Globalization and Structural Transformation: The Role of Tradable Services

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September 19, 2025

Abstract

This paper studies how globalization impacts structural transformation from goods to services. I construct a multi-country, multi-sector model in which the transformation occurs through changes in income, prices, comparative advantage, or input-output linkages. I parameterize it with data from 1995 to 2018 for 66 countries covering diverse stages of economic development. Decomposition exercises show that globalization outweighs productivity growth in shaping structural transformation and that globalization's impact primarily operates through comparative advantage. Counterfactual exercises reveal globalization's heterogeneous impact on countries' structural transformation. I characterize the underlying factor behind this result: Globalization affected countries' transformation to the extent that it altered their comparative advantage. In countries with sector-neutral globalization—where export trade costs relative to import trade costs changed at similar rates for goods and services—comparative advantage and structural transformation were minimally impacted. In countries with sector-biased globalization, the transformation accelerated when the globalization shifted comparative advantage toward services, but decelerated otherwise.

JEL Codes: F41, F62, O11, O14

Keywords: Globalization, structural transformation, trade in services, sector bias of globalization, comparative advantage, asymmetric trade costs

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1 Introduction

Structural transformation is a secular reallocation of production shares across broad sectors as a country develops.[1] Since specialization through international trade allows a country's production and consumption to be separated, globalization can, in principle, play a major role in structural transformation. Globalization has also received much attention from policymakers who intend to adjust the speed of structural transformation. For example, protecting the US manufacturing sector was one of the objectives behind the US-China Trade War (White House 2018).

A sector of growing importance in globalization and structural transformation is the services sector. In 2018, services accounted for 72% of world GDP and 35% of world trade. Furthermore, from 1995 to 2018, services trade as a share of world GDP increased from 6% to 9%—for goods, it was from 13% to 16%.[2] I study the interaction of globalization and structural transformation with a focus on services trade.[3]

This paper asks, "How did globalization (i.e., a reduction in trade costs for goods and services) affect the pace of structural transformation (i.e., a reallocation of production shares in value added from goods to services)?" To address this question, I construct a multi-country, multi-sector model in which globalization and productivity growth drive structural transformation through changes in a country's income, relative prices of goods and services, comparative advantage, and input-output linkages. Next, I parameterize the model using data from 1995 to 2018 for 66 countries, which accounted for more than 90% of world trade and GDP in 2018. These countries span low-, middle-, and high-income economies, with 2018 GDP per capita of the richest and poorest countries differing by two orders of magnitude. This broad inclusion of countries over nearly a quarter-century enables the model to capture diverse stages of structural transformation.

With the model, I decompose each country's structural transformation into globalization and productivity growth, each operating through four channels (income, price,

[1] See Herrendorf, Rogerson, and Valentinyi (2014) for a survey of the literature and the implications of structural transformation for economic issues, such as aggregate productivity growth and wage inequality.

[2] The statistics are based on the OECD Inter-Country Input-Output Tables (OECD 2021).

[3] After reviewing the literature on open economy and structural transformation, which started with Matsuyama (2009) and Uy, Yi, and Zhang (2013), Herrendorf, Rogerson, and Valentinyi (2014) conclude that "an open question moving forward concerns the extent to which increased trade in services will influence the nature of structural transformation."

comparative-advantage, and input-output effects). This exercise illustrates that globalization outweighs productivity growth in shaping structural transformation and that globalization's impact primarily operates through comparative advantage. Motivated by this result, I run counterfactual exercises to quantify the impact of globalization on structural transformation in general equilibrium.

Through the counterfactuals, I show that globalization had a limited impact on the transformation of some countries, while significantly accelerating or decelerating it in others. The main contribution of this paper is to characterize the underlying factor behind this heterogeneity: Globalization affected a country's structural transformation to the extent it affected the country's comparative advantage. Countries whose transformation was minimally affected were those whose export trade costs relative to import trade costs changed at similar rates across goods and services. I term this scenario, where comparative advantage is largely unchanged, *sector-neutral* globalization. In contrast, *sector-biased* globalization had a significant impact. For instance, consider the scenario in which a country's export trade costs for goods decrease while all else remains equal—one example of *goods-biased* globalization. This shifts the country's comparative advantage toward goods, thereby decelerating its transformation. This finding that globalization's heterogeneous impact operates primarily through comparative advantage contrasts with the existing literature, which emphasizes a more uniform impact through the relative price channel (e.g., Cravino and Sotelo 2019; Sposi, Yi, and Zhang 2021; Bonadio et al. 2025).

To reach this result, I first construct a multi-country, multi-sector model similar to Cravino and Sotelo (2019) and Lewis et al. (2021). Trade and production occur as in the Eaton and Kortum (2002, EK, hereafter) model with input-output linkages, and households have non-homothetic preferences with a non-unitary substitution elasticity, following Comin, Lashkari, and Mestieri (2021).

In the model, exogenous changes in the primitives (sectoral productivities and bilateral iceberg trade costs) generate structural transformation through four channels: income, price, comparative-advantage, and input-output effects. First, productivity growth or lower trade costs raise households' real income, shifting expenditure toward more income-elastic sectors. Second, when the primitives evolve differentially across sectors, relative prices move. If sectoral outputs are complements in household preferences, the sector with a rising relative price gains a larger expenditure share. The income and price effects alter expenditure patterns and, in turn, production shares.

Third, changes in the primitives shift countries' comparative advantage, affecting cross-sector specialization and, consequently, production shares. Finally, changes in relative prices alter intermediate demands for sectoral outputs (i.e., input-output linkages), impacting production shares.

For model parameterization, I divide the economy into three sectors: goods, highly tradable services, and barely tradable (or almost non-tradable) services. I classify services industries into highly and barely tradable services because the identification of trade costs depends on prices, and the prices for non-market services suffer from measurement issues that affect cross-country comparisons (Deaton and Heston 2010). Since market and non-market services largely align with highly and barely tradable services, this mitigates the measurement concern. Under this three-sector definition, the general pattern of structural transformation is that, as a country develops, the GDP share of goods decreases while the shares of both services increase.

I parameterize the model in two steps. First, I estimate the preference and production parameters using generalized method of moments on cross-country panel data. For instance, I find that outputs of the three sectors are complements and that both services are more income-elastic than goods in household preferences.

Second, I identify sectoral trade costs and productivities by inverting the model following Święcki (2017) and Lewis et al. (2021). I infer trade costs as the level that rationalizes the data on prices and bilateral import shares and measure sectoral productivities as the gap between input and output prices. I further show that the identified trade costs are not limited to the EK model. If I were to embed a different workhorse gravity model of trade—such as Armington (Anderson 1979), Bernard et al. (2003, BEJK), or Krugman (1980)—into the model of structural transformation, I would obtain the same globalization pattern.

From the trade costs for goods and highly tradable services, I find an asymmetry: developing countries face higher export trade costs than advanced countries. This implies that export trade costs are higher than import trade costs for developing countries and vice versa for advanced countries. Furthermore, I discover that the asymmetry has been decreasing over time in both sectors. These findings contribute to the literature on trade-cost asymmetry (e.g., Waugh 2010), which has primarily focused on static analyses of goods trade. Furthermore, this paper also highlights the implications of the asymmetry for structural transformation. Trade costs for barely tradable services are prohibitively high. Therefore, globalization in the sector has negligible effects on the results, and I focus on globalization in goods and highly tradable services.

With the parameterized model, I conduct an exact decomposition of a country's structural transformation into the four mechanisms. From the equilibrium conditions, a country-year's sectoral production shares can be expressed as a function of real income, relative sectoral prices, sectoral net exports, and input-output coefficient matrix. Leveraging this expression, I can decompose a change in the production shares across two equilibria into marginal contributions of the four elements. Since the path of decomposition matters, I adopt the Shapley (1953) decomposition: I compute all 24 possible paths and obtain the average of the marginal contributions. To the best of my knowledge, this is the first paper to conduct an exact decomposition of structural transformation in open economy.[4]

By decomposing the changes in sectoral value-added shares from 1995 to 2018 in the baseline, I demonstrate that the comparative-advantage and price effects are the main channels of structural transformation driven by both productivity growth and globalization. Their median contributions are 41.5% and 39.2%, respectively.[5] The input-output and income effects follow, in that order.

Next, I extend the decomposition method to study the respective impacts of globalization and productivity growth on structural transformation. I implement an eight-fold exact decomposition, splitting the transformation into globalization and productivity growth, each operating through four mechanisms (details are outlined in the main text). The results show that globalization outweighs productivity growth in shaping structural transformation: Their median contributions are 58.1% and 41.9%, respectively. Moreover, the impact of globalization operates mainly through comparative advantage, with a median contribution of 39.9%. This finding underscores the importance of incorporating trade into models of structural transformation.

Despite its partial-equilibrium nature, the decomposition exercise provides useful insight that globalization has a significant impact on structural transformation

[4] Święcki (2017) discusses the path dependence of the decomposition, but does not perform an exact decomposition. Sposi, Yi, and Zhang (2021) study how each mechanism of their model drives deindustrialization and industry polarization by turning one channel on at a time. For a closed-economy model, Comin, Lashkari, and Mestieri (2021) exactly decomposes structural transformation into the income and price effects.

[5] The median is across country–sectors whose value-added share changed by more than 1 percentage point. The 1 p.p. cutoff avoids the cases where dividing one very small number by another yields an artificially large contribution.

through the comparative-advantage mechanism. Motivated by this, I run counterfactual exercises to quantify the impact of globalization on the structural transformation of 67 economies (66 countries plus the rest-of-the-world aggregate) in general equilibrium. I assess the effects of (1) globalization in goods, (2) globalization in services, and (3) the overall globalization in all sectors by fixing the corresponding trade costs at their initial-year levels. I compare the evolution of production shares across the baseline and three counterfactual economies. For each exercise, I let productivities evolve following their historical changes so that the structural transformation resulting from productivity growth is accounted for.

To understand the mechanisms underlying the main results—that the overall globalization had a heterogeneous impact across countries and that the comparative-advantage channel is the key driver behind it—it is instructive to begin by examining individual countries.

I first study China, one of the countries with the most rapid transformation. Regarding globalization, its initially high export trade costs (measured as the export-volume-weighted average of its bilateral export trade costs) were converging to its lower import trade costs (similarly measured) in both the goods and highly tradable services sectors, consistent with the general pattern of decreasing trade-cost asymmetry. Globalization was sector-neutral: For goods, export trade costs relative to import trade costs decreased by 81% from 1995 to 2018. For highly tradable services, the decline was close at 86%. Its structural transformation followed the common pattern of a shift from goods to the two service sectors: Its goods share in GDP decreased by 10.6 percentage points (p.p.) from 1995 to 2018 in the baseline. Meanwhile, the shares of highly and barely tradable services increased by 5.4 and 5.2 p.p., respectively.

Counterfactual analyses reveal that goods globalization, which promoted goods exports relative to imports, substantially decelerated the transformation, whereas services globalization, which facilitated services exports relative to imports, significantly accelerated it. Specifically, the decline in the goods share of GDP would have been 20.0 and -1.2 p.p., if globalization in goods and that in services had not occurred, respectively. Despite the significant individual effects, the impact of globalization in both goods and services was limited: The decline in the goods share would have been 9.2 p.p. without the overall globalization. Most differences in the rate of decline in the goods share between the baseline and each counterfactual were offset by changes in the rate of expansion of highly tradable services. The shares of barely tradable services were not much affected by the counterfactuals.

The examination of China yields a striking insight: The overall globalization had a limited impact on the country's structural transformation, not because globalization was insignificant, but because goods globalization and services globalization exerted opposing forces, offsetting each other.

In contrast, in Vietnam, which experienced goods-biased globalization, where its export trade costs relative to import trade costs for goods decreased faster than those for highly tradable services, globalization significantly decelerated its structural transformation. Lithuania, with services-biased globalization, exhibited the opposite result. The results for the three countries suggest that sector bias, determined by the cross-sector difference in the dynamics of asymmetric trade costs, is the crucial factor behind the heterogeneous impacts of globalization.

Cross-country results for 67 economies confirm this finding. Before presenting this evidence, I first examine the correlation between the level of economic development and the impact of globalization on structural transformation. The results are consistent with the decreasing trade-cost asymmetry in each sector, which implies that export trade costs decreased faster than import trade costs for developing countries and vice versa for advanced countries. Goods globalization generally decelerated the transition from goods to highly tradable services for developing countries and accelerated that for advanced countries. Services globalization had the opposite effect. However, the impact of the overall globalization was not correlated with the countries' per-capita income.

Instead, I find that the effect of the overall (both goods and services) globalization depended on which force—goods or services globalization—dominated and that it significantly varied across countries. The effect is measured as the gap between the speed of structural transformation in the baseline and that in the counterfactual. In terms of the decline in the goods share of GDP, 17 countries (approximately one-fourth of the 67) experienced minimal effects of less than 1.4 p.p., while for another 17, the transition away from goods was either decelerated or accelerated by more than 7.4 p.p. For most countries, the impact on the goods value-added share was accompanied by that on highly tradable services, and the share of barely tradable services was not significantly affected.

Next, I demonstrate that this heterogeneity in structural transformation induced by globalization is mostly explained by a *Globalization Bias Index,* which measures the sector bias of globalization. The index is calculated as the log growth rate of export trade costs relative to import trade costs for goods minus that for highly tradable services. Negative and positive values imply goods-biased and services-biased globalization, respectively. The index exhibits a strong linear relationship with the impact of globalization. I find that the closer a country's index is to zero, the closer the impact for that country is to zero. For countries with negative indices, globalization slowed their transformation from goods to highly tradable services. The opposite holds for the countries with positive indices. These effects are more pronounced for countries with indices further from zero.

Both the decomposition and counterfactual exercises imply that comparative advantage is the main mechanism through which globalization affects structural transformation. However, it is challenging to verify this, since changes in trade costs affect income, prices, net exports, and input-output linkages simultaneously. I overcome this difficulty through two strategies.

First, to measure a country's comparative advantage, I extend the definition of comparative advantage by Deardorff (2014)—which is a sufficient statistic for whether a country is a net exporter of goods in his two-country, asymmetric-trade-cost model—to a multi-country setting. A country's comparative advantage is assessed by comparing its productivity in goods relative to highly tradable services with the rest of the world and adjusting it for the country's sectoral export and import trade costs. Notably, the Globalization Bias Index coincides with the change in the comparative advantage induced by globalization. Negative and positive values of the index mean that globalization moved a country's comparative advantage toward goods and highly tradable services, respectively. Given this, the main result can be re-stated: For countries with sector-neutral globalization, globalization had a limited impact on their comparative advantage and structural transformation. In contrast, for countries with sector-biased globalization, the transformation accelerated or decelerated to the direction and extent of the shift in comparative advantage.

Second, I compare the results with those from two alternative models: one with non-tradable services and the other assuming symmetric trade costs, as in Cravino and Sotelo (2019). In the first model, there is no cross-sector specialization by construction. In the second model, in which export and import trade costs are assumed to be equal, globalization is always sector-neutral. Analyses based on these models yielded results where globalization had a muted impact on most countries' structural transformation. Comparison with the baseline results demonstrates that, for globalization to have significant and heterogeneous impacts on structural transformation in a model, the model should allow for tradable services and asymmetric trade costs so that globalization can directly affect countries' comparative advantage.

So far, the analysis has assumed that trade costs and productivities evolve independently. Yet spillovers may exist. For example, lower trade costs can raise productivity via learning by importing or exporting, while productivity gains in transportation or communication can reduce trade costs. I propose and estimate stochastic processes for trade costs and productivities that capture the spillovers and incorporate them parsimoniously into the model. This approach is applicable to a wide range of models of international trade and economic growth. The results show statistically significant spillovers from trade-cost reductions to productivity growth in goods: a 1% drop in average trade costs raises productivity by approximately 0.07%. The main results remain robust to incorporating this spillover into the model. Spillovers in the opposite direction and in the other sectors are insignificant.

This paper is organized as follows: Section 1.1 reviews the literature. Section 2 outlines the model. Sections 3 and 4 describe the data and the model parameterization. Sections 5 and 6 present the decomposition and counterfactual exercises. Section 7 provides the comparison with the two alternative models. Section 8 extends the model to incorporate the spillovers. Lastly, Section 9 concludes.

1.1 Related Literature

The most closely related literature is on structural transformation in an open economy. Cravino and Sotelo (2019, CS, hereafter) and Bonadio et al. (2025, BHLP) argue that globalization accelerates the transformation in most countries due to the price effect: Goods and services are complements, and faster globalization in goods than in services decreases the prices of goods relative to services. Despite a different focus on premature deindustrialization, Sposi, Yi, and Zhang (2021, SYZ) also emphasize the price effect of globalization.[6] In contrast, I demonstrate that globalization's impact is heterogeneous across countries and is driven by the comparative-advantage effect.

[6]The three papers address different questions from this paper. CS examine how globalization affects the rising skill premium through structural transformation. SYZ assess the impact of globalization and productivity growth on premature deindustrialization, a feature of structural transformation highlighted by Rodrik (2016), and industry polarization. BHLP study how globalization and structural transformation affect international GDP comovement.

In Section 7, I illustrate why the results differ by comparing the main results with those from the symmetric-trade-cost model as in CS.[7]

The core mechanism is related to Betts, Giri, and Verma (2016), who study how the dynamics of export and import trade costs influenced Korea's transition from agriculture to manufacturing. I demonstrate that this mechanism is more general with a multi-country model. Additionally, this paper is connected to studies that analyze the role of trade in the structural transformation of specific countries (e.g., Kehoe, Ruhl, and Steinberg 2018; Reyes-Heroles 2018; Teignier 2018).

Other contributions to the open-economy structural-transformation literature are as follows: First, it is one of the earliest to highlight the significant role of services trade, demonstrating that services globalization can offset the impact of goods globalization.[8] Second, I construct a dataset covering 66 countries over 24 years capturing diverse stages of structural transformation and economic development. Third, I propose an exact decomposition method for an open-economy, structural-transformation model with input-output linkages. Fourth, I develop a strategy to parsimoniously incorporate spillovers between trade costs and productivities in a wide range of models of international trade and economic growth.

This work complements the literature on the heterogeneous paths of structural transformation across countries. For a closed-economy study, Huneeus and Rogerson (2024) uncovers heterogeneous productivity growth as a reason behind the countries' different industrialization episodes. For an open-economy study, Święcki (2017) demonstrates that the role of trade greatly varied across countries while decomposing the agriculture-manufacturing-services transition of 45 countries.

Lastly, this paper contributes to the literature on asymmetric trade costs, as previously discussed, and on identifying services trade costs. Regarding the latter, most existing papers from Mirza and Nicoletti (2004) to Benz and Jaax (2022) estimate the gravity equations or rely on the index-based measures, such as the OECD Services Trade Restrictiveness Index. In contrast, I invert gravity models, which requires more data—prices for all sample countries and years—but allows me to capture the unobservable components of trade costs and trace the dynamics of trade costs.

[7] The model in SYZ features endogenous capital accumulation and the three sectors of agriculture, manufacturing, and services. BHLP is based on an international business cycle model, which does not feature the income effect. These model-wise differences complicate the direct comparison.

[8] Relatedly, Han, Miranda-Pinto, and Tanaka (2022) argue the importance of the domestic inter-province services trade in the structural transformation of Canadian provinces.

2 Model of Trade and Structural Transformation

To assess the effect of globalization on structural transformation, I construct a multi-country, multi-sector model, similar to Cravino and Sotelo (2019) and Lewis et al. (2021). Trade and production follow the EK model with input-output linkages, and households have non-homothetic constant elasticity of substitution (non-homothetic CES) preferences as in Comin, Lashkari, and Mestieri (2021, CLM, hereafter).

There are a discrete number of countries and sectors, denoted by the sets $\mathcal{I}$ and $\mathcal{S}$, respectively. Time is discrete. All markets are perfectly competitive. Each period and in each country, a representative household inelastically supplies labor and consumes sectoral outputs. In each sector, there is a unit continuum of tradable varieties. Production of a variety requires labor and intermediate inputs. (Since the model abstracts from capital, labor should be interpreted as value added.) In the initial period, productivities for variety production are drawn. Productivity growth in subsequent years differs across countries and sectors. Cross-border trade of a variety incurs an iceberg trade cost, which differs across origin, destination, sector, and time. Exogenous dynamics of productivities and trade costs drive structural transformation. Since the model does not have endogenous dynamics, I omit time notation for brevity and introduce it later.

2.1 Technology

2.1.1 Production of Varieties

In each sector, there is a unit continuum of tradable varieties. Each country has technologies for producing all varieties. The production function for variety $z \in [0,1]$ of sector $k \in \mathcal{S}$ in country $i \in \mathcal{I}$ is given by

$$y_i^k(z) = A_i^k \alpha_i^k(z) \left\{ \left(\psi_i^{Lk}\right)^{\frac{1}{\rho^k}} \left(L_i^k(z)\right)^{\frac{\rho^k-1}{\rho^k}} + \sum_{h \in \mathcal{S}} \left(\psi_i^{hk}\right)^{\frac{1}{\rho^k}} \left(Q_i^{hk}(z)\right)^{\frac{\rho^k-1}{\rho^k}} \right\}^{\frac{\rho^k}{\rho^k-1}}, \qquad (1)$$

where A_i^k and $\alpha_i^k(z)$ are country-sector-wide and country-sector-variety-specific productivities, respectively. $L_i^k(z)$ and $Q_i^{hk}(z)$ are the labor employed and sector-h aggregates used. ψ_i^{Lk} and ψ_i^{hk} denote the corresponding input weights. Production of a variety in sector k requires inputs from all sectors, reflecting input-output linkages. ρ^k is the elasticity of substitution among labor and intermediate inputs.

A_i^k is exogenously given each period. $\alpha_i^k(z)$ is drawn from a sector-specific Frèchet distribution of $F^k(\alpha) = e^{-\alpha^{-\theta^k}}$ in the initial period.[9] It stays constant throughout the period.[10] As in EK, I impose $\eta^k < \theta^k + 1$ for well-defined prices.

Cost minimization yields the production cost given by $r_i^k(z) = \frac{R_i^k}{A_i^k \alpha_i^k(z)}$, where R_i^k is the price of an input bundle.

$$R_i^k = \left(\psi_i^{Lk} W_i^{1-\rho^k} + \sum_{h \in \mathcal{S}} \psi_i^{hk} \left(P_i^h \right)^{1-\rho^k} \right)^{\frac{1}{1-\rho^k}}, \tag{2}$$

where W_i and P_i^h are the wage rate and the price for a sector-h aggregate, respectively.

Notably, the results of this paper are robust to an alternative specification of a nested CES production function, where the inner nest aggregates intermediate inputs and the outer nest combines labor with the aggregated intermediate inputs (Online Appendix O.E).[11]

2.1.2 Production of Aggregates and International Trade

In each sector, a unit continuum of tradable varieties are combined into a non-tradable aggregate, which is then used for variety production and household consumption. The production function for sector-k aggregates in country i is given by

$$Y_i^k = \left(\int_0^1 q_i^k(z)^{\frac{\eta^k - 1}{\eta^k}} dz \right)^{\frac{\eta^k}{\eta^k - 1}},$$

where Y_i^k is the amount of an aggregate produced, $q_i^k(z)$ is the amount of variety z used as inputs, and η^k governs the substitutability among varieties.

Varieties can be traded internationally subject to iceberg trade costs. For an origin-j, sector-k variety producer to export to destination i, a trade cost of τ_{ji}^k is

[9]This is isomorphic to setting sector-wide productivities to 1 and assuming a country-sector-specific Frèchet distribution of $F_i^k(\alpha) = e^{-T_i^k \alpha^{-\theta^k}}$, where $T_i^k = \left(A_i^k\right)^{\theta^k}$. This alternative aligns with the notation of EK; however, my approach yields a more convenient expression for productivity when I parameterize the model.

[10]An alternative is to assume that $\alpha_i^k(z)$ is drawn each period. The two assumptions yield identical equilibrium conditions, hence the same macroeconomic implications.

[11]The alternative specification is as follows: $y_i^k(z) =$

$$A_i^k \alpha_i^k(z) \left[\left(\chi_i^{Lk}\right)^{\frac{1}{\mu^k}} \left(L_i^k(z)\right)^{\frac{\mu^k - 1}{\mu^k}} + \left(1 - \chi_i^{Lk}\right)^{\frac{1}{\mu^k}} \left\{ \sum_{h \in \mathcal{S}} \left(\psi_i^{hk}\right)^{\frac{1}{\rho^k}} \left(Q_i^{hk}(z)\right)^{\frac{\rho^k - 1}{\rho^k}} \right\}^{\frac{\rho^k}{\rho^k - 1} \frac{\mu^k - 1}{\mu^k}} \right]^{\frac{\mu^k}{\mu^k - 1}}.$$

incurred. For one unit of the variety to arrive in country i, $\tau_{ji}^k \geq 1$ units need to be shipped. Domestic trade is frictionless: $\tau_{ii}^k = 1 \ \forall i \in \mathcal{I}$. Additionally, re-exporting is not allowed: It is forbidden to import a variety and sell it to another country.[12]

The aggregate producer buys a variety from the producer with the lowest total cost (gross of production and trade cost): $p_i^k(z) = \min_{j\in\mathcal{I}} \tau_{ji}^k r_j^k(z)$. The minimization problem yields the expressions for the prices of aggregates and import shares:[13]

$$P_i^k = \gamma^k \left\{ \sum_{j\in\mathcal{I}} \left(\frac{\tau_{ji}^k R_j^k}{A_j^k} \right)^{-\theta^k} \right\}^{-\frac{1}{\theta^k}}, \tag{3}$$

$$\pi_{ji}^k \equiv \frac{X_{ji}^k}{P_i^k Y_i^k} = \frac{\left(\frac{\tau_{ji}^k R_j^k}{A_j^k}\right)^{-\theta^k}}{\sum_{o\in\mathcal{I}} \left(\frac{\tau_{oi}^k R_o^k}{A_o^k}\right)^{-\theta^k}}, \tag{4}$$

where $\gamma^k = \Gamma\left(\frac{\theta^k+1-\eta^k}{\theta^k}\right)^{\frac{1}{1-\eta^k}}$, and $X_{ji}^k \equiv \int_0^1 \mathbb{1}_{ji}^k(z) p_i^k(z) q_i^k(z) dz$ is the expenditure on varieties from country j. $\mathbb{1}_{ji}^k(z)$ denotes an indicator function which equals one if the aggregate producer buys variety z from j, and zero otherwise. Equations (3) and (4) capture how domestic and foreign productivities, costs of input bundles, and trade costs affect an equilibrium.

