio-Economic Accounts (SEA). Thus, we can compute $\ln \widehat{A}_l^i$ as

$$\ln \widehat{A}_l^i = \ln \frac{\widehat{X}_l^i}{\widehat{\mathcal{P}}_l^i} - \left(1 - \beta_l^i\right) \ln \widehat{M}_l^i - \beta_l^i \mu^i \widehat{L}_l^i - \beta_l^i \left(1 - \mu^i\right) \widehat{K}_l^i$$

[10] Equation (12) makes intuitive sense: if we observe that $\ln \widehat{\pi}_{ll}^{Fi}$ is higher, then it means that country l has become more competitive than before in producing sector-i final good compared with foreign countries. This implies that everything else being equal, country l must have higher technology stock than before. Similarly, if we observe that $\ln \widehat{A}_l^i$ is larger, then it means that country l must have higher technology stock than before, everything else being equal.

which leads to our estimated value of $\ln \widehat{T}_l^i$ using equation (12), given $\widehat{\pi}_{ll}^{Fi}$ from the WIOD dataset.

The second step of our quantitative exercise is to obtain estimates of international trade costs $\{\kappa_{nlt}^{ji}\}$ by estimating the following structural gravity equation year by year, derived from equation (4):

$$\ln\left(\frac{\pi_{nlt}^{ji}}{\pi_{nnt}^{ji}}\right) = \ln\left(\frac{X_{nlt}^{ji}}{X_{nnt}^{ji}}\right) = \ln\left(T_{lt}^i\left(c_{lt}^i\right)^{-\theta}\right) - \theta ex_{lt}^i - \ln\left(T_{nt}^i\left(c_{nt}^i\right)^{-\theta}\right) - \theta v_{nlt}^{ji}, \tag{13}$$

where $\ln\left(T_{lt}^i\left(c_{lt}^i\right)^{-\theta}\right)$ is the competitiveness of Country l in sector i at time t; X_{nlt}^{ji} is the country-pair-sector-pair export value, obtained from the WIOT;[11] $\ln\left(T_{lt}^i\left(c_{lt}^i\right)^{-\theta}\right) - \theta ex_{lt}^i$ is estimated as the exporter-sector fixed effect, $-\ln\left(T_{nt}^i\left(c_{nt}^i\right)^{-\theta}\right)$ is estimated as the importer-sector fixed effect, and $-\theta v_{nlt}^{ji}$ is the residual of the estimation.

We follow Waugh (2010) to interpret θex_{lt}^i as part of the exporter-sector fixed effect in year t, which captures the additional fixed costs facing the sector-i exports of exporting country l (relative to the US as normalization). The estimated asymmetric bilateral international trade cost $\{\kappa_{nlt}^{ji}\}$ is composed of two parts, the exporter fixed cost in Waugh (2010) ex_{lt}^i and the actual "bilateral" international trade cost v_{nlt}^{ji}:

$$\ln \kappa_{nlt}^{ji} = ex_{lt}^i + v_{nlt}^{ji}. \tag{14}$$

The yearly changes in domestic trade costs $\{\widehat{\delta}_n^j\}$ will be estimated from the general equilibrium analysis below.

3.3 Solving the general-equilibrium model computationally

We first explain the calibration exercise by describing the algorithm to estimate $\{\widehat{\delta}_n^j\}$ and solve for $\{\widehat{w}_l\}$, $\{\widehat{r}_l\}$, $\{\widehat{c}_l^i\}$ and $\{\widehat{P}_l^i\}$ in general equilibrium. To simplify notation, we suppress the time subscript. We also use a superscript outside the curly brackets to denote the round of iteration. Throughout our calibration exercise, we impose $\theta = 4$, following Simonovska & Waugh (2014). For each year, using $\ln\left(T_{lt}^i\left(c_{lt}^i\right)^{-\theta}\right)$ and $\ln \kappa_{nl}^{ji}$ estimated from the gravity equation (13), we calculate $\{\widehat{T}_l^i\left(\widehat{c}_l^i\right)^{-\theta}\}$ and $\{\widehat{\kappa}_{nl}^{ji}\}$ as initial values. After we have estimated $\{\widehat{T}_l^i\}$ from equation (12), we can obtain $\{\widehat{c}_l^i\}$ as initial values. The steps of solving the general equilibrium model are as follows.

[11] In order to deal with the treatment of inventories in the WIOD table, which causes some negative export volumes in the sample, we follow Antras, Chor, Fally and Hillberry (2012) to apply a "net inventory" adjustment, which apportions the reported net inventory of each destination-sector across purchasing countries and sectors, according to the corresponding proportions computed using data on intermediate uses.

1. Set the start values of $\{\widehat{w}_l\}^0$ and $\{\widehat{r}_l\}^0$, for all l, to be equal to one.

2. Simultaneously solve for $\{\widehat{\delta}_l^i\}^0$, $\{\widehat{\Phi}_l^{ji}\}^0$ and $\{\widehat{P}_l^i\}^0$ in the following system of $2NJ + NJ^2$ equations derived directly from our model:

$$\widehat{c}_l^i = \left(\widehat{P}_l^i\right)^{1-\beta_l^i} (\widehat{w}_l)^{\beta_l^i \mu_l^i} (\widehat{r}_l)^{\beta_l^i (1-\mu_l^i)} \tag{15}$$

$$\widehat{\Phi}_n^{ji} = \sum\nolimits_{l=1}^{N} \pi_{nl}^{ji} \widehat{T}_l^i \left(\widehat{c}_l^i \widehat{\kappa}_{nl}^{ji}\right)^{-\theta} \tag{16}$$

$$\widehat{P}_n^j = \widehat{\delta}_n^j \prod\nolimits_{i=1}^{J} \left(\widehat{\Phi}_n^{ji}\right)^{-\frac{\gamma_n^{ji}}{\theta}}$$

3. Calculate the changes in the sourcing shares at the country-pair sector-pair level $\{\widehat{\pi}_{nl}^{ji}\}^0$ as

$$\widehat{\pi}_{nl}^{ji} = \frac{\widehat{T}_l^i \left(\widehat{c}_l^i \widehat{\kappa}_{nl}^{ji}\right)^{-\theta}}{\widehat{\Phi}_n^{ji}}$$

and the corresponding predicted sourcing shares of the following year as

$$\left(\pi_{nl}^{ji}\right)' = \pi_{nl}^{ji} \widehat{\pi}_{nl}^{ji}.$$

4. Solve for $\left\{\left(X_n^i\right)'\right\}^0$ from the following NJ equations (goods market clearing condition)

$$\underbrace{\left(X_n^i\right)'}_{\text{sector-}i\text{ gross output of }n} = \underbrace{\sum\nolimits_{k=1}^{J} \sum\nolimits_{l=1}^{N} \left(1-\beta_l^k\right) \gamma_l^{ki} \left(\pi_{ln}^{ki}\right)' \left(X_l^k\right)'}_{\text{expenditure on intermediate inputs produced by }n} + \underbrace{\sum\nolimits_{l=1}^{N} \left(\pi_{ln}^{Fi}\right)' \alpha_l^i E_l'}_{\text{expenditure on final goods produced by }n} \tag{17}$$

with the restriction that the total expenditure on final goods must be equal to the payments to the factors of production plus the trade deficit (D_n') as follows

$$E_n' = w_n L_n \widehat{w}_n \widehat{L}_n + r_n K_n \widehat{r}_n \widehat{K}_n + D_n'. \tag{18}$$

5. Solve for $\{\widehat{w}_l\}^1$ and $\{\widehat{r}_l\}^1$ using the $2N$ capital and labor market clearing conditions

$$\begin{aligned} r_n K_n \widehat{r}_n \widehat{K}_n &= \sum\nolimits_{i=1}^{J} \beta_n^i \left(1-\mu_n^i\right) \left(X_n^i\right)'; \\ w_n L_n \widehat{w}_n \widehat{L}_n &= \sum\nolimits_{i=1}^{J} \beta_n^i \mu_n^i \left(X_n^i\right)'. \end{aligned} \tag{19}$$

6. Repeat steps 2 to 5 iteratively, until the equilibrium values of $\{\widehat{w}_l\}$ and $\{\widehat{r}_l\}$ are determined when $|| \{\widehat{w}_l\}^b - \{\widehat{w}_l\}^{b-1} ||$ approaches zero.[12] With the converged values of $\{\widehat{w}_l\}$ and $\{\widehat{r}_l\}$, we solve for the equilibrium values of $\{\widehat{\delta}_l^i\}$ from step 2.

[12] We iterate the system until the sum of all elements of $|| \{\widehat{w}_l\}^b - \{\widehat{w}_l\}^{b-1} ||$ becomes smaller than 0.001. Note also that the convergence of $\{\widehat{w}_l\}$ goes hand in hand with the convergence of $\{\widehat{r}_l\}$, according to (19).

7. We repeat steps 1 to 6 for each year, using the model-predicted trade shares for the following year $\left\{ \left(\pi_{nl}^{ji} \right)' \right\}$ as the initial value for $\{\pi_{nl}^{ji}\}$ of the next year. The process repeats itself every year until we have the full dynamic path of $\{\pi_{nl}^{ji}\}$, $\{w_l\}$, $\{r_l\}$, $\{X_n^i\}$ and prices ($\{P_l^i\}$ and $\{p_l^{ji}\}$) every year from 1995 to 2008. Using these endogenous variables and parameters, we can compute the dynamic path of DVARs at the country-sector level based on equation (7) for each year.

Notice that during the calibration process, all production and preference parameters (α_n^i, β_n^k, γ_n^{ki} $\forall i, k, n$) are kept constant at the 1995 value, while we take the values of the endowments ($\{K_n\}$, $\{L_n\}$) and the trade deficit ($\{D_n\}$) directly from the data.[13] We summarize the statistics of the parameters estimated in the calibration in Table 2.

< Table 2 about here >

Parameter	Source	Mean	Standard Deviation
α_l^i	WIOD	0.029	0.032
β_l^i	WIOD	0.477	0.167
μ_l^i	WIOD	0.609	0.206
γ_n^{ji}	WIOD	0.029	0.063
θ	Simonovska & Waugh (2014)	4	0
$\ln \widehat{K}_n$	WIOD SEA	0.036 (annual)	0.024
$\ln \widehat{L}_n$	WIOD SEA	0.012 (annual)	0.021
$\ln \widehat{T}_l^i$	Authors' Estimation	0.0035 (annual)	0.316
$\ln \left(\widehat{\kappa}_{nl}^{ji} \right)$	Authors' Estimation	-0.014 (annual)	0.268
$\ln \widehat{\delta}_n^j$	Authors' Estimation	-0.060 (annual)	0.436

Table 2: Statistics of the Parameters

Let us first show the changes in the main factors, namely technology, international trade costs and domestic trade costs, that shape countries' and global DVARs. The time series of the cumulative change in average technology is shown in Figure 1.

<Figure 1 about here>

The time series of the cumulative change in the average international trade cost is shown in Figure 2.

<Figure 2 about here >

[13] As robustness checks, when carrying out the calibration, we have tried keeping the production and preference parameters constant at the values in each year in the sample period, and we find that the results are quantitatively similar.

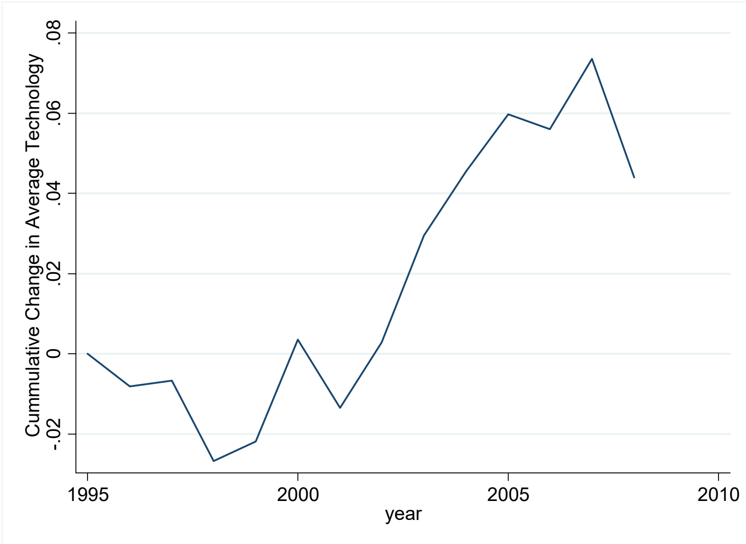

Figure 1: The time series of cumulative change in average technology

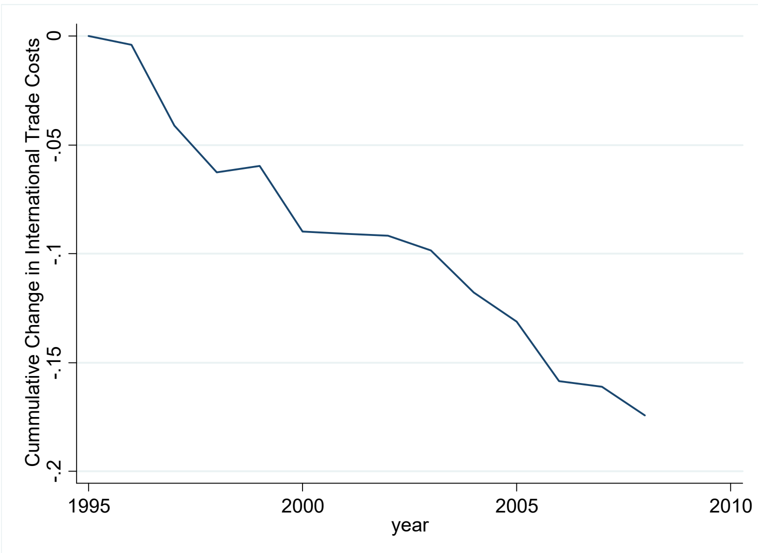

Figure 2: The time series of the cumulative change in the average international trade cost

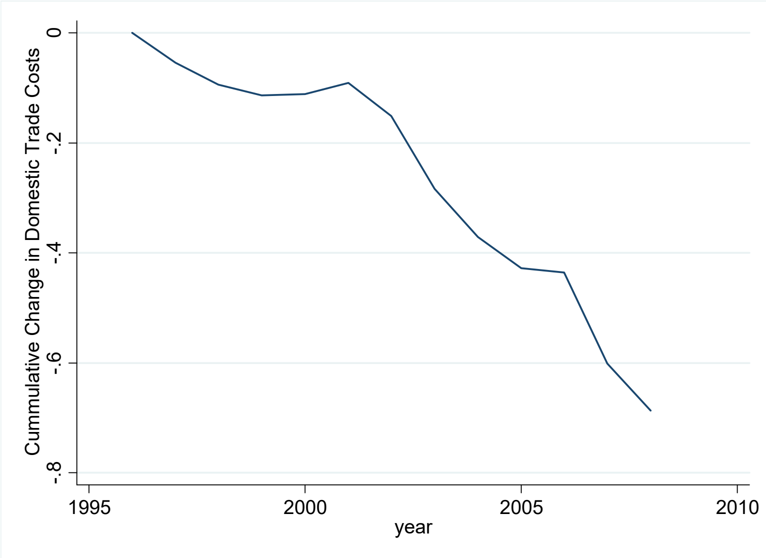

Figure 3: Time series of the cumulative change in the average domestic trade costs

The time series of the cumulative change in the average domestic trade costs is shown in Figure 3.

<Figure 3 about here>

In all the decomposition and counterfactual exercises conducted below, we will repeat the calibration exercise (steps 1 to 7 except for the estimation of $\{\widehat{\delta}_l^i\}$) by starting with the same set of production and preference parameters (α_n^i, β_n^k, γ_n^{ki}) and exogenous variables $\{K_n\}$, $\{L_n\}$, $\{D_n\}$.[14] $\{\widehat{T}_l^i\}$, $\{\widehat{\kappa}_{nl}^{ji}\}$, $\{\widehat{\delta}_l^i\}$ are exercise-specific values.

In each exercise, we start with some initial guesses of $\{\widehat{w}_l\}^0$ and $\{\widehat{r}_l\}^0$, then solve for $\{\widehat{c}_l^i\}$ and $\{\widehat{P}_l^i\}$, thereby obtaining the new trade shares $\left(\pi_{nl}^{ji}\right)'$. The general equilibrium values of $\{\widehat{w}_l\}$ and $\{\widehat{r}_l\}$ are solved computationally. They are plugged back into the system for the next iteration. The iteration process stops when we obtain $\{\widehat{w}_l\}$ and $\{\widehat{r}_l\}$ such that $|| \{\widehat{w}_l\}^b - \{\widehat{w}_l\}^{b-1} ||$ approaches zero. After that, we compute the dynamic path of DVARs at the country-sector level based on the model-generated dynamic path of $\{\pi_{nl}^{ji}\}$ and equation (7).