2.2 Preferences

Country i has L_i units of a representative household, who has non-homothetic CES preferences.[14] The household's utility, U_i, is implicitly defined by

$$\sum_{k\in\mathcal{S}} (\phi_i^k)^{\frac{1}{\sigma}} U_i^{\frac{1-\sigma}{\sigma}\epsilon^k} (C_i^k)^{\frac{\sigma-1}{\sigma}} = 1, \tag{5}$$

[12] EK assumes the triangle inequality, where $\tau_{ij}^k < \min_{o\in\mathcal{I}\setminus\{i,j\}} \tau_{io}^k \tau_{oj}^k, \ \forall i,j \in \mathcal{I}$. In this case, albeit possible, re-exporting is not economically feasible. This assumption is violated by the trade costs from model inversion—4.6% of country pairs in all sector-years violated the triangle inequality. Therefore, I impose the assumption of no re-exports. For more discussions on the violation, see Foellmi, Hepenstrick, and Torun (2022).

[13] For derivations, see EK.

[14] Unlike Stone-Geary preferences, non-homothetic CES preferences feature Engel curves that do not level off as income grows. CLM provide micro and macro evidence of this. I also find the pattern in my data. Regarding the assumption of representative households, CLM demonstrate that it is straightforward to incorporate households with heterogeneous incomes within a country if the income distribution is log-normal with a small standard deviation (Online Appendix B of CLM).

where C_i^k and ϕ_i^k denote the consumption and utility weight of sector-k aggregates, respectively. σ is a substitution elasticity, and ϵ^k is a sectoral non-homotheticity parameter.[15] (Note that the non-homothetic CES preferences equal the homothetic CES preferences, when $\epsilon^h = \epsilon^k, \ \forall h, k \in \mathcal{S}$.) A unit of the household inelastically supplies one unit of labor and makes exogenous net transfers, NX_i, to the outside world.[16] The per-capita budget constraint is

$$\sum_{k \in \mathcal{S}} P_i^k C_i^k = W_i - NX_i. \tag{6}$$

The utility maximization yields the following:

$$P_i = \left\{ \sum_{k \in \mathcal{S}} \phi_i^k (P_i^k)^{1-\sigma} U_i^{(1-\sigma)(\epsilon^k - 1)} \right\}^{\frac{1}{1-\sigma}}. \tag{7}$$

$$\frac{P_i^k C_i^k}{P_i U_i} = \phi_i^k \left(\frac{P_i^k}{P_i} \right)^{1-\sigma} U_i^{(1-\sigma)(\epsilon^k - 1)}, \ \forall k \in \mathcal{S}. \tag{8}$$

Equation (7) provides the definition of a non-homothetic CES price index, or equivalently a unit price of utility. Equation (8) is the demand function for sectoral aggregates, where σ governs the substitutability across sectoral outputs, and $(1-\sigma)(\epsilon^k - 1)$ is the real-income elasticity of a sector.

2.3 Market Clearing

Labor markets clear: $L_i = \sum_{k \in \mathcal{S}} L_i^k, \ \forall i \in \mathcal{I}$, where $L_i^k \equiv \int_0^1 L_i^k(z) dz$. Aggregate markets clear: $Y_i^k = L_i C_i^k + \sum_{h \in \mathcal{S}} Q_i^{kh}, \ \forall i \in \mathcal{I}, \forall k \in \mathcal{S}$, where $Q_i^{kh} \equiv \int_0^1 Q_i^{kh}(z) dz$. Variety markets clear: $y_i^k(z) = \sum_{j \in \mathcal{I}} \mathbb{1}_{ij}^k(z) \tau_{ij}^k q_j^k(z) \ \forall i \in \mathcal{I}, \forall k \in \mathcal{S}, \forall z \in [0,1]$. Net transfers sum to zero: $\sum_{i \in \mathcal{I}} L_i NX_i = 0$.[17]

The definition of an equilibrium is in Appendix A. For the rest of the paper, I introduce time subscripts for the model objects that are time-variant.

---

[15] If $\epsilon^k > 0, \ \forall k \in \mathcal{S}$, and $\sigma \in (0,1) \cup (1, \infty)$, this utility is globally monotone and quasi-concave, yielding a well-defined utility function (Hanoch 1975). This restriction is satisfied by the point estimates of this paper.

[16] This is to capture the large trade imbalances of some countries in the data. The quantitative result is robust to the alternative assumption of balanced trade (Online Appendix O.E).

[17] It is possible to assume otherwise; however, since I collect data for the rest-of-world aggregate, net transfers sum to zero in the data.

2.4 Mechanisms of Structural Transformation

Exogenous changes in model primitives—such as productivities and trade costs—generate structural transformation through four channels: changes in income, relative prices, sectoral net exports, and input-output linkages. Since sectoral net exports and comparative advantage are closely related, I use the terms comparative-advantage effect and net-export effect interchangeably.

First, productivity growth or a reduction in trade costs in any sector increases the household's real income. Then, the household shifts its expenditure toward more income-elastic sectors (those with higher $(1-\sigma)(\epsilon^k - 1)$ in Equation (8)).

Second, changes in the primitives that differ across sectors generate relative price movements. If sectoral outputs are complements in the household's preferences (i.e., $\sigma \in (0,1)$ in Equation (8)), then, when the relative price of a sector rises, the expenditure share of that sector increases. Through the income and price effects, the expenditure shares change, which in turn alters the production pattern, i.e., how L_i is allocated across sectors.

The third channel is through net exports or comparative advantage. In an open economy, the sectoral output of country i ($\sum_{j \in \mathcal{I}} \pi^k_{ij,t} P^k_{j,t} Y^k_{j,t}$) is not necessarily equal to its sectoral absorption ($P^k_{i,t} Y^k_{i,t}$) due to cross-sector specialization. Changes in the primitives can shift countries' comparative advantage, affecting their specialization pattern.

The last mechanism is through input-output linkages. Changes in prices caused by shifts in productivities or trade costs can alter the input-output linkages, impacting the intermediate demands for sectoral outputs. Furthermore, the linkages can interact with the above three mechanisms. For example, if the production of a sectoral variety uses intermediate inputs from the same sector more intensively, then the sectoral price reduction in response to sectoral productivity growth or trade-cost reduction is greater. Additionally, input-output linkages can mute or amplify the price effects from final demand, depending on whether production inputs are substitutes or complements, i.e., $\rho^k > 1$ or $\rho^k \in (0,1)$.

The relationship between structural transformation and the four mechanisms can be viewed through the lens of an equation. From the equilibrium conditions, total sectoral wages can be expressed in terms of real income (aggregate consumption), sectoral prices, and net exports per capita, along with an input-output coefficient matrix and population size:

$$
\begin{aligned}
&W_{i,t}\vec{\mathbf{L}}_{i,t} \\
&= \underbrace{\left[\left\{\mathbf{I}-\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)^T\right\}\vec{\mathbf{e}}\right]}_{\text{(Sectoral labor input shares)}} \\
&\odot\left[\underbrace{\left\{\mathbf{I}-\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)\right\}^{-1}}_{\text{(Leontief inverse)}}L_{i,t}\left(\underbrace{\vec{\mathbf{P}}_{i,t}\odot C_i(\vec{\mathbf{P}}_{i,t},U_{i,t})}_{\text{(Sectoral final consumption)}}+\underbrace{\vec{\mathbf{NX}}_{i,t}}_{\text{(Sectoral net exports)}}\right)\right].
\end{aligned} \tag{9}
$$

Vectors are denoted using boldface and an overhead arrow. For example, $\vec{\mathbf{L}}_{i,t}\equiv[L^1_{i,t},L^2_{i,t},...,L^{|\mathcal{S}|}_{i,t}]$, where $|\mathcal{S}|$ denotes the number of sectors. $\mathbf{I}$ denotes an identity matrix, and $\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)$ denotes an input-output coefficient matrix, whose (i,j)-th element denotes the input share of sector-i aggregates for sector-j variety production—for details, see Equation (Eq.F.3) in Appendix A. Notably, this matrix depends on sectoral prices and wages. $\vec{\mathbf{e}}$ denotes a unit vector, and $\odot$ denotes an element-wise product. $C_i(\vec{\mathbf{P}}_{i,t},U_{i,t})$ is a vector-valued function whose output is the sectoral consumption (in quantity), which is determined by sectoral prices and real income. Specifically, $C_i(\vec{\mathbf{P}}_{i,t},U_{i,t})$ represents the relationship in Equations (Eq.H.1) to (Eq.H.3) in Appendix A. Lastly, sectoral net exports per capita are defined by $NX^k_{i,t}\equiv\left(\sum_{j\in\mathcal{I}}\pi^k_{ij,t}P^k_{j,t}Y^k_{j,t}-P^k_{i,t}Y^k_{i,t}\right)\Big/L_{i,t}$. The derivation of Equation (9) is provided in Appendix B.

In model terms, structural transformation corresponds to changes in $\frac{1}{L_{i,t}}\vec{\mathbf{L}}_{i,t}$. In Equation (9), dividing sectoral total wages ($W_{i,t}L^k_{i,t}$) by their sum ($\sum_{k\in\mathcal{S}}W_{i,t}L^k_{i,t}$) yields $\frac{1}{L_{i,t}}\vec{\mathbf{L}}_{i,t}$. Therefore, the equation can be utilized to study structural transformation.

To interpret Equation (9) from the rightmost side, the final demand for sectoral output is the sum of per-capita sectoral final consumption and net exports, multiplied by the population size. Through the income and price effects, the former changes. Through the net-export effect, the latter changes. The final demand does not directly translate into the total sectoral demand, since there are intermediate demands through input-output linkages. Therefore, to derive the total sectoral demand, we multiply the final demand by the Leontief inverse.[18] Since production uses both la-

[18]Note that $\left\{\mathbf{I}-\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)\right\}^{-1}=\mathbf{I}+\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)+\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t},w_{i,t}\right)^2+\cdots$, which exposes

bor and intermediate inputs, to obtain total sectoral wages, the total sectoral demand is multiplied by the labor input shares. The input-output effects operate through the labor input shares and the Leontief inverse.

Two points are worth noting. First, Equation (9) serves as the basis for the decomposition exercise in Section 5. Second, the equation can also be used for understanding structural transformation in the model without input-output linkages or international trade. To see this, assume that there are no input-output linkages or trade, that is, $\tilde{\mathbf{B}}_i(\cdot) = \mathbf{0}$ and $\vec{\mathbf{NX}}_{i,t} = \vec{\mathbf{0}}$. Then, the equation simplifies to

$$W_{i,t}\vec{\mathbf{L}}_{i,t} = L_{i,t}\vec{\mathbf{P}}_{i,t} \odot C_i(\vec{\mathbf{P}}_{i,t}, U_{i,t}).$$

In the above, dividing $W_{i,t}L^k_{i,t}$ by $W_{i,t}L^g_{i,t}$ yields

$$\begin{aligned}\log\left(\frac{L^k_{i,t}}{L^g_{i,t}}\right) &= \log\left(\frac{P^k_{i,t}C^k_{i,t}}{P^g_{i,t}C^g_{i,t}}\right) \\ &= \underbrace{(1-\sigma)\log\left(\frac{P^k_{i,t}}{P^g_{i,t}}\right)}_{\text{(Price effects)}} + \underbrace{(1-\sigma)(\epsilon^k - 1)\log(U_{i,t})}_{\text{(Income effects)}} + \log\left(\frac{\phi^k_i}{\phi^g_i}\right).\end{aligned} \tag{10}$$

The second equality is due to Equation (8). Equation (10) describes the relative sectoral labor shares in terms of relative prices and real income and therefore can be used to understand the price and income effects of structural transformation.

3 Data

To parameterize the model, I utilize annual data from 1995 to 2018 covering 66 countries and the rest-of-the-world aggregate (ROW). The 66 countries represent a wide range of levels in economic development: In 2018, their nominal GDP per capita ranged from \$1,289 to \$116,787. Furthermore, they accounted for more than 90% of world trade and GDP in 2018. The list of countries is in Appendix C.

The data consist of three primary components: data on trade, input-output, and price. The first two are from the OECD Inter-Country Input-Output Tables (OECD 2021, ICIO, hereafter), which covers 45 industries. To address the measurement challenges of services trade flows, the ICIO utilizes a wide array of data sources,

the relationship between the final demand and the total demand through the intermediate demand.

including national accounts, balance of payments, and trade-in-services statistics from the IMF, the OECD, the WTO, and other organizations. In general, goods trade can be measured more precisely using detailed product-level customs data, while services trade is more prone to measurement errors.[19]

Price levels for country-sector-years are constructed in two steps. First, I compile data on within-country cross-time price variation from gross-output price deflators (GOPD) from sources, such as the OECD and the UN.[20] Second, I convert them to price levels by utilizing data on the cross-country sectoral price levels for a single benchmark year: the Productivity Level Database 2005 Benchmark (PLD 2005) of the Groningen Growth and Development Centre (Inklaar and Timmer 2014). More details about the data construction are in Online Appendix O.C.

It is noteworthy that the results of this paper do not significantly depend on converting price deflators to price levels. In Online Appendix O.D, I demonstrate that using only price deflators, it is possible to infer changes in trade costs and productivities, and with these, I can perform counterfactual exercises through the Exact Hat Algebra (Dekle, Eaton, and Kortum 2008). However, obtaining price levels enables identification of the levels of trade costs and productivities.

3.1 Goods, Highly Tradable Services, and Barely Tradable Services

For the rest of the paper, I divide the economy into three broad sectors: goods, highly tradable services, and barely tradable services (G, HTS, and BTS). I aggregate 45 industries in the ICIO into the three sectors. I classify 24 industries that span ISIC Rev. 4 industry codes 01 to 39 as goods. I allocate each service industry to highly and barely tradable services based on its tradability. An industry where more than 5% of its world total outputs are traded in 2018 is classified as highly tradable services. Table 1 lists all 21 services industries, their tradedness (world total trade/world total

[19] See Francois and Hoekman (2010) for more details.

[20] Unlike value-added price deflators (VAPD), not all countries report GOPD for all sector-years. To address this, for countries using double deflation in national accounting, I propose and apply a method to construct GOPD from VAPD by leveraging the relationship between the two in the double deflation method. For the countries using single deflation, GOPD and VAPD are equal by definition. One technical contribution of this paper is confirming the validity of the approach by comparing the GOPD in data and the GOPD imputed from VAPD for countries where data for both GOPD and VAPD are available. Unlike VAPD, which exhibits a significant discrepancy with GOPD for some country-sectors, the imputed GOPD closely aligns with the actual GOPD.

Table 1: Classification of Industries into Three Sectors

Sector	Industry	ISIC	Trd.	Sector	Industry	ISIC	Trd.
G	Goods	01-39	21.9	HTS	Financial & insurance	64-66	8.7
HTS	Water transport	50	39.4	HTS	Art & entertainment	90-93	7.6
HTS	Air transport	51	38.4	HTS	Postal services	53	7.5
HTS	IT	62-63	18.4	HTS	Telecom	61	6.1
HTS	Publishing & audiovisual	58-60	17.8	BTS	Education	85	2.2
HTS	Land transport	49	16.2	BTS	Other services	94-96	1.7
HTS	Warehousing	52	15.3	BTS	Real estate	68	1.1
HTS	Wholesale & retail	45-47	14.1	BTS	Health	86-88	0.4
HTS	Accommodation & food	55-56	10.8	BTS	Public	84	0.4
HTS	Professional & scientific	69-75	10.2	BTS	Construction	41-43	0.2
HTS	Admin	77-82	9.1	BTS	Household	97-98	0.0

* Note: Industry names are shortened for brevity. ISIC denotes ISIC Rev. 4 two-digit industry classification. Trd. denotes tradedness (%).

output), and their sector classifications.

The main rationale behind splitting the services sector into highly and barely tradable services is to mitigate the measurement issues behind the prices for non-market services.[21] Cross-country comparisons of prices for non-market services are challenging due to underlying measurement assumptions (Deaton and Heston 2010). One of the examples by the authors is as follows. Suppose that one wants to compare prices of public health services across two countries, rich and poor, and that healthcare workers are getting paid more in the rich country. Without market prices, prices and quantities of healthcare services are alternatively calculated using information on inputs. Suppose that the measurement assumption is that workers in the rich and poor countries have equal productivity. Then, prices for healthcare services in the poor country are underestimated, since the workers are getting paid less—in reality, it is likely that the wage gap partly reflects a productivity difference. Subsequently, the quantities of healthcare services in the poor country are overestimated. Deaton and Heston (2010) further argue that this type of problem makes both within-country, cross-time and cross-country, within-time price comparison difficult and leads to large differences among the aggregate macroeconomic statistics generated with different measurement assumptions for non-market services.

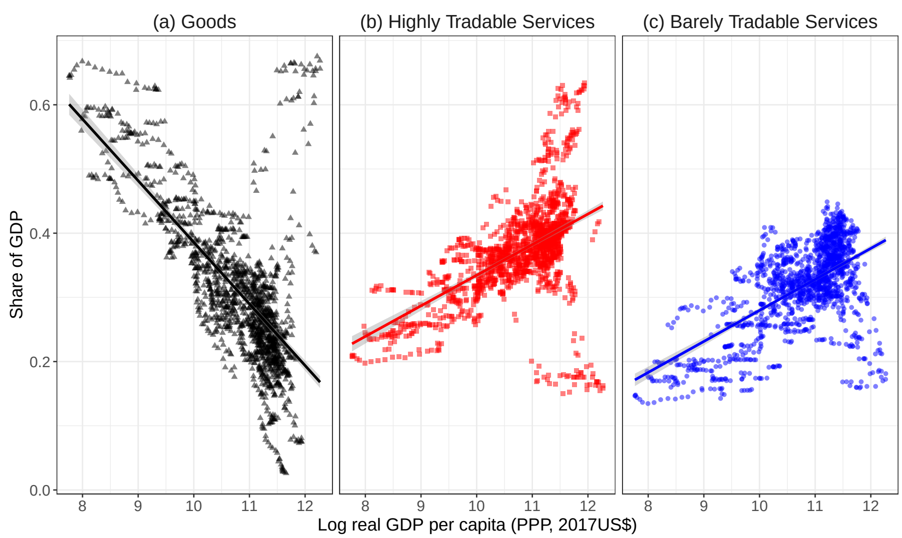
Since the identification of trade costs depends on prices later in Section 4.2, it is possible that the measurement issues of non-market services affect the measurement

[21] Another benefit is that it allows for differential productivity growth across services sectors. The distinction between highly and barely tradable services largely coincides with the two-fold split of services based on productivity growth by Duernecker, Herrendorf, and Valentinyi (2017).

of services trade costs. As Table 1 demonstrates, market and non-market services largely align with highly and barely tradable services, so having two services sectors mitigates this issue. I identify trade costs for highly tradable services with better-measured prices, and barely tradable services are almost non-tradable by construction.

In the three-sector definition, goods and highly tradable services are the (more) tradable segments of the economy. In 2018, 21.7% of goods and 12.7% of highly tradable services were traded internationally. In contrast, only 0.8% of barely tradable services were traded.[22] The structural transformation pattern for 66 countries from 1995 to 2018 is that as a country develops, its GDP share of goods decreases, while the shares of both highly and barely tradable services increase (Figure 1).

Figure 1: Sectoral Shares in Production of Country-years by Per-Capita Real Income



* Source: GDP shares are from the ICIO. Real GDP per capita is expenditure-side real GDP at chained PPPs in 2017 USD divided by total employment ("rgdpe"/"emp" from PWT 10.0).
* Note: In each panel, each dot represents a country-year, and there are a total of 1584 country-years (66 countries from 1995 to 2018). The solid lines and the shaded areas around them represent the regression lines and the 95% confidence intervals, respectively.

4 Parameterization

This section describes the parameterization of the model. I first estimate parameters using data or take them from the literature. Then, I identify the sectoral trade costs

[22] 62% of trade in barely tradable services was GATS (General Agreement on Trade in Services) Mode 2, which captures services consumed in the country of production by non-residents.

and productivities by inverting the estimated model.

4.1 Estimation

I estimate the preference parameters (substitution elasticity, σ, and non-homotheticity parameters, $\{\epsilon^k\}_{k\in\mathcal{S}}$) using cross-country panel data on sectoral final expenditures, prices, and income, following the approach of CLM. I estimate the technology parameters (elasticities of substitution in production, $\{\rho^k\}_{k\in\mathcal{S}}$) through the macro-data approach (Herrendorf, Rogerson, and Valentinyi 2013; Cravino and Sotelo 2019). Trade elasticities, $\{\theta^k\}_{k\in\mathcal{S}}$, are directly obtained from Simonovska and Waugh (2014). The elasticities of substitution among varieties, $\{\eta^k\}_{k\in\mathcal{S}}$, can be set to any $\eta^k < \theta^k+1$ given the parameterization strategy. The parameters are provided in Table 2. The estimation procedures and the derivation of the weight terms of the utility and production functions ($\{\phi_i^k\}_{i\in\mathcal{I},k\in\mathcal{S}}$ and $\{\psi_i^{Lk}, \{\psi_i^{hk}\}_{h\in\mathcal{S}}\}_{i\in\mathcal{I},k\in\mathcal{S}}$) are provided in Appendix D.

Table 2: Parameter Values

Type	Variable	Est.	(95% CI) or [std. err.]	Nobs.	(Method) or [source]
Preference	σ	0.59	(0.51, 0.65)	1584	(Comin, Lashkari, and Mestieri 2021)
	ϵ^{hts}	1.78	(1.55, 1.93)		
	ϵ^{bts}	1.33	(1.12, 1.45)		
Production (variety)	ρ^g	1.22	[0.04]	1584	(Herrendorf, Rogerson, and Valentinyi 2013; Cravino and Sotelo 2019)
	ρ^{hts}	0.93	[0.04]	1584	
	ρ^{bts}	0.93	[0.04]	1584	
Trade	$\{\theta^k\}_{k\in\mathcal{S}}$	4	-	-	[Simonovska and Waugh 2014]
Production (aggregate)	$\{\eta^k\}_{k\in\mathcal{S}}$	2	-	-	Any $\eta^k < \theta^k + 1$

* Note: "Est.," "CI," "std. err.," and "Nobs." denote estimates, confidence intervals, standard errors, and the number of observations, respectively. Preference parameters are jointly estimated via GMM with bootstrapped confidence intervals. Production (variety) parameters are separately estimated through GMM, and the standard errors are reported.

4.2 Model Inversion

In this section, I identify sectoral trade costs and productivities by inverting the model following Święcki (2017) and Lewis et al. (2021). Since the work of Head and Ries (2001), the inversion approach has been widely used to obtain trade costs, including studies by Jacks, Meissner, and Novy (2011) and Novy (2013).[23] Furthermore, obtaining model primitives through inversion has been widely used in quantitative spatial economics (e.g., those reviewed by Redding and Rossi-Hansberg 2017).

4.2.1 Sectoral Trade Costs from 1995 to 2018

From Equations (3) and (4), a sectoral bilateral trade cost can be expressed as a function of import shares and price levels:

$$\tau_{ji}^{k} = \left(\frac{\pi_{ji}^{k}}{\pi_{jj}^{k}}\right)^{-\frac{1}{\theta^{k}}} \frac{P_{i}^{k}}{P_{j}^{k}}. \tag{11}$$

Given the shape parameter of the Frèchet distribution (or equivalently, the trade elasticity), θ^k, we can infer trade costs from the data on import shares and prices. The intuition behind identification is as follows. Given fixed relative prices, if country i imports more from country j, it means that the trade cost from j to i must have been lower. Given constant trade shares, a lower relative price in destination country i suggests that, compared to the origin, either demand is lower in the destination or the destination has more efficient production or importing technologies. Then, the implied trade cost is lower.

The benefits of this inversion approach are that it can capture the dynamics of trade costs by incorporating both observable and unobservable barriers to trade and that it allows trade costs to differ across origin, destination, and sector. In contrast, an estimation approach that parameterizes trade costs as a function of gravity variables (e.g., bilateral distance, a common language, a colonial relationship, or a shared land border) is not ideal for analyzing the dynamics of trade costs, as these variables are typically stable over time.

Trade costs from the inversion formula (Equation (11)) are not specific to the model of this paper, which extends the EK model of trade. In Online Appendix O.A, I show that the same inversion formula can be applied to obtain the globalization pattern if I were to embed a different workhorse gravity model, such as Armington (Anderson 1979), BEJK (Bernard et al. 2003), and Krugman (1980), into the model of structural transformation in open economy. I also illustrate how the inversion formula can be adjusted for the Melitz (2003)-Chaney (2008) model.

[23] The method is also called model-based inference, residual approach, or "wedges" approach.

I assume that the trade elasticity for the goods sector (θ^g) is four, following Simonovska and Waugh (2014). I further assume that trade elasticities of services (θ^{hts} and θ^{bts}) are four as well, because there is no consensus on the estimate.[24] In Equation (11), the trade elasticity governs the relative contribution of import shares and relative price levels to the identification of trade costs. With low trade elasticities, inferred changes in trade costs will be governed more by changes in import share terms than by changes in relative prices. Therefore, it is possible that different trade elasticities for services can affect the main results of this paper. However, in Online Appendix O.E, I show that even with alternative trade elasticities for services (i.e., $\theta^{hts} = \theta^{bts} = 2$, and $\theta^{hts} = \theta^{bts} = 6$), the results remain robust.

When Equation (11) yields trade costs below one, I set them equal to one so that the assumption $\tau^k_{ij,t} \geq 1$ is satisfied. Among all bilateral trade costs, 0.7% fell below one. For barely tradable services, among all origin-destination-years, 24 exhibited zero trade (i.e., $\pi^{bts}_{ji,t} = 0$), leading to infinite trade costs (i.e., $\tau^{bts}_{ji,t} = \infty$). Since this complicates the calculation of average trade costs, I set the trade costs for those pairs equal to the maximum finite bilateral trade cost observed in that year. Alternatively, I could allow trade costs to fall below one, reflecting export-facilitating factors, and to be infinite. The quantitative results remain robust under this alternative specification (Online Appendix O.E).