[14]In the counterfactuals, as we have already estimated $\{\widehat{\delta}_l^i\}$, we solve for $\{\widehat{c}_l^i\}$ instead of $\{\widehat{\delta}_l^i\}$ in step 2.

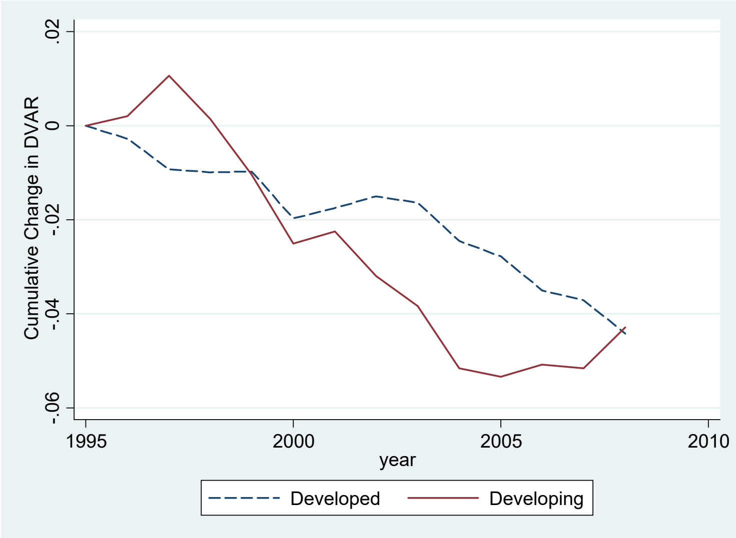

Figure 4: Developed and Developing Countries' DVAR

4 Quantitative results

Before reporting the results of our calibration exercises, let us present the trends of the DVARs for advanced and developing economies respectively, as well as for individual countries in our sample. The DVARs are computed directly based on equation (7), using annual data from the WIOD (1995-2008).

4.1 DVAR trends

Figure 4 shows the change in the DVAR of exports from developed and developing countries respectively. As the figure shows, the DVAR of exports from both groups of countries have by and large been on a generally declining trend, with the cumulative decline for developing countries (solid line) and developed countries (dash line) both equal to about 4.5% (solid line) from 1995 to 2008.

< Figure 4 about here >

Figures 5 and 6 show the individual countries' DVAR for the fast-growing countries and the developed (OECD) countries, respectively. For some countries, such as Canada, China, Indonesia, Ireland, Luxembourg, Russia, the DVAR did not decline over the period 1995-2008, while the trend is generally declining for all the other 34 (out of 40) countries in the sample. Besides explaining why the global trend was negative, our decomposition and counterfactual exercises below will shed light on the reasons why certain countries experienced non-decreased or even increased DVARs in their exports, defying the global trend.

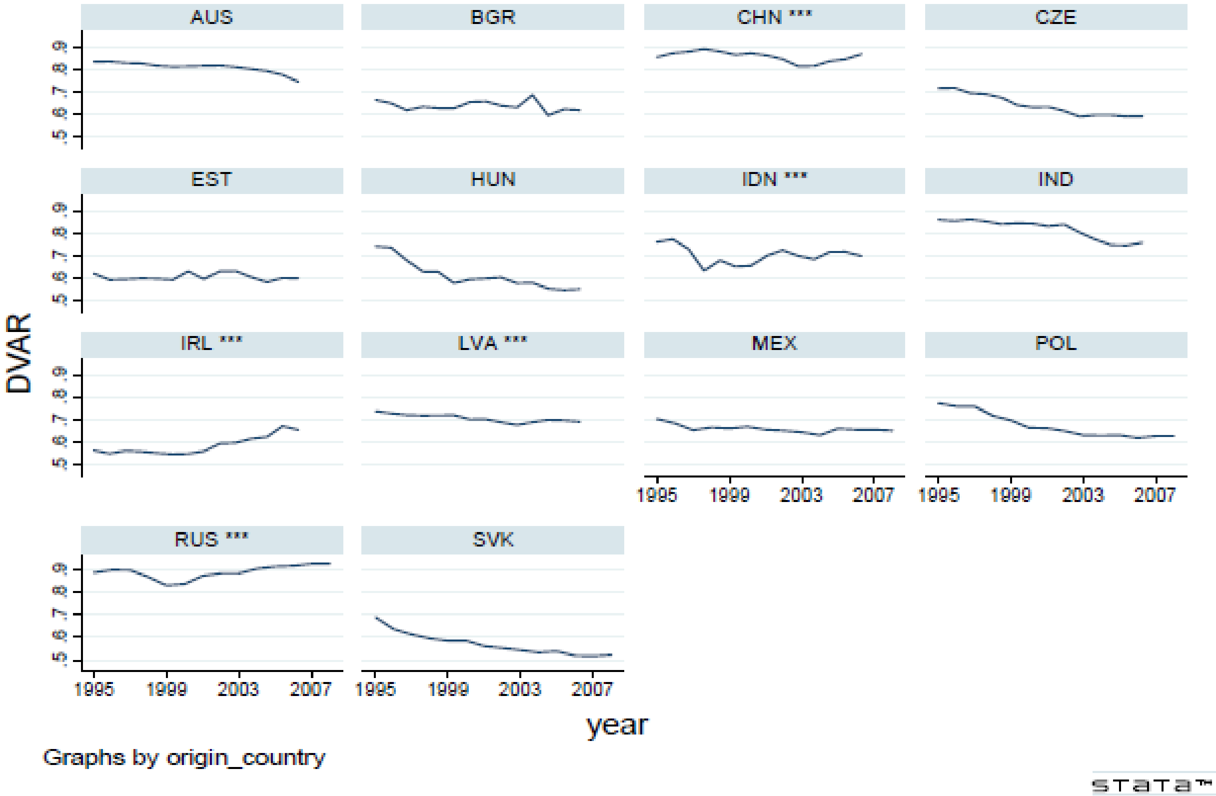

Figure 5: Fast-Growing Countries' DVAR

< Figures 5 and 6 about here >

4.2 Calibration results

First, we examine the fit of our calibration. Figure 7 plots for each country the simulated cumulative change in DVAR against that based on data from 1995 to 2008. As is shown, the simulated cumulative changes in DVAR are very close to the 45-degree line, implying that our calibrated model, which focuses on the total effect of the combination of the global changes in exogenous factors of technology, international trade costs, domestic trade costs, factor endowments and trade balances, performs very well. Notice that though we target each country-pair-sector-pair sourcing share in the WIOD, the fit is not perfect as we assume that the production and preference parameters in the Cobb-Douglas functions ($\alpha's$, $\beta's$ and $\gamma's$) are constants (specifically, equal to the 1995 computed values) across years within countries. In the data, however, they are changing, though our model has nothing to say about those changes. Another reason for the imperfect fit is that we replace zero trade with US$1 in our sample (see the appendix for details).

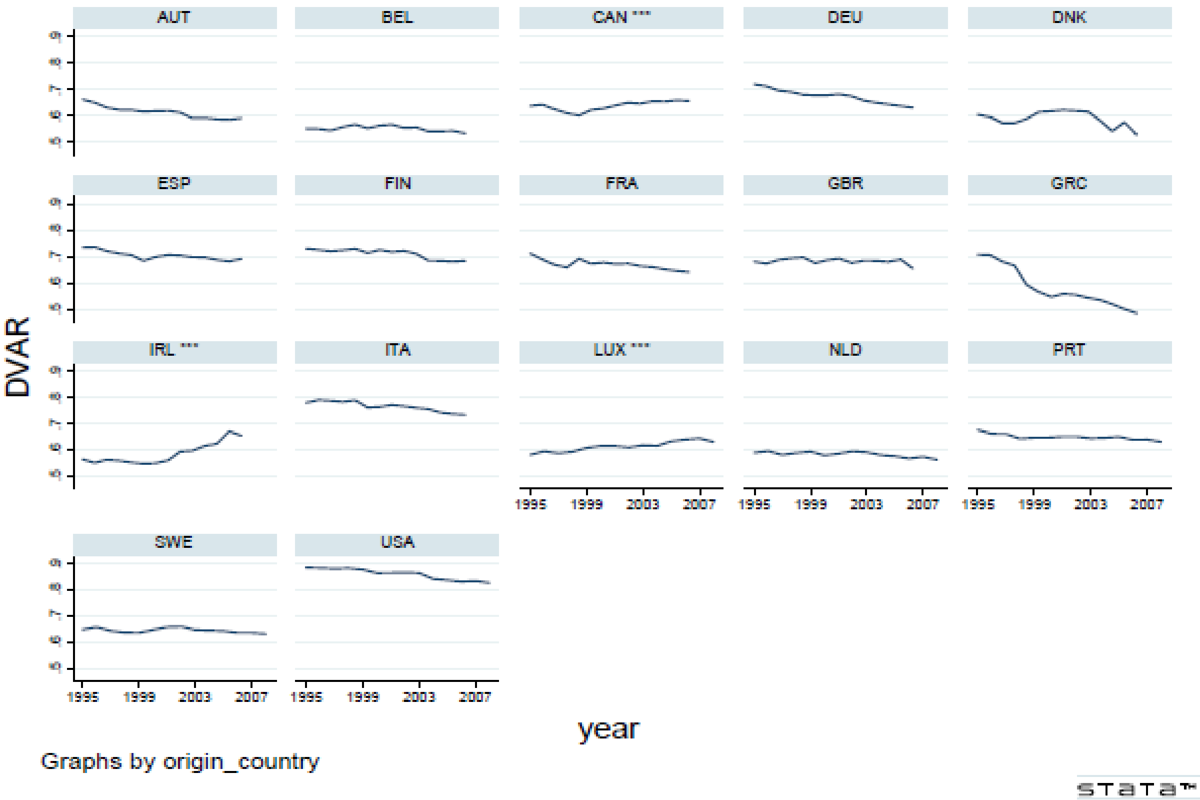

Figure 6: Developed Countries' (OECD) DVAR

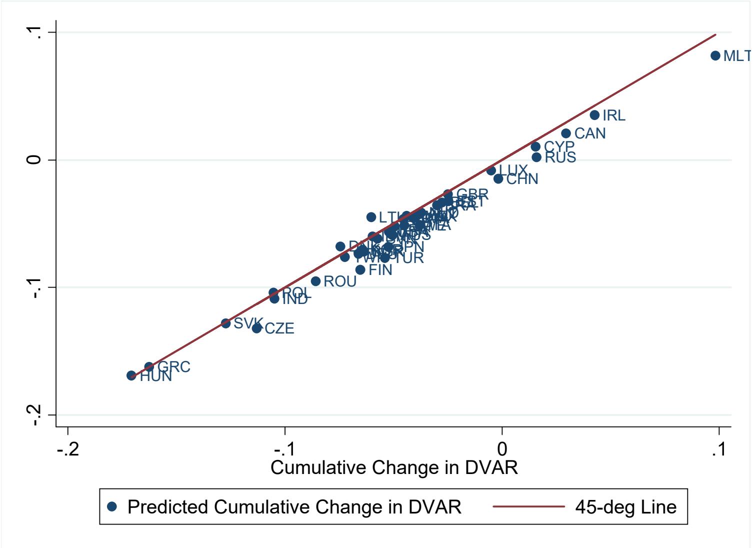

Figure 7: The Fit of the Model — the total effect of the combination of all factors. The predicted cumulative change in DVAR on the y-axis is plotted against the actual cumulative change in DVAR on the x-axis.

$<$ Figure 7 about here $>$

Second, we examine the model fit of a series of pure effects. We focus on four factors: technology, total trade costs (the relevant trade costs for both international and intra-national trade), domestic trade costs (the relevant trade costs for intra-national trade) and other factors.[15] Figure 8 shows the pure (stand-alone) effect of changing total trade costs ($\left\{\tau_{nlt}^{ji}\right\}$) on the cumulative changes in individual countries' DVAR, which is the focus of the literature (e.g., Johnson and Noguera, 2017). The pure effect of total trade costs is obtained by shutting down any change in technology ($\{T_n\}$), and other factors (factor endowment and trade imbalances), keeping only the changes in $\left\{\kappa_{nlt}^{ji}\right\}$ and $\left\{\delta_n^j\right\}$ for the calibration exercise. That is, we assume that the values of all T's and other factors take on the same values as those in the first sample year (i.e., 1995). As expected, changes in total trade costs alone cannot explain the data well. The effect under-predicts the DVARs for almost all countries, as shown in Figure 8. As Figure 25 and Table 3 in Appendix D show, the magnitude of the pure effect of total trade costs is much greater than that of the data as the (negative) pure effects of both international and domestic costs are large, despite there being a positive interactive effect between the two.

$<$ Figure 8 about here $>$

[15] We do not examine the effects of international trade costs as it is neither the relevant trade cost for international trade nor that for intra-national trade.

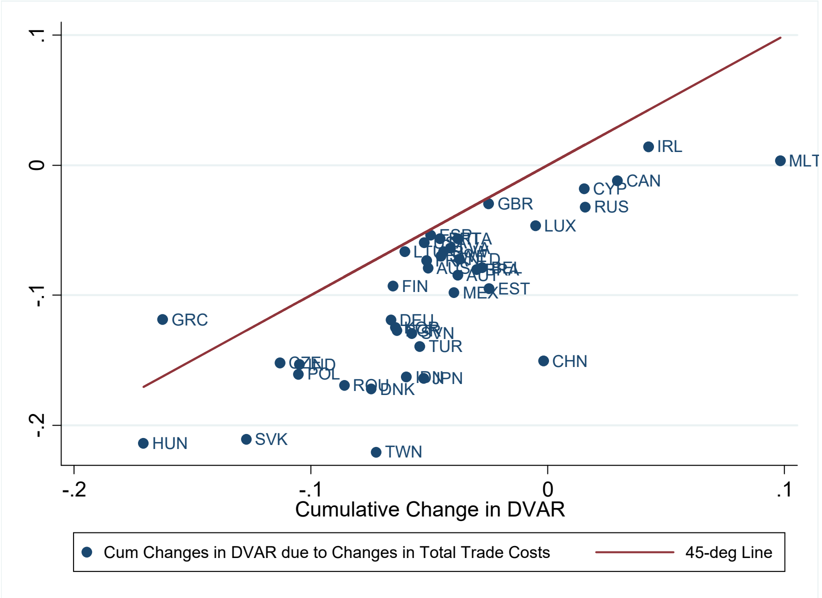

Figure 8: Pure (stand-alone) effect of changing total trade costs τ. The predicted cumulative change in DVAR due to changes in total trade costs alone on the y-axis is plotted against the actual cumulative change in DVAR on the x-axis.

Figure 9 shows the pure effect of changing domestic trade costs on the cumulative changes in individual countries' DVAR, an aspect that has not received much attention in the literature. To gauge the pure effects of domestic trade costs, we shut down all changes in technology, international trade costs and other factors (factor endowment and trade imbalances) in our calibration exercises. As expected, changes in domestic trade costs alone cannot explain the data well, and in general under-predicts the level of DVAR for many countries. As Figure 25 in Appendix D shows, the pure effect of domestic trade costs under-predicts the DVAR on average, explaining why more countries are below the 45-degree line than above it in Figure 9.

< Figure 9 about here >

Figure 10 shows the pure effect of changing technology on the cumulative change in individual countries' DVAR, an aspect that has been downplayed in the existing literature. To gauge the pure effects of technology, we shut down all changes in international and domestic trade costs and other factors (factor endowment and trade imbalances) in our calibration exercises. As expected, changes in technology alone cannot explain the data well. As Figure 25 in Appendix D shows, the pure effect of technology over-predicts the DVAR on average. This explains why more countries are above the 45-degree line than below it in Figure 10. There is one notable exception that lie significantly below the 45-degree line — Japan, whose technology stock *decreased* the most among all countries.

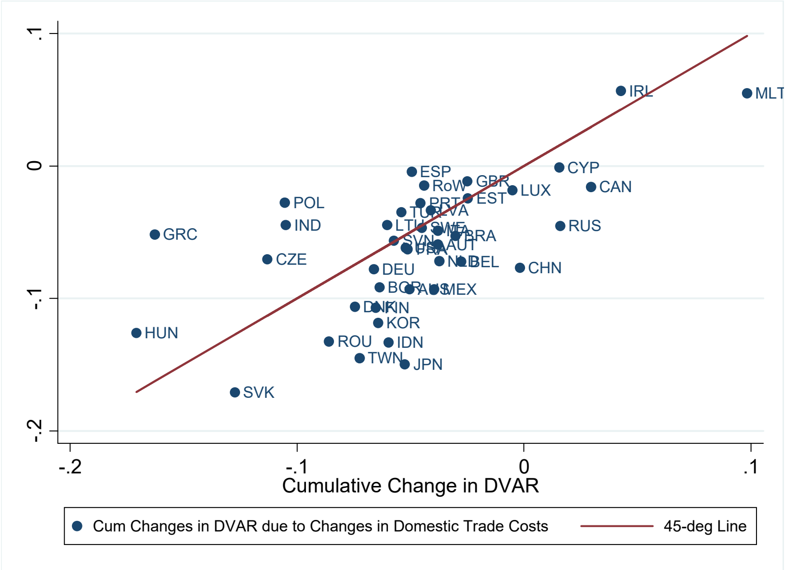

Figure 9: Pure (stand-alone) effect of changing domestic trade costs δ. The predicted cumulative change in DVAR due to changes in domestic trade costs alone on the y-axis is plotted against the actual cumulative change in DVAR on the x-axis.

< Figure 10 about here >

Figure 11 shows the pure effect of changes in “other factors” (factor endowment and trade imbalances) on cumulative changes in individual countries’ DVAR, with changes in technology and international and domestic trade costs being shut down in the counterfactual exercise. As expected, changes in other factors alone cannot explain the data well, and over-predicts the level of DVAR on average, as shown in Figure 11. This is consistent with Figure 25 in Appendix D.

< Figure 11 about here >

4.3 Total effect of each factor

After examining the goodness of fit of our model, in this section, we examine the total effects of each of four main factors, technology, total trade costs, domestic trade costs and other factors. To this end, we study the difference between the calibration with all changes allowed and the counterfactual with only one of the factors shut down. For instance, to examine the total effect of technology (T), we subtract the predicted DVAR with all changes allowed but T shut down (call it $DVAR^{-T}$) from the predicted DVAR with all changes allowed.

Figure 12 shows the results of different counterfactual exercises. The total effect of technology, as illustrated by the blue solid line, is significantly positive, accounting for a close to

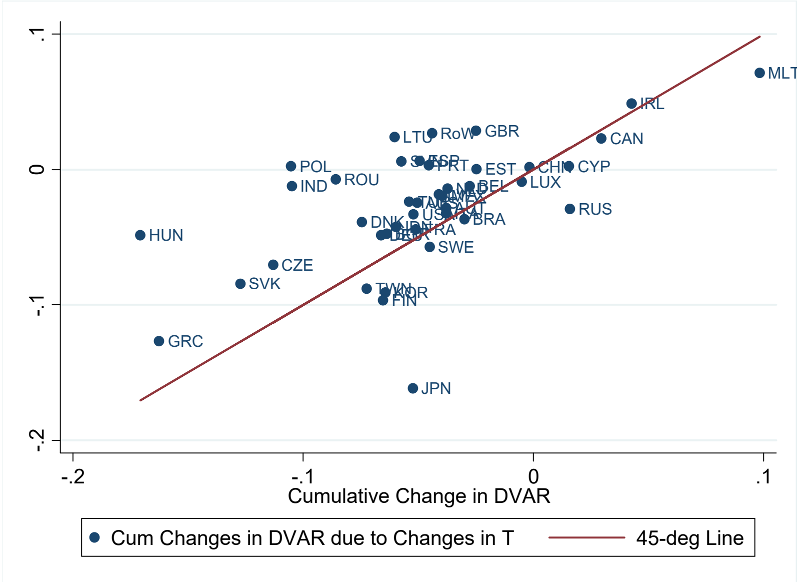

Figure 10: Pure (stand-alone) effect of changing technology T. The predicted cumulative change in DVAR due to changes in technology alone on the y-axis is plotted against the actual cumulative change in DVAR on the x-axis.

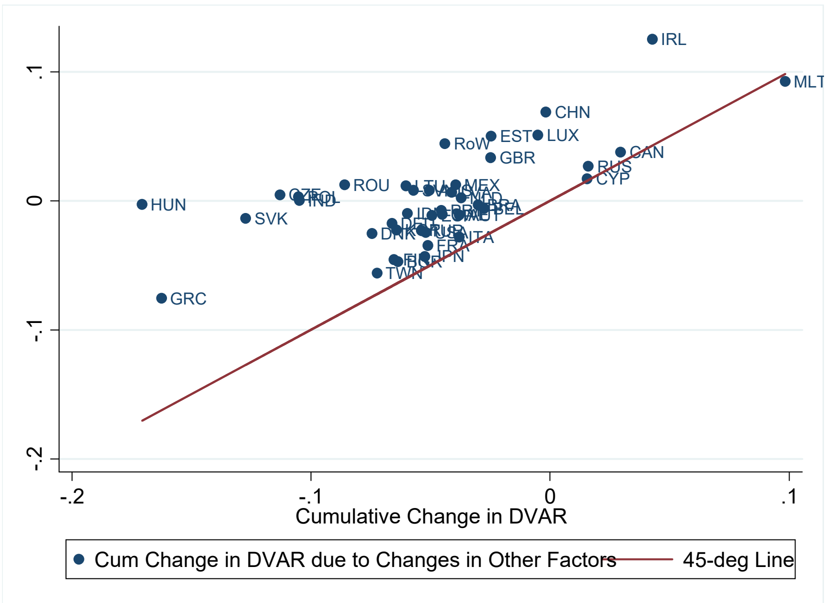

Figure 11: Pure (stand-alone) effect of changes in Other Factors (i.e. K, L and trade balance). The predicted cumulative change in DVAR due to changes in Other Factors alone on the y-axis is plotted against the actual cumulative change in DVAR on the x-axis.

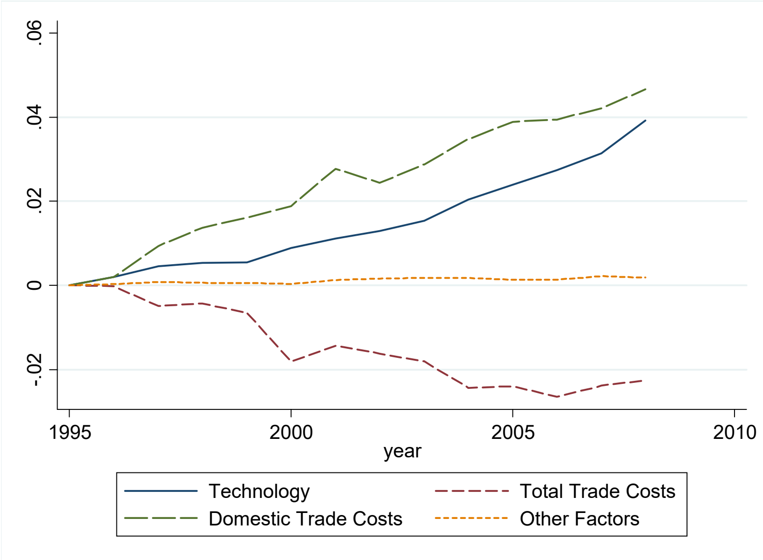

Figure 12: Total Effects of T, τ, δ and Other Factors on Global DVAR

4.0 percentage-points increase in the world's DVAR. The total effect of total trade costs is significantly negative (around -2.3 percentage-points), consistent with previous findings (e.g., Johnson and Noguera, 2017). The total effect of domestic trade costs is positive at around 4.7 percentage-points. The total effect of other factors is marginally positive. Notice that the sum of the total effects of technology, total trade costs and other factors is not supposed to be equal to the data, as there will be double-counting of the interactive effects that we highlight in Figure 26 in the appendix.

< Figure 12 about here >

In Figures 13 and 14, we repeat the same exercises to gauge the total effects of the four sets of exogenous determinants on the DVAR for the developed and developing countries, respectively. The results look quite similar to the one we showed for all countries in Figure 12. It is worth noting that the magnitudes of the total effects of technology, total trade costs and domestic trade costs for the developing countries are all larger than those for the developed countries. This is because the changes in the magnitudes of the determinants of DVAR are larger for developing countries, which underwent faster economic changes. Notably, the average magnitude of the total effect of total trade costs on the DVAR of developing countries is much larger than that of developed countries as the domestic trade costs and international trade costs of the developing countries both fell faster than those of the developed countries on average.

< Figures 13 and 14 about here >

Before discussing other counterfactual exercises, let us show the results of our calibration

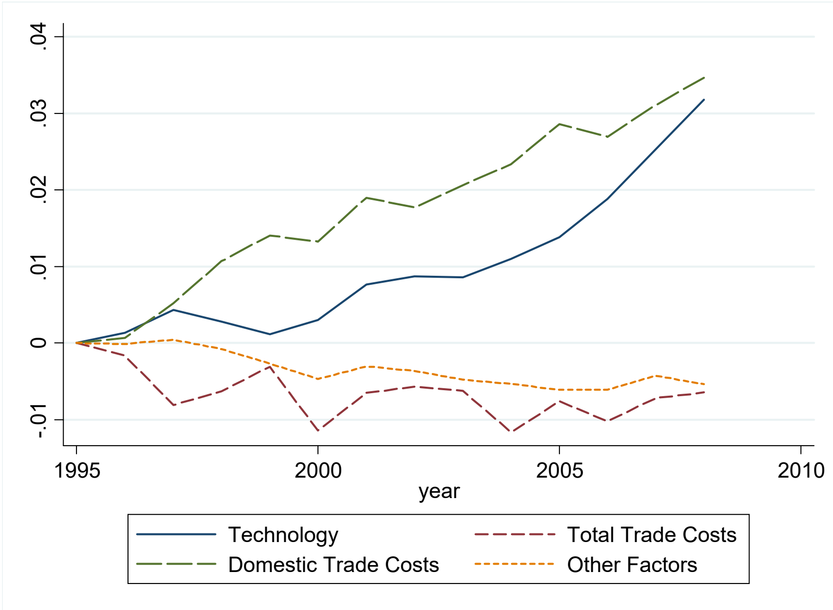

Figure 13: Total Effects of T, τ, δ and Other Factors on Developed Countries

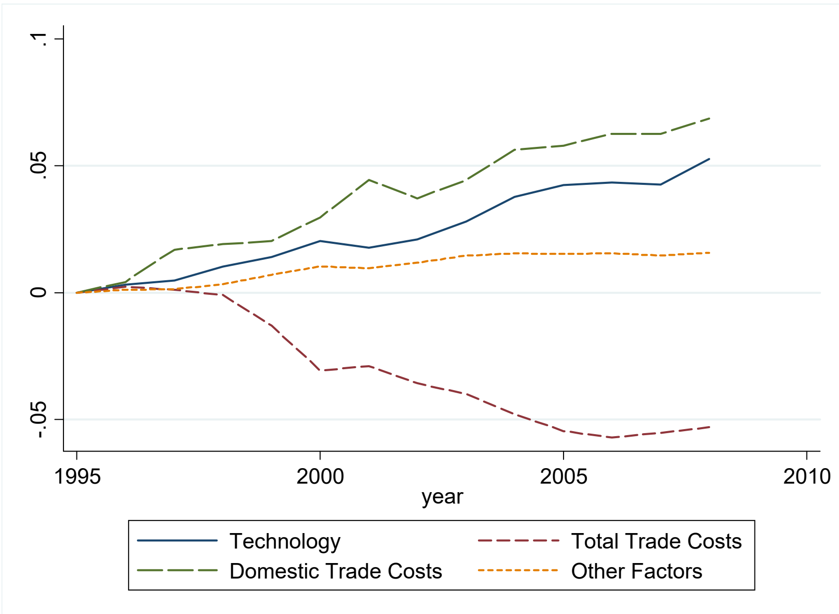

Figure 14: Total Effects of T, τ, δ and Other Factors on Developing Countries

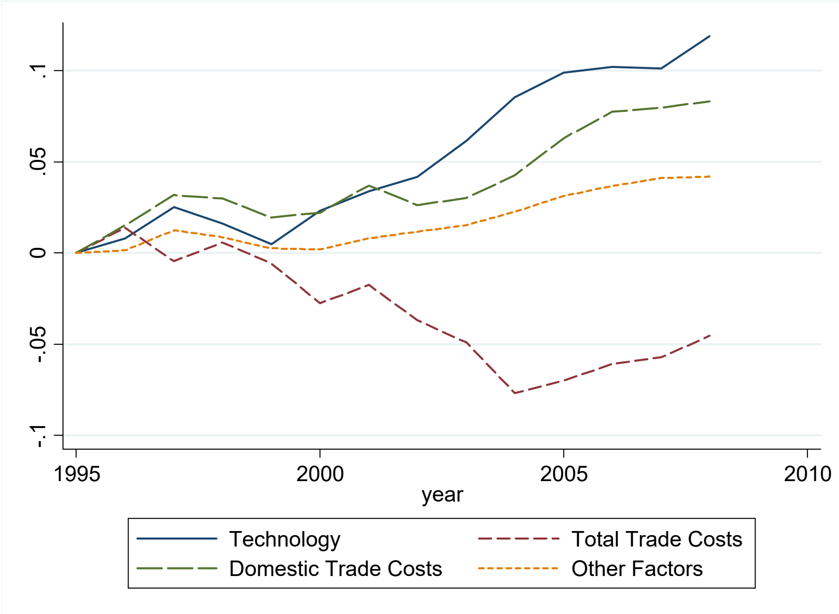

Figure 15: Total Effects of T, τ, δ and Other Factors on China

to assess the total effects of the four determinants of the DVARs of China and the US. As Figure 15 shows for China, the total effect of technology, as represented by the blue solid line, is significantly positive, reaching about 12% by 2008. This is much greater than the average developing country, reflecting the fast technological progress of China. The total effect of total trade costs is generally on a declining trend until the cumulative effect reaches about -7.5% in 2004 and then rises back to about -5% by 2008. China's accession to the WTO is obviously an important reason behind this generally declining trend from 2001. The total effect of "other factors", which include capital accumulation and trade balance (which was positive and increasing fast since 2001), increasingly pushes up China's DVAR and the cumulative effect reaches +4% in 2008.[16] This effect is much larger than that of the average developing country, reflecting that fast capital accumulation and sustained large trade surplus of China during the sample period. To understand the exceptional trend of China's DVAR, one would need to consider both the total effects and the interactive effects of the factors. This will be our first counterfactual exercise in the next section.

< Figure 15 about here >

Figure 16 shows that for the US, the total effect of technology, as represented by the blue solid line, is significantly positive, reaching about +1.7% by 2008. The total effect of domestic trade costs is positive, reaching about +2.0% in 2008. The total effect of total trade

[16] An increase in trade surplus must be accompanied by a fall in the wage (see Dekle, Eaton and Kortum 2007), which in turn makes domestic goods more competitive, increasing the DVAR. Thus, the effect of trade surplus is similar to that of technology.

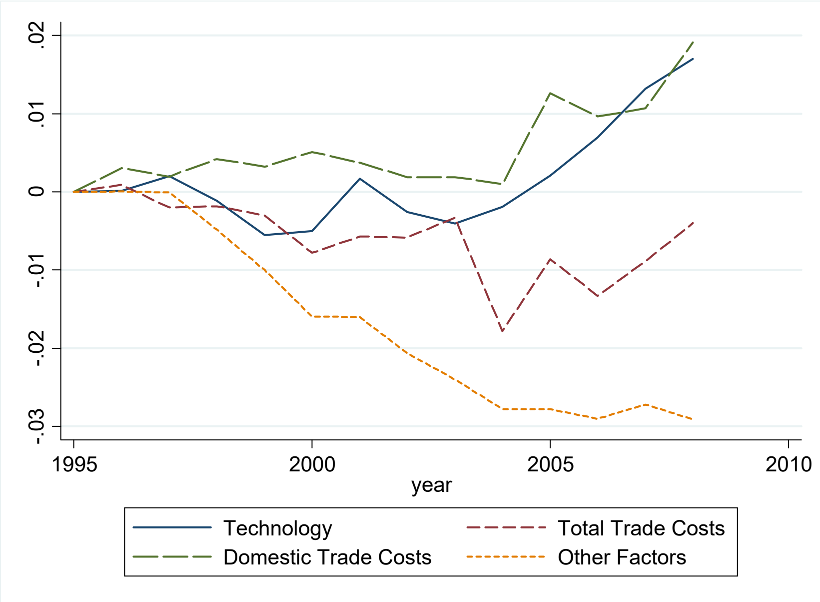

Figure 16: Total Effects of T, τ, δ and Other Factors on the US.

costs fluctuates but with a slight downward trend, reaching about -0.5% in 2008. The "other factors", which include trade balance (which was negative, large and generally increasing throughout the sample period), contribute significantly and increasingly negatively to the US's DVAR, with the effect reaching all the way to about -2.9% in 2008.[17] This effect is much larger than that of the average developed country, possibly due to the sustained large trade deficits of the US during the sample period.