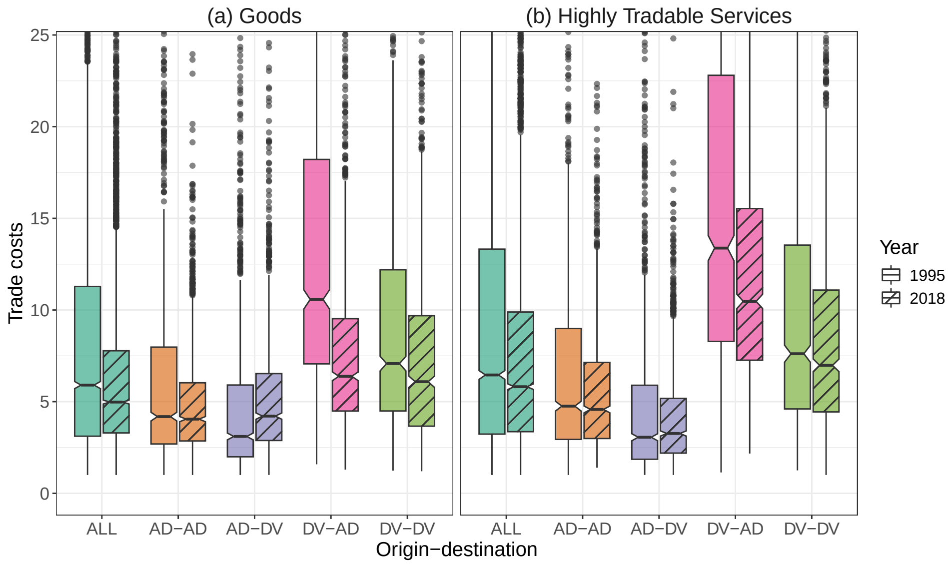
Because barely tradable services exhibit prohibitively high trade costs, they do not significantly impact the quantitative results. For brevity, I discuss only the globalization patterns of goods and highly tradable services.

Figure 2 displays box plots of trade costs (excluding trade costs for own-country pairs, $\tau^k_{ii,t} = 1$) in 1995 and 2018 for goods and highly tradable services, highlighting the first quartile, median, and third quartile within each country-group pair.[25] Country pairs are grouped based on whether the exporter or importer is a developing or an advanced country. The classification of developing and advanced economies follows the IMF's World Economic Outlook. Two prominent patterns are observed. First, there exists trade-cost asymmetry for both goods and highly tradable services in both 1995 and 2018. Developing countries tend to face higher export trade costs

[24] For the EK model, Muñoz (2022) estimates the services trade elasticity to be 1.1 from Europe's cross-border job posting policies, and Sposi (2019) finds it to be 6.2 from the cross-country price data by the International Comparison Program. As for Melitz (2003)-type models, the estimates range from 2.54 to 3.67 (footnote 7 of Benz and Jaax 2022).

[25] For the globalization pattern across all years, see Figure O.B1 in Online Appendix O.B.

Figure 2: Box Plots for Trade Costs in 1995 and 2018 by Country-group Pairs



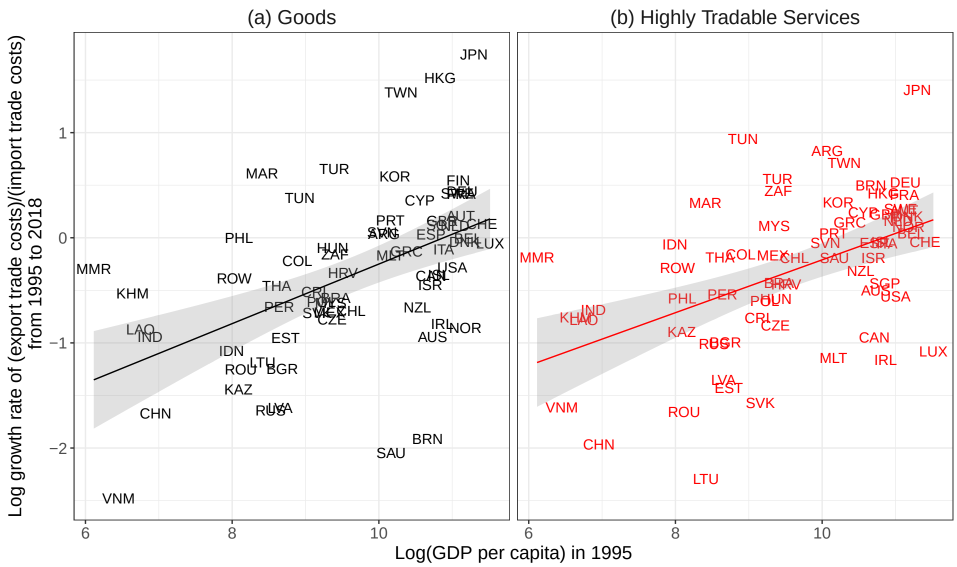
* Note: AD-DV represents trade costs from advanced to developing economies. Other country-group pairs are defined analogously. The top of the box plots describing outlier observations is truncated for illustration purposes, since maximum trade costs are high reflecting trade flows close to zero for some country pairs.

than advanced countries. In other words, for developing countries, the trade costs of exporting are generally higher than those of importing, whereas the opposite holds true for advanced countries. Second, in both sectors, the asymmetry has decreased over time. Whereas the distributions of the advanced countries' export trade costs remained relatively stable, those of the developing countries shifted downwards.

To describe changes in trade costs for each country focusing on the asymmetry, Figure 3 plots each country's log GDP per capita in 1995 against the log growth rate of its export trade costs relative to import trade costs for each sector from 1995 to 2018. A country's export trade costs are measured as the export-volume-weighted average of trade costs for exporting to all of its trade partners. The import trade costs are calculated analogously. Trade flows from 1995 are used as weights to control for the endogenous response of trade flows to changes in trade costs. Throughout the rest of the paper, I use the same weighted averages to calculate each country's export and import trade costs. The figure indicates the decrease in export trade costs relative to import trade costs was faster in poorer countries. This reconfirms the decreasing asymmetry.

Two remarks are in order. First, there exists ample empirical evidence of the

Figure 3: GDP per Capita and the Growth Rate of Relative Export Trade Costs



trade-cost asymmetry for goods, such as policy barriers (Kee, Nicita, and Olarreaga 2009), transportation or inventory costs (Limao and Venables 2001; Mesquita-Moreira, Volpe, and Blyde 2008; Blum et al. 2019), financial constraints on fixed costs of trade (Merga 2021), and estimates based on gravity models using trade and price data (Waugh 2010; De Sousa, Mayer, and Zignago 2012).

I provide novel evidence that asymmetry exists in services trade and declines over time for both goods and services. Moreover, through the counterfactuals (Section 6), I highlight the implications of trade-cost asymmetry in the open-economy structural transformation.

Second, the iceberg trade costs are high, in line with the previous literature. Anderson and Van Wincoop (2004) discuss the underlying factors behind the high costs, such as policy barriers, information costs, and costs of using different currencies.[26]

[26] Apart from these factors, it is also important to note that the trade costs are the average across all varieties. The average is affected by some varieties facing high trade costs. For real-world examples, China does not allow US subscription video-on-demand service operators, such as Netflix, in its domestic market (USITC 2022). For goods, there are sanitary or phytosanitary measures or technical regulations that block imports of certain goods.

4.2.2 Sectoral Productivities

From Equations (3) and (4), I expose the relationship between the productivity of a country-sector and data observables:

$$A_{i,t}^k = \gamma^k \left(P_{i,t}^k\right)^{-1} R_{i,t}^k \left(\pi_{ii,t}^k\right)^{\frac{1}{\theta^k}} . \tag{12}$$

Using the above equation, I recover productivities from the data on prices and domestic trade shares. Identification comes from the gap between input and output prices, adjusted for international trade. If a country-sector does not import any varieties, that is, $\pi_{ii,t}^k = 1$, the price gap directly implies the level of productivity under the assumption of perfect competition. In contrast, if $\pi_{ii,t}^k < 1$, the sectoral price, $P_{i,t}^k$, consists of prices of both domestic and imported varieties; therefore, the adjustment of $\left(\pi_{ii,t}^k\right)^{\frac{1}{\theta^k}}$ is needed.

The main benefit of the inversion is reduced data requirements, making it possible to include 66 countries. An alternative approach is to calculate total factor productivities from industry-level production accounts, such as KLEMS. However, such data are not available for many countries, especially developing economies.

In Appendix E, I show that growth in labor productivity for goods and highly tradable services was faster than barely tradable services, which is important in understanding the role of relative sectoral prices in structural transformation. My finding resonates with studies that identify differential productivity growth among services sectors (e.g., Jorgenson and Timmer 2011, and Duernecker, Herrendorf, and Valentinyi 2017).

As for the remaining model primitives, I calculate net exports $\left(\{NX_{i,t}\}_{i\in\mathcal{I}}\right)$ in terms of the numeraire, $W_{us,t}$.[27] $L_{i,t}$ is taken from the variable "Number of persons engaged" in PWT 10.0.

4.3 Model Fit

Model inversion typically results in a model being perfectly fitted to data. However, in this paper, the model provides an almost exact fit to the data (Figure O.B2 in Online Appendix O.B). The model departs from the data for two reasons. First, the utility and production functions are estimated with errors (Equations (D3) to (D5)).

[27] Under the assumption that net transfers are in units of US wages, a country's net transfers relative to other countries in the model are equal to those in the data.

Second, trade costs are set to one when the inversion formula (Equation (11)) results in trade costs below one and to the maximum finite trade cost when the formula leads to an infinite trade cost. If I add two additional "wedges" by allowing utility weights $\left(\{\phi_i^k\}_{i\in\mathcal{I},k\in\mathcal{S}}\right)$ and production weights $\left(\{\psi_i^{Lk},\{\psi_i^{hk}\}_{h\in\mathcal{S}}\}_{k\in\mathcal{S}}\right)$ to vary over time to account for the error terms and permit trade costs to be below one or to be infinite, then the model fits the data perfectly—the results remain robust to this alternative specification (Online Appendix O.E). However, in this case, productivities calculated from Equation (12) are not interpretable, since the cost of input bundles, $R_{i,t}^k$, is calculated with a different production function each period in Equation (2).[28]

Due to the almost exact fit to the data, the biggest downside of the inversion is that the model-based analysis is valid only to the extent that the model is well-specified. To address the potential concern of model misspecification, in Appendix G, I calibrate a two-country (the US and the rest of the world) version of the model following Kehoe, Ruhl, and Steinberg (2018). I demonstrate that my model well-predicts the non-targeted structural transformation pattern of the US. I also show that it outperforms the model with non-tradable services, answering the question: "Why do we need models with tradable services to study structural transformation?"

5 Decomposition of Structural Transformation

To solve the models in Sections 5 to 7, I use the method of Alvarez and Lucas (2007). Details are provided in Appendix F. In this section, with the parameterized model, I decompose the structural transformation of 67 economies (66 plus ROW) from 1995 to 2018.[29]

5.1 Four Mechanisms

I perform a decomposition (accounting) exercise to quantify the contributions of four mechanisms—income, price, comparative-advantage (net-export), and input-output

[28]Furthermore, with time-varying utility functions, welfare analysis—though not discussed in this paper—is infeasible. Relaxing the assumption of trade costs being greater than or equal to one is rather innocuous since trade costs being below one could reflect export-facilitating factors. Infinite trade costs are also innocuous, as they occur in only 24 country–sector–year observations in the barely tradable services sector.

[29]I am grateful to the anonymous referees for suggesting this exercise.

effects, discussed in Section 2.4—to countries' structural transformation. (Since sectoral net exports and comparative advantage are closely related, I use the terms 'comparative-advantage effect' and 'net-export effect' interchangeably.) Decomposition of structural transformation has previously been conducted in the literature, such as CLM for a closed economy and Święcki (2017); Sposi, Yi, and Zhang (2021) for an open economy. I contribute to the literature by developing an exact decomposition method that can be applied to an open-economy model with input-output linkages, in which the contributions of the four channels sum exactly to the total change in value-added shares.

Defining $\mathbf{B}_{i,t} \equiv \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)$, I can rewrite Equation (9) succinctly as

$$W_{i,t}\vec{\mathbf{L}}_{i,t} = \tilde{G}\left(C_i(\vec{\mathbf{P}}_{i,t}, U_{i,t}), \vec{\mathbf{P}}_{i,t}, \vec{\mathbf{NX}}_{i,t}, \mathbf{B}_{i,t}, L_{i,t}\right),$$

where $\tilde{G}$ represents the right-hand side of Equation (9).

In the above equation, dividing the sectoral total wages ($W_{i,t}L^k_{i,t}$) by their sum ($\sum_{k\in\mathcal{S}} W_{i,t}L^k_{i,t}$) shows that the sectoral wage share can be expressed as a function of real per-capita income, sectoral prices, sectoral net exports, and an input-output matrix:

$$\frac{1}{L_{i,t}}\vec{\mathbf{L}}_{i,t} = G\left(U_{i,t}, \vec{\mathbf{P}}_{i,t}, \vec{\mathbf{NX}}_{i,t}, \mathbf{B}_{i,t}\right). \tag{13}$$

Equation (13) serves as the key for the decomposition exercise.

It is important to note that the levels of $\vec{\mathbf{P}}_{i,t}$ do not affect $\frac{1}{L_{i,t}}\vec{\mathbf{L}}_{i,t}$. To elaborate, given fixed $U_{i,t}$, $\vec{\mathbf{NX}}_{i,t}$, and $\mathbf{B}_{i,t}$, $\vec{\mathbf{P}}_{i,t}$ can affect the left-hand side of Equation (9) only through the sectoral final consumption, $C_i(\vec{\mathbf{P}}_{i,t}, U_{i,t})$. $C_i(\vec{\mathbf{P}}_{i,t}, U_{i,t})$ is invariant to the level of prices—this can be verified through Equations (Eq.H.1) to (Eq.H.3) in Appendix A.[30] Therefore, the contribution of the change in $\vec{\mathbf{P}}_{i,t}$ reflects only the effects of changes in the relative sectoral prices (price effects).

Let t_0 and t_1 represent the initial and final years of the model (1995 and 2018), respectively. Then, structural transformation, in model terms, is the change from $\frac{1}{L_{i,t_0}}\vec{\mathbf{L}}_{i,t_0}$ to $\frac{1}{L_{i,t_1}}\vec{\mathbf{L}}_{i,t_1}$. This change can be decomposed into the four effects by iteratively changing the values of U_{i,t_0}, $\vec{\mathbf{P}}_{i,t_0}$, $\vec{\mathbf{NX}}_{i,t_0}$, and $\mathbf{B}_{i,t_0}$ to U_{i,t_1}, $\vec{\mathbf{P}}_{i,t_1}$, $\vec{\mathbf{NX}}_{i,t_1}$, and $\mathbf{B}_{i,t_1}$, respectively, in Equation (13).

Note that the quantitative results depend on the order (path) of decomposition.

[30] In the three equations representing the non-homothetic CES demand, when the real income, $U_{i,t}$, is fixed, the level of prices only affect the nominal income.

To mitigate this issue, I apply Shapley (1953) decomposition: I compute the marginal contributions of the four channels for each of the 24 possible paths and take the average across all paths. This yields an exact decomposition by allocating the interactions among mechanisms to each individual mechanism.[31]

With this method, I study how the four effects contributed to the change in the value-added share of each country-sector from 1995 to 2018; that is $\frac{L^k_{i,t_1}}{L_{i,t_1}} - \frac{L^k_{i,t_0}}{L_{i,t_0}}$. Calculating each channel's contribution can entail a division of a small number by another small number, which can yield a spuriously large contribution. For example, if a country-sector's value-added share changed by 0.1 p.p., and the contribution of real income change is 0.2 p.p., its contribution is calculated as 200%. Therefore, I only consider the country-sectors whose value-added shares changed by more than 1 p.p. This reduces the total number of country-sector observations from 201 ($= 67 \times 3$) to 146. In Online Appendix O.B, I demonstrate that the results are robust to the alternative cutoffs of 3 and 5 p.p.

Table 3: Summary Statistics for the Decomposition of Structural Transformation into Four Mechanisms (Cutoff = 1 p.p., Nobs. = 146)

Effects	Mean	Q1	Q2	Q3
Income	1.1	-16.0	-0.8	13.9
Price	42.2	3.7	39.2	87.7
Net-export	34.1	-9.7	41.5	71.0
Input-output	22.7	4.5	17.4	42.4

* Note: The contributions are in percentages.

Table 3 reports the mean, first quartile, median, and third quartile of the contributions across country-sectors. It demonstrates that the price and net-export effects are the most important: Their median contributions are 39.2% and 41.5%, and the means are 42.2% and 34.1%, respectively. The quantitative importance of the net-export effect serves as evidence that open economy models are important for understanding structural transformation. The input-output and income effects follow in that order, with the latter trailing by a wide margin.[32]

[31] An alternative is to turn one channel on or off at a time, as in Święcki (2017), but this does not provide an exact decomposition, which reduces the interpretability of the results.

[32] Notably, the median contribution of the income effect is negative: 79 out of 146 country–sector observations exhibit a negative income effect. This is not because incomes generally failed to grow—all but one economy experienced real income growth—but rather reflects the role of input-output linkages in shaping how final consumption translates into sectoral production. In Equation (9),

It is worthwhile to discuss the result in the context of the literature. Herrendorf, Rogerson, and Valentinyi (2013) find that when the utility function is defined with final expenditures, the income effect is the most important for the post-war US structural transformation. CLM decompose the structural transformation of the 39 countries into income and price effects and find the importance of the former. Święcki (2017) studies 45 countries and discovers that the sector-biased technological change, which has strong implications for the price effect, is most important.

The differences between this paper's results and those of the aforementioned studies can be attributed to multiple underlying differences. First, this paper's model includes both international trade and input-output linkages. Second, the sectoral definitions of the three papers are agriculture, manufacturing, and services, whereas I focus on the more recent phase of structural transformation with the three sectors of goods, highly tradable services, and barely tradable services. Third, the decomposition methods differ across the papers.

It is worth noting that the special case of the model where there are no input-output linkages and international trade, i.e., $\mathbf{B}_{i,t} = \mathbf{0}$ and $\vec{\mathbf{NX}}_{i,t} = \vec{\mathbf{0}}$, the accounting equation simplifies to that in CLM. Specifically, Equation (10) can be expressed as

$$
\begin{aligned}
&\log\left(\frac{L^k_{i,t}}{L^g_{i,t}}\right) \\
=&(1-\sigma)\log\left(\frac{P^k_{i,t}}{P^g_{i,t}}\right) + (1-\sigma)(\epsilon^k-1)\log(U_{i,t}) + \log\left(\frac{\phi^k_i}{\phi^g_i}\right) \\
=&\underbrace{(1-\sigma)\log\left(\frac{P^k_{i,t}}{P^g_{i,t}}\right)}_{\text{(Price effect)}} + \underbrace{(1-\sigma)(\epsilon^k-1)\log\left(\frac{P_{i,t}U_{i,t}}{P^g_{i,t}}\right) + (\epsilon^k-1)\log\left(\frac{P^g_{i,t}C^g_{i,t}}{P_{i,t}U_{i,t}}\right)}_{\text{(Income effect)}} + S^k_i.
\end{aligned}
$$

This is identical to Equation (39) of CLM. The second equality expresses real income in terms of observables—the derivation is in Appendix D.1. Since $P_{i,t}U_{i,t}$ equals nominal income, all terms in the last line of the equation, except the time-invariant

ceteris paribus, suppose $C^g_{i,t}$ decreases while $C^{hts}_{i,t}$ and $C^{bts}_{i,t}$ increase. This does not necessarily imply a decline in $W^g_{i,t}L^g_{i,t}$ and an increase in $W^{hts}_{i,t}L^{hts}_{i,t}$ and $W^{bts}_{i,t}L^{bts}_{i,t}$, owing to the Leontief inverse. For example, if the reduction in final goods demand is offset by a larger increase in intermediate goods demand, goods value added can rise. The negative income effect due to the input-output linkages accounts for 60 of the 79 cases. The remaining 19 are explained by the changes in the sectoral shares that are inconsistent with the typical pattern of structural transformation, in which the share of goods declines while those of both services expand.

S_i^k, can be obtained directly from data. Thus, as in CLM, structural transformation in this special case can be decomposed into price and income effects using data when the preference parameters (σ and $\{\epsilon^k\}_{k\in\mathcal{S}}$) are known.[33]

5.2 Globalization and Productivity Growth

Next, I explore which of the two main model primitives, i.e., trade costs and productivities, contributed more to the structural transformation. To do so, I compute two counterfactual equilibria, where either trade costs or productivities are fixed at their initial levels in 1995 with all the other primitives at their 2018 levels. Let subscripts NT and NP denote the former and latter, respectively. The contribution of globalization and productivity growth to structural transformation can be decomposed through two paths: (i) $\frac{1}{L_{i,t_0}}\vec{\mathbf{L}}_{i,t_0} \to \frac{1}{L_{i,NT}}\vec{\mathbf{L}}_{i,NT} \to \frac{1}{L_{i,t_1}}\vec{\mathbf{L}}_{i,t_1}$, or (ii) $\frac{1}{L_{i,t_0}}\vec{\mathbf{L}}_{i,t_0} \to \frac{1}{L_{i,NP}}\vec{\mathbf{L}}_{i,NP} \to \frac{1}{L_{i,t_1}}\vec{\mathbf{L}}_{i,t_1}$. In the same spirit as the Shapley decomposition in the previous section, I calculate the marginal contributions of globalization and productivity growth for both paths and take their average. Moreover, for each step of the decomposition, represented by an arrow in (i) and (ii), I measure the contributions of the income, price, net-export, and input-output effects through the 24-way Shapley decomposition. Then, I take the average across (i) and (ii). This eight-fold exact decomposition quantifies the respective contributions of globalization and productivity growth to structural transformation and identify the channels through which they operate.

The results are reported in Table 4 with the 1 p.p. cutoff for the change in country-sectors' value-added shares. The table demonstrates that globalization contributed more than productivity growth to the structural transformation, with median contributions of 58.1% and 41.9%, respectively—due to outliers, the mean contributions are less informative. In both first and third quartiles, globalization's contribution also exceeds that of productivity growth. The result that globalization outweighs productivity growth in first, second, and third quartiles is robust to alternative cutoffs of 3 and 5 p.p. (see Online Appendix O.B).

[33] In this paper's model, if the utility function is known (e.g., the preference parameters and utility weights, $\{\phi_i^k\}_{k\in\mathcal{S}}$, are already estimated), the decomposition with Equation (13) can also be conducted directly with data. $\vec{\mathbf{P}}_{i,t}$, $\vec{\mathbf{NX}}_{i,t}$, and $\mathbf{B}_{i,t}$ can be obtained from data; $U_{i,t}$ can be expressed in terms of data observables; and $C_i(\vec{\mathbf{P}}_{i,t}, U_{i,t})$ can be evaluated. However, to maintain consistency with the counterfactuals, which utilize the parameterized model, I use model-implied prices and allocations for the decomposition.

Table 4: Summary Statistics for the Decomposition of Structural Transformation into Globalization and Productivity Growth (Cutoff = 1 p.p., Nobs. = 146)

Type	Effects	Mean	Q1	Q2	Q3
Globalization	Income	-3.1	-4.4	-1.1	1.4
	Price	7.2	-9.1	3.4	20.7
	Net-export	88.6	-2.1	39.9	117.5
	Input-output	2.5	0.4	1.8	4.2
	Total	95.2	14.3	58.1	126.6
Productivity growth	Income	3.4	-14.1	0.3	18.6
	Price	37.5	-1.8	34.8	72.4
	Net-export	-56.4	-101.9	-12.5	43.5
	Input-output	20.3	3.0	15.2	37.6
	Total	4.8	-26.6	41.9	85.7

* Note: The contributions are in percentages.

Two additional remarks are in order. First, the channels through which the primitives influence structural transformation are different: Globalization mostly affected the structural transformation through the net-export effect, whereas productivity growth impacted it mostly through the price effect. Second, the significant heterogeneity in the contributions is noticeable: The interquartile ranges for components, such as globalization/net-export or productivity growth/price, are above 70 p.p. This suggests that the dominant primitive and channel behind structural transformation can vary substantially across countries and sectors.

Furthermore, the exercise demonstrates the importance of utilizing open economy models to understand structural transformation. First, changes in trade costs had large quantitative impacts. Second, the pattern that productivity growth had negative contributions through the net-export effect (median of -12.5%) suggests that it is important to account for the interaction of trade and productivity growth.

One shortcoming of the decomposition exercises is their partial-equilibrium nature. In the model, the primitives (e.g., productivities and trade costs) determine the equilibrium prices and allocations. Therefore, income, sectoral prices, sectoral net exports, and input-output matrices are all determined simultaneously. However, the decomposition does not account for this simultaneity. Despite this limitation, the decomposition is still useful for understanding the quantitative importance of the primitives and the mechanisms.

To briefly summarize the findings of Section 5, I find that for the 67 economies' structural transformation from 1995 to 2018, the price and comparative-advantage effects are most important. Then, I demonstrate that globalization is quantitatively more important than productivity growth in explaining the transformation. Finally, globalization operates mainly through the net-export channel. Given these findings, I analyze how globalization affects structural transformation in general equilibrium in the following section.

6 Counterfactuals

In all exercises, I let sectoral productivities $\left(\{A^k_{i,t}\}_{i\in\mathcal{I},k\in\mathcal{S}}\right)$, population $\left(\{L_{i,t}\}_{i\in\mathcal{I}}\right)$, and net transfers $\left(\{NX_{i,t}\}_{i\in\mathcal{I}}\right)$ evolve according to their calculated historical paths. Let $\tau^k_{ij,t}$ and $\overline{\tau}^k_{ij,t}$ denote the calculated trade costs and the trade costs in a counterfactual economy, respectively. I conduct the following three counterfactual exercises: For $t = 1995, ..., 2018$ and for all $i, j \in \mathcal{I}$,

1. Changes in services trade costs only: $\overline{\tau}^g_{ij,t} = \tau^g_{ij,1995}$, $\overline{\tau}^{hts}_{ij,t} = \tau^{hts}_{ij,t}$, and $\overline{\tau}^{bts}_{ij,t} = \tau^{bts}_{ij,t}$.
2. Changes in goods trade costs only: $\overline{\tau}^g_{ij,t} = \tau^g_{ij,t}$, $\overline{\tau}^{hts}_{ij,t} = \tau^{hts}_{ij,1995}$, and $\overline{\tau}^{bts}_{ij,t} = \tau^{bts}_{ij,1995}$.
3. No change in trade costs for all sectors: $\overline{\tau}^g_{ij,t} = \tau^g_{ij,1995}$, $\overline{\tau}^{hts}_{ij,t} = \tau^{hts}_{ij,1995}$, and $\overline{\tau}^{bts}_{ij,t} = \tau^{bts}_{ij,1995}$.

I compare the evolution of production shares in value added between the baseline and each of the counterfactual economies. Specifically, I assess the impact of goods globalization (counterfactual #1), services globalization (counterfactual #2), and the overall globalization in all sectors (counterfactual #3).

Since barely tradable services are almost non-tradable, the results do not significantly depend on globalization in that sector. For brevity, I focus on globalization in goods and highly tradable services.

6.1 Results for Individual Countries

To understand the mechanisms underlying the main results—that globalization in all sectors impacted countries differently and that the comparative advantage channel is the key driver of this heterogeneity—it is instructive to begin by examining individual countries. I first study China, one of the countries with the most rapid structural transformation.

Panel (a)(i) of Figure 4 presents the time series of China's weighted-average trade costs for goods and highly tradable services. For both sectors, China's export trade costs declined sharply, in contrast to its relatively stable import trade costs. Furthermore, the dynamics of trade costs were proportional across sectors: export trade costs relative to import trade costs decreased in an almost parallel fashion for goods and highly tradable services (Panel (a)(ii)).

Panel (b) compares the evolution of production shares from 1995 to 2018 across the baseline and the three counterfactuals. Comparing the baseline and counterfactual #1 illustrates that changes in goods trade costs had a significant impact on the speed of China's structural transformation. In the baseline, China's GDP share of goods decreased from 56% to 45% over 23 years. In counterfactual #1, the decrease was from 56% to 36%—the production shares of the initial year are equal to those in the baseline by construction. This means that globalization in goods significantly decelerated China's structural transformation away from goods. Another noticeable pattern is that goods globalization mainly affected the production shares of goods and highly tradable services, the two highly tradable sectors. Barely tradable services were minimally affected.

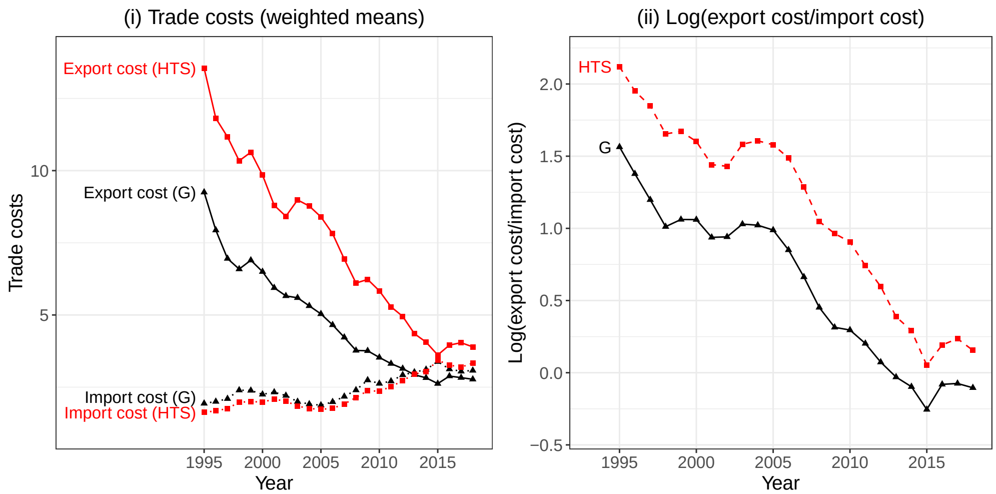
Globalization in services had the opposite effect. A comparison of the baseline and counterfactual #2 shows that it accelerated China's structural transformation. In counterfactual #2, the goods share of GDP remained at 57% in 2018, approximately equal to its 1995 level. Again, the counterfactual treatment of trade costs primarily affected the production shares of the two highly tradable sectors.

Although globalization in goods and that in services individually had significant effects on China's structural transformation, the resemblance of counterfactual #3 to the baseline suggests that the overall effect of the trade-cost reduction in all sectors was minimal. Without changes in goods and services trade costs, the goods share of GDP decreased to 47% by 2018, closely matching the baseline.

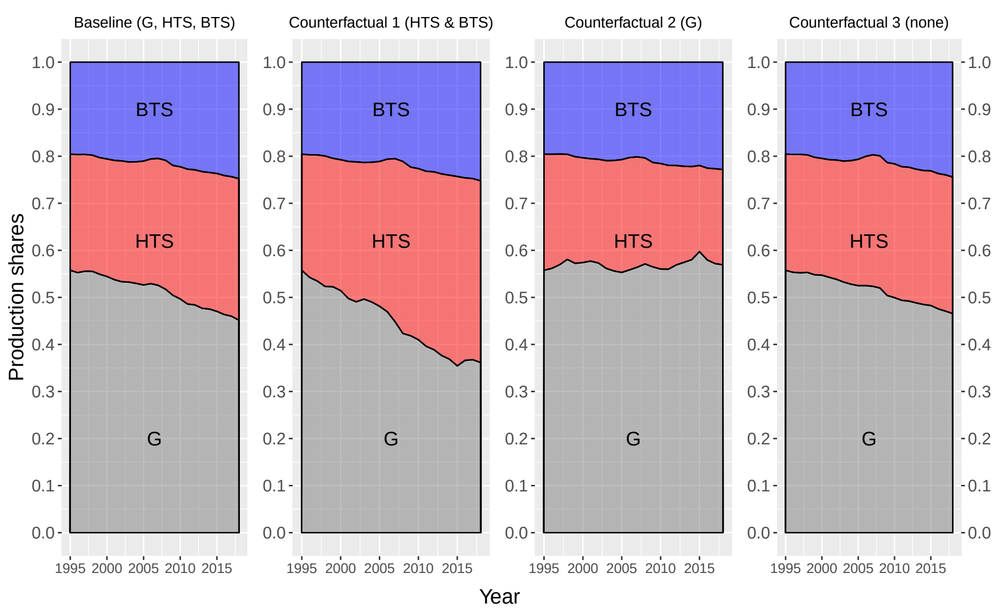
These results can be interpreted as follows. Goods globalization, which facilitated China's exports more than its imports in the goods sector, decelerated its structural transformation from goods to highly tradable services. In contrast, globalization in services accelerated the transition by promoting exports over imports in the highly tradable services sector. Despite the substantial impacts of goods and services globalization, their effects largely offset each other, resulting in a limited overall impact on structural transformation. Additionally, the speed of structural transformation

Figure 4: China's Globalization and Structural Transformation

(a) Dynamics of Sectoral Trade Costs



(b) Structural Transformation in the Baseline and Counterfactuals #1 to #3



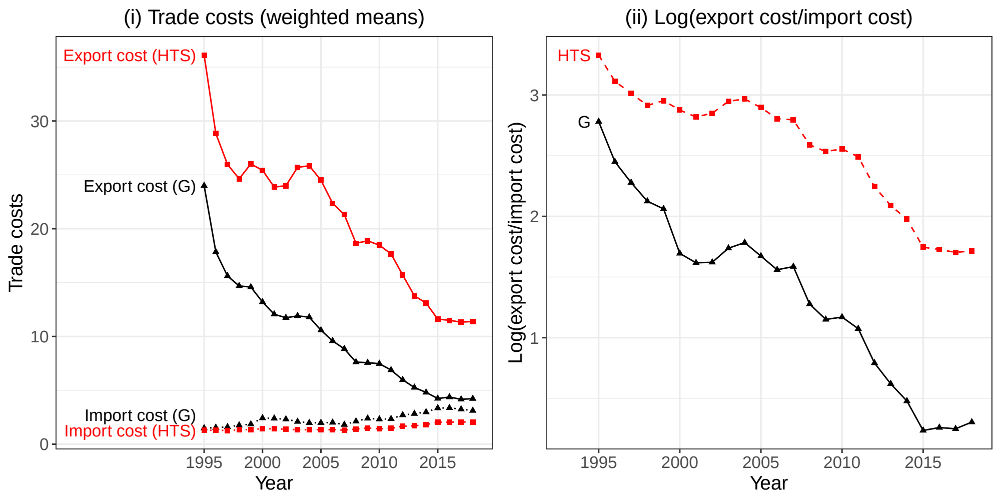
* Note: Export costs are the weighted average of China's trade costs of exporting to its trade partners, with export volumes in 1995 as weights. Import costs are analogously defined.

toward barely tradable services—which are hardly subject to cross-sector specialization due to prohibitively high trade costs—is largely unaffected by any globalization scenario.

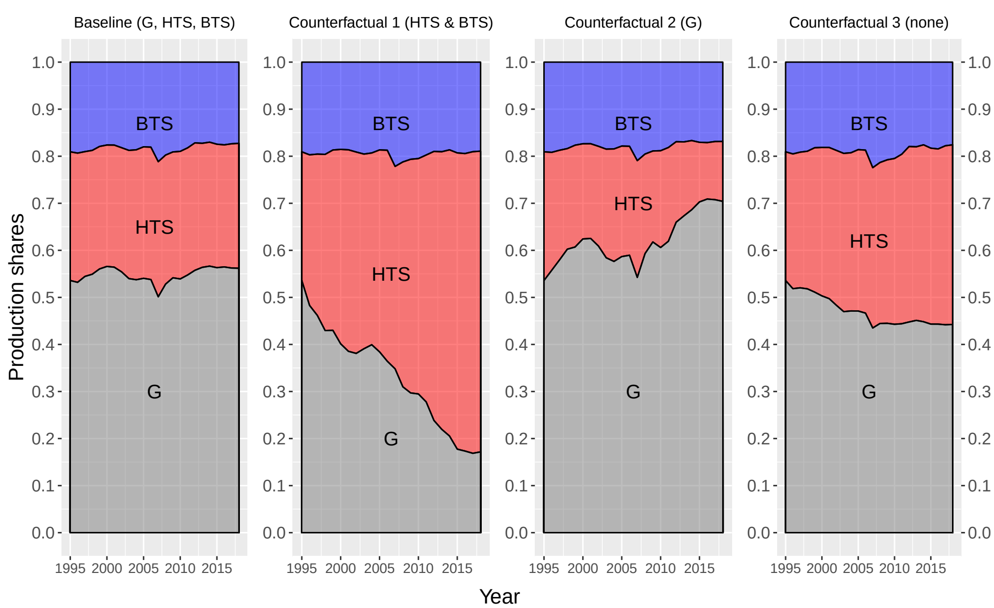
The result is due to the proportional decrease in export trade costs relative to import trade costs for goods and highly tradable services, as shown in Panel (a)(ii).

Figure 5: Vietnam's Globalization and Structural Transformation

(a) Dynamics of Sectoral Trade Costs



(b) Structural Transformation in the Baseline and Counterfactuals #1 to #3



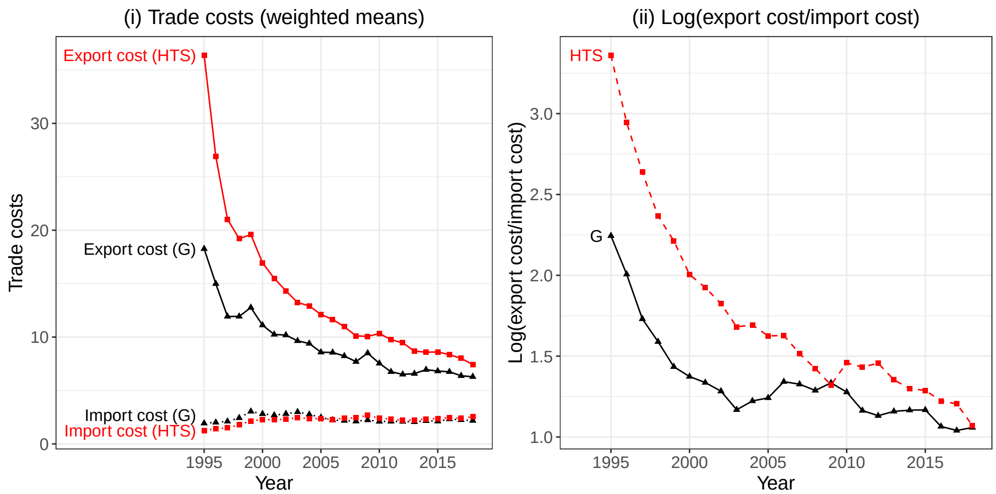
* Note: Export costs are the weighted average of Vietnam's trade costs of exporting to its trade partners, with export volumes in 1995 as weights. Import costs are analogously defined.

(In the next section, I use cross-country variation to verify this claim.) I term this type of globalization as *sector-neutral* globalization.

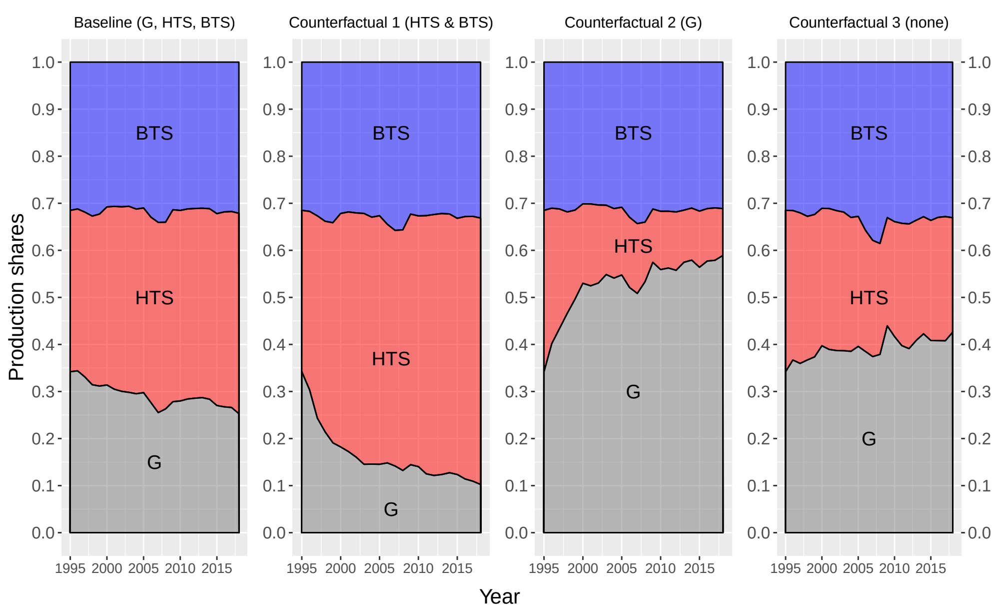
Next, I study two countries that exhibited *sector-biased* globalization, in which the dynamics of the asymmetric trade costs differed across sectors. Vietnam experienced *goods-biased* globalization, where the export trade costs relative to import trade

Figure 6: Lithuania's Globalization and Structural Transformation

(a) Dynamics of Sectoral Trade Costs



(b) Structural Transformation in the Baseline and Counterfactuals #1 to #3



* Note: Export costs are the weighted average of Lithuania's trade costs of exporting to its trade partners, with export volumes in 1995 as weights. Import costs are analogously defined.

costs decreased more for goods (by 92% from 1995 to 2018) than for highly tradable services (by 80%). As in the case of China, the individual sectors' globalization had a significant impact on the structural transformation but operated in the opposite direction. However, due to the bias toward goods, the effect of goods globalization dominated. In other words, the decelerating force of goods globalization outweighed the accelerating effect of services globalization, resulting in a significant deceleration of Vietnam's structural transformation by the overall globalization. The results are provided in Figure 5.

In contrast, Lithuania, which experienced *services-biased* globalization—the export trade costs relative to import trade costs decreased by 69% for goods and 90% for highly tradable services—exhibits the opposite pattern (Figure 6).

The results for three countries highlight the implications of the dynamics of asymmetric trade costs for structural transformation. China, Vietnam, and Lithuania are developing countries, and their export trade costs decreased relative to import trade costs.[34] This implies that goods globalization decelerated their structural transformation, whereas services globalization accelerated it. The overall effect depended on the sector bias of globalization, which determines whether goods or services globalization dominated. I verify this claim using cross-country variation in the next section.

6.2 Results for 67 Economies

To study the 67 economies (66 countries and ROW), I measure the impact of (1) globalization in goods, (2) globalization in services, and (3) the overall globalization in all sectors on each country's structural transformation by calculating the gap between the speed of structural transformation in the baseline and in each corresponding counterfactual.

Definition 1.

$$(Effect)_i^c = \Delta_t \left(\frac{L_{i,t}^g}{L_{i,t}}, \frac{L_{i,t}^{hts}}{L_{i,t}}, \frac{L_{i,t}^{bts}}{L_{i,t}} \right) - \Delta_t \left(\frac{\overline{L}_{i,t}^{g,c}}{L_{i,t}}, \frac{\overline{L}_{i,t}^{hts,c}}{L_{i,t}}, \frac{\overline{L}_{i,t}^{bts,c}}{L_{i,t}} \right),$$

where $\Delta_t(z_t) \equiv z_{2018} - z_{1995}$*, and* $\overline{L}_{i,t}^{g,c}$ *denotes the employment in the goods sector of country* i *in year* t *for counterfactual* $\#c$*.* $\overline{L}_{i,t}^{hts,c}$ *and* $\overline{L}_{i,t}^{bts,c}$ *are defined similarly.*

To illustrate the use of this measure, suppose that from 1995 to 2018, a hypothetical country's GDP shares in goods, highly tradable services, and barely tradable services changed by -5, $+4$, and $+1$ p.p. in the baseline, and by -2, $+1$, and $+1$ p.p. in counterfactual #3. Then, $(Effect)_i^3 = (-3 \text{ p.p.}, +3 \text{ p.p.}, 0 \text{ p.p.})$, indicating that overall globalization across all sectors accelerated the country's structural transformation

[34] Please note that the IMF reclassified Lithuania as an advanced economy in 2015.

from goods to highly tradable services, but had minimal impact on the transition to barely tradable services.

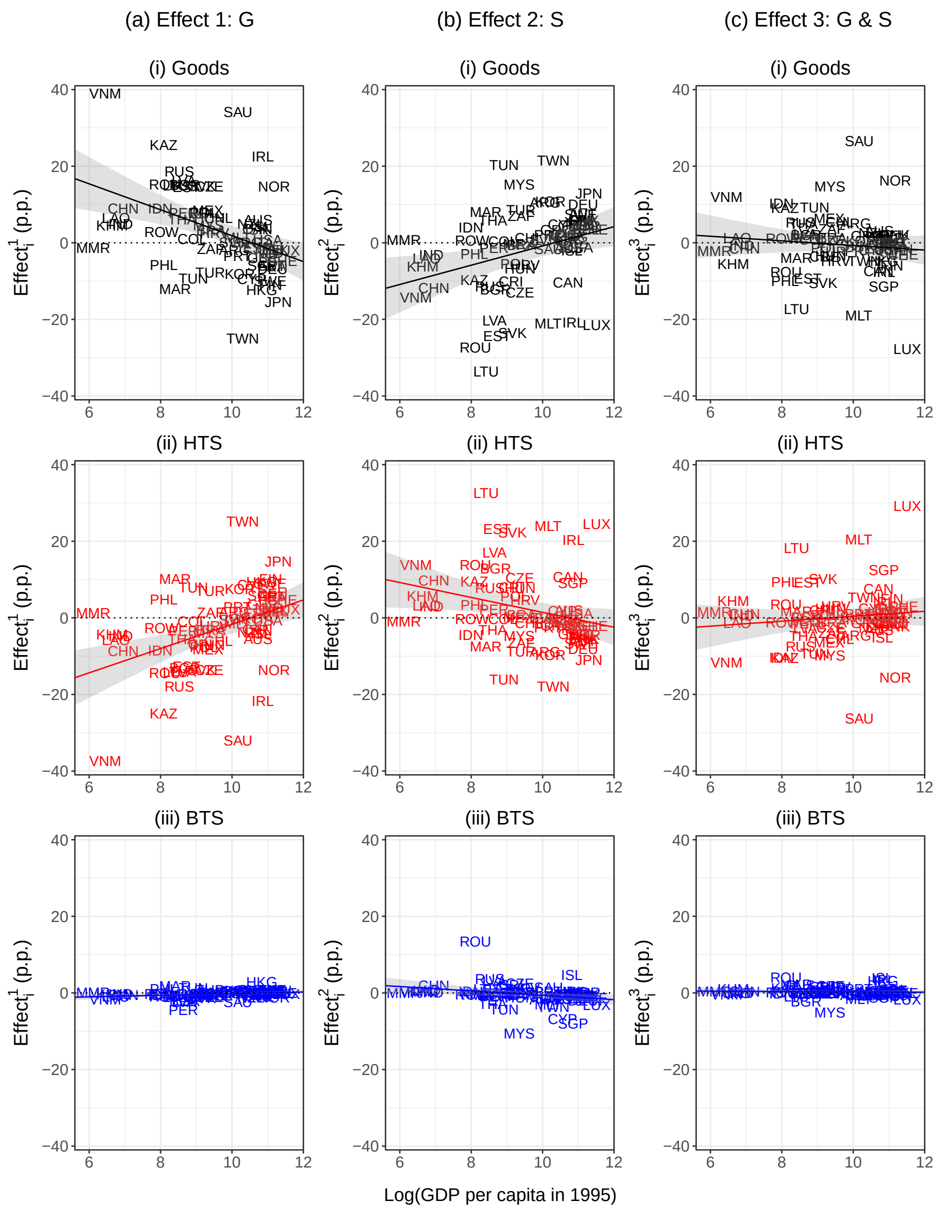
An alternative measure would be to calculate the extent to which a country's structural transformation is explained by globalization. However, this incurs a comparison between small values, especially for advanced economies that had already undergone significant structural transformation by 1995. For example, in the baseline, the goods share of GDP for the US was 21% in 1995 and changed by -3.7 p.p. from 1995 to 2018. In counterfactual #3, the rate of decline in the goods share of GDP was -2.0 p.p. Although the absolute effect is small at -1.7 p.p., the relative effect appears large $(-1.7/-3.7)$. For this reason, I use the absolute measure throughout the main text and report the results in the relative effects in Online Appendix O.B.

6.2.1 Globalization and Structural Transformation Across Income Levels

Since the prominent globalization pattern is the decreasing asymmetry in trade costs for both goods and services, I investigate how the effects of globalization on structural transformation vary with countries' initial development levels. To do so, I plot each country's GDP per capita in 1995 against $(Effect)_i^1$, $(Effect)_i^2$, and $(Effect)_i^3$ in Figure 7. The figure demonstrates that goods globalization generally decelerated the structural transformation from goods to highly tradable services in poorer countries while accelerating it in richer countries. (The effects observed in richer countries are comparatively smaller in magnitude, primarily because their trade costs were already low in the initial year.) $(Effect)_i^2$, plotted in Panel (b), shows the opposite effects induced by services globalization. Regarding the effect on barely tradable services, both goods and services globalization had a minimal impact (Panels (a)(iii) and (b)(iii)). $(Effect)_i^1$ and $(Effect)_i^2$ illustrate results consistent with the decreasing asymmetry in each sector—the decrease in export trade costs relative to import trade costs was faster in poorer countries in both the goods and highly tradable services sectors, as previously shown in Figure 3 of Section 4.2.1.

Although the impact of globalization in goods and that in services exhibit significant correlations with countries' initial development level, Panel (c) describes that the effects of globalization in all sectors, $(Effect)_i^3$, do not exhibit this correlation. Instead, in the next section, I show that *Globalization Bias Index,* which compares the opposing forces exerted by globalization in goods and that in highly tradable services, explains most of the cross-country variation in $(Effect)_i^3$, i.e., the structural

Figure 7: GDP per Capita and the Effects of Globalization in (a) Goods, (b) Services, and (c) All Sectors on Structural Transformation



* Note: The solid lines and the shaded areas around them represent the regression lines and the 95% confidence intervals, respectively. Brunei, an outlier country, is not plotted.

transformation induced by the overall globalization.

6.2.2 Sector Bias of Globalization, Comparative Advantage, and Structural Transformation

I define the *Globalization Bias Index* to measure sector bias in the overall globalization. The index is calculated as the log growth rate of export trade costs relative to import trade costs for goods minus that for highly tradable services. Values close to zero indicate sector-neutral globalization. Negative and positive values imply goods-biased and services-biased globalization, respectively.

Definition 2.

$$\textit{(Globalization Bias Index)}_i = \Delta_t \log\left(\frac{\tilde{\tau}^{g}_{ir,t}}{\tilde{\tau}^{g}_{ri,t}}\right) - \Delta_t \log\left(\frac{\tilde{\tau}^{hts}_{ir,t}}{\tilde{\tau}^{hts}_{ri,t}}\right),$$

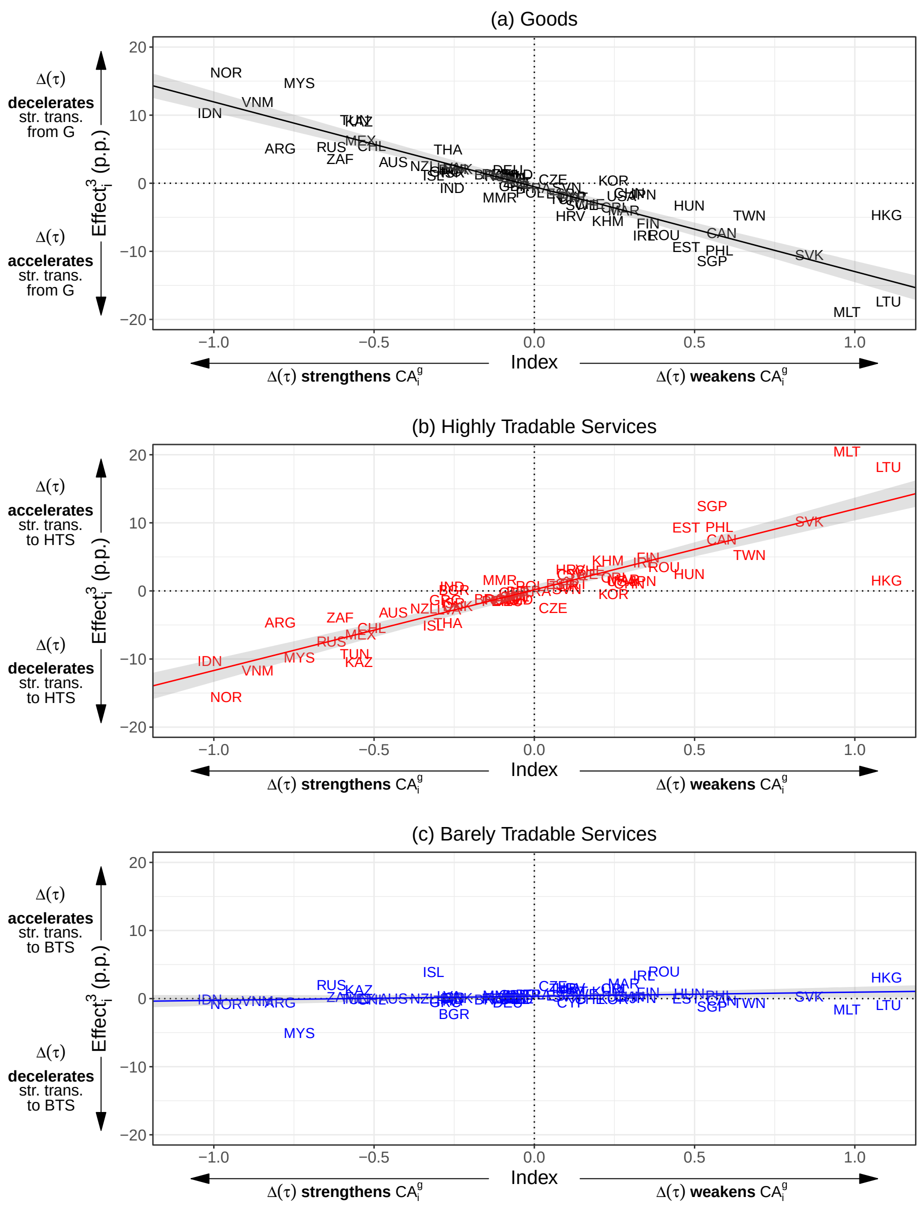
where $\Delta_t(z_t) \equiv z_{2018} - z_{1995}$*, and* $\tilde{\tau}^{g}_{ir,t}$ *denotes the weighted average of trade costs for exporting goods to country i's trade partners, with weights based on the export volumes in 1995. Other terms are defined analogously.*

Figure 8 plots the Globalization Bias Index against $(Effect)^3_i$, presenting the main result of this paper. The first noticeable pattern is that the impact of globalization was heterogeneous across countries, which is in line with the decomposition exercise (Section 5.2). Regarding the rate of decline in the goods share of GDP, 17 countries (approximately one-fourth of the 67) experienced minimal effects of less than 1.4 p.p., while in another 17 countries, structural transformation away from goods was either decelerated or accelerated by more than 7.4 p.p. For most countries, the impact on the goods share of GDP was offset by changes in the share for highly tradable services, while the share for barely tradable services remained largely unaffected.