< Figure 16 about here >

4.4 Counterfactuals on the impacts of China

We first conduct the counterfactual exercise of shutting down China's technological progress (i.e., assuming that the technology stock of each sector of China for all years are equal to its initial level in 1995). Before reporting the results of the counterfactuals, it is worth noting that Figure 17 shows that the DVAR of China rose sharply from 2004 to 2008 by 5%, pushing the cumulative change in DVAR from 1995 to 2008 up to zero. As we shall show below, this unusual trend is caused by the significant increase in technology together with reduction in domestic trade costs of China. Now we turn to the counterfactuals. First, as Figure 17 shows, the predicted DVAR of China's exports in the absence of technological progress is significantly lower than the data (solid line), by about 7.0% in 2008. In other words, technological progress

[17] An increase in trade deficit must be accompanied by a rise in the wage (see Dekle, Eaton and Kortum 2007), which in turn makes domestic goods less competitive, reducing the DVAR.

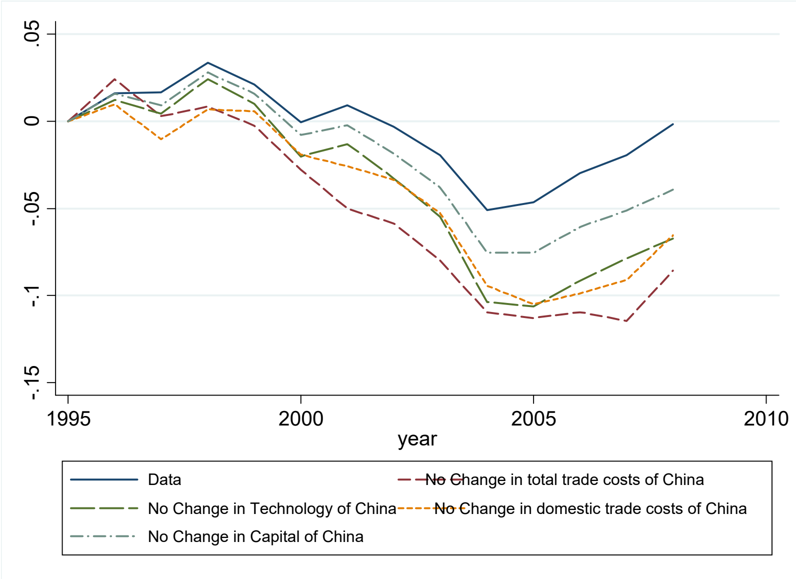

Figure 17: Effects of Shutting Down Changes in China's T, τ, δ and Capital on China's DVAR.

in China significantly raised its DVAR, with the cumulative effect increasing over time (as the gap between the curves for the data and the counterfactual widens over time).

< Figure 17 about here >

Next we conduct a counterfactual of shutting down the reduction in domestic trade costs of China on China's own DVAR (i.e., assuming that China's level of domestic trade costs at each country-sector pair level for all years is equal to its initial level in 1995). Figure 17 shows that the predicted DVAR of China's exports in the absence of reduction in domestic trade costs is significantly lower than the data (solid line). Specifically, the total effect of the reduction in domestic trade costs of China cumulatively accounts for about 7% increase in China's DVAR during the sample period. As expected, the reduction in domestic trade costs makes it cheaper to source domestically, increasing the DVAR.

We next conduct the counterfactual exercise of shutting down China's reduction in total trade costs (i.e., assuming that China's levels of domestic and international trade costs at each country-cum-sector-pair level for all years are equal to their initial levels in 1995). As Figure 17 shows, the predicted DVAR of China's exports in the absence of the reduction in total trade costs will be significantly lower than the data (solid line). This is consistent with the finding in Tombe and Zhu (2019). During our sample period, the reduction in total trade costs of China reflects two facts: first, the total trade costs of trading with foreign trading partners declined; second, the total trade costs of trading with domestic trading partners declined. The first effect tends to lower China's DVAR but the second effect tends to raise it. It turns out that there was such a significant internal trade liberalization in China during

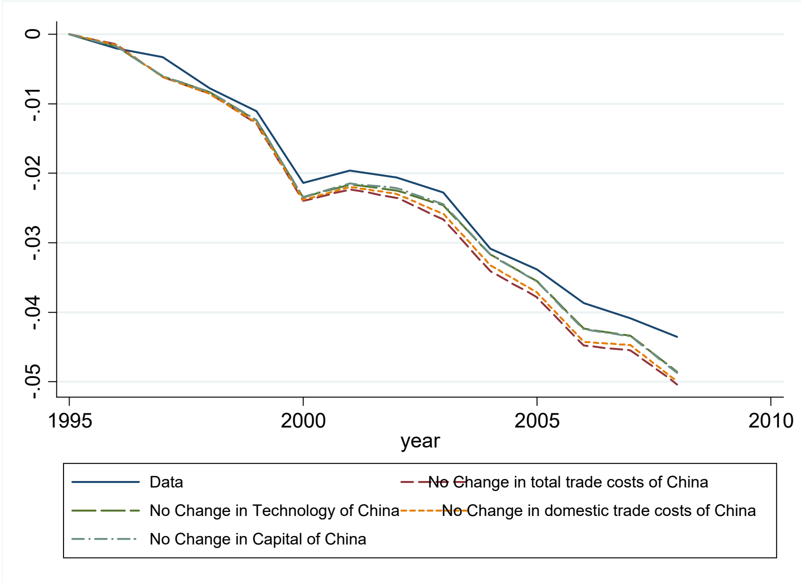

Figure 18: Effects of Shutting Down Changes in China's T, τ, δ and Capital stock on ROW's DVAR.

this period that the second effect dominates the first, leading to a positive total effect of the reduction in total trade costs on China's DVAR. The positive interactive effect of the reduction in total trade costs and the increase in technology might be one important reason for the dominance of the domestic trade costs over the international trade costs. Thus, the reduction of total trade cost leads to more sourcing from domestic markets for the Chinese producers, raising China's DVAR.

Next, we conduct the counterfactual exercise of shutting down the changes in the capital stocks of China — China's capital stocks in all years take on their initial value in 1995. As Figure 17 shows, the predicted DVAR of China's exports in the absence of any change in the capital stock will be lower than the data (solid line), as expected, since an increase in the capital stock raises the competitiveness of the country, raising its DVAR.

The next two counterfactual exercises examine how shutting down changes in the four exogenous factors T, τ and δ, and capital stock in China will affect the DVAR of exports from the rest of the world (ROW) and that from the US, respectively. Figure 18 shows that shutting down changes in China's technology, total trade costs, domestic trade costs and capital stock all lower the average DVAR of the rest of the world, but the effects are all quantitatively quite small (with all of them being less than 1% cumulatively).

$<$ Figure 18 about here $>$

On the other hand, shutting down China's technological progress, changes in capital stock

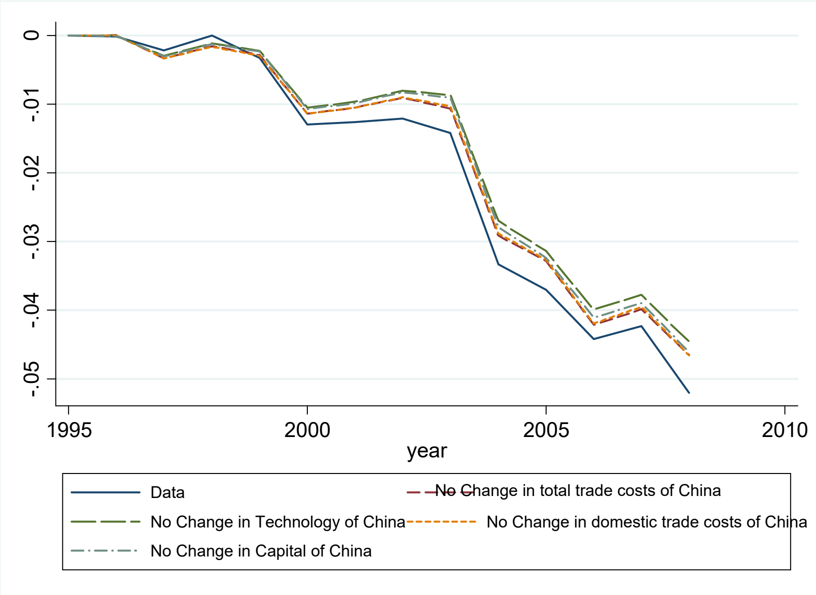

Figure 19: Effects of Shutting Down Changes in China's T, τ, δ and Capital on US's DVAR.

or reduction of total or domestic trade costs all have opposite effects on the DVAR of the US from those on the DVAR of the rest of the world, though the effects of all counterfactuals are quantitatively small. Specifically, Figure 19 shows that the DVAR of US exports will be higher than the data (dash line) in the absence of growth in China's technology stock or capital stock during the sample period, as expected. Likewise, Figure 19 reveals that the DVAR of US exports will also be higher than the data (dashed line) in the counterfactual world where China's total and domestic trade costs remain at their high levels in 1995, as expected.

$<$ Figure 19 about here $>$

5 Is a country's DVAR related to welfare?

This section studies whether a country' DVAR is related to welfare, as has been presumed to be positively related by many policy makers. We also want to know whether and how the determinants of the changes in a country's DVAR affect the country's welfare.

Relationship between DVAR and domestic sourcing share

For the changes in DVAR of a country, as we assume that the parameters in the Cobb-Douglas production function and utility function ($\alpha's$, $\beta's$ and $\gamma's$) are constants in all the counterfactual exercises, we have

$$d\mathbf{r} = [\mathbf{I} - (\mathbf{I} - \mathbf{B})\,\mathbf{G}]^{-1}\,(\mathbf{I} - \mathbf{B})\,(d\mathbf{G})\,\mathbf{r}$$

where $d\mathbf{G} = \mathbf{d}\left\{\pi_{mn}^{ik}\gamma_{m}^{ik}\right\} = \left\{\gamma_{m}^{ik}d\pi_{mn}^{ik}\right\}$, all the changes come from the changes in intermediate goods sourcing shares π_{mn}^{ik}. When the country is initially close enough to autarky, $\pi_{mn}^{ik} \approx 0$ for $n \neq m$ and $\pi_{nn}^{ik} \approx 1$. Since the average values in the data for these two variables are 0.006 and 0.75 respectively, we can regard the countries in our sample to be sufficiently close to autarky on average. In this case, the DVARs are sufficiently close to one, and it can be shown below that the changes in the DVAR of a country (aggregated over all sectors), denoted by $DVAR_n$, is closely correlated with the changes in the domestic sourcing share of the country (aggregated over all sector-pairs), denoted by π_{nn}. Specifically, based on the above matrix equation, we have[18]

$$\begin{aligned} dDVAR_n^j &\approx \sum_{i=1}^{J}\sum_{k=1}^{J}\lambda_n^{ji}\left(1-\beta_n^i\right)\gamma_n^{ik}d\pi_{nn}^{ik} \\ &\approx \sum_{i=1}^{J}\sum_{k=1}^{J}\lambda_n^{ji}\left(1-\beta_n^i\right)\gamma_n^{ik}d\ln\pi_{nn}^{ik} \end{aligned}$$

where $DVAR_n^j$ is the DVAR of sector j of country n, λ_n^{ji} is the row j column i element of $[\mathbf{I}-(\mathbf{I}-\mathbf{B_n})\,\mathbf{\Gamma_n}]^{-1}$, $\mathbf{B_n}$ is defined as a diagonal matrix with the jth diagonal element being β_n^j, $\mathbf{\Gamma_n}{\equiv}\{\gamma_n^{ji}\}$ is the $J \times J$ input-output matrix of country n. The second approximation above follows from $d\ln x = dx/x \approx dx$ when x is close to one. As $dDVAR_n = \sum_{j=1}^{J} m_n^j dDVAR_n^j$, where $DVAR_n$ is the DVAR of country n aggregated over all sectors, and m_n^j is the share of exports of sector j goods in the total exports of country n, we have

$$dDVAR_n \approx \sum_{j=1}^{J} m_n^j \sum_{i=1}^{J}\sum_{k=1}^{J}\lambda_n^{ji}\left(1-\beta_n^i\right)\gamma_n^{ik}d\ln\pi_{nn}^{ik}\ . \tag{20}$$

Thus, the change in DVAR of a country aggregated over all sectors is approximately equal to the weighted average of the changes in domestic trade shares in intermediate goods. The relationship between the DVAR (aggregated over all sectors) and the domestic sourcing share (aggregated over all sector-pairs) is most easily seen by simplifying the model to a multi-country one-sector model, in which case the above equation becomes[19]

$$dDVAR_n \approx \frac{1-\beta_n}{\beta_n}d\ln\pi_{nn}$$

[18] When $\pi_{nn}^{ik} \approx 1$, $\mathbf{I} - (\mathbf{I} - \mathbf{B})\,\mathbf{G} \approx \mathbf{I} - (\mathbf{I} - \mathbf{B})\,\mathbf{\Gamma}$. Thus, we have

$$\begin{aligned} d\mathbf{r} &\approx [\mathbf{I} - (\mathbf{I} - \mathbf{B})\,\mathbf{\Gamma}]^{-1}\,(\mathbf{I} - \mathbf{B})\,(d\mathbf{G})\,\mathbf{r} \\ \Rightarrow \quad d\mathbf{r_n} &= [\mathbf{I} - (\mathbf{I} - \mathbf{B}_n)\,\mathbf{\Gamma}_n]^{-1}\,(\mathbf{I} - \mathbf{B}_n)\,(d\mathbf{G}_n)\,\mathbf{r}_n \end{aligned}$$

as all matrices become block diagonal matrices.

[19] In the special case of a multi-country, one-sector model, $\mathbf{\Gamma}_n = 1$, $\mathbf{B}_n = \beta_n$, $d\mathbf{G}_n = d\pi_{nn}$. With $\pi_{nn} \approx 1$, and $r_{nn} \approx 1$, we get the following equation.

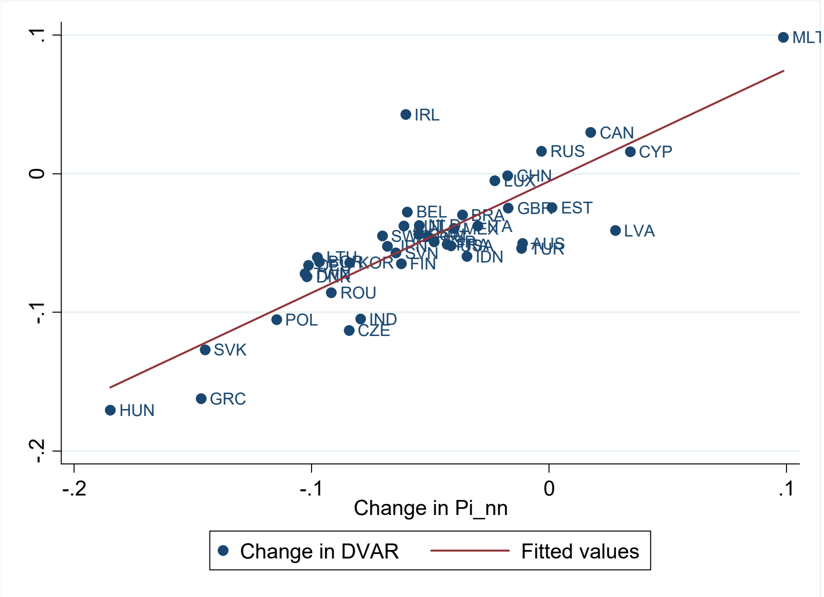

Figure 20: Change in domestic value-added ratio (aggregated over all sectors) $\Delta DVAR_n$ on the y-axis plotted against change in domestic sourcing share (aggregated over all sector-pairs) $\Delta\pi_{nn}$ on the x-axis.

where π_{nn} is the domestic sourcing share of intermediate goods.