The figure characterizes the underlying factor contributing to this heterogeneity. Specifically, I find a strong linear relationship between the Globalization Bias Index and the effects. The figure shows that the closer a country's index is to zero, the closer $(Effect)^3_i$ is also to zero. This means that for countries whose trade costs changed proportionally across sectors (e.g., China), globalization had a limited impact. For countries with negative indices (e.g., Vietnam), globalization slowed their structural transformation from goods to highly tradable services. The opposite holds for countries with positive indices (e.g., Lithuania). These effects are more pronounced for countries with indices further from zero.

Figure 8 shows that the relative strength of globalization in facilitating exports

Figure 8: Globalization Bias Index and the Effects of Globalization in All Sectors on Structural Transformation



* Note: The solid lines and the shaded areas around them represent the regression lines and the 95% confidence intervals, respectively. Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.

versus imports across goods and services is key to understanding its impact on structural transformation. Therefore, it serves as suggestive evidence for the importance of the comparative advantage channel. However, verifying this is challenging, as changes in trade costs affect income, prices, net exports, and input-output linkages simultaneously.

I address this challenge by extending the definition of comparative advantage by Deardorff (2014) to the multi-country model in this paper. In Deardorff's two-country model with asymmetric trade costs, the measure serves as a sufficient statistic for determining whether a country is a net exporter of goods. In Appendix H, I show that it is a sufficient statistic in a simplified two-country EK model as well. Although in the richer multi-country model with input-output linkages, the measure is no longer a sufficient statistic, it remains an informative tool for analyzing how globalization and productivity growth influence comparative advantage.[35] The extended definition is as follows.

Definition 3. *The strength of country i's comparative advantage in goods relative to the rest of the world r at time t is given by*

$$CA^g_{i,t} \equiv \left(\frac{A^g_{i,t}}{A^{hts}_{i,t}} \Big/ \frac{\tilde{A}^g_{r,t}}{\tilde{A}^{hts}_{r,t}} \right) \left(\frac{\tilde{\tau}^g_{ir,t}}{\tilde{\tau}^g_{ri,t}} \Big/ \frac{\tilde{\tau}^{hts}_{ir,t}}{\tilde{\tau}^{hts}_{ri,t}} \right)^{-\frac{1}{2}},$$

where $A^g_{i,t}$ represents country i's productivity in goods; $\tilde{A}^g_{r,t}$ denotes the GDP-weighted average of goods productivity in r; and $\tilde{\tau}^g_{ir,t}$ is the export-volume-weighted average of trade costs for exporting goods to country i's trade partners. Other terms are defined analogously. The weights are from 1995, the initial year, to control for the endogenous response of output and trade to changes in productivities and trade costs.

$CA^g_{i,t}$ measures the strength of country i's comparative advantage in goods by comparing its productivity in goods relative to highly tradable services with the rest of the world and adjusting it for the country's sectoral export and import trade costs.[36] Because barely tradable services are nearly non-tradable, the definition excludes productivity or trade-cost terms for that sector.

Notably, the Globalization Bias Index coincides with the change in the comparative advantage induced by globalization. Specifically, the change in the log of $CA^g_{i,t}$

[35] Alternatively, empirical measures such as Revealed Comparative Advantage (Balassa 1965) could be used. However, they cannot be directly mapped into underlying productivity or trade cost differences.

[36] Alviarez (2019) distinguishes between "fundamental" comparative advantage that only depends on productivities and "effective" comparative advantage that also depends on the trade costs. Since fundamental comparative advantage is not the main focus of this paper, I use "comparative advantage" to denote "effective comparative advantage."

can be decomposed into the parts induced by productivity growth and globalization:

$$
\begin{aligned}
\Delta_t \log\left(CA^g_{i,t}\right) =& \Delta_t \log\left(\frac{A^g_{i,t}}{A^{hts}_{i,t}} \bigg/ \frac{\tilde{A}^g_{r,t}}{\tilde{A}^{hts}_{r,t}}\right) - \frac{1}{2}\Delta_t \log\left(\frac{\tilde{\tau}^g_{ir,t}}{\tilde{\tau}^g_{ri,t}} \bigg/ \frac{\tilde{\tau}^{hts}_{ir,t}}{\tilde{\tau}^{hts}_{ri,t}}\right) \\
=& \Delta_t \log\left(\frac{A^g_{i,t}}{A^{hts}_{i,t}} \bigg/ \frac{\tilde{A}^g_{r,t}}{\tilde{A}^{hts}_{r,t}}\right) - \frac{1}{2}\textit{(Globalization Bias Index)}
\end{aligned}
\tag{14}
$$

Negative and positive values of the index mean that globalization moved a country's comparative advantage toward goods (increasing $CA^g_{i,t}$) and highly tradable services (decreasing $CA^g_{i,t}$), respectively. Given this, the main result can be re-stated: For countries with sector-neutral globalization, globalization had a limited impact on their comparative advantage and structural transformation. In contrast, for countries with sector-biased globalization, the transformation accelerated or decelerated to the direction and extent of the shift in comparative advantage.

My finding that the comparative advantage effect is important contrasts with the existing focus on the price effect (e.g., Cravino and Sotelo 2019; Sposi, Yi, and Zhang 2021; Bonadio et al. 2025). In the next section, I compare my results with those from an alternative model with symmetric costs—a key assumption in Cravino and Sotelo (2019)—to discuss the differences in detail.

Before proceeding to the next section, three additional remarks are worth noting. First, the structural transformation of most large countries was not significantly impacted by globalization in all sectors—they are located near the origin of Figure 8. Specifically, the ten largest countries by aggregate GDP, excluding Canada, belong to this case.[37] The difference between the nine countries' rate of decline in the goods share of GDP in the baseline and that in counterfactual #3 was less than 2 p.p. This should be interpreted with caution. The small quantitative effects are generally not attributable to trade being a minor part of their economies. Rather, it is because the effects of globalization in goods and those in services offset each other. In six out of the nine large countries, globalization in goods and that in services individually had a sizable impact. The complete results across the baseline and three counterfactuals for all countries, ordered by aggregate GDP, are provided in Online Appendix O.B.

Second, the finding that globalization does not significantly affect the production shares of barely tradable services reinforces the idea that globalization primar-

[37] Canada's services-biased globalization was mainly due to the reduction in trade costs for exporting services to the US.

ily affects structural transformation through comparative advantage and cross-sector specialization. This result also contributes to the literature on structural transformation with multiple types of services (e.g., Buera and Kaboski 2012, and Duarte and Restuccia 2020)—the finding is not immediately obvious, as the income and price effects could, in theory, lead globalization to significantly impact the production shares of barely tradable services, despite their low tradability.

Third, although this paper focuses on how globalization impacts structural transformation, the decomposition of the change in comparative advantage (Equation (14)) also allows for an assessment of how productivity growth affects the transformation through comparative advantage in general equilibrium. However, given the partial-equilibrium decomposition (Section 5.2), which shows a modest negative median contribution of -12.5% from productivity growth through the comparative-advantage (net-export) channel, the analysis in this paper focuses on globalization, because its effects are quantitatively more significant.

7 Comparison with Alternative Models

Another way to demonstrate the significance of the comparative advantage channel is to contrast the results with those from models that mechanically close down the channel. Tradable services and asymmetric trade costs are the two model ingredients under which globalization can affect a country's comparative advantage. Without services trade, there is no cross-sector specialization; specialization occurs only within the goods sector. If we impose symmetry on trade costs (i.e., $\tau^k_{ij,t} = \tau^k_{ji,t}$ $\forall i, j \in \mathcal{I}, \forall k \in \mathcal{S}$), comparative advantage between a bilateral pair of countries measured by $\left(\frac{A^g_{i,t}}{A^{hts}_{i,t}} \Big/ \frac{A^g_{j,t}}{A^{hts}_{j,t}}\right)\left(\frac{\tau^g_{ij,t}}{\tau^g_{ji,t}} \Big/ \frac{\tau^{hts}_{ij,t}}{\tau^{hts}_{ji,t}}\right)^{-\frac{1}{2}}$ does not change with globalization. Note that $CA^g_{i,t}$ (comparative advantage measured with respect to the rest of the world) could indirectly change, only because export and import trade costs are measured as weighted averages with export and import volumes from 1995 as weights.

I compare the results from the main model with those from the model assuming non-tradable services and the model with tradable services assuming symmetric trade costs. For the first model, I set $\tau^{hts}_{ij,t} = \tau^{bts}_{ij,t} = \infty$, $\forall i \neq j \in \mathcal{I}$, for each period.[38] For

[38] I further assume balanced trade: $NX_{i,t} = 0\ \forall i \in \mathcal{I}$. This is because, under the unbalanced-trade assumption, equilibria do not exist for some years in the no-globalization counterfactual. Countries pay net transfers in terms of the numeraire, $W_{us,t}$, and in the counterfactual, some countries' income

the second model, I calculate trade costs following Head and Ries (2001). Assuming the symmetry, Equation (11) yields

$$\tau_{ij,t}^{k} = \tau_{ji,t}^{k} = \left(\frac{\pi_{ij,t}^{k}}{\pi_{ii,t}^{k}} \frac{\pi_{ji,t}^{k}}{\pi_{jj,t}^{k}} \right)^{-\frac{1}{2\theta^{k}}} . \tag{15}$$

I use the above formula to calculate trade costs from import shares. Importantly, symmetric trade costs can be recovered without price data, which makes them less data-intensive than asymmetric ones. Cravino and Sotelo (2019) utilized these symmetric trade costs in their analysis and demonstrated the importance of the price effect. For both alternative models, all the other model primitives were set equal to those in the main model.

I utilize $(Effect)_i^3$, the effect of overall globalization in all sectors, to compare the main model with the two alternative models. Table 5 demonstrates that, in terms of magnitude (absolute values), the impact of globalization is smaller and less heterogeneous in the alternative models.

Table 5: Summary Statistics for the Absolute Values of the Effect of Globalization in the Main, Non-tradable Services, Symmetric Trade Cost Models

		Main				Non-tradable services				Symmetric trade costs			
Sector	Obs	Mean	Q1	Q2	Q3	Mean	Q1	Q2	Q3	Mean	Q1	Q2	Q3
G	67	6.0	1.4	3.1	7.4	0.5	0.2	0.3	0.6	2.1	0.5	0.9	2.5
HTS	67	5.6	1.2	2.5	6.9	0.2	0.1	0.1	0.3	1.4	0.4	0.7	1.7
BTS	67	0.9	0.1	0.5	1.1	0.3	0.1	0.2	0.3	1.2	0.2	0.6	1.2

* Note: The statistics are for the absolute values of $(Effect)_i^3$. Units are in percentage points.

In the model with non-tradable services, globalization affects nearly all countries in the same direction. For 64 out of 67 economies, globalization accelerated structural transformation from goods to both types of services. (The table reporting each element of the triple $(Effect)_i^3$ for all countries is provided in Online Appendix O.B.) Moreover, the key mechanism through which globalization affects structural transformation is different from the main model. Since the goods sector is the only tradable sector, there is no cross-sector specialization, and globalization decreased goods prices relative to both types of services and increased the real income of households. Due to the price and income effects, structural transformation was accelerated. Further-

relative to the US becomes lower than their net transfers.

more, in 53 out of 67 countries, barely tradable services were impacted more than highly tradable services. Since the estimated income elasticity is higher for highly tradable services, this suggests the importance of relative prices and input-output linkages. Since goods and highly tradable services are tightly linked through input-output linkages, goods globalization tends to lower the prices of both goods and highly tradable services relative to barely tradable services.

In the model with symmetric trade costs, it is theoretically possible for globalization to have a significant impact on structural transformation. For example, as Cravino and Sotelo (2019) and Bonadio et al. (2025) argued, if goods globalization is faster than services globalization, relative prices of goods decrease. Given the (estimated) complementarity between goods and services in consumption, this can lead to accelerated structural transformation.

Furthermore, although globalization in the symmetric-trade-cost model does not change a country's bilateral export and import trade costs, it can still lead to more specialization through the interaction with productivity growth. For example, compared to the rest of the world, China's goods productivity relative to highly tradable services grew more quickly, leading it to increasingly specialize in goods. A reduction in symmetric trade costs could, in theory, strengthen this specialization pattern.

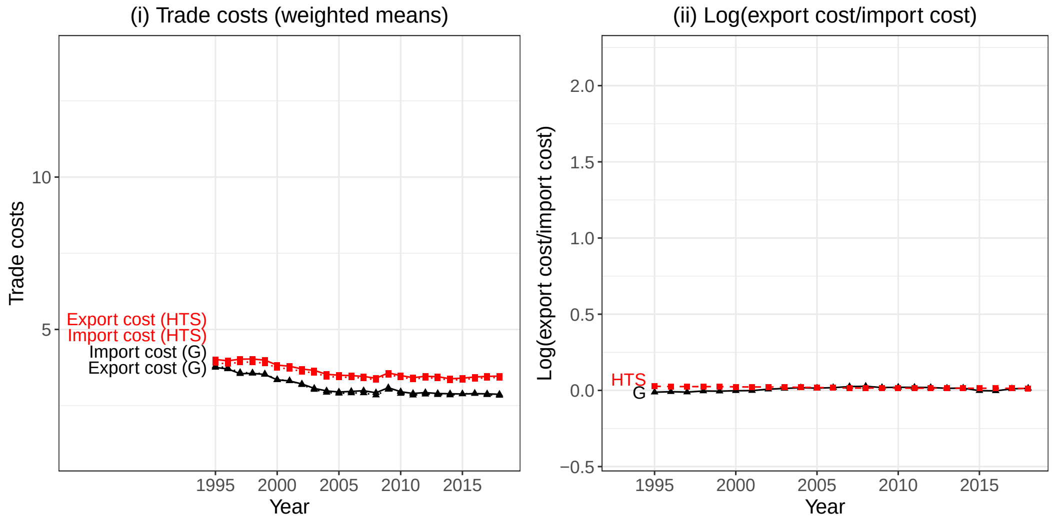
However, quantitatively, none of the above is the case. Repeating the exercise in Figure 4 for China illustrates this point. The results are provided in Figure 9 with axes identical to Figure 4 for direct comparison. China's export and import trade costs for goods decreased by 23% and 26%, respectively.[39] Its export and import trade costs for highly tradable services both declined by 13%. Despite significant globalization in both sectors and for both exports and imports, Panel (b) shows that none of the globalization in goods, that in services, and that in all sectors had a sizable impact on the speed of China's structural transformation.

Lastly, the comparison with the two alternative models highlights the significance of services trade. Without services trade or without incorporating the asymmetric nature of services trade costs, the analysis of how globalization impacts structural transformation would yield strikingly different conclusions, as shown above.

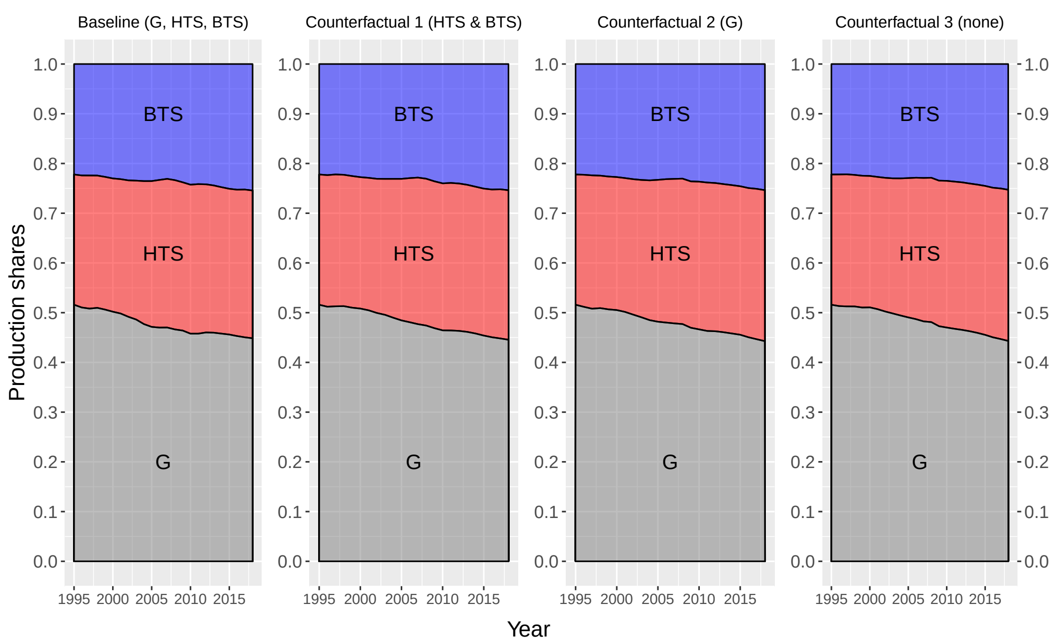
[39]The reason why export and import trade costs do not necessarily change by the exact same amount is that they are measured as weighted averages with the weights being export and import volumes in 1995.

Figure 9: Results for China (Model with Symmetric Trade Costs)

(a) Dynamics of Sectoral Trade Costs



(b) Structural Transformation in the Baseline and Counterfactuals #1 to #3



8 Spillovers Between Trade Costs and Productivities

The analyses so far have assumed that trade costs and productivities evolve independently of each other. However, the two primitives can interact: there can be spillovers between trade costs and productivities, which has implications not only for structural transformation but also for general economic development. Increased trade through lower trade costs can increase productivity (Pavcnik 2002; Lileeva and Trefler 2010; Bustos 2011). For example, this can happen through learning by importing or exporting or through increased incentive for firms to improve technologies. In the other direction, productivity growth can lower trade costs (Hummels 2007). Examples include technology improvement in transportation or communication.

In this section, I propose a strategy to parsimoniously incorporate these interactions into the model. This method is applicable to a wide range of models of international trade and economic growth. I also discuss how this extension alters the quantitative results; as a preview, the main results remain robust.

Assume that spillovers exist only within sectors between trade costs and productivities and that there do not exist any cross-sector interactions. For each sector $k \in \mathcal{S}$, I estimate the following dynamic processes of weighted-average trade costs and productivities.[40]

$$\log\left(\ddot{\tau}_{i,t}^{k}\right) = \zeta_{\tau}^{k}\log\left(\ddot{\tau}_{i,t-1}^{k}\right) + \lambda_{A,\tau}^{k}\log\left(A_{i,t}^{k}\right) + \Upsilon_{\tau,i}^{k} + \Omega_{\tau,t}^{k} + u_{\tau,i,t}^{k}, \tag{16}$$

where $\ddot{\tau}_{i,t}^{k}$ denotes the trade-volume-weighted average trade costs for country i. Specifically, $\ddot{\tau}_{i,t}^{k} \equiv \sum_{j\in\mathcal{I}}\left(X_{ij,t}^{k}\tau_{ij,t}^{k} + X_{ji,t}^{k}\tau_{ji,t}^{k}\right)\Big/\sum_{j\in\mathcal{I}}\left(X_{ij,t}^{k} + X_{ji,t}^{k}\right)$, where $X_{ij,t}^{k}$ denotes the volume of sector-k exports from country i to country j at time t. $\Upsilon_{\tau,i}^{k}$ and $\Omega_{\tau,t}$ are country and time fixed effects, respectively. $u_{\tau,i,t}^{k}$ is the error term, representing the shock to the trade cost. Similarly,

$$\log\left(A_{i,t}^{k}\right) = \zeta_{A}^{k}\log\left(A_{i,t-1}^{k}\right) + \lambda_{\tau,A}^{k}\log\left(\ddot{\tau}_{i,t}^{k}\right) + \Upsilon_{A,i}^{k} + \Omega_{A,t}^{k} + u_{A,i,t}^{k}, \tag{17}$$

with analogous definitions for the remaining terms. The parameters ζ_{τ}^{k} and ζ_{A}^{k} govern the persistence of trade costs and productivities, respectively. The parameters $\lambda_{A,\tau}^{k}$ and $\lambda_{\tau,A}^{k}$ capture the spillovers from productivities to trade costs and vice versa, respectively.

The baseline model provides productivities and trade costs for 67 economies across 24 years for each sector. Using them, I estimate Equations (16) and (17) separately using the Blundell and Bond (1998) estimator. In each case, I use the second lag of both sectoral log trade costs and log productivities as instruments.[41]

[40] I thank an anonymous referee for suggesting this type of estimation for the extension.

[41] Arellano-Bond estimator could be an alternative. However, since trade costs and productivities are highly persistent, I utilize the Blundell-Bond estimator instead.

Table 6: Estimation Results for the Dynamics of Trade Costs and Productivities

Sector	Equation	Parameter	Estimate	(Std. err.)
G	(16)	ζ_τ^g	0.80^{***}	(0.04)
		$\lambda_{A,\tau}^g$	-0.01	(0.01)
	(17)	ζ_A^g	0.97^{***}	(0.01)
		$\lambda_{\tau,A}^g$	-0.07^{*}	(0.02)
HTS	(16)	ζ_τ^{hts}	0.92^{***}	(0.05)
		$\lambda_{A,\tau}^{hts}$	0.11	(0.06)
	(17)	ζ_A^{hts}	1.00^{***}	(0.02)
		$\lambda_{\tau,A}^{hts}$	0.03	(0.02)
BTS	(16)	ζ_τ^{bts}	0.97^{***}	(0.05)
		$\lambda_{A,\tau}^{bts}$	0.07	(0.04)
	(17)	ζ_A^{bts}	1.03^{***}	(0.03)
		$\lambda_{\tau,A}^{bts}$	0.07	(0.03)

* Note: Significance levels: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$. For each estimation, there are 1608 observations (67 countries $\times$ 24 years). At the 5% level, first-order serial correlation (AR(1)) is detected, which is consistent with first-differenced equations in Blundell–Bond GMM; second-order serial correlation (AR(2)) is absent, supporting the validity of using second lags as instruments; and the Hansen/Sargan test supports the validity of the instruments in all cases except the HTS–(17) specification.

The results are in Table 6. The statistically significant ζ_τ^k's and ζ_A^k's suggest strong persistence of trade costs and productivities. Regarding the spillovers, only the spillover from trade costs to productivities in the goods sector is statistically significant at the 5% level. $\lambda_{\tau,A}^g = -0.07$ implies that 1% reduction in goods average trade costs leads to approximately 0.07% increase in goods productivity. The results, where only one out of six spillover terms is statistically significant, should not be interpreted as the absence of spillover effects in general. Rather, this likely reflects that spillovers occur at more localized industry or geographic levels, while the model aggregates to three broad sectors at the country level.