To illustrate this empirically, we plot the change in DVAR of each country (aggregated over all sectors) against the change in domestic sourcing share (aggregated over all sector-pairs) in Figure 20, which shows a positive and highly significant correlation between the two variables.

< Figure 20 about here >

Relationship between welfare and domestic sourcing share

Let us define the welfare of country n, W_n, as the real income of its workers:

$$W_n = \frac{w_n}{P_n^F}$$

where P_n^F is the ideal price index of final consumption. It can be shown that the price index of final good j in country n, denoted by P_n^{Fj}, is equal to $\left(\Phi_n^{Fj}\right)^{-\frac{1}{\theta}}$, where

$$\Phi_n^{Fj} = \sum_{l=1}^{N} T_l^j (c_l^j \tau_{nl}^{Fj})^{-\theta}.$$

Thus, the percentage change in real income in country n is given by (see the appendix for details):

$$d\ln W_n = d\ln w_n - \sum_{j=1}^{J} \alpha_n^j \left(\frac{d\ln T_n^j}{\theta} - \frac{d\ln \pi_{nn}^{Fj}}{\theta} - d\ln c_n^j \right)$$

where we invoke $d\ln\pi_{nn}^{Fj}=d\ln T_n^j-\theta d\ln c_n^j-d\ln\Phi_n^{Fj}$, where π_{nn}^{Fj} is the final goods domestic sourcing share of country n in sector j.

Detailed derivation shown in the appendix yields the following welfare change equation

$$d\ln W_n=\sum_{j=1}^{J}\alpha_n^j\left\{\frac{1}{\theta}\sum_{i=1}^{J}\lambda_n^{ji}\left[d\ln T_n^i-\left(1-\beta_n^i\right)d\ln\delta_n^i\right]-\frac{1}{\theta}\left(d\ln\pi_{nn}^{Fj}+\sum_{i=1}^{J}\lambda_n^{ji}\sum_{k=1}^{J}\eta_n^{ik}d\ln\pi_{nn}^{ik}\right)\right\} \tag{21}$$

where $\eta_n^{ik}=\left(1-\beta_n^i\right)\gamma_n^{ik}$ is the row i column k element of the matrix $\left(\mathbf{I}-\mathbf{B_n}\right)\mathbf{\Gamma_n}$.

Notice that the welfare gains can come from direct imports of final goods, and imports of intermediate goods for the production of final goods through the IO linkage, as well as technological progress in either final goods or intermediate goods. In the roundabout production setting of Eaton and Kortum (2002), $\pi_{nn}^{Fi}=\pi_{nn}^{ji}\equiv\pi_{nn}^i$, the term $d\ln\pi_{nn}^{Fj}+\sum_{i=1}^{J}\lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^{J}\gamma_n^{ik}d\ln\pi_{nn}^{ik}$ will reduce to a simple term $\sum_{i=1}^{J}\lambda_n^{ji}d\ln\pi_{nn}^i$, similar to the effect of changes in technology stock. When there is neither roundabout production nor IO linkage, $\mathbf{B}_n=\mathbf{\Gamma}_n=\mathbf{I}$, so that $\left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}=\mathbf{I}$. Thus, equation (21) will reduce to equation (11) in Donaldson (2018).

Equation (21) implies that

$$\widehat{W}_n=\prod_{j=1}^{J}\prod_{i=1}^{J}\left[\frac{\widehat{T}_n^i}{\left(\widehat{\delta}_n^i\right)^{1-\beta_n^i}}\right]^{\frac{\alpha_n^j\lambda_n^{ji}}{\theta}}\cdot\prod_{j=1}^{J}\prod_{i=1}^{J+1}\prod_{k=1}^{J}\left(\widehat{\pi}_{nn}^{ik}\right)^{-\frac{\alpha_n^j\lambda_n^{ji}\eta_n^{ik}}{\theta}} \tag{22}$$

where the superscript $i=J+1$ stands for final good F, and $\lambda_n^{Fj}\eta_n^{Fk}=I^{jk}$, which equals 1 when $j=k$ and zero otherwise. For the yearly change in welfare, $\widehat{\pi}_{nn}^{ji}$ can be obtained from the data, $\widehat{T}_n^j$ are estimated in Section 3.2, $\widehat{\delta}_n^i$ are solved from the general equilibrium conditions of the model, and θ, α_n^j, η_n^{ik}, μ_n^j as well as λ_n^{ji} are exogenous parameters. Thus the value of $\widehat{W}_n$ of each year can be directly calculated.

We can also compute the gains from trade relative to autarky. When country n moves from autarky, where $\pi_{nn}^{Fj}=\pi_{nn}^{ji}=1$ for all i, j, to the observed equilibrium, the gains from trade is

$$\widehat{W}_{n,A}-1=\prod_{j=1}^{J}\prod_{i=1}^{J+1}\prod_{k=1}^{J}\left(\pi_{nn}^{ik}\right)^{-\frac{\alpha_n^j\lambda_n^{ji}\eta_n^{ik}}{\theta}}-1 \tag{23}$$

In the one-sector setting, $\mathbf{B}_n=\beta_n$ and $\mathbf{\Gamma}_n=1$, which leads to $\left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}=1/\beta_n$, the RHS of equation (23) will reduce to

$$\left(\pi_{nn}^F\right)^{-\frac{1}{\theta}}\left(\pi_{nn}\right)^{-\frac{1-\beta_n}{\theta\beta_n}}-1,$$

which is the gains from trade expression in Section 7 of Antras and de Gortari (2020) when the number of production stages is equal to 1.

The theoretical linkage between change in welfare and change in DVAR

According to equation (22), the welfare gains in the model comes from four sources: (i) direct welfare gains from technological improvement (through $\widehat{T}_n^i$), (ii) direct welfare gains from domestic trade cost reduction (through $\widehat{\delta}_n^i$); (iii) gains from trade in final goods (through effects of $\widehat{\pi}_{nn}^{ik}$, for $i = J+1$, $j = 1...J$, $k = 1...J$); (iv) gains from trade in intermediate goods (through the effects of $\widehat{\pi}_{nn}^{ik}$, for $i = 1...J$, $j = 1...J$, $k = 1...J$). Only the fourth source is closely related to the change in the DVAR (aggregated over all sectors) of a country, as it is related to the domestic sourcing shares in intermediate goods. If we focus on the expression for gains from trade in intermediate goods, W_n^I, which is extracted from the second term in the parentheses in (21), we have

$$d\ln W_n^I = -\frac{1}{\theta}\sum_{j=1}^{J}\alpha_n^j\sum_{i=1}^{J}\sum_{k=1}^{J}\lambda_n^{ji}\left(1-\beta_n^i\right)\gamma_n^{ik}d\ln\pi_{nn}^{ik} \tag{24}$$

which only assigns different weights to $d\ln\pi_{nn}^{ik}$ compared to the expression in equation (20), and the two expressions have opposite signs. Thus it is quite clear that the gains from trade in intermediate goods tends to be negatively related to the change in DVAR of a country aggregated over all sectors, when the country is initially sufficiently close to autarky. However, this is not true for the first two sources of change in welfare, viz. direct welfare effect from technological improvement (T) and reduction in domestic trade costs (δ). Thus, in general, we expect there to be no statistically significant relationship between the change in welfare and the change in DVAR of a country. However, equation (22) shows that if we shut down the changes in T and δ and only allow κ to change, we should expect there to be a negative relationship between the change in welfare and change in DVAR. Below, we present some empirical evidence to support this theory.

The empirical linkage between change in welfare and change in DVAR

We present four charts to support our theory.

- We estimate the change in welfare of each country from 1995 to 2008 according to (22) and plot it against the corresponding change in DVAR and change in π_{nn}, respectively. Notably, there is empirically no relationship between welfare changes and changes in DVAR in the data (Figure 21). Neither is there any relationship between welfare changes and changes in π_{nn} in the data (Figure 22).

It is noteworthy that, during the sample period, on average, the DVAR of the countries fell, and their welfare increased. On average, the increases in welfare were due to increases in gains from trade as well as increases in technology stock T and reduction of domestic trade costs δ. The average changes in T, δ and κ for the countries are shown in Appendix G.

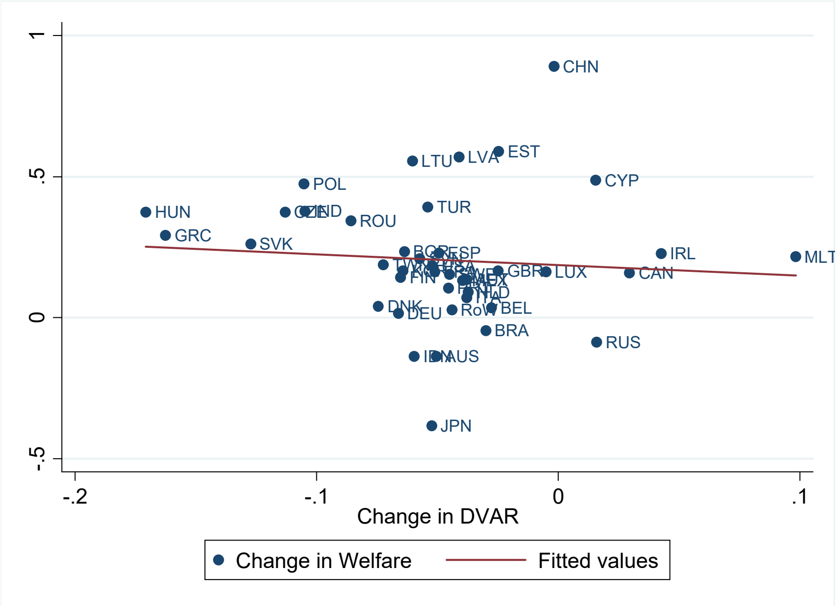

Figure 21: Change in natural log of welfare $\Delta \ln W_n$ on the y-axis is plotted against change in domestic value-added ratio $\Delta DVAR_n$ on the x-axis when no effect is shut down.

$<$ Figures 21 and 22 about here $>$

- For each country, we carry out a counterfactual of shutting down the changes in its technology stocks and domestic trade costs, while allowing its importing international trade costs and all three factors in ROW to change. Then we plot the estimated change in welfare of each country from 1995 to 2008 according to (22) against the corresponding change in DVAR and change in π_{nn} in that country, respectively. The results are shown in Figures 23 and 24. As shown in (22), when there are only changes in international trade costs, countries increase their gains from trade due to the reduction in domestic sourcing shares. Thus, there is a negative correlation between the changes in welfare and changes in π_{nn}. (The slope of the OLS best-fit line in Figure 23 is significantly different from zero at 1% level.) As the change in DVAR and change in π_{nn} of a country are positively correlated, there is also a negative correlation between the changes in welfare and changes in DVAR of a country (Figure 24).

$<$ Figures 23 and 24 about here $>$

In sum, based on the theory and the empirical evidence, we conclude that there is no relationship between the change in welfare and the change in DVAR across countries. If the changes in DVARs are all due to changes in international trade costs κ, as Figures 23 and 24 show, then the welfare effects on countries all come from gains from trade, and, according to

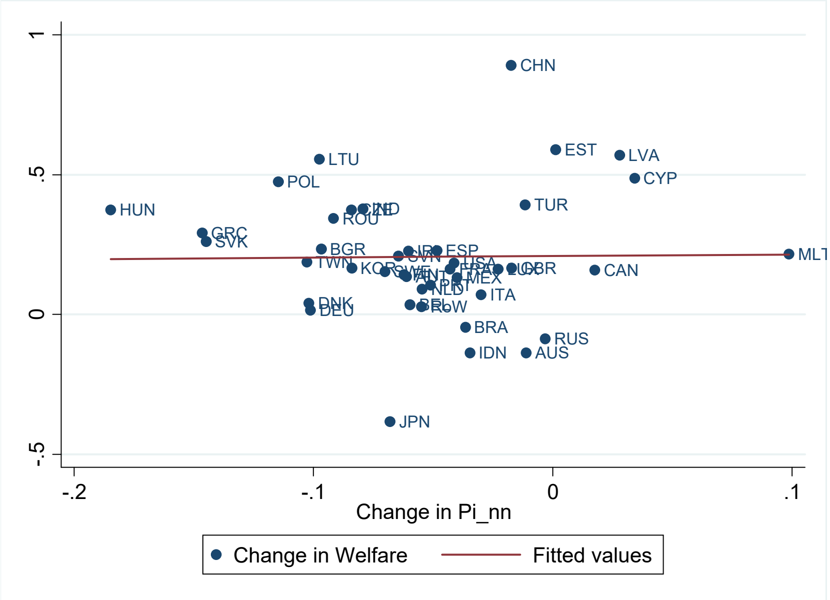

Figure 22: Change in natural log of welfare $\Delta \ln W_n$ on the y-axis is plotted against change in domestic sourcing share $\Delta\pi_{nn}$ on the x-axis when no effect is shut down.

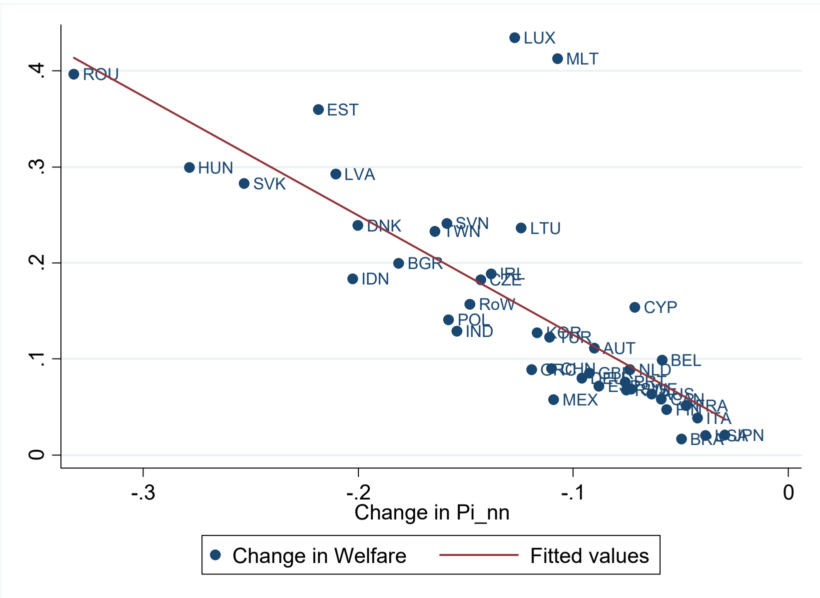

Figure 23: $\Delta \ln W_n$ on the y-axis is plotted against $\Delta\pi_{nn}$ on the x-axis when changes in factors other than international importing trade costs of that country are shut down while all factors in ROW are allowed to change.

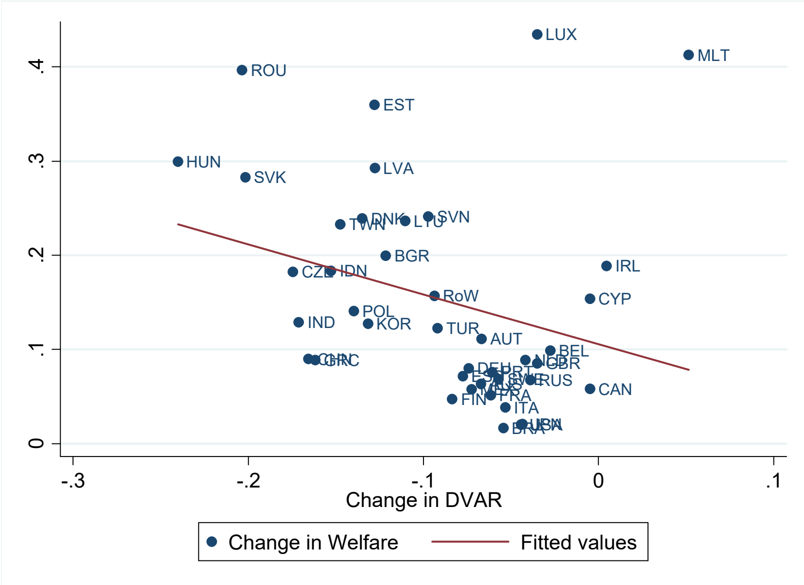

Figure 24: $\Delta \ln W_n$ on the y-axis is plotted against $\Delta DVAR_n$ on the x-axis when changes in factors other than international importing trade costs of that country are shut down while all factors in ROW are allowed to change.

Arkolakis, Costinot and Rodriguez-Clare (2012), the change in welfare is negatively correlated with the change in domestic sourcing share and therefore with change in DVAR. In this sense, the fall in DVAR contributes to welfare gains by increasing the gains from trade. However, if welfare is also significantly affected by changes in technology T or domestic trade costs δ, then there may not be any correlation between change in DVAR and change in welfare, as the effect of (an increase in) T or (a reduction of) δ can be so large that DVAR increases while welfare also increases, despite a decrease in κ. In Figures 27-30 in Appendix F, we present counterfactuals of allowing only T or δ to change in each country, respectively. Although the counterfactuals show that there is a significant negative relationship between welfare and DVAR in each case (i.e. the indirect effect dominates the direct effect in each case), we treat it as just historical coincidence. In any case, all empirical evidence and counterfactuals indicate that there is no positive relationship between welfare and DVAR.

The implications of our analysis above is that governments should not treat DVAR as a target for policy-making. A higher DVAR may or may not be associated with higher (or lower) welfare. Governments should target welfare and allow DVAR to change endogenously according to the forces of global changes in technology, domestic trade costs, international trade costs and other factors. The resulting DVAR may increase or decrease, but it does not matter as long as target welfare level is achieved. This also implies that it is possible that welfare increases but gains from trade decreases (because of an increase in DVAR), but the former is all that matters.

6 Conclusion

Based on a multi-sector Eaton-Kortum (2002) model with domestic and global input-output linkages, we quantify the contributions of different global factors to the changes in individual countries' DVARs and global DVAR during 1995-2008. In addition to identifying the significant effects of global changes in international and domestic trade costs, we discover the significant positive impacts of changes in global technology stocks on individual countries' DVARs and global DVAR. The contribution of other exogenous factors (global changes in factor endowments and trade balances) are small. Last but not least, fast-growing countries, like China, which experienced substantial improvements in technology and reduction in domestic trade barriers, despite falling average total trade costs, could have their DVARs increasing over time.

Counterfactual exercises show that the effects of China's technological progress, reduction of domestic and total trade costs and increase in trade surplus on the DVAR of its exports are all significantly positive. While shutting down China's technological progress or reducing the domestic trade costs or total trade costs of China reduce the DVAR of the rest of the world, they increase the DVAR of the US.

We find that there is no relationship between the change in DVAR and welfare change across countries. However, if we allow only the international trade cost of each country to change, then the welfare change of each country arises only from the change in gains from trade, and, according to Arkolakis, Costinot and Rodriguez-Clare (2012), the change in welfare is negatively correlated with the change in DVAR across countries.

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Online Appendix

A Proofs about the two-country, one-sector simple model

The DVAR of country 1, r_{11}, is a function of π_{11} and π_{22}, and therefore a function of t, τ_1 and τ_2. The second-order Taylor expansion gives

$$\begin{aligned}
dr_{11} &= Ad\pi_{11} - Bd\pi_{22} \\
&= \left(A\frac{\partial \pi_{11}}{\partial t} - B\frac{\partial \pi_{22}}{\partial t}\right) dt + \frac{1}{2}\left(A\frac{\partial^2 \pi_{11}}{\partial t^2} - B\frac{\partial^2 \pi_{22}}{\partial t^2}\right)(dt)^2 \\
&\quad + \left(A\frac{\partial \pi_{11}}{\partial \kappa_1^{-\theta}} - B\frac{\partial \pi_{22}}{\partial \kappa_1^{-\theta}}\right) d\kappa_1^{-\theta} + \frac{1}{2}\left(A\frac{\partial^2 \pi_{11}}{\left(\partial \kappa_1^{-\theta}\right)^2} - B\frac{\partial^2 \pi_{22}}{\left(\partial \kappa_1^{-\theta}\right)^2}\right)\left(d\kappa_1^{-\theta}\right)^2 \\
&\quad + \left(A\frac{\partial \pi_{11}}{\partial \kappa_2^{-\theta}} - B\frac{\partial \pi_{22}}{\partial \kappa_2^{-\theta}}\right) d\kappa_2^{-\theta} + \frac{1}{2}\left(A\frac{\partial^2 \pi_{11}}{\left(\partial \kappa_2^{-\theta}\right)^2} - B\frac{\partial^2 \pi_{22}}{\left(\partial \kappa_2^{-\theta}\right)^2}\right)\left(d\kappa_2^{-\theta}\right)^2 \\
&\quad + \left(A\frac{\partial^2 \pi_{11}}{\partial t \partial \kappa_1^{-\theta}} - B\frac{\partial^2 \pi_{22}}{\partial t \partial \kappa_1^{-\theta}}\right) dt d\kappa_1^{-\theta} + \left(A\frac{\partial^2 \pi_{11}}{\partial t \partial \kappa_2^{-\theta}} - B\frac{\partial^2 \pi_{22}}{\partial t \partial \kappa_2^{-\theta}}\right) dt d\kappa_2^{-\theta} \\
&\quad + \left(A\frac{\partial^2 \pi_{11}}{\partial \kappa_1^{-\theta} \partial \kappa_2^{-\theta}} - B\frac{\partial^2 \pi_{22}}{\partial \kappa_1^{-\theta} \partial \kappa_2^{-\theta}}\right) d\kappa_1^{-\theta} d\kappa_2^{-\theta} + \text{ pure effect of } \delta \\
&\quad + \text{interactive effects involving } \delta + \text{higher order terms}
\end{aligned}$$

$$\begin{aligned}
&= (C+D)\frac{dt}{t} - \left[C\pi_{11} + D\left(1-\pi_{22}\right)\right]\left(\frac{dt}{t}\right)^2 \\
&\quad -C\left[\frac{d\kappa_1^{-\theta}}{\kappa_1^{-\theta}} - (1-\pi_{11})\left(\frac{d\kappa_1^{-\theta}}{\kappa_1^{-\theta}}\right)^2\right] + D\left[\frac{d\kappa_2^{-\theta}}{\kappa_2^{-\theta}} - (1-\pi_{22})\left(\frac{d\kappa_2^{-\theta}}{\kappa_2^{-\theta}}\right)^2\right] \\
&\quad +C\left(2\pi_{11}-1\right)\left(\frac{dt}{t}\right)\left(\frac{d\kappa_1^{-\theta}}{\kappa_1^{-\theta}}\right) + D\left(2\pi_{22}-1\right)\left(\frac{dt}{t}\right)\left(\frac{d\kappa_2^{-\theta}}{\kappa_2^{-\theta}}\right) \\
&\quad + (C+D)\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right) - \left[C\pi_{11} + D\pi_{21}\right]\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right)^2 \\
&\quad + \text{interactive effects involving } \delta + \text{higher order terms}
\end{aligned}$$

where $C = A\pi_{11}(1-\pi_{11}) > 0$ and $D = B\pi_{22}(1-\pi_{22}) > 0$. The last equality follows from

$$
\begin{aligned}
\frac{\partial \pi_{11}}{\partial t} &= \frac{\pi_{11}(1-\pi_{11})}{t}, \quad \frac{\partial \pi_{11}}{\partial \kappa_1^{-\theta}} = -\frac{\pi_{11}(1-\pi_{11})}{\kappa_1^{-\theta}}, \quad \frac{\partial \pi_{11}}{\partial \kappa_2^{-\theta}} = 0, \\
\frac{\partial \pi_{22}}{\partial t} &= -\frac{\pi_{22}(1-\pi_{22})}{t}, \quad \frac{\partial \pi_{22}}{\partial \kappa_1^{-\theta}} = 0, \quad \frac{\partial \pi_{22}}{\partial \kappa_2^{-\theta}} = -\frac{\pi_{22}(1-\pi_{22})}{\kappa_2^{-\theta}}, \\
\frac{\partial^2 \pi_{11}}{\partial t^2} &= -\frac{2(\pi_{11})^2(1-\pi_{11})}{t^2}, \quad \frac{\partial^2 \pi_{11}}{\left(\partial \kappa_1^{-\theta}\right)^2} = \frac{2\pi_{11}(1-\pi_{11})^2}{\left(\kappa_1^{-\theta}\right)^2}, \quad \frac{\partial^2 \pi_{11}}{\left(\partial \kappa_2^{-\theta}\right)^2} = 0, \\
\frac{\partial^2 \pi_{22}}{\partial t^2} &= \frac{2\pi_{22}(1-\pi_{22})^2}{t^2}, \quad \frac{\partial^2 \pi_{22}}{\left(\partial \kappa_1^{-\theta}\right)^2} = 0, \quad \frac{\partial^2 \pi_{22}}{\left(\partial \kappa_2^{-\theta}\right)^2} = \frac{2\pi_{22}(1-\pi_{22})^2}{\left(\kappa_2^{-\theta}\right)^2}, \\
\frac{\partial^2 \pi_{11}}{\partial t \partial \kappa_1^{-\theta}} &= \frac{\pi_{11}(1-\pi_{11})(2\pi_{11}-1)}{t\kappa_1^{-\theta}}, \quad \frac{\partial^2 \pi_{11}}{\partial t \partial \kappa_2^{-\theta}} = 0, \quad \frac{\partial^2 \pi_{11}}{\partial \kappa_1^{-\theta} \partial \kappa_2^{-\theta}} = 0, \\
\frac{\partial^2 \pi_{22}}{\partial t \partial \kappa_1^{-\theta}} &= 0, \quad \frac{\partial^2 \pi_{22}}{\partial t \partial \kappa_2^{-\theta}} = -\frac{\pi_{22}(1-\pi_{22})(2\pi_{22}-1)}{t\kappa_2^{-\theta}}, \quad \frac{\partial^2 \pi_{22}}{\partial \tau_1^{-\theta} \partial \kappa_2^{-\theta}} = 0.
\end{aligned}
$$

The pure effect of technology on r_{11} will be

$$(C+D)\frac{dt}{t} - [C\pi_{11} + D\pi_{21}]\left(\frac{dt}{t}\right)^2.$$

The pure effect of international trade costs on r_{11} will be

$$-C\left[\frac{d\kappa_1^{-\theta}}{\kappa_1^{-\theta}} - (1-\pi_{11})\left(\frac{d\kappa_1^{-\theta}}{\kappa_1^{-\theta}}\right)^2\right] + D\left[\frac{d\kappa_2^{-\theta}}{\kappa_2^{-\theta}} - (1-\pi_{22})\left(\frac{d\kappa_2^{-\theta}}{\kappa_2^{-\theta}}\right)^2\right].$$

The pure effect of domestic trade costs on r_{11} will be

$$(C+D)\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right) - [C\pi_{11} + D\pi_{21}]\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right)^2.$$

B Interactive effects for the two-country, one-sector simple model

Other than the pure effects, we also have the following interactive effects for the two-country, one-sector simple model.

- The interactive effect between technology and international trade costs

$$C(\pi_{11} - \pi_{12})\left(\frac{dt}{t}\right)\left(\frac{d\left(\kappa_1^{-\theta}\right)}{\kappa_1^{-\theta}}\right) + D(\pi_{22} - \pi_{21})\left(\frac{dt}{t}\right)\left(\frac{d\left(\kappa_2^{-\theta}\right)}{\kappa_2^{-\theta}}\right). \tag{25}$$

Suppose $d\kappa_1 < 0$ and $d\kappa_2 < 0$ (so that $d\kappa_1^{-\theta} > 0$ and $d\kappa_2^{-\theta} > 0$) and $\pi_{ii} > 0.5$ for $i = 1, 2$ (so that $\pi_{11} - \pi_{12} > 0$ and $\pi_{22} - \pi_{21} > 0$). If $dt > 0$ ($dt < 0$), then the term is positive (negative). So, this interactive effect tends to be positive (negative) for a country that has a larger (smaller) technological progress than the average of the rest of the world. **Thus, in a multi-country setting, if larger countries tend to have smaller (larger) technological progress, then the aggregate interactive effect on DVAR will likely be negative (positive).**

- The interactive effect between technology and domestic trade costs

$$-C\left(\pi_{11} - \pi_{12}\right)\left(\frac{dt}{t}\right)\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right) - D\left(\pi_{22} - \pi_{21}\right)\left(\frac{dt}{t}\right)\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right) \tag{26}$$

Suppose $\pi_{ii} > 0.5$ for $i = 1, 2$ (so that $\pi_{11} - \pi_{12} > 0$ and $\pi_{22} - \pi_{21} > 0$). Note that $\frac{d\left(c^{-\theta}\right)}{d\delta} < 0$.[20] Thus, we have: 1. If dt and $d\delta$ are negatively (positively) correlated, then the term is negative (positive). **Thus, in a multi-country setting, if larger countries tend to have dt and $d\delta$ being positively (negatively) correlated, then the aggregate interactive effect on global DVAR will likely be positive (negative).**

- The interactive effect between international trade costs and domestic trade costs

$$C\left(\pi_{11} - \pi_{12}\right)\left(\frac{d\left(\kappa_1^{-\theta}\right)}{\kappa_1^{-\theta}}\right)\left(\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right) + D\left(\pi_{22} - \pi_{21}\right)\left(\frac{d\left(\kappa_2^{-\theta}\right)}{\kappa_2^{-\theta}}\right)\left[\frac{d\left(c^{-\theta}\right)}{d\delta}\frac{d\delta}{c^{-\theta}}\right] \tag{27}$$

Suppose $d\kappa_1 < 0$ and $d\kappa_2 < 0$ (so that $d\kappa_1^{-\theta} > 0$ and $d\kappa_2^{-\theta} > 0$) and $\pi_{ii} > 0.5$ for $i = 1, 2$ (so that $\pi_{11} - \pi_{12} > 0$ and $\pi_{22} - \pi_{21} > 0$). Note that $\frac{d\left(c^{-\theta}\right)}{d\delta} < 0$. 1. If $d\delta < 0$ ($d\delta > 0$), then the term is positive (negative). **Thus, in a multi-country setting, if larger countries tend to have $d\delta < 0$ ($d\delta > 0$), then the aggregate interactive effect on global DVAR will likely be positive (negative).**

C Details about the calibration exercises

This section contains some additional technical details about our estimation and calibration process, which have been omitted in the main text to save space.

[20] Note that $p_1(\omega) = \frac{\tau_1 \delta_1 c_1}{z_1(\omega)}$ and $c_1 = \left(\frac{P_1}{1-\beta_1}\right)^{1-\beta_1}\left(\frac{w_1}{\beta_1 \mu_1}\right)^{\beta_1}$. Ignoring the general equilibrium adjustments in w_1, we have $\frac{dP_1}{P_1} = \frac{d\delta_1}{\delta_1} + \frac{dc_1}{c_1}$ and $\frac{dc_1}{c_1} = \left(1 - \beta_1\right)\frac{dP_1}{P_1}$. This leads to $\frac{dc_1}{c_1} = \frac{1-\beta_1}{\beta_1}\frac{d\delta_1}{\delta_1}$. Thus $\frac{\partial c_1}{\partial \delta_1} > 0$ and $\frac{d\left(c^{-\theta}\right)}{d\delta} < 0$.

- We have combined the last two sectors of the World Input-Output Tables from the WIOD, namely, the "Other community, social and personal services" and "Private households with employed persons", into one. The main reason is that most countries do not have statistics for the last sector "Private households with employed persons", which contributes about 2/3 of zeros in the WIOD IO tables.

- In estimating the structural gravity equations, we follows Antras and Chor (2017) to set zero trade flows to $1.

- To smoothen the yearly fluctuations in the values of trade, we winsorize the estimated competitiveness and the changes in competitiveness by setting the bottom and top 1% values to the one-percentile and 99-percentile respectively. Similarly, we winsorize the estimated changes in trade costs by setting the bottom and top 0.5% values to the 0.5-percentile and 99.5-percentile respectively. We also winsorize the yearly changes in domestic final goods sourcing shares while calculating changes in T using changes in TFP, by setting the bottom and top 0.5% values equal to the 0.5-percentile and 99.5-percentile respectively. These treatments aim to eliminate the close-to-zero and very large values (they will appear when the trade values drop to zero or jump from zero to a positive value). We have tried different cutoffs for the winsorizing and the results are not sensitive to the cutoffs used.

- All the data come from the 2013 version of the WIOD Table, or the corresponding Socio-Economic Accounts (SEA) dataset of the WIOD database for consistency purpose. All the variables and parameters are either directly obtained from the data, or calculated from the data.

D Decomposition exercises

We now discuss how to use our quantitative model as an accounting framework to decompose the changes in the global and selected countries' DVARs over time due to the various calibrated (exogenous) changes in the data. We first quantitatively assess the change in global DVAR due to changes in only one of the determinants, by shutting down all other determinants in each counterfactual exercise. The simulated change in the DVAR in each counterfactual exercise by allowing one determinant to change is referred to as the pure effect of that determinant.