For counterfactual exercises, I assume that no spillovers exist in the two services sector, and hence their trade costs and productivities evolve independently of each other as in the baseline model. i.e., $\tilde{\lambda}_{A,\tau}^k = \tilde{\lambda}_{\tau,A}^k = 0$ for $k \in \{hts, bts\}$. Tilde notation represents the values that I set for the model. For goods, I assume that the spillover effects only exist in the direction of trade costs to productivities. I set $\tilde{\lambda}_{\tau,A}^g = -0.07$ and $\tilde{\lambda}_{A,\tau}^g = 0$. For the counterfactuals, the fixed effect terms are needed. However, the Blundell-Bond estimator does not allow for consistent estimation of the country fixed effects, $\Upsilon^k_{\tau,i}$ and $\Upsilon^k_{A,i}$. I recover it through the following average:

$$\hat{\Upsilon}^k_{\tau,i} = \frac{1}{T-1}\sum_{t=2}^{T}\left(\ddot{\tau}^k_{i,t} - \hat{\zeta}^k_{\tau}\ddot{\tau}^k_{i,t-1} - \tilde{\lambda}^k_{A,\tau}A^k_{i,t} - \hat{\Omega}^k_{\tau,t}\right),$$

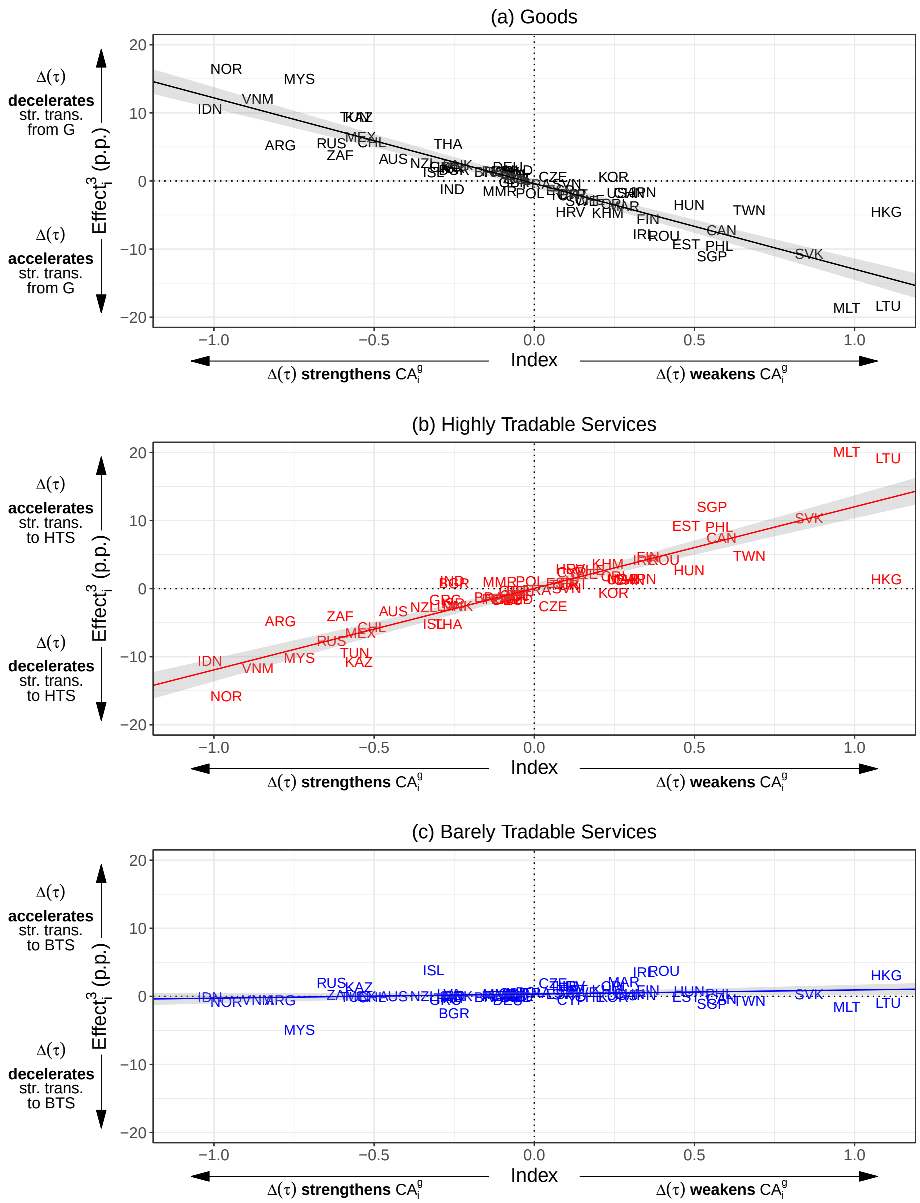
where $T = 24$ is the total number of years. Likewise explanation holds for $\hat{\Upsilon}^k_{A,i}$. With the parameters and fixed effects, I recover the shocks, $\hat{u}^k_{\tau,i,t}$ and $\hat{u}^k_{A,i,t}$. Furthermore, note that the trade cost $\ddot{\tau}^k_{i,t}$ is the average. I assume that a bilateral trade cost equals a time-varying wedge multiplied by the origin and destination average trade costs: $\tau^k_{ij,t} = \xi^k_{ij,t}\ddot{\tau}^k_{i,t}\ddot{\tau}^k_{j,t}$.

With this structure, I can assess the impact of globalization on structural transformation under the existence of the spillover effects. However, Equations (16) and (17) allow for multiple interpretations of a no-globalization scenario: First, I can define it as the absence of any changes in the bilateral trade costs, i.e., $\tau^k_{ij,t} = \tau^k_{ij,1},\ \forall i, j \in \mathcal{I},\ \forall k \in \mathcal{S},\ \forall t \in \mathcal{T}$. Second, it can be defined as no changes in the average trade costs, i.e., $\ddot{\tau}^k_{i,t} = \ddot{\tau}^k_{i,1},\ \forall i \in \mathcal{I},\ \forall k \in \mathcal{S},\ \forall t \in \mathcal{T}$. Third, it can be assumed as the case without any shocks to the trade costs, i.e., setting $\tilde{u}^k_{\tau,i,t} = 0,\ \forall i \in \mathcal{I},\ \forall k \in \mathcal{S},\ \forall t \in \mathcal{T}$. On top of these three, spillovers from trade costs to productivities can be regarded as part of globalization, and one could assume that no globalization entails no such spillovers, i.e., $\tilde{\lambda}^k_{\tau,A} = 0,\ \forall k \in \mathcal{S}$.

Among the various possible definitions, I adopt the first one, because it is consistent with the no-globalization counterfactual defined in Section 6. When globalization does not occur, there is one additional effect in contrast to the baseline model. For goods, due to the spillover from trade costs to productivities ($\tilde{\lambda}^g_{\tau,A} = -0.07$), goods productivities generally increase slower in the spillover case than in the baseline case. This is due to the downward trend in average goods trade costs for most countries. In theory, this difference can affect how globalization affects structural transformation. For example, since globalization increases goods productivity, whereas the lack of spillovers in services sectors implies globalization does not affect services productivity, it can accelerate the structural transformation through the price effects by lowering relative prices of goods. Furthermore, faster goods productivity growth through the spillover can accelerate the transformation through the income effect.

However, the comparative-advantage mechanism remains the channel through which globalization primarily affects structural transformation. I repeat the main

Figure 10: Results from the Model with Spillover Effects



* Note: The solid lines and the shaded areas around them represent the regression lines and the 95% confidence intervals, respectively. Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.

exercise of comparing the Globalization Bias Index and the effect of the overall globalization, $(Effect)_i^3$, with the extended model with the spillover effects. The results are in Figure 10. The main takeaway remains unchanged: Globalization affected a country's structural transformation to the extent it affected the country's comparative advantage.

9 Conclusion

How does globalization in goods and services affect the pace of structural transformation from goods to services? I find that from 1995 to 2018, globalization had heterogeneous effects on countries' structural transformation. I characterize the underlying factor behind this result: Globalization affected a country's structural transformation to the extent it affected the country's comparative advantage. In countries with *sector-neutral* globalization—where export trade costs relative to import trade costs changed at similar rates for goods and highly tradable services—comparative advantage and structural transformation were minimally impacted. Most large economies fall into this sector-neutral category. In countries with *sector-biased* globalization, the transformation accelerated when the globalization shifted comparative advantage toward services, but decelerated otherwise.

It is important to note that the limited impact of globalization on some countries' structural transformation should not be interpreted as trade being a minor component of their economies. Instead, it is generally because services globalization was commensurate with goods globalization (in terms of changes in asymmetric trade costs), which implies that the impact of services globalization on structural transformation largely offsets that of goods globalization.

Finally, this study opens two avenues for future research. First, the model abstracts from the dynamics of capital accumulation. Since goods production is capital intensive (Valentinyi and Herrendorf 2008), and investment production is goods intensive (García-Santana, Pijoan-Mas, and Villacorta 2021), incorporating the dynamics could amplify the main results of this paper. In particular, *goods-biased* globalization could generate reinforcing feedback effects. Additionally, allowing different trade costs for consumption goods, investment goods, consumption services, and investment services could alter the results; however, the direction of change is ambiguous ex ante, making it a promising topic for future research. Second, further investigation is needed into the underlying causes of the novel globalization patterns documented in this paper. While there is ample evidence of asymmetry in trade costs for goods, micro-level evidence on the asymmetry in services trade costs and on the decline of trade-cost asymmetry in both goods and services remains scarce. Understanding the micro-level factors driving these patterns could provide deeper insight into how technological and policy trade barriers shape structural transformation.

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Appendix

A Definition of an Equilibrium

This section collects equilibrium conditions.[42] Let $\mathcal{T}$ denote the set of time periods.

Definition. *The competitive equilibrium at time $t \in \mathcal{T}$ is (a) prices $\left(\left\{W_{i,t}, \{P_{i,t}^k\}_{k\in\mathcal{S}}\right\}_{i\in\mathcal{I}}\right)$ and (b) allocations $\left(\left\{C_{i,t}^k, L_{i,t}^k, Y_{i,t}^k \{Q_{i,t}^{hk}\}_{h\in\mathcal{S}}\right\}_{i\in\mathcal{I},k\in\mathcal{S}}\right)$ that satisfy the following 12 sets of conditions, given (i) country-sector productivities $\left(\{A_{i,t}^k\}_{i\in\mathcal{I},k\in\mathcal{S}}\right)$, (ii) origin-destination-sector iceberg trade costs $\left(\{\tau_{ij,t}^k\}_{i,j\in\mathcal{I},k\in\mathcal{S}}\right)$, (iii) net transfer terms $\left(\{NX_{i,t}\}_{i\in\mathcal{I}}\right)$, and (iv) populations $\left(\{L_{i,t}\}_{i\in\mathcal{I}}\right)$.*

The equilibrium conditions from the household maximization are

$$\text{(Sectoral demand)} \qquad \frac{P_{i,t}^k C_{i,t}^k}{P_{i,t}U_{i,t}} = \phi_i^k \left(\frac{P_{i,t}^k}{P_{i,t}}\right)^{1-\sigma} (U_{i,t})^{(1-\sigma)(\epsilon^k-1)}, \quad \forall i \in \mathcal{I},\ \forall k \in \mathcal{S}; \tag{Eq.H.1}$$

$$\text{(Price index)} \qquad P_{i,t} = \left\{\sum_{k\in\mathcal{S}} \phi_i^k (P_{i,t}^k)^{1-\sigma} U_{i,t}^{(1-\sigma)(\epsilon^k-1)}\right\}^{\frac{1}{1-\sigma}}, \quad \forall i \in \mathcal{I}; \tag{Eq.H.2}$$

$$\text{(Budget constraint)} \qquad \sum_{k\in\mathcal{S}} P_{i,t}^k C_{i,t}^k = P_{i,t}U_{i,t} = W_{i,t} - NX_{i,t}, \quad \forall i \in \mathcal{I}. \tag{Eq.H.3}$$

The conditions from the variety-producing firms' problem are

$$\text{(Input cost)} \qquad R_{i,t}^k = \left(\psi_i^{Lk} W_{i,t}^{1-\rho^k} + \sum_{h\in\mathcal{S}} \psi_i^{hk} \left(P_{i,t}^h\right)^{1-\rho^k}\right)^{\frac{1}{1-\rho^k}}, \quad \forall i \in \mathcal{I},\ \forall k \in \mathcal{S}; \tag{Eq.F.1}$$

$$\text{(Value-added share)} \qquad W_{i,t}L_{i,t}^k = \frac{\psi_i^{Lk} W_{i,t}^{1-\rho^k}}{\left(R_{i,t}^k\right)^{1-\rho^k}} \sum_{j\in\mathcal{I}} \pi_{ij,t}^k P_{j,t}^k Y_{j,t}^k, \quad \forall i \in \mathcal{I},\ \forall k \in \mathcal{S}; \tag{Eq.F.2}$$

[42] Following the convention of the international trade literature, I do not lay out conditions for the equilibrium price and quantity of each variety since the model is disciplined with macro data. See EK for the derivation of the price and quantity of a variety.

$$\text{(Intermediate share)} \quad P^h_{i,t}Q^{hk}_{i,t} = \frac{\psi^{hk}_i \left(P^h_{i,t}\right)^{1-\rho^k}}{\left(R^k_{i,t}\right)^{1-\rho^k}} \sum_{j\in\mathcal{I}} \pi^k_{ij,t}P^k_{j,t}Y^k_{j,t}, \quad \forall i\in\mathcal{I},\ \forall h,k\in\mathcal{S}. \tag{Eq.F.3}$$

The conditions from the aggregate producers' problem, which entails international trade of varieties, and the assumption on net transfers are

$$\text{(Price of aggregates)} \qquad P^k_{i,t} = \gamma^k \left\{ \sum_{j\in\mathcal{I}} \left(\frac{\tau^k_{ji,t}R^k_{j,t}}{A^k_{j,t}} \right)^{-\theta^k} \right\}^{-\frac{1}{\theta^k}}, \quad \forall i\in\mathcal{I},\ \forall k\in\mathcal{S}; \tag{Eq.G.1}$$

$$\text{(Import share)} \qquad \pi^k_{ji,t} = \frac{\left(\frac{\tau^k_{ji,t}R^k_{j,t}}{A^k_{j,t}}\right)^{-\theta^k}}{\sum_{o\in\mathcal{I}}\left(\frac{\tau^k_{oi,t}R^k_{o,t}}{A^k_{o,t}}\right)^{-\theta^k}}, \quad \forall i,j\in\mathcal{I},\ \forall k\in\mathcal{S}; \tag{Eq.G.2}$$

$$\text{(Net transfers)} \qquad \sum_{k\in\mathcal{S}} P^k_{i,t}Y^k_{i,t} = \sum_{k\in\mathcal{S}}\sum_{j\in\mathcal{I}} \pi^k_{ij,t}P^k_{j,t}Y^k_{j,t} - L_{i,t}NX_{i,t}, \quad \forall i\in\mathcal{I}; \tag{Eq.G.3}$$

$$\text{(Assumption on net transfers)} \qquad \sum_{i\in\mathcal{I}} L_{i,t}\cdot NX_{i,t} = 0. \tag{Eq.G.4}$$

Finally, the market clearing conditions are

$$\text{(Aggregate goods)} \qquad Y^k_{i,t} = L_{i,t}C^k_{i,t} + \sum_{h\in\mathcal{S}} Q^{kh}_{i,t}, \quad \forall i\in\mathcal{I},\ \forall k\in\mathcal{S}; \tag{Eq.M.1}$$

$$\text{(Labor market)} \qquad L_{i,t} = \sum_{k\in\mathcal{S}} L^k_{i,t}, \quad \forall i\in\mathcal{I}. \tag{Eq.M.2}$$

B Derivation of Equation (9)

Supply of the sectoral aggregate is the sum of sectoral consumption and intermediate demands. Rewriting the market clearing condition,

$$Y^k_{i,t} = L_{i,t}C^k_{i,t} + \sum_{h\in\mathcal{S}} Q^{kh}_{i,t}. \tag{B1}$$

Intermediate demand, $Q_{i,t}^{kh}$, is given by

$$P_{i,t}^{k} Q_{i,t}^{kh} = \frac{\psi_i^{kh}\left(P_{i,t}^{k}\right)^{1-\rho^h}}{\left(R_{i,t}^{h}\right)^{1-\rho^h}} \sum_{j\in\mathcal{I}} \pi_{ij,t}^{h} P_{j,t}^{h} Y_{j,t}^{h} = \frac{\psi_i^{kh}\left(P_{i,t}^{k}\right)^{1-\rho^h}}{\left(R_{i,t}^{h}\right)^{1-\rho^h}} \left(P_{i,t}^{k} Y_{i,t}^{k} + L_{i,t} N X_{i,t}^{k}\right). \quad \text{(B2)}$$

This is from Equation (Eq.F.3) and the definition of $NX_{i,t}^{k}$.

Plugging in Equation (B2) into Equation (B1), domestic absorptions in nominal terms can be expressed as

$$\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{Y}}_{i,t} = L_{i,t} \vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{C}}_{i,t} + \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)\left(\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{Y}}_{i,t} + L_{i,t} \mathbf{N}\vec{\mathbf{X}}_{i,t}\right), \quad \text{(B3)}$$

where the input-output coefficient matrix $\tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)$ denotes the matrix comprises terms, $\frac{\psi_i^{kh}\left(P_{i,t}^{k}\right)^{1-\rho^h}}{\left(R_{i,t}^{h}\right)^{1-\rho^h}}$. Note that $R_{i,t}^{h}$ depends on $W_{i,t}$ and $\{\psi_i^{kh}\}_k$. Reorganizing Equation (B3) yields

$$\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{Y}}_{i,t} + L_{i,t} \mathbf{N}\vec{\mathbf{X}}_{i,t} = \left(\mathbf{I} - \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)\right)^{-1} L_{i,t}\left(\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{C}}_{i,t} + \mathbf{N}\vec{\mathbf{X}}_{i,t}\right). \quad \text{(B4)}$$

From Equation (Eq.F.2), labor input share is given by

$$W_{i,t} L_{i,t}^{k} = \left[1 - \sum_{h\in\mathcal{S}} \left\{ \frac{\psi_i^{hk}\left(P_{i,t}^{h}\right)^{1-\rho^k}}{\left(R_{i,t}^{k}\right)^{1-\rho^k}} \right\}\right] \left(P_{i,t}^{k} Y_{i,t}^{k} + L_{i,t} N X_{i,t}^{k}\right).$$

In vector notation,

$$W_{i,t} \vec{\mathbf{L}}_{i,t} = \left[\left\{\mathbf{I} - \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)^{T}\right\} \vec{\mathbf{e}}\right] \odot \left(\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{Y}}_{i,t} + L_{i,t} \mathbf{N}\vec{\mathbf{X}}_{i,t}\right). \quad \text{(B5)}$$

Merging Equation (B4) and Equation (B5) yields

$$\begin{aligned} & W_{i,t} \vec{\mathbf{L}}_{i,t} \\ = & \left[\left\{\mathbf{I} - \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)^{T}\right\} \vec{\mathbf{e}}\right] \odot \left[\left\{\mathbf{I} - \tilde{\mathbf{B}}_i\left(\vec{\mathbf{P}}_{i,t}, w_{i,t}\right)\right\}^{-1} L_{i,t}\left(\vec{\mathbf{P}}_{i,t} \odot \vec{\mathbf{C}}_{i,t} + \mathbf{N}\vec{\mathbf{X}}_{i,t}\right)\right]. \end{aligned}$$

C List of Countries

36 advanced countries: AUS (Australia), AUT (Austria), BEL (Belgium), CAN (Canada), CHE (Switzerland), CYP (Cyprus), CZE (Czech Republic), DEU (Germany), DNK (Denmark), ESP (Spain), EST (Estonia), FIN (Finland), FRA (France), GBR (Great Britain), GRC (Greece), HKG (Hong Kong), IRL (Ireland), ISL (Iceland), ISR (Israel), ITA (Italy), JPN (Japan), KOR (Korea), LTU (Lithuania), LUX (Luxembourg), LVA (Latvia), MLT (Malta), NLD (Netherlands), NOR (Norway), NZL (New Zealand), PRT (Portugal), SGP (Singapore), SVK (Slovak Republic), SVN (Slovenia), SWE (Sweden), TWN (Taiwan), USA (United States)

30 developing countries: ARG (Argentina), BGR (Bulgaria), BRA (Brazil), BRN (Brunei Darussalam), CHL (Chile), CHN (China), COL (Colombia), CRI (Costa Rica), HRV (Croatia), HUN (Hungary), IDN (Indonesia), IND (India), KAZ (Kazakhstan), KHM (Cambodia), LAO (Laos), MAR (Morocco), MEX (Mexico), MMR (Myanmar), MYS (Malaysia), PER (Peru), PHL (Philippines), POL (Poland), ROU (Romania), RUS (Russia), SAU (Saudi Arabia), THA (Thailand), TUN (Tunisia), TUR (Turkey), VNM (Viet Nam), ZAF (South Africa)

D Estimation

D.1 Preference Parameters

To estimate the substitution elasticity, σ, and the sectoral non-homotheticity parameters, $\{\epsilon^k\}_{k\in\mathcal{S}}$, I adopt the approach of CLM and use cross-country panel data on sectoral final expenditures, prices, and income.

Since any positive monotone transformation of U_i in Equation (5) leads to observationally equivalent utility functions, a normalization of $\{\epsilon^k\}_{k\in\mathcal{S}}$ is required. I normalize $\epsilon^g = 1$. From the sectoral demand function (Equation (8)), expenditures on sector $k \in \{hts,\ bts\}$ relative to sector g, can be expressed as follows:

$$\log\left(\frac{P^k_{i,t}C^k_{i,t}}{P^g_{i,t}C^g_{i,t}}\right) = (1-\sigma)\log\left(\frac{P^k_{i,t}}{P^g_{i,t}}\right) + (1-\sigma)(\epsilon^k - 1)\log(U_{i,t}) + \log\left(\frac{\phi^k_i}{\phi^g_i}\right). \quad \text{(D1)}$$

Although $U_{i,t}$ is not directly observable from data, it can be expressed in terms of data observables and parameters using Equation (8):

$$\log(U_{i,t}) = \frac{1}{1-\sigma}\log\left(\frac{1}{\phi^g_i}\right) + \log\left(\frac{P_{i,t}U_{i,t}}{P^g_{i,t}}\right) + \frac{1}{1-\sigma}\log\left(\frac{P^g_{i,t}C^g_{i,t}}{P_{i,t}U_{i,t}}\right). \quad \text{(D2)}$$

Note that $P_{i,t}U_{i,t}$ is the income of a household, hence observable. Combining Equa-

Table D1: Estimation Result for Preference Parameters

	Estimate (95% confidence interval)
σ	0.59 (0.51, 0.65)
ϵ^{hts}	1.78 (1.55, 1.93)
ϵ^{bts}	1.33 (1.12, 1.45)
Observations	1584

* Note: The confidence intervals are computed from bootstrapping with 1,000 runs of resampling with replacement from the original data at the same sample size.[43]

tions (D1) and (D2) and adding error terms yield the estimating equation:

$$\begin{aligned}\log\left(\frac{P^k_{i,t}C^k_{i,t}}{P^g_{i,t}C^g_{i,t}}\right) &= (1-\sigma)\log\left(\frac{P^k_{i,t}}{P^g_{i,t}}\right) + (1-\sigma)(\epsilon^k-1)\log\left(\frac{P_{i,t}U_{i,t}}{P^g_{i,t}}\right) \\ &\quad + (\epsilon^k-1)\log\left(\frac{P^g_{i,t}C^g_{i,t}}{P_{i,t}U_{i,t}}\right) + S^k_i + \nu^k_{i,t},\end{aligned} \tag{D3}$$

where $S^k_i = (\epsilon^k - 1)\log\left(\frac{1}{\phi^g_i}\right) + \log\left(\frac{\phi^k_i}{\phi^g_i}\right)$.

Using the data for 66 countries from 1995 to 2018, I run a two-step GMM estimation jointly for the two equations above (one for $k = hts$ and the other for $k = bts$) with a country-sector fixed effect to control for S^k_i. The results are in Table D1: I find that the sectoral outputs are complements and that two services are more income-elastic than goods. The fact that highly tradable services are estimated to be more income-elastic than barely tradable services echoes Duarte and Restuccia (2020), who find a significant heterogeneity of income elasticities across different services sectors. The utility weights $\{\phi^k_i\}_{k\in\mathcal{S}}$ are normalized so that their sum equals one and are obtained from the estimated fixed effects.

Identification comes from within-country variation in prices, income, and sectoral final expenditures. The identifying assumption is that shocks to relative demand ($\nu^k_{i,t}$) are uncorrelated with the regressors. The violation of this assumption could lead to endogeneity problems. However, the results are similar to the studies that utilized different datasets. Using US country-level data from 1977 to 2012, Cravino and Sotelo (2019) estimated the substitution elasticity to be 0.58 and the non-homotheticity

[43] I report bootstrapped confidence intervals instead of those based on standard errors, which are high due to a collinearity issue for some countries. For instance, Brunei's predictor variables are stable over time, being highly collinear with the fixed effect terms.

parameters for skill-intensive and non-skill-intensive services—which largely coincide with highly and barely tradable services, respectively—to be 1.82 and 1.42. Using 1992-2017 data from Canadian provinces, Han, Miranda-Pinto, and Tanaka (2022) find the substitution elasticity to be 0.59 and the non-homotheticity parameter for services to be 1.59.[44] Furthermore, CLM show that the estimation results from macro data are similar to those from the IV estimation with household-level data in their agriculture-manufacturing-services structure.

D.2 Technology Parameters

In the production function for a variety (Equation (1)), $\{\rho^k\}_{k\in\mathcal{S}}$ govern the substitutability of inputs. I estimate them through the macro-data approach (Herrendorf, Rogerson, and Valentinyi 2013; Cravino and Sotelo 2019)—unlike the two papers utilizing the US data, I employ the data for 66 sample countries.

From the cost minimization, input shares relative to goods, with added error terms, are given below. For $k \in \{g, hts, bts\}$,

$$\log\left(\frac{P^h_{i,t}Q^{hk}_{i,t}}{P^g_{i,t}Q^{gk}_{i,t}}\right) = (1-\rho^k)\log\left(\frac{P^h_{i,t}}{P^g_{i,t}}\right) + \log\left(\frac{\psi^{hk}_i}{\psi^{gk}_i}\right) + \chi^{hk}_{i,t}, \quad h \in \{hts, bts\}, \text{ and} \tag{D4}$$

$$\log\left(\frac{W_{i,t}L^k_{i,t}}{P^g_{i,t}Q^{gk}_{i,t}}\right) = (1-\rho^k)\log\left(\frac{W_{i,t}}{P^g_{i,t}}\right) + \log\left(\frac{\psi^{Lk}_i}{\psi^{gk}_i}\right) + \chi^{Lk}_{i,t}. \tag{D5}$$

For each k, I jointly estimate the three equations above by running a two-step GMM estimation with a country-input-sector fixed effect to control for $\{\psi^{hk}_i/\psi^{gk}_i\}_{h\in\{hts,bts\}}$ and ψ^{Lk}_i/ψ^{gk}_i. The results are in Table D2. The weights, ψ^{Lk}_i and $\{\psi^{hk}_i\}_{h\in\mathcal{S}}$, are normalized so that their sum equals one and are recovered from the estimated fixed effects.

Identification comes from within-country-sector variation in relative input shares and relative factor prices under the identifying assumption that shocks to the relative factor demand are uncorrelated with the relative factor prices. Despite endogeneity concerns, my result is in line with the previous literature. For instance, Sposi, Yi, and Zhang (2021) and Lewis et al. (2021) use Cobb-Douglas production functions based on the observation that input shares are generally constant across time for a

[44] They normalized the non-homotheticity parameter for services to one and estimated that for goods as 0.41. Re-normalizing the goods parameter to one yields 1.59 for the services parameter.

Table D2: Estimation Result for Production Parameters

	Estimate (standard error)
ρ^{g}	1.22 (0.04)
ρ^{hts}	0.93 (0.04)
ρ^{bts}	0.93 (0.04)
Observations	1584

* Note: Each line comes from a separate estimation.

country-sector, and my estimates are close to $\rho^k = 1$.

Notably, my estimates differ from studies that use only US data. Atalay (2017) and Cravino and Sotelo (2019) find that sectoral production functions are nearly Leontief (i.e., $\rho^k = 0$). Using the US subset of my dataset, I obtain similar results; however, incorporating data from other countries shifts the estimates closer to one.