Figure 25 shows the pure effect of each of the determinants. The blue solid line shows the data. The orange line indicates the effect of shutting down the changes in all determinants but domestic trade costs. The cumulative effect on global DVAR is about 6% below the 1995

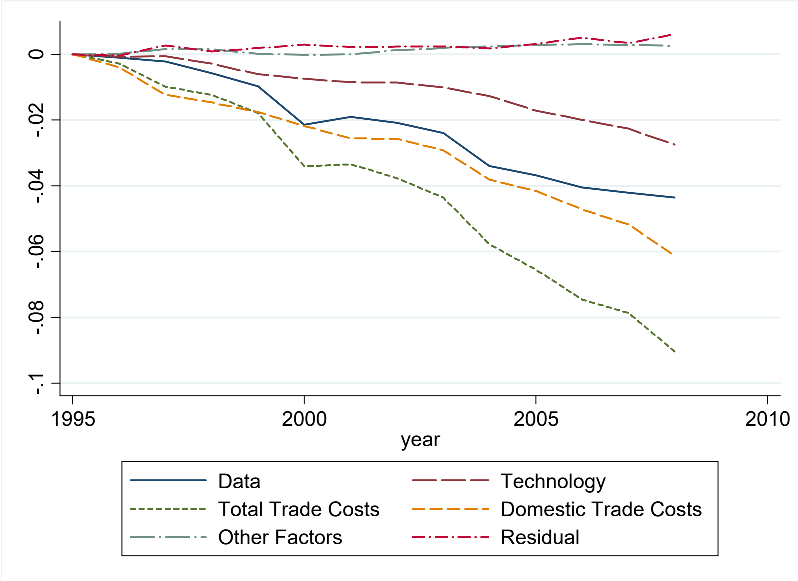

Figure 25: Different Pure Effects on Global DVAR

level. The green short-dash line shows that by shutting down the changes in all determinants but total trade costs (i.e. allowing international trade costs (κ) and domestic trade costs (δ) to change), there is a significantly larger decline in the predicted DVAR relative to the data. Specifically, the predicted DVAR with only changes in total trade costs will be about 9% lower than its 1995 level, compared to around 4.4% decline in the data. Again, this is not surprising, as we have discussed both theoretically and empirically about a significantly negative effect of declining international trade costs on countries' DVAR during the sample period.

< Figure 25 about here >

When we shut down all other changes but keep the changes in technology (T), we find that the pure effect of technology is negative (lowers the DVAR). Specifically, as the red long-dash line illustrates, the predicted DVAR with only changes in technology will be about 2.8% lower than its 1995 level, compared to about 4.4% decline in the data. We also examine the effect of shutting down all changes but keeping the changes in "other factors" (F), including factor endowments and trade balances. As the grey chain line illustrates, the pure effect of "other factors" is positive, implying a cumulative impact of 0.25% (insignificant) increase in the DVAR of world exports, compared to the value in 1995. The remaining plot is for the residuals, which are insignificant. This is not surprising as we allow κ to vary at the country-pair-cum-sector-pair level, the most granular level in our data, so that the degree of freedom is very large. This means that we can match the yearly changes in the sourcing shares $\left\{\pi_{nl}^{ji}\right\}$ very accurately.

Next we examine the interactive effects. To gauge each interactive effect, we need to conduct three counterfactuals. For instance, to quantitatively assess the interactive effect from changes in T and κ, we first conduct the counterfactual calibration with only changes in T, and obtain predicted DVARs (call them $DVAR^T$). We then conduct another counterfactual calibration due to changes in κ only, and obtain another set of DVARs (call them $DVAR^\kappa$). Finally, we conduct the counterfactual calibration with changes in both T and κ, from which we obtain the predicted DVARs that we refer to as $DVAR^{T\kappa}$. The interactive effect of T and κ is obtained by computing $DVAR^{T\kappa} - DVAR^T - DVAR^\kappa$. We repeat the same exercise to gauge the interactive effects for other combinations of sets of two determinants out of T, κ, δ, and F. Then we evaluate the interactive effects of the different combinations of sets of three determinants. Finally, the interactive effect across all four determinants is evaluated.

As Figure 26 shows, the interactive effect from changes in technology and domestic trade costs as represented by the green long-dash line, is significantly positive. The impact on the cumulative change of DVAR up to 2008 is about 6.7%. On the other hand, the interactive effect between international trade costs and domestic trade costs on the cumulative change of DVAR is about 5.1%. The interactive effect of the changes in technology and other factors, as represented by the pink short-chain line, is negative but very small (-0.23%). The interactive effect from the changes in international trade costs and other factors (the orange long-chain line) is also negative and very small (-0.21%). In sum, among the interactive effects, the most important ones are those that involve changes in technology and domestic trade costs.

< Figure 26 about here >

Table 3 summarizes the pure (i.e. stand-alone) effects of each factor, as well as all possible interactive effects. For the global DVAR, the stand-alone effects of technology, international trade costs and domestic trade costs are -2.75%, -8.01%, and -6.13% respectively, while the stand-alone effect of other factors (i.e., changes in trade balances and factor endowments) is only about 0.25%. The four stand-alone effects add up to a number that is much more negative than the data, because there are positive interactive effects, in particular, the ones that involve the interaction between changes in technology and changes in domestic trade costs and interaction between international trade costs and domestic trade costs. They contribute to 6.71% and 5.10% increases in the global DVAR, respectively.

For the developed countries, the stand-alone effects of technology, international and domestic trade costs and other factors are -4.12%, -6.10%, -6.71% and -1.22% respectively. On the other hand, for developing countries, they are -0.15%, -11.63%, -5.03% and +2.98% respectively. As Table 3 shows, the sum of the pure effects, all the interactive effects and the residual, is equal to the total effect at the top of table.

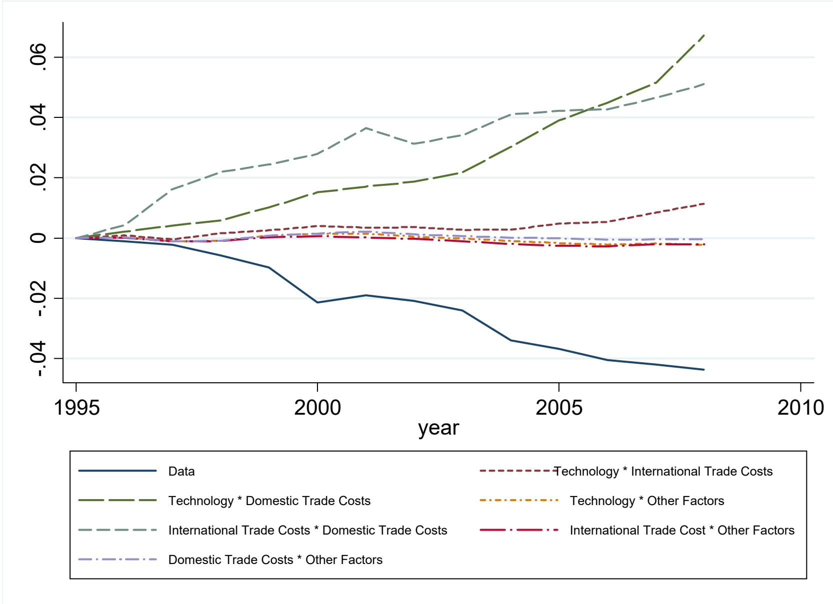

Figure 26: Effects of Interactive Terms on Global DVAR. κ = international trade costs; T = technology; δ = domestic trade costs.

< Table 3 about here >

E Detailed derivation concerning the relationship between a country's DVAR and the gains from trade

Define the consumer welfare of country n, W_n, as its real income:

$$W_n = \frac{w_n}{P_n^F}$$

where P_n^F is the ideal price index of the entire set of final consumption goods $j \in \{1, ..., J\}$. Denote the price index of final good j in country n by $P_n^{Fj} = \left(\Phi_n^{Fj}\right)^{-\frac{1}{\theta}}$, where

$$\Phi_n^{Fj} = \textstyle\sum_{l=1}^{N} T_l^j (c_l^j \tau_{nl}^{Fj})^{-\theta}$$

Thus the percentage change in real income in country n is given by

$$\begin{aligned} d\ln W_n &= d\ln w_n - \textstyle\sum_{j=1}^{J} \alpha_n^j d\ln P_n^{Fj} \\ &= \textstyle\sum_{j=1}^{J} \alpha_n^j \left(\frac{1}{\theta} d\ln \Phi_n^{Fj} + d\ln w_n\right) \\ &= \textstyle\sum_{j=1}^{J} \alpha_n^j \left(\frac{d\ln T_n^j}{\theta} - \frac{d\ln \pi_{nn}^{Fj}}{\theta} + d\ln w_n - d\ln c_n^j\right) \end{aligned} \tag{28}$$

	Global	Developed	Developing
Total	-4.36	-4.42	-4.29
Due to global changes in			
Technology alone	-2.75	-4.12	-0.15
International Trade Costs alone	-8.01	-6.10	-11.63
Domestic Trade Costs alone	-6.13	-6.71	-5.03
Other Factors alone	0.25	-1.22	2.98
Tech * International Trade Costs	1.14	1.92	-0.29
Tech * Domestic Trade Costs	6.71	7.79	4.59
Tech * Other Factors	-0.23	0.88	-2.26
International Trade Costs * Domestic Trade Costs	5.10	4.59	6.12
International Trade Costs * Other Factors	-0.21	0.95	-2.34
Domestic Trade Costs * Other Factors	-0.04	1.12	-2.17
$T * \kappa * \delta$	-1.22	-1.94	0.07
$T * \kappa * F$	0.16	-0.88	2.07
$T * \delta * F$	0.16	-0.96	2.24
$\kappa * \delta * F$	0.14	-0.90	2.07
All Four Forces (κ, T, δ, F)	-0.05	0.49	-1.00
Residual	0.61	0.69	0.46

Table 3: Percentage-point Changes in DVAR (1995-2008)

where the last equality follows from $d\ln\pi_{nn}^{Fj} = d\ln T_n^j - \theta d\ln c_n^j - d\ln\Phi_n^{Fj}$, where π_{nn}^{Fj} is the Home sector-j final good market share of country n.

The percentage change in the unit cost of the input bundle is given by

$$\begin{aligned} d\ln c_n^j &= \beta_n^j d\ln w_n + \left(1-\beta_n^j\right) d\ln P_n^j \\ &= \beta_n^j d\ln w_n + \left(1-\beta_n^j\right) d\ln\delta_n^j - \left(1-\beta_n^j\right)\textstyle\sum_{i=1}^J \gamma_n^{ji}\frac{d\ln\Phi_n^{ji}}{\theta} \\ \Rightarrow d\ln w_n - d\ln c_n^j &= \left(1-\beta_n^j\right)\textstyle\sum_{i=1}^J \gamma_n^{ji}\left(d\ln w_n - d\ln\delta_n^j + \frac{d\ln\Phi_n^{ji}}{\theta}\right) \end{aligned}$$

which leads to

$$d\ln w_n - d\ln c_n^j = \left(1-\beta_n^j\right)\textstyle\sum_{i=1}^J \gamma_n^{ji}\left[\left(d\ln w_n - d\ln c_n^i\right) + \left(\frac{d\ln T_n^i}{\theta} - d\ln\delta_n^j - \frac{d\ln\pi_{nn}^{ji}}{\theta}\right)\right] \tag{29}$$

where the last equality follows from $d\ln\pi_{nn}^{ji} = d\ln T_n^i - \theta d\ln c_n^i - d\ln\Phi_n^{ji}$.

For country n, define $\mathbf{c}_n \equiv \{d\ln w_n - d\ln c_n^i\}$, which is a $J\times 1$ vector, $\mathbf{B}_n$ is defined as a diagonal matrix with the jth diagonal element being β_n^j, $\mathbf{\Gamma}_n \equiv \{\gamma_n^{ji}\}$ is the $J\times J$ input-output matrix of country n, $\mathbf{\Pi}_n \equiv \{\left(1-\beta_n^j\right)\sum_{i=1}^J \gamma_n^{ji}\left(\frac{d\ln T_n^i}{\theta} - d\ln\delta_n^j - \frac{d\ln\pi_{nn}^{ji}}{\theta}\right)\}$, which is a $J\times 1$ vector. Thus, equation (29) can be rewritten as

$$\begin{aligned} \mathbf{c}_n &= \left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\mathbf{c}_n + \mathbf{\Pi}_n \qquad \text{for } n = 1,2,...,N \\ \Rightarrow \quad \mathbf{c}_n &= \left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}\mathbf{\Pi}_n \end{aligned}$$

where $\left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}$ is a typical Leontief inverse matrix. Define λ_n^{ji} as the row j column i element of $\left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}$. Then

$$d\ln w_n - d\ln c_n^j = \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik}\left(\frac{d\ln T_n^k}{\theta} - d\ln\delta_n^i - \frac{d\ln\pi_{nn}^{ik}}{\theta}\right)$$

Thus (28) can be rewritten as

$$\begin{aligned} d\ln W_n &= \sum_{j=1}^J \alpha_n^j\left[\frac{d\ln T_n^j}{\theta} - \frac{d\ln\pi_{nn}^{Fj}}{\theta} + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik}\left(\frac{d\ln T_n^k}{\theta} - d\ln\delta_n^i - \frac{d\ln\pi_{nn}^{ik}}{\theta}\right)\right] \\ &= \sum_{j=1}^J \alpha_n^j\left\{\frac{1}{\theta}\left[d\ln T_n^j + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik} d\ln T_n^k\right] - \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)d\ln\delta_n^i \right. \\ &\quad \left. -\frac{1}{\theta}\left[d\ln\pi_{nn}^{Fj} + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik} d\ln\pi_{nn}^{ik}\right]\right\} \end{aligned} \tag{30}$$

The term $d\ln T_n^j + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik} d\ln T_n^k$ can be rewritten as

$$\begin{aligned} & \mathbf{T}_n + \left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\mathbf{T}_n \\ = \; & \left[\mathbf{I}-\left(\mathbf{I}-\mathbf{B}_n\right)\mathbf{\Gamma}_n\right]^{-1}\mathbf{T}_n \end{aligned}$$

where $\mathbf{T}_n \equiv \{d\ln T_n^i\}$. Thus, in (30), $d\ln T_n^j + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik} d\ln T_n^k = \sum_{i=1}^J \lambda_n^{ji} d\ln T_n^i$. Therefore, (30) can be rewritten as

$$d\ln W_n = \sum_{j=1}^J \alpha_n^j \left\{ \frac{1}{\theta}\sum_{i=1}^J \lambda_n^{ji}\left[d\ln T_n^i - \left(1-\beta_n^i\right) d\ln \delta_n^i\right] - \frac{1}{\theta}\left[d\ln \pi_{nn}^{Fj} + \sum_{i=1}^J \lambda_n^{ji} \sum_{k=1}^J \eta_n^{ik} d\ln \pi_{nn}^{ik}\right]\right\},$$

where $\eta_n^{ik} = \left(1-\beta_n^i\right)\gamma_n^{ik}$ is the row i column k element of the matrix $(\mathbf{I}-\mathbf{B}_n)\,\mathbf{\Gamma}_n$. This equation is just (21).

The welfare gains can come from direct imports of final goods, and imports of intermediate goods for production of final goods through the IO linkage, as well as technological progress in either final goods or intermediate goods. In the roundabout production setting of Eaton and Kortum (2002), $\pi_{nn}^{Fi} = \pi_{nn}^{ji} \equiv \pi_{nn}^i$, the term $d\ln \pi_{nn}^{Fj} + \sum_{i=1}^J \lambda_n^{ji}\left(1-\beta_n^i\right)\sum_{k=1}^J \gamma_n^{ik} d\ln \pi_{nn}^{ik}$ will reduce to a simple term $\sum_{i=1}^J \lambda_n^{ji} d\ln \pi_{nn}^i$, similar to the effect of changes in technology. When there is neither roundabout production nor IO linkage, $\mathbf{B}_n = \mathbf{\Gamma}_n = \mathbf{I}$, $\left[\mathbf{I} - (\mathbf{I}-\mathbf{B}_n)\,\mathbf{\Gamma}_n\right]^{-1} = \mathbf{I}$, equation (21) will reduce to equation (11) in Donaldson (2018).