D.3 Other Parameters

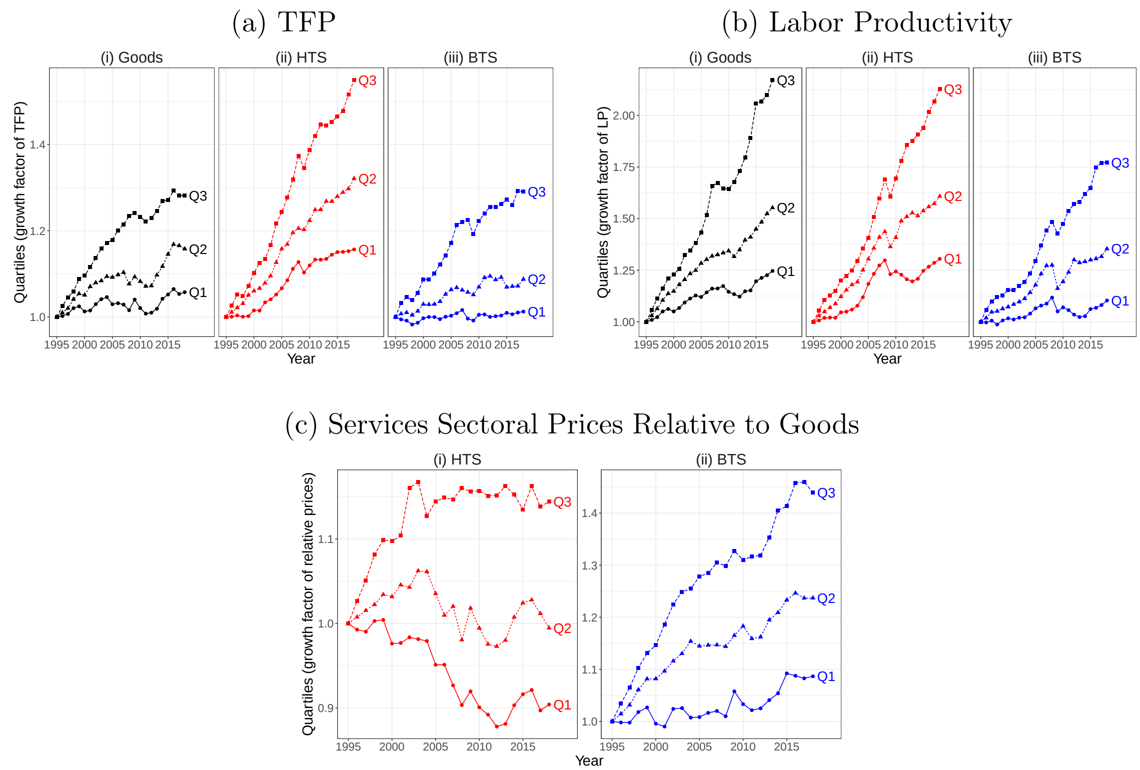
Following Simonovska and Waugh (2014), I set the trade elasticity, $\theta^k = 4$, $\forall k \in \mathcal{S}$. (I discuss this choice in detail in Section 4.2.1.) Regarding the elasticities of substitution across varieties, I can choose any $\eta^k < \theta^k + 1$, given the parameterization strategy. Proof of this claim that the equilibrium prices and allocations remain the same under any $\eta^k < \theta^k + 1$ is as follows. Suppose that there are two choices of η^k: $\hat{\eta}^k$ and $\tilde{\eta}^k$. Let hat and tilde denote corresponding model objects. In the inversion for sectoral productivity (Equation (12)), $\frac{\hat{A}^k_{i,t}}{\tilde{A}^k_{i,t}} = \frac{\hat{\gamma}^k}{\tilde{\gamma}^k}$. In Equations (3) and (4), this implies $\hat{P}^k_{i,t} = \tilde{P}^k_{i,t}$ and $\hat{\pi}^k_{ij,t} = \tilde{\pi}^k_{ij,t}$. This, in turn, means that all the equilibrium prices and allocations are identical across the two equilibria.

E Productivity Growth

Figure E1 describes the dynamics of total factor productivities $\left(A^k_{i,t}\right)$, measured labor productivity $\left(Y^k_{i,t}/L^k_{i,t}\right)$, and relative prices $\left(\left\{P^k_{i,t}/P^g_{i,t}\right\}_{k\in\{hts,bts\}}\right)$.[45] Changes in labor productivity have more direct implications for sectoral prices, whereas changes in TFP are not directly mapped into prices due to input-output linkages. In general, labor productivity growth in goods and that in highly tradable services are comparable, whereas barely tradable services exhibited slower growth (Panel (b)). In connection

[45] To calculate measured labor productivity, one needs to solve the baseline model to obtain $Y^k_{i,t}$.

Figure E1: Growth Factors of Sectoral Productivities and Relative Prices



* Note: A growth factor is a statistic of a country-sector divided by the same statistic for that country-sector in 1995. Q1, Q2, and Q3 represent first, second, and third quartiles, respectively.

with this, relative prices for the barely tradable services were increasing, whereas prices for the highly tradable services show more mixed patterns (Panel (c)).

Since the outputs of the three sectors are complements, it means that the price effect had a stronger implication for the structural transformation to barely tradable services than that to highly tradable services. This reinforces Jorgenson and Timmer (2011) and Duernecker, Herrendorf, and Valentinyi (2017), arguing that Baumol's cost disease (Baumol 1967) should be reexamined with disaggregated services. It has been believed that since services productivities are growing slower than goods and because goods and services are complements, structural transformation incurs a slowdown in the aggregate productivity growth.

The stronger price effect for the barely tradable services contrasts with the role of the income effect. Highly tradable services exhibited higher income elasticity than barely tradable services: $\epsilon^{hts} = 1.78$, $\epsilon^{bts} = 1.33$, and $\sigma = 0.59$.

F Solution Method

I use a modified version of the solution method from Alvarez and Lucas (2007). Given the model primitives, for each time period,

1. Guess $\{W_i\}_{i \in \mathcal{I}} \in \Delta_{\overrightarrow{W}} \equiv \left\{ \overrightarrow{W} \in \mathbb{R}^I_+ : \sum_{i \in \mathcal{I}} W_i L_i = 1 \right\}$.
2. From Equations (Eq.F.1) and (Eq.G.1), derive P_i^k and R_i^k.[46]
3. From Equations (Eq.H.2) and (Eq.H.3), derive P_i and U_i.
4. From Equation (Eq.H.1), derive C_i^k.
5. From Equation (Eq.G.2), derive π_{ij}^k.
6. From Equations (Eq.F.3) and (Eq.M.1), derive Q_i^{kh} and Y_i^k.
7. Modifying Equation (Eq.G.3), define the excess demand for country i's products in terms of wage rates.
$$Z_i(\overrightarrow{W}) \equiv \frac{1}{W_i} \left(\sum_{k \in \mathcal{S}} \sum_{j \in \mathcal{I}} \pi_{ij}^k P_j^k Y_j^k - nx_i W_{USA} L_i - \sum_{k \in \mathcal{S}} P_i^k Y_i^k \right).$$
8. If $Z_i(\overrightarrow{W}) = 0 \ \forall i \in \mathcal{I}$, stop. Otherwise, update $\overrightarrow{W}$ using the following mapping:
$$T_i(\overrightarrow{W}) = W_i \left(1 + \kappa \frac{Z_i(\overrightarrow{W})}{L_i} \right),$$
where κ is a small number.

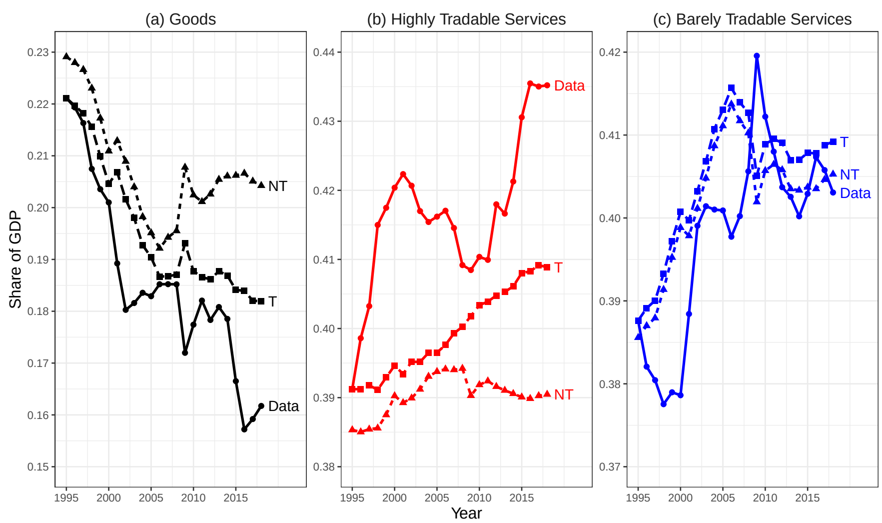
G Model Fit (Non-targeted Moments)

This section studies the model's performance in predicting the structural transformation pattern of the US as non-targeted moments. I calibrate a two-country (the US and the rest of the world) model in four steps:

[46] In Alvarez and Lucas (2007), this step is a contraction mapping. In this paper, it is a non-expansive mapping, which numerically converged to fixed points.

1. Preference and production parameters are re-estimated using the data from 65 countries (66 countries minus the US). This is because the sectoral prices in the US are correlated with the country's sectoral productivity. Sectoral weights in the utility and production functions are set such that the initial year of the model fits the data perfectly.
2. Sectoral TFP growth rates for the US are calculated from the BEA-BLS KLEMS data. Output quantities of the industries belonging to each of the three broad sectors are aggregated through the Törnqvist index.
3. I calculate sectoral trade costs following Kehoe, Ruhl, and Steinberg (2018): Assuming that sectoral prices each year are equal across the two countries, Equation (11) becomes $\tau^k_{ij,t} = \left(\pi^k_{ij,t}/\pi^k_{ii,t}\right)^{-1/\theta^k}$, $\forall i, j \in \{USA, ROW\}$, $\forall k \in \mathcal{S}$.
4. Sectoral TFP growth rates for the ROW are calibrated such that the sectoral prices are equalized across the US and the ROW.

Figure G1: Model Fit (Structural Transformation of the US, Non-targeted)



* Note: In step #1, since the sectoral weights were calibrated to fit Model T perfectly to the data in 1995, Model NT does not align perfectly with the data in 1995.

Figure G1 provides the model fit for the baseline model with tradable services (Model T) and the model with non-tradable services (Model NT), where $\tau^k_{USA,ROW,t} = \tau^k_{ROW,USA,t} = \infty$, $\forall k \in \{hts, bts\}$. The baseline model correctly replicates the directional trends of the sectoral GDP shares. The two models' performance is similar until 2005, but after that, Model T outperforms Model NT. The likely cause is that Model NT cannot capture the increased cross-sector specialization after 2005. From

2005 to 2018, the goods share of exports decreased from 56% to 50%, whereas the goods share of imports decreased from 74% to 71%.

H Comparative Advantage

This section shows that the measure of comparative advantage is a sufficient statistic for whether a country is a net exporter of goods in a simplified two-country model. The proposition and proof are adaptations of those by Deardorff (2014) to the EK model.

Assume the world with two countries, denoted by a and b, and two sectors, g (good) and s (services). Additionally, I abstract away from input-output linkages, i.e., $\psi_i^{Lk} = 1$, $\psi_i^{hk} = 0$, $\forall i \in \mathcal{I}$, $\forall h, k \in \mathcal{S}$. For conciseness, I omit time subscripts. In this economy, the measure of comparative advantage for country a, $\overline{CA}_{ab}^g = \left(\frac{A_{a,t}^g}{A_{a,t}^s} \Big/ \frac{A_{b,t}^g}{A_{b,t}^s}\right)\left(\frac{\tau_{ab,t}^g}{\tau_{ba,t}^g} \Big/ \frac{\tau_{ab,t}^s}{\tau_{ba,t}^s}\right)^{-\frac{1}{2}}$.

Proposition 1. *Suppose that the GDPs and sectoral consumption shares are equal across countries (i.e., $W_a L_a = W_b L_b$, and $\omega_a^s = \omega_b^s$, where $\omega_a^s \equiv \frac{P_a^s C_a^s}{W_a}$) and that the trade elasticities are equal across sectors ($\theta^g = \theta^s$). Then, if country a has comparative advantage in goods, i.e., $\overline{CA}_{ab}^g > 1$, then, it is a net exporter of goods.*

Proof. From Equation (4),

$$\left(\frac{\pi_{ab}^g}{1-\pi_{ab}^g} \Big/ \frac{\pi_{ba}^g}{1-\pi_{ba}^g}\right) \Big/ \left(\frac{\pi_{ab}^s}{1-\pi_{ab}^s} \Big/ \frac{\pi_{ba}^s}{1-\pi_{ba}^s}\right)$$
$$= \left\{\frac{\tau_{ab}^g}{\tau_{ba}^g}\left(\frac{W_a A_b^g}{W_b A_a^g}\right)^2\right\}^{-\theta^g} \Bigg/ \left\{\frac{\tau_{ab}^s}{\tau_{ba}^s}\left(\frac{W_a A_b^s}{W_b A_a^s}\right)^2\right\}^{-\theta^s}.$$

The assumptions of $\theta^s = \theta^g > 0$ and $CA_{ab}^g > 1$ imply

$$\left(\frac{\pi_{ab}^g}{1-\pi_{ab}^g} \Big/ \frac{\pi_{ba}^g}{1-\pi_{ba}^g}\right) \Big/ \left(\frac{\pi_{ab}^s}{1-\pi_{ab}^s} \Big/ \frac{\pi_{ba}^s}{1-\pi_{ba}^s}\right) > 1.$$
$$\Rightarrow \left(\frac{X_{ab}^g}{\omega_b^g W_b L_b - X_{ab}^g} \Big/ \frac{X_{ba}^g}{\omega_a^g W_a L_a - X_{ba}^g}\right) \Big/ \left(\frac{X_{ab}^s}{\omega_b^g W_b L_b - X_{ab}^s} \Big/ \frac{X_{ba}^s}{\omega_a^s W_a L_a - X_{ba}^s}\right) > 1. \quad \text{(H1)}$$

Assume to the contrary that $X_{ab}^g - X_{ba}^g \leq 0$. This, along with $\omega_a^g = \omega_b^g \Leftrightarrow \omega_a^s = \omega_b^s$, and $W_a L_a = W_b L_b$ implies that left-hand side of Equation (H1) is less than or equal to 1. $\square$

Online Appendix

O.A Inversion of Other Gravity Models

The gravity equation for the EK model, derived from Equations (3) and (4), is

$$X_{ji}^{k} = c^{k} \left(\tau_{ji}^{k}\right)^{-\theta^{k}} \left(\frac{R_{j}^{k}}{A_{j}^{k}}\right)^{-\theta^{k}} \left(P_{i}^{k}\right)^{\theta^{k}} \left(P_{i}^{k} Y_{i}^{k}\right), \tag{O.A1}$$

where $c^{k} = \left(\gamma^{k}\right)^{-\theta^{k}}$ is a constant. Using this equation, one can derive the inversion formula (Equation (11)). For each of other gravity models of sectoral trade, I list the objective of buyers (producers of aggregates), technology structure, and the underlying assumption on competition. Then, I state the associated gravity equation. For all models, a unit cost of input bundles is R_{i}^{k}, and trade incurs iceberg trade costs.

1. Armington (Anderson 1979) Model

Each country produces a single differentiated good. The buyers' objective is to maximize

$$Y_{i}^{k} = \left(\sum_{j \in \mathcal{I}} \left(a_{ji}^{k}\right)^{\frac{1}{\eta^{k}}} \left(q_{j}^{k}\right)^{\frac{\eta^{k}-1}{\eta^{k}}} dz\right)^{\frac{\eta^{k}}{\eta^{k}-1}},$$

where $\eta^{k} \geq 0$. Note that, to have a model where trade decreases with increasing trade costs, $\eta^{k} > 1$ is needed. Production of country-j, sector-k goods requires $\frac{1}{A_{j}^{k}}$ units of input bundle. All markets are perfectly competitive. Then, the gravity equation and the associated inversion formula are given by

$$X_{ji}^{k} = a_{ji}^{k} \left(\tau_{ji}^{k}\right)^{1-\eta^{k}} \left(\frac{R_{j}^{k}}{A_{j}^{k}}\right)^{1-\eta^{k}} \left(P_{i}^{k}\right)^{\eta^{k}-1} \left(P_{i}^{k} Y_{i}^{k}\right).$$

$$\tau_{ji}^{k} = \left(\frac{a_{ji}^{k}}{a_{jj}^{k}}\right)^{-\frac{1}{1-\eta^{k}}} \left(\frac{\pi_{ji}^{k}}{\pi_{jj}^{k}}\right)^{\frac{1}{1-\eta^{k}}} \frac{P_{i}^{k}}{P_{j}^{k}}.$$

Given the trade elasticity, $\left(\eta^{k}-1\right)$, if the CES weights ($\{a_{ij}^{k}\}_{i,j \in \mathcal{I}}$) are time-invariant, then, from the data on import shares and price levels, we can infer over-time changes in trade costs. If we further assume that the weights are known (for instance, when $a_{ji}^{k} = a_{ii}^{k},\ \forall j \neq i, \forall i \in \mathcal{I}$), then we can infer the levels as well.

2. BEJK (Bernard et al. 2003) Model

BEJK extends the EK model into a Bertrand competition, where the price set by the lowest cost supplier is affected by the cost of the second-lowest cost supplier. (For the pricing rule, see Equation (6) of BEJK.) Another departure from EK is that now the productivity draw of a variety producer is not from a Frèchet distribution. Instead, the joint distribution of first and second highest productivity (α_1 and α_2) of country-sector producers follows the cumulative distribution function of $F^k(\alpha_1, \alpha_2) = \left(1 + \alpha_2^{-\theta^k} - \alpha_1^{-\theta^k}\right) e^{-z^{-\theta^k}}$, where $\eta^k < \theta^k + 1$ is imposed for well-defined prices. The other model environments are identical to EK. The gravity equation only differs from EK in constant terms:

$$X_{ji}^k = \tilde{c}^k \left(\tau_{ji}^k\right)^{-\theta^k} \left(\frac{R_j^k}{A_j^k}\right)^{-\theta^k} \left(P_i^k\right)^{\theta^k} \left(P_i^k Y_i^k\right),$$

where $\tilde{c}^k \equiv \left\{ \frac{1+\theta^k-\eta^k+(\eta^k-1)\left(\frac{\eta^k}{\eta^k-1}\right)^{-\theta^k}}{1+\theta^k-\eta^k} \Gamma\left(\frac{2\theta^k+1-\eta^k}{\theta^k}\right) \right\}^{\frac{-\theta^k}{1-\eta^k}}$. Therefore, the inversion formula is identical to that in EK (Equation (11)).

3. Krugman (1980) Model

In each country $i \in \mathcal{I}$, there are measure M_i^k firms that produce differentiated products. Each firm owns the technology to produce its own variety (monopolistic competition). Every firm in country i has productivity A_i^k, so the marginal cost is $\frac{R_i^k}{A_i^k}$. Each firm pays f_i^k units of numeraires as entry costs. The buyers maximize the following CES aggregate:

$$Y_i^k = \left(\sum_{j \in \mathcal{I}} \int_0^{M_j} q_{ji}^k(z)^{\frac{\eta^k-1}{\eta^k}} dz \right)^{\frac{\eta^k}{\eta^k-1}}.$$

The gravity equation under this environment is given by:

$$X_{ji}^k = \left(\frac{\eta^k}{\eta^k-1}\right)^{1-\eta^k} \left(\tau_{ji}^k\right)^{1-\eta^k} \left(\frac{R_j^k}{A_j^k}\right)^{1-\eta^k} M_j^k \left(P_i^k\right)^{\eta^k-1} \left(P_i^k Y_i^k\right),$$

where, as in the Armington model, it is reasonable to impose $\eta^k > 1$. Then,

$$\tau_{ji}^k = \left(\frac{\pi_{ji}^k}{\pi_{jj}^k}\right)^{\frac{1}{1-\eta^k}} \frac{P_i^k}{P_j^k}.$$

This is identical to the case of EK, except that the trade elasticity is now $(\eta^k - 1)$.

4. Melitz (2003)-Chaney (2008) Model

Unlike the Krugman model, firms are heterogeneous. In country i, there are M_i^k measure of potential firms. Again, each firm is the only producer of its specific variety (monopolistic competition). Each firm draws its idiosyncratic productivity from a Pareto distribution with a cumulative distribution $F_i^k(\alpha) = 1 - \alpha^{-\theta^k}$, for $\alpha \geq 1$. As before, A_i^k governs sector-wide productivity, so the marginal cost of production is $\frac{R_i^k}{A_i^k \alpha_i^k(z)}$. Furthermore, to sell in destination j, they need to pay fixed costs of f_{ij} in numeraire. Therefore, the varieties consumed by a consumer are determined in equilibrium, although the buyers' problem is identical to the Krugman model. $\eta^k < \theta^k + 1$ is imposed for a well-defined equilibrium.

The gravity equation in this environment is as follows:

$$X_{ji}^k = \bar{c}^k \left(\tau_{ji}^k\right)^{-\theta^k} \left(\frac{R_j^k}{A_j^k}\right)^{-\theta^k} M_j^k \left(f_{ji}^k\right)^{\frac{\eta^k - \theta^k - 1}{\eta^k - 1}} \left\{\left(P_i^k\right)^{\eta^k - 1} Y_i^k\right\}^{\frac{\theta^k}{\eta^k - 1}},$$

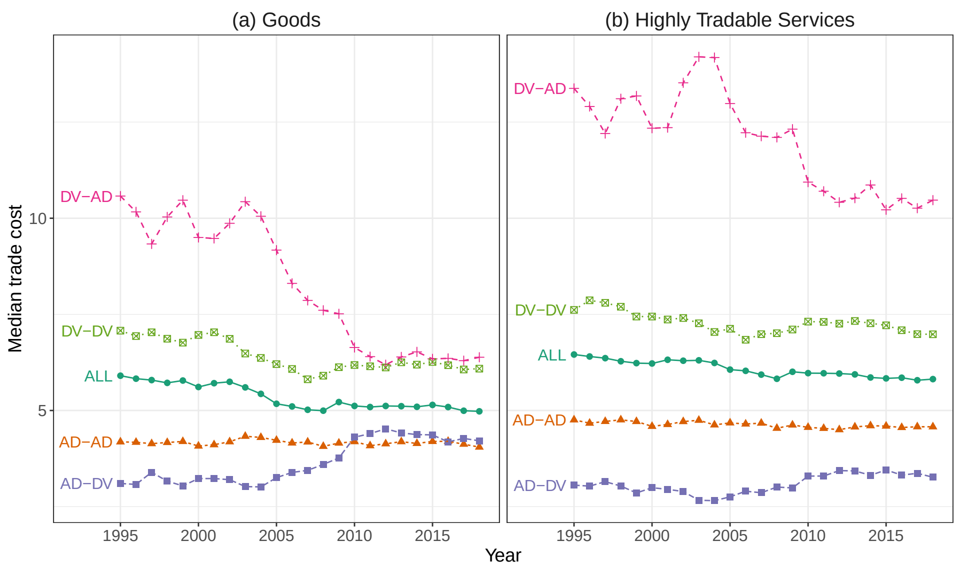
where $\bar{c}^k = \left(\eta^k\right)^{\frac{\eta^k - \theta^k - 1}{\eta^k - 1}} \left(\frac{\eta^k}{\eta^k - 1}\right)^{-\theta^k} \left(-\frac{\theta^k}{\eta^k - \theta^k - 1}\right)$. Then, the inversion formula is

$$\tau_{ji}^k = \left(\frac{\pi_{ji}^k}{\pi_{jj}^k}\right)^{-\frac{1}{\theta^k}} \left(\frac{P_i^k}{P_j^k}\right)^{1 - \frac{1}{\eta^k - 1}} \left(\frac{P_i^k Y_i^k}{P_j^k Y_j^k}\right)^{\frac{1}{\eta^k - 1} - \frac{1}{\theta^k}} \left(\frac{f_{ji}^k}{f_{jj}^k}\right)^{\frac{1}{\eta^k - 1} - \frac{1}{\theta^k}}.$$

Unlike the previous gravity models, the inversion formula requires an estimate of another elasticity (η^k) and additional data on sectoral expenditures and fixed costs. Given the elasticities, θ^k and η^k, if the relative fixed costs $\left(\frac{f_{ji}^k}{f_{jj}^k}\right)$ are known, then, with sectoral expenditure data, which the dataset for this paper already includes, the trade costs can be recovered.

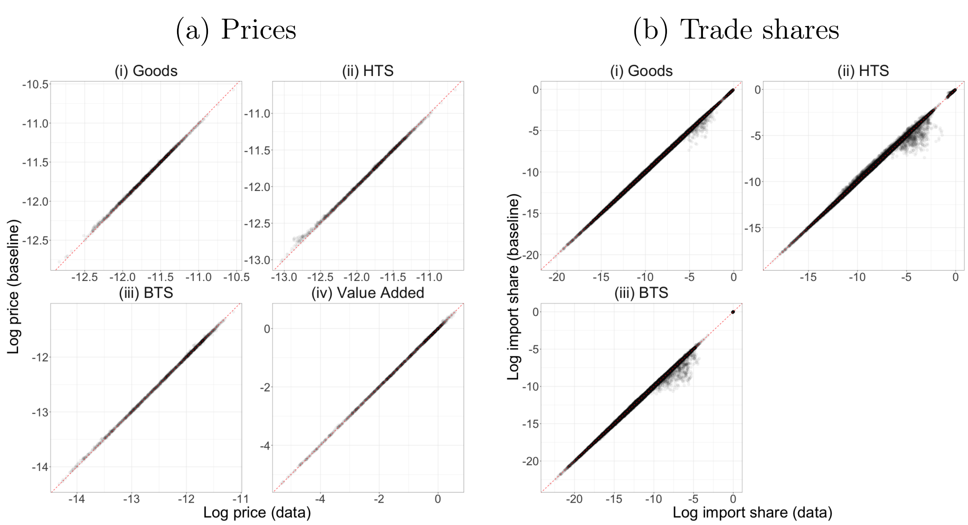
O.B Additional Figures and Tables

Figure O.B1: Median Trade Costs by Country-group Pairs from 1995 to 2018



* Note: The increase in median trade costs from advanced to developing economies in both sectors from around 2008 partly reflects the slowdown of global trade after the 2008 Financial Crisis.

Figure O.B2: Model Fit (Prices and Trade Shares)



* Note: The figure compares the prices and trade shares from the data, which are the inputs for the model inversion, with those in the equilibrium of the baseline model. Each point represents a country-year in Panel (a) and an origin-destination-year in Panel (b). The points that deviate more from the 45-degree lines are due to the adjustment of below-one trade costs. For prices, the numeraire is $W_{us,t}$.