Equation (21) implies that

$$\widehat{W}_n = \prod_{j=1}^J \prod_{i=1}^J \left[\frac{\widehat{T}_n^i}{\left(\widehat{\delta}_n^i\right)^{1-\beta_n^i}}\right]^{\frac{\alpha_n^j \lambda_n^{ji}}{\theta}} \cdot \prod_{j=1}^J \prod_{i=1}^{J+1} \prod_{k=1}^J \left(\widehat{\pi}_{nn}^{ik}\right)^{-\frac{\alpha_n^j \lambda_n^{ji} \eta_n^{ik}}{\theta}}$$

where $i = J+1$ stand for final goods F, and $\lambda_n^{Fj}\eta_n^{Fk} = I^{jk}$ which equals to 1 when $j = k$ and zero otherwise. For the yearly change in welfare, $\widehat{\pi}_{nn}^{ik}$ can be obtained from data, $\widehat{T}_n^j$ are estimated from data, and $\widehat{\delta}_n^i$ are solved from the general equilibrium of the model, and θ, α_n^j, β_n^j, η_n^{ji} as well as λ_n^{ji} are exogenous parameters. Thus the value of $\widehat{W}_n$ of each year can be directly calculated.

Gains from Trade relative to Autarky

When we move from autarky, where $\pi_{nn}^{Fj} = \pi_{nn}^{ij} = 1$, to the current equilibrium, the gains from trade is

$$\widehat{W}_{n,A} - 1 = \prod_{j=1}^J \left(\pi_{nn}^{Fj}\right)^{-\frac{\alpha_n^j}{\theta}} \cdot \prod_{j=1}^J \prod_{i=1}^J \prod_{k=1}^J \left(\pi_{nn}^{ik}\right)^{-\frac{\alpha_n^j \lambda_n^{ji}\left(1-\beta_n^i\right)\gamma_n^{ik}}{\theta}} - 1$$

In the one-sector setting, $\mathbf{B}_n = \beta_n$ and $\mathbf{\Gamma}_n = 1$, so $\left[\mathbf{I} - (\mathbf{I}-\mathbf{B}_n)\,\mathbf{\Gamma}_n\right]^{-1} = 1/\beta_n$, the RHS of equation (23) will reduce to

$$\left(\pi_{nn}^F\right)^{-\frac{1}{\theta}} \left(\pi_{nn}\right)^{-\frac{1-\beta_n}{\theta\beta_n}} - 1$$

which is the gains from trade expression in Section 7 of Antras and de Gortari (2020) when $N = 1$.

F Further results concerning empirical relationship between welfare and DVAR

The following two counterfactuals show that there is a negative relationship between welfare and DVAR when we only allow technology of a country to change or its domestic trade cost to change, respectively, while all the factors are allowed to change in the rest of the world. These results indicate that the indirect effect through the gains from trade dominates the direct effect in both counterfactuals.

- For each country, we shut down the changes in its international importing trade costs and domestic trade costs while allowing its technology stocks and all factors in ROW to change, then plot the estimated change in welfare of each country from 1995 to 2008 according to (22) against the corresponding change in DVAR and change in domestic sourcing share of each country, respectively. The results are shown in Figures 27 and 28. From (22), there are two effects on welfare when a country only changes its technology stock, the direct welfare gains from technology improvement, and the indirect welfare effect through the changes in domestic sourcing shares. As Figure 27 shows, there is a negative correlation between change in welfare and change in domestic trade share. (The slope of the OLS best-fit line in Figure 27 is significantly different from zero at 5% level.). In other words, the indirect effect dominates the direct effect. As the change in DVAR and change in π_{nn} of a country are positively correlated, there is also a negative correlation between the changes in welfare and changes in DVAR of a country. (Figure 28).

< Figures 27 and 28 about here>

- For each country we shut down the changes in its technology stocks and international importing trade costs, while allowing its domestic trade costs and all factors in ROW to change, then plot the estimated changes in welfare of each country from 1995 to 2008 according to (22) against the corresponding changes in DVAR and changes in π_{nn} of each country, respectively. The results are shown in Figures 29 and 30. There are again two effects on welfare, the direct welfare effect from changes in domestic trade costs, and the indirect welfare effect acting through the change in domestic sourcing share. As Figure 29 shows, there is a negative correlation between change in welfare and change in domestic sourcing share. (The slope of the OLS best-fit line in Figure 29 is significantly different from zero at 5% level.) Thus, the indirect effect dominates the direct effect. As the change in DVAR and change in π_{nn} of a country are positively correlated, there

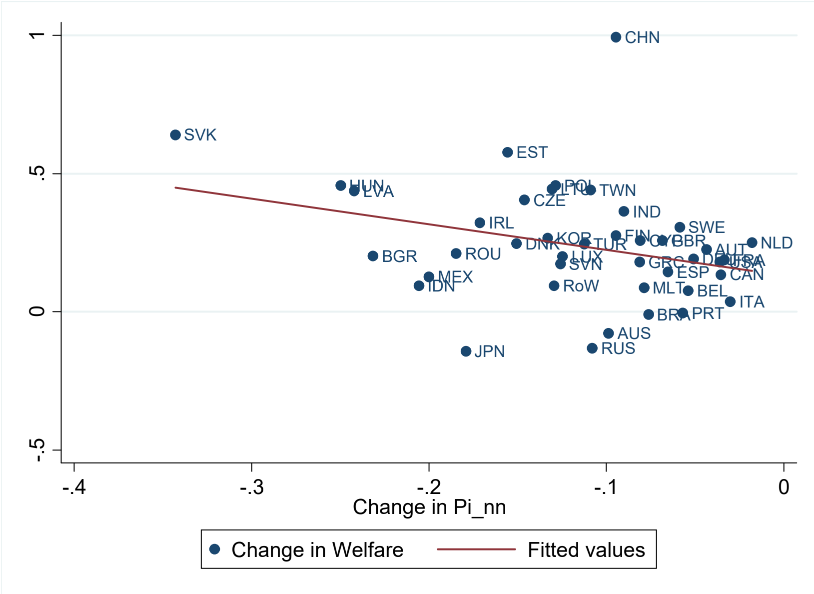

Figure 27: Change in natural log of welfare $\Delta \ln W_n$ on the y-axis plotted against change in domestic sourcing share $\Delta\pi_{nn}$ on the x-axis when changes in determinants other than technology in that country are shut down while all factors in ROW are allowed to change.

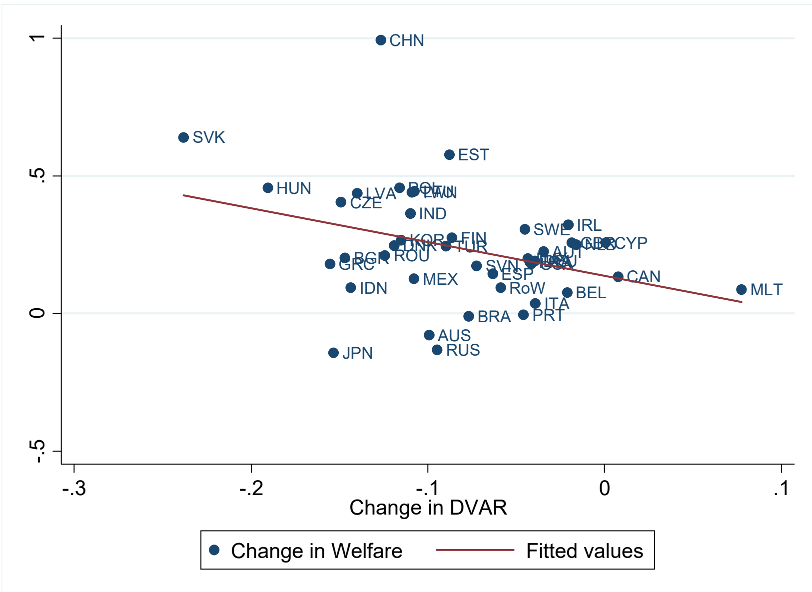

Figure 28: Change in natural log of welfare $\Delta \ln W_n$ on the y-axis plotted against change in domestic value-added ratio $\Delta DVAR_n$ on the x-axis when change in determinants other than technology in that country are shut down while all factors in ROW are allowed to change.

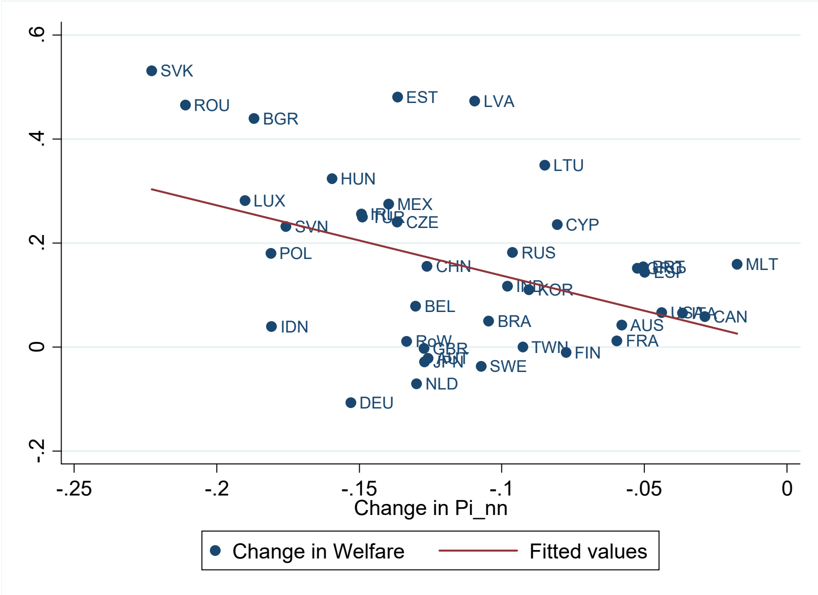

Figure 29: $\Delta \ln W_n$ on the y-axis against $\Delta \pi_{nn}$ on the x-axis when the changes in factors other than domestic trade costs in that country are shut down while all factors in ROW are allowed to change.

is also a negative correlation between the changes in welfare and changes in DVAR of a country (Figure 30).

$<$ Figures 29 and 30 about here $>$

G List of developing and developed countries, and tables of estimated changes in T, κ and δ

- Developed countries: AUS, AUT, BEL, CAN, DEU, DNK, ESP, FIN, FRA, GBR, GRC, IRL, ITA, JPN, KOR, LUX, NLD, PRT, SWE, USA.
- Developing countries: BGR, BRA, CHN, CYP, CZE, EST, HUN, IDN, IND, LTU, LVA, MEX, MLT, POL, ROU, RUS, SVK, SVN, TUR, TWN.
- Table 4 shows the average yearly changes of T, κ and δ by country, while Table 5 shows the time series of changes in T, κ and δ in China.

<Tables 4 and 5 about here>

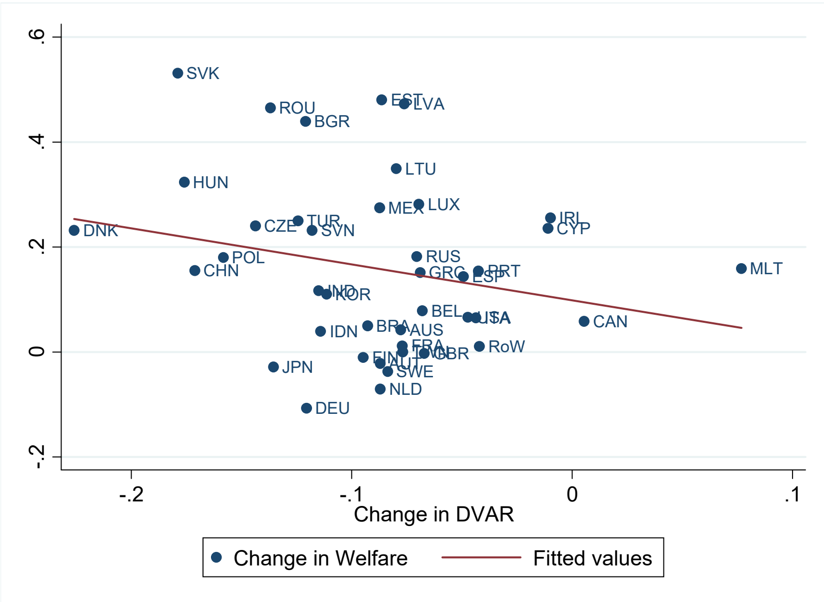

Figure 30: $\Delta \ln W_n$ on the y-axis against $\Delta DVAR_n$ on the x-axis when the changes in factors other than domestic trade costs in that country are shut down while all factors in ROW are allowed to change.

Period: 1995-2008					
Country	Mean Yearly Change in $\ln T$ in ascending order	Country	Mean Yearly Change in $\ln \kappa$ in ascending order	Country	Mean Yearly Change in $\ln \delta$ in ascending order
JPN	-0.0685	RoW	-0.0178	LUX	-0.6791
DNK	-0.0322	RUS	-0.0168	TUR	-0.3858
RUS	-0.0295	KOR	-0.0168	BGR	-0.2535
LUX	-0.0278	ROU	-0.0167	CYP	-0.2407
IRL	-0.0238	TWN	-0.0166	LVA	-0.1950
SVN	-0.0235	IND	-0.0157	IDN	-0.1729
MLT	-0.0220	MLT	-0.0152	DNK	-0.1611
BGR	-0.0218	GRC	-0.0150	ITA	-0.1038
AUS	-0.0193	SVN	-0.0147	POL	-0.1024
ESP	-0.0185	CYP	-0.0145	HUN	-0.0628
ROU	-0.0185	DEU	-0.0143	BEL	-0.0548
BRA	-0.0175	ITA	-0.0143	BRA	-0.0521
ITA	-0.0161	LVA	-0.0142	IRL	-0.0516
PRT	-0.0114	LTU	-0.0141	KOR	-0.0513
BEL	-0.0090	FIN	-0.0141	MLT	-0.0480
GBR	-0.0063	CZE	-0.0141	ESP	-0.0419
DEU	-0.0037	SWE	-0.0140	ROU	-0.0358
IDN	-0.0019	PRT	-0.0138	AUT	-0.0312
RoW	0.0000	DNK	-0.0138	CZE	-0.0309
HUN	0.0033	LUX	-0.0138	CHN	-0.0292
MEX	0.0035	HUN	-0.0137	SVK	-0.0287
AUT	0.0038	BGR	-0.0137	CAN	-0.0262
SVK	0.0059	JPN	-0.0135	PRT	-0.0164
FRA	0.0071	NLD	-0.0135	EST	-0.0162
SWE	0.0093	SVK	-0.0134	SVN	-0.0090
LVA	0.0103	CAN	-0.0133	FRA	-0.0051
CZE	0.0132	AUS	-0.0133	TWN	-0.0013
CAN	0.0134	GBR	-0.0133	GBR	0.0011
KOR	0.0135	FRA	-0.0132	JPN	0.0039
NLD	0.0152	BEL	-0.0132	DEU	0.0043
GRC	0.0182	AUT	-0.0130	NLD	0.0087
FIN	0.0191	TUR	-0.0130	GRC	0.0152
CYP	0.0191	USA	-0.0129	SWE	0.0158
POL	0.0230	IRL	-0.0127	FIN	0.0170
TWN	0.0231	MEX	-0.0126	AUS	0.0227
USA	0.0276	ESP	-0.0125	RUS	0.0242
EST	0.0290	BRA	-0.0125	USA	0.0259
TUR	0.0312	EST	-0.0123	RoW	0.0546
LTU	0.0496	CHN	-0.0114	LTU	0.0614
IND	0.0566	IDN	-0.0111	IND	0.0898
CHN	0.1152	POL	-0.0096	MEX	0.0957
Average	**0.0034**		**0.0139**		**-0.0597**

Table 4: Average yearly changes of T, κ and δ by country

Period: 1995-2008			
Year	Yearly Change in $\log T$ of China	Yearly Change in $\log \kappa$ when China is the importer	Yearly Change in $\log \delta$ when China is the importer
1995	0	0	0
1996	0.0341	0.0014	-0.2188
1997	0.0955	-0.0229	-0.1747
1998	0.0963	-0.0205	0.0306
1999	0.1224	-0.0031	0.1011
2000	0.1207	-0.0364	0.1017
2001	0.1234	-0.0050	0.0486
2002	0.1234	0.0048	0.1332
2003	0.0860	0.0238	0.1322
2004	0.0685	-0.0228	0.0957
2005	0.2515	-0.0093	0.0600
2006	0.1431	-0.0241	-0.2916
2007	0.0704	-0.0066	-0.1642
2008	0.1625	-0.0278	-0.2334
Average	0.1152	-0.0114	-0.0292

Table 5: Time series of changes in T, κ and δ in China