Table O.B1: Summary Statistics for the Decomposition of Structural Transformation into Four Mechanisms (Cutoff = 3 p.p., Nobs. = 62)

Effects	Mean	Q1	Q2	Q3
Income	-9.6	-18.8	-3.4	5.6
Price	49.8	12.6	36.5	81.8
Net-export	39.3	6.7	51.9	72.1
Input-output	20.5	7.2	15.7	35.3

* Note: The contributions are in percentages.

Table O.B2: Summary Statistics for the Decomposition of Structural Transformation into Four Mechanisms (Cutoff = 5 p.p., Nobs. = 34)

Effects	Mean	Q1	Q2	Q3
Income	-0.2	-11.0	-1.2	9.5
Price	34.5	5.4	24.7	58.4
Net-export	43.6	7.7	57.2	72.3
Input-output	22.1	9.8	17.1	32.9

* Note: The contributions are in percentages.

Table O.B3: Summary Statistics for the Decomposition of Structural Transformation into Globalization and Productivity Growth (Cutoff = 3 p.p., Nobs. = 62)

Type	Effects	Mean	Q1	Q2	Q3
Globalization	Income	-8.1	-5.3	-1.3	0.4
	Price	4.9	-4.2	2.7	15.0
	Net-export	115.5	23.9	64.1	122.6
	Input-output	1.3	0.7	1.6	2.8
	Total	113.6	34.1	69.4	127.9
Productivity growth	Income	-0.7	-14.0	-0.2	16.9
	Price	45.9	8.3	38.4	71.4
	Net-export	-78.0	-82.0	-28.2	21.4
	Input-output	19.3	5.5	14.8	33.9
	Total	-13.6	-27.9	30.6	65.9

* Note: The contributions are in percentages.

Table O.B4: Summary Statistics for the Decomposition of Structural Transformation into Globalization and Productivity Growth (Cutoff = 5 p.p., Nobs. = 34)

Type	Effects	Mean	Q1	Q2	Q3
Globalization	Income	-4.4	-2.5	-0.5	1.3
	Price	5.9	-4.0	1.0	12.0
	Net-export	93.1	23.9	64.1	108.8
	Input-output	1.8	0.9	1.5	2.6
	Total	96.5	34.1	70.6	119.8
Productivity growth	Income	8.3	-2.6	4.6	17.7
	Price	25.2	-1.8	21.7	40.0
	Net-export	-50.4	-62.9	-24.3	18.8
	Input-output	20.4	7.5	15.6	31.3
	Total	3.5	-19.8	29.4	65.9

* Note: The contributions are in percentages.

Table O.B5: Globalization's Impact on Structural Transformation (Model with Non-tradable Services)

Country	G	HTS	BTS	Country	G	HTS	BTS	Country	G	HTS	BTS	Country	G	HTS	BTS
ARG	-0.2	0.1	0.1	FRA	-0.3	0.1	0.2	MAR	-0.8	0.3	0.5	TUN	-0.6	0.3	0.4
AUS	-0.2	0.1	0.1	GBR	-0.1	0.0	0.0	MEX	-0.9	0.4	0.5	TUR	-0.5	0.3	0.3
AUT	-0.5	0.2	0.3	GRC	-0.4	0.2	0.2	MLT	-0.4	0.2	0.2	TWN	-0.8	0.3	0.4
BEL	-0.2	0.1	0.1	HKG	-0.3	0.0	0.3	MMR	-0.3	0.2	0.1	USA	-0.1	0.0	0.0
BGR	-1.1	0.4	0.7	HRV	-0.4	0.2	0.2	MYS	0.2	-0.1	-0.1	VNM	-1.6	1.0	0.6
BRA	-0.2	0.1	0.1	HUN	-2.0	0.7	1.3	NLD	-0.3	0.1	0.2	ZAF	-0.3	0.1	0.2
BRN	0.3	-0.2	-0.1	IDN	-0.0	0.0	0.0	NOR	-0.2	0.1	0.1	ROW	-0.3	0.1	0.1
CAN	-0.1	0.0	0.0	IND	-0.3	0.1	0.2	NZL	-0.1	0.1	0.1				
CHE	-0.3	0.2	0.2	IRL	-0.9	0.4	0.5	PER	-0.5	0.3	0.2				
CHL	-0.3	0.1	0.2	ISL	-0.4	0.1	0.2	PHL	-0.2	0.1	0.1				
CHN	-0.2	0.1	0.1	ISR	-0.1	0.0	0.1	POL	-0.9	0.4	0.5				
COL	-0.1	0.0	0.1	ITA	-0.2	0.1	0.1	PRT	-0.5	0.2	0.3				
CRI	-0.3	0.1	0.2	JPN	-0.3	0.1	0.2	ROU	-0.6	0.2	0.3				
CYP	0.5	-0.2	-0.3	KAZ	-0.1	0.1	0.0	RUS	-0.1	0.0	0.0				
CZE	-1.3	0.5	0.7	KHM	-1.0	0.6	0.4	SAU	-0.0	0.0	0.0				
DEU	-0.5	0.2	0.3	KOR	-0.5	0.2	0.3	SGP	-0.3	0.1	0.1				
DNK	-0.3	0.1	0.2	LAO	-0.7	0.4	0.3	SVK	-1.7	0.7	1.0				
ESP	-0.4	0.1	0.2	LTU	-1.1	0.5	0.6	SVN	-1.1	0.5	0.6				
EST	-0.8	0.3	0.4	LUX	-0.0	0.0	0.0	SWE	-0.3	0.1	0.2				
FIN	-0.2	0.1	0.1	LVA	-0.6	0.2	0.4	THA	-0.5	0.3	0.2				

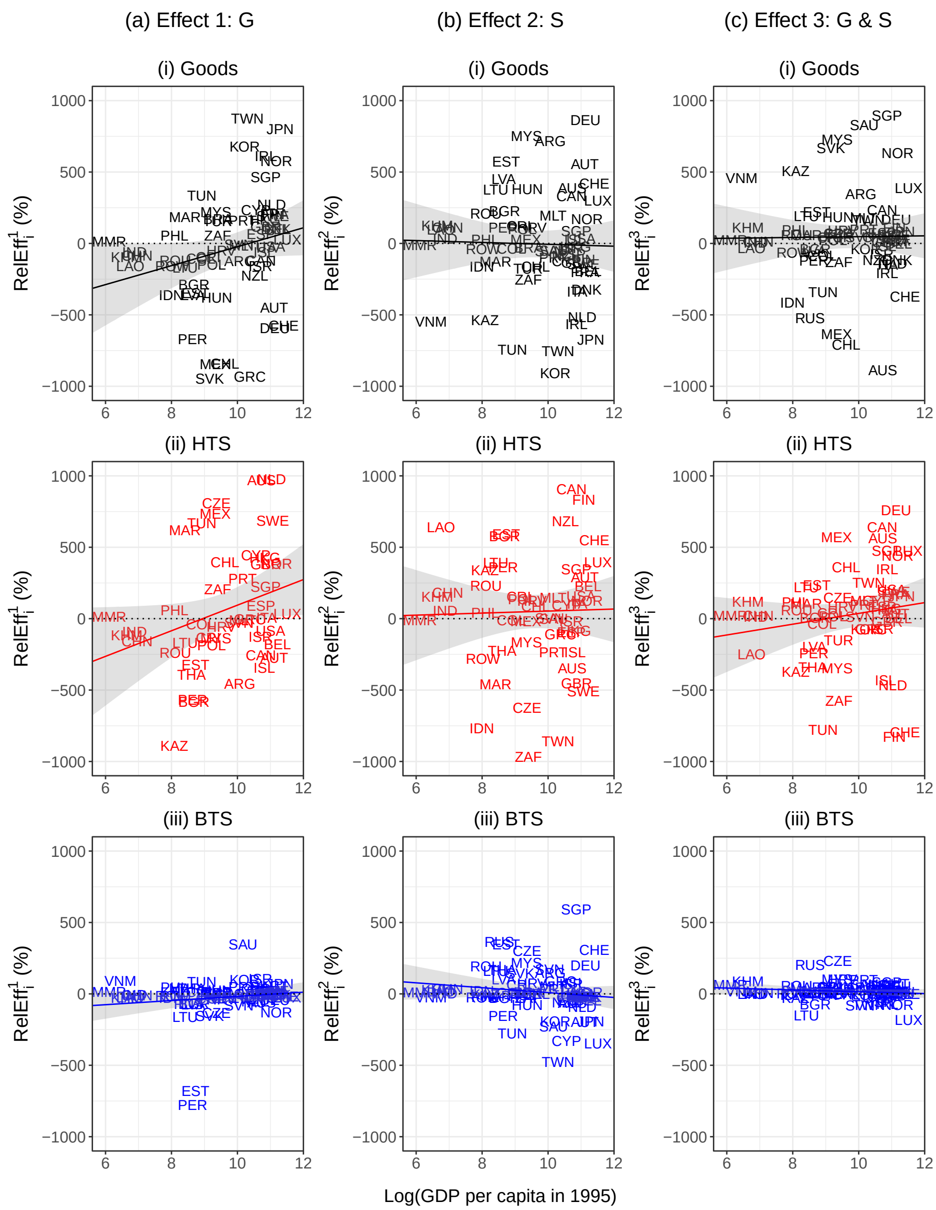
* Note: G, HTS, and BTS denote each element of $(Effect)_i^3$. Units are in percentage points.

Table O.B6: Full Results for 66 Countries + ROW

							Data				Baseline				C1		C2		C3	
							1995		2018		1995		2018		2018		2018		2018	
	Country	GDP	Dev	T(G)	T(HTS)	Index	G	HTS	G	HTS	G	HTS	G	HTS	G	HTS	G	HTS	G	HTS
1	USA	20.6	N	-0.28	-0.55	0.27	22	39	16	44	21	41	17	42	17	43	19	41	19	41
2	CHN	13.9	Y	-1.67	-1.96	0.30	57	24	42	32	56	25	45	30	36	39	57	20	47	29
3	JPN	5.0	N	1.75	1.41	0.34	30	37	26	39	28	39	27	39	42	25	14	50	28	38
4	DEU	4.0	N	0.44	0.53	-0.08	28	34	27	37	26	37	27	36	34	30	17	45	25	38
5	GBR	2.9	N	0.16	0.22	-0.06	23	39	15	45	20	42	17	43	21	40	12	47	17	43
6	FRA	2.8	N	0.42	0.41	0.01	23	38	16	42	20	40	17	40	24	35	12	46	18	40
7	IND	2.8	Y	-0.94	-0.68	-0.26	52	22	39	31	48	25	40	30	35	35	43	27	41	30
8	ITA	2.1	N	-0.11	-0.05	-0.06	28	39	23	40	25	40	24	39	24	39	22	40	23	40
9	BRA	1.9	Y	-0.57	-0.43	-0.14	28	34	26	37	27	34	29	34	26	37	30	33	28	35
10	CAN	1.7	N	-0.36	-0.95	0.58	28	33	21	38	26	35	23	36	19	39	33	26	30	29
11	KOR	1.7	N	0.59	0.34	0.25	35	34	33	35	34	35	33	36	41	28	22	45	33	36
12	RUS	1.7	Y	-1.64	-1.01	-0.63	36	37	36	34	36	36	35	36	17	54	47	28	30	43
13	AUS	1.4	N	-0.94	-0.50	-0.44	25	40	21	40	23	41	23	40	17	45	24	38	19	43
14	ESP	1.4	N	0.03	-0.05	0.08	26	40	20	42	23	40	21	41	23	40	20	42	23	40
15	MEX	1.2	Y	-0.71	-0.17	-0.54	33	37	29	41	32	39	31	38	22	46	31	38	25	44
16	IDN	1.0	Y	-1.07	-0.06	-1.01	50	32	44	32	47	33	45	34	36	42	41	38	34	44
17	NLD	0.9	N	0.12	0.16	-0.05	25	41	18	47	21	45	20	46	22	43	15	50	19	47
18	SAU	0.8	Y	-2.04	-0.19	-1.85	48	18	46	21	46	21	49	19	15	51	51	19	23	45
19	TUR	0.8	Y	0.66	0.56	0.09	41	36	32	39	38	38	33	38	40	31	24	46	35	37
20	CHE	0.7	N	0.14	-0.04	0.17	25	42	22	45	23	45	24	44	29	40	20	47	27	41
21	POL	0.6	Y	-0.61	-0.60	-0.01	36	33	28	43	34	37	28	41	20	49	34	36	30	41
22	SWE	0.6	N	0.43	0.28	0.15	30	32	20	41	28	37	22	38	32	29	15	45	26	36
23	TWN	0.6	N	1.39	0.71	0.67	33	37	34	38	34	37	31	39	56	13	10	57	36	33
24	ARG	0.5	Y	0.04	0.83	-0.79	41	34	31	37	34	35	35	35	37	33	25	44	30	39
25	AUT	0.5	N	0.21	0.26	-0.05	27	37	24	40	25	40	26	38	32	32	19	44	26	39
26	BEL	0.5	N	-0.00	0.04	-0.04	26	38	18	45	23	42	21	41	23	39	17	43	21	41
27	THA	0.5	Y	-0.46	-0.19	-0.27	44	39	43	38	42	38	43	40	37	45	37	43	38	44
28	DNK	0.4	N	-0.04	0.20	-0.24	24	36	19	40	23	38	21	38	23	36	15	43	19	40
29	HKG	0.4	N	1.52	0.43	1.10	11	55	3	60	10	54	2	57	15	47	1	58	7	55
30	IRL	0.4	N	-0.82	-1.16	0.34	30	39	37	42	30	42	33	43	11	65	54	23	41	39
31	ISR	0.4	N	-0.44	-0.19	-0.25	24	32	17	41	21	37	19	39	16	43	18	40	17	41
32	MYS	0.4	Y	-0.62	0.12	-0.73	38	31	39	34	36	31	38	34	33	38	23	39	23	44
33	NOR	0.4	N	-0.86	0.11	-0.96	31	34	30	31	30	33	32	30	18	44	28	34	16	46
34	SGP	0.4	N	0.12	-0.43	0.56	26	51	20	56	22	53	21	56	27	50	22	47	33	43
35	ZAF	0.4	Y	-0.16	0.45	-0.61	31	32	25	36	29	35	27	35	28	34	20	42	23	39
36	CHL	0.3	Y	-0.70	-0.19	-0.51	34	31	28	37	32	36	32	35	25	41	30	36	26	40
37	COL	0.3	Y	-0.22	-0.16	-0.06	33	32	30	35	33	32	32	34	31	35	32	34	31	35
38	FIN	0.3	N	0.55	0.19	0.36	32	31	24	34	30	33	25	32	36	22	19	37	31	27
39	PHL	0.3	Y	0.00	-0.58	0.58	44	33	41	38	46	34	35	42	41	37	38	38	45	32
40	CZE	0.2	N	-0.78	-0.83	0.06	36	34	32	37	33	37	34	35	19	49	47	25	34	38
41	GRC	0.2	N	-0.13	0.15	-0.28	24	40	19	42	22	39	22	41	22	41	18	43	20	42
42	HUN	0.2	Y	-0.10	-0.58	0.48	35	32	29	38	32	36	31	36	24	43	37	28	34	33
43	KAZ	0.2	Y	-1.44	-0.90	-0.55	39	36	34	40	34	37	36	40	10	65	45	30	27	50
44	NZL	0.2	N	-0.66	-0.31	-0.35	30	37	21	39	26	39	24	39	19	43	22	39	21	41
45	PER	0.2	Y	-0.65	-0.54	-0.12	43	31	35	37	39	34	38	34	30	38	40	32	37	36
46	PRT	0.2	N	0.17	0.04	0.12	27	37	21	41	25	39	23	40	26	37	21	42	25	39
47	ROU	0.2	Y	-1.25	-1.66	0.41	50	27	30	38	46	30	33	36	18	50	60	22	41	32
48	VNM	0.2	Y	-2.48	-1.61	-0.86	58	24	57	26	54	27	56	27	17	64	70	13	44	38
49	BGR	0.1	Y	-1.24	-0.99	-0.25	27	33	26	43	35	36	29	38	14	51	42	25	27	38
50	CRI	0.1	Y	-0.52	-0.76	0.25	38	34	21	42	34	34	26	39	18	46	36	31	29	37
51	HRV	0.1	Y	-0.33	-0.44	0.11	34	34	25	43	31	37	26	41	23	43	32	37	31	38
52	LTU	0.1	N	-1.19	-2.29	1.10	36	30	25	45	34	34	25	43	10	57	59	10	43	24
53	LUX	0.1	N	-0.05	-1.08	1.03	16	51	8	62	15	54	8	60	10	58	30	35	36	31
54	MAR	0.1	Y	0.61	0.33	0.28	38	30	39	27	43	27	36	28	48	18	28	36	40	26
55	MMR	0.1	Y	-0.29	-0.18	-0.11	65	21	62	23	65	19	56	27	58	26	56	28	59	25
56	SVK	0.1	N	-0.71	-1.57	0.86	33	32	29	38	32	36	30	37	15	51	54	15	41	27
57	SVN	0.1	N	0.05	-0.05	0.10	34	34	29	40	32	36	30	38	30	38	30	38	31	38
58	BRN	0.0	Y	-1.91	0.50	-2.41	65	18	61	18	54	22	63	18	17	61	47	32	6	68
59	CYP	0.0	N	0.36	0.24	0.12	18	47	11	52	15	48	11	50	20	41	6	48	13	47
60	EST	0.0	N	-0.95	-1.42	0.47	30	33	24	41	30	37	26	40	11	53	50	17	35	31
61	ISL	0.0	N	-0.35	-0.04	-0.31	29	34	19	40	28	37	21	38	16	42	23	41	19	43
62	KHM	0.0	Y	-0.53	-0.76	0.23	58	24	56	25	59	25	54	29	50	33	60	23	60	24
63	LAO	0.0	Y	-0.87	-0.78	-0.09	49	31	45	27	51	29	47	30	40	35	51	26	46	31
64	LVA	0.0	N	-1.62	-1.35	-0.27	35	35	20	43	27	43	22	44	6	58	42	27	20	47
65	MLT	0.0	N	-0.16	-1.14	0.98	27	43	11	62	22	45	12	61	10	62	33	37	31	40
66	TUN	0.0	Y	0.38	0.94	-0.56	38	35	32	37	36	35	33	36	42	28	13	52	24	45
67	ROW	6.0	Y	-0.39	-0.29	-0.10	45	28	44	29	46	28	44	28	41	31	43	29	43	30

* Note: "GDP" is 2018 nominal GDP of a country in trillion dollars. "Dev" indicates whether a country is a developing country. "T(G)" and "T(HTS)" denote log growth rates of the ratio of export trade costs to import trade costs for goods and highly tradable services, respectively, from 1995 to 2018. "Index" denotes the Globalization Bias Index. The GDP shares are expressed as percentages. "C1," "C2," and "C3" denote counterfactuals #1, #2, and #3. The counterfactuals and the baseline exhibit the same production shares in 1995.

Figure O.B3: GDP per Capita and the Effects of Globalization in Relative Effects

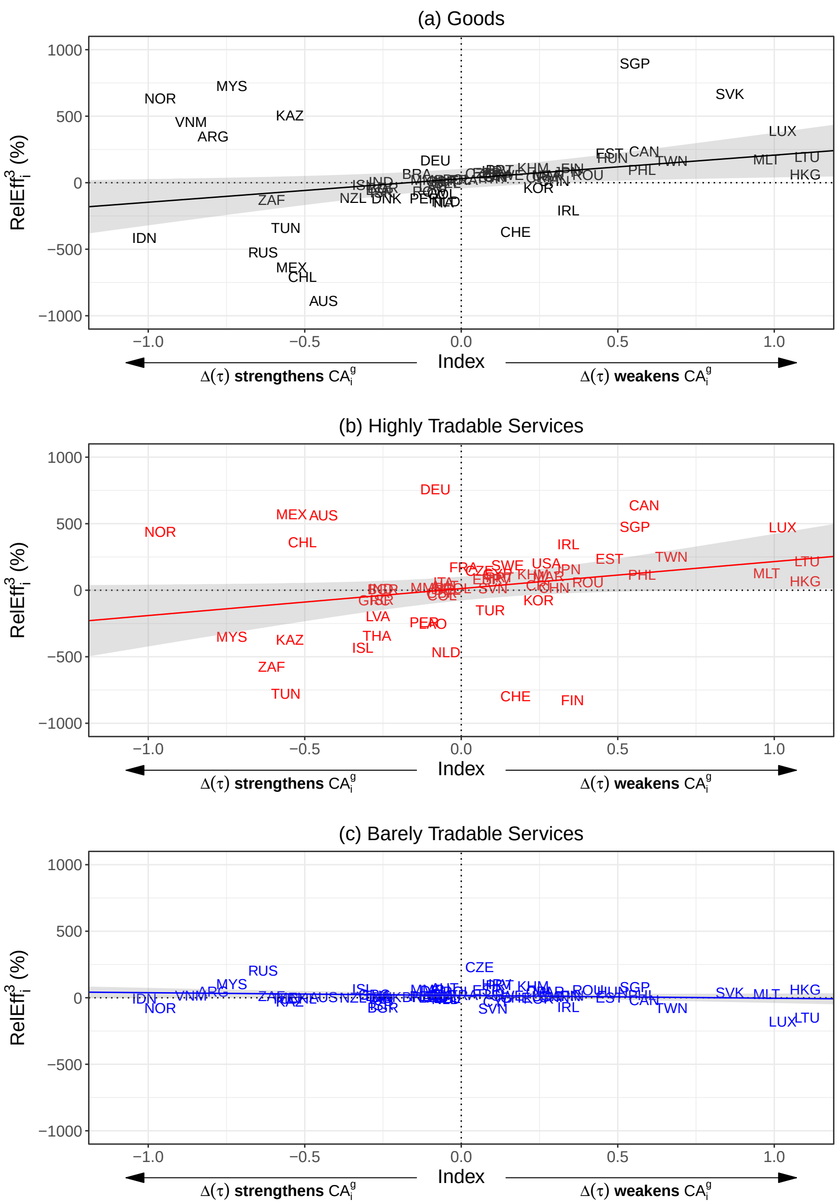


* Note: This figure repeats the exercise in Figure 7 with relative effects. Figure 7 reports the effects in absolute terms (percentage points), whereas this figure presents the contribution of globalization to structural transformation in percent. Specifically, the relative effect, measured by contrasting the baseline with counterfactual $\#c$, is defined as follows.

$$(RelEff)_i^c = \left\{ \Delta_t \left(\frac{L_{i,t}^g}{L_{i,t}}, \frac{L_{i,t}^{hts}}{L_{i,t}}, \frac{L_{i,t}^{bts}}{L_{i,t}} \right) - \Delta_t \left(\frac{\overline{L}_{i,t}^{g,c}}{L_{i,t}}, \frac{\overline{L}_{i,t}^{hts,c}}{L_{i,t}}, \frac{\overline{L}_{i,t}^{bts,c}}{L_{i,t}} \right) \right\} \Big/ \Delta_t \left(\frac{L_{i,t}^g}{L_{i,t}}, \frac{L_{i,t}^{hts}}{L_{i,t}}, \frac{L_{i,t}^{bts}}{L_{i,t}} \right).$$

Importantly, the sign of $(RelEff)_i^c$ cannot be interpreted directly as indicating whether globalization accelerated or decelerated the transformation. For example, a positive relative effect on the goods share of GDP implies acceleration if the baseline change is negative, and deceleration otherwise.

Figure O.B4: Main Results in Relative Effects



* Note: This figure repeats the exercise in Figure 8 with relative effects. For the definition of $(RelEff)_i^3$, see the note of the previous figure. Importantly, the sign of $(RelEff)_i^3$ cannot be interpreted directly as indicating whether globalization accelerated or decelerated the transformation. For example, a positive relative effect on the goods share of GDP implies acceleration if the baseline change is negative, and deceleration otherwise.

O.C Data Construction

O.C.1 Input-Output Tables from the OECD ICIO

This section outlines how I make adjustments to the multi-region input-output tables from the OECD ICIO so that the tables meet the model assumptions. First, since the model abstracts away from investment, all consumption and investment variables in the data are merged into a single consumption term.

Second, I condense the input-output tables into three aggregate sectors.

Third, since there are no taxes and subsidies in the model, I convert the original tables measured in basic prices into the tables under purchaser's prices. This process ensures that aggregate and sectoral GDPs do not change and that the two key input-output table identities are satisfied (a country-sector's output volume = sum of the input volumes used by the country-sector, and GDP in production = GDP in expenditure). The conversion is done in the following ways. TAXSUB, the variable denoting taxes less subsidies, on a country-sector's intermediate consumption is allocated to the value-added of the country-sector. TAXSUB on the final consumption of the households of a country is allocated to itself (column-wise adjustment) and to the value-added of the domestic and foreign country-sectors whose output comprises the final consumption (row-wise adjustment). Since the OECD ICIO does not provide information of which producing country-sector the TAXSUB is imposed on, I assume proportionality. For example, hypothetically, if half of country a's final consumption on goods comes from country b, I allocate half of TAXSUB of country a's goods consumption to country-b's goods sector.

O.C.2 Construction of Prices

This section lays out the process to construct the gross-output price levels for a country-sector. First, I describe how I add up price deflators of industries that belong to each of the three broad sectors (goods, highly and barely tradable services). Second, I show the data availability of price deflators for each country. Third, I discuss how I construct price deflators for countries whose sectoral details on prices are missing. Fourth, I demonstrate how I impute gross-output price deflator from value-added price deflator, if the former are not available. Fifth, I discuss how I obtain cross-country price levels. Lastly, I discuss how I impute the prices for the ROW.

(i) Aggregation of Price Deflators for Industries

Chain-linked quantities are not additive. Therefore, to aggregate quantities of industries into three broad sectors, I use the aggregation method laid out in Whelan (2002) for the chain-linked Fisher index. For the chain-linked Laspeyres index, I use the method from Annex 6 of Horvát and Webb (2020), which provides the Laspeyres version of the method by Whelan (2002). After aggregating the industry prices and quantities into those of three broad sectors, I assume that the sectoral prices are additive.

(ii) Availability of Price Deflators

The price notion most coherent with the model structure is gross output prices. However, not all countries report gross-output price deflators (GOPD). For countries without GOPD, I utilize the information from value-added price deflators (VAPD). Table O.C1 lays out the availability of each country's price deflator data. STAN (GO) and STAN (VA) denote the availability for the GOPD and VAPD from the OECD Structural Analysis database (STAN). They offer industry details that can be easily mapped to the three broad sectors. As for Taiwan, National Statistics of the Republic of China offers VAPD with the equivalent level of industry details.

For the other countries, I obtained their VAPD from the UN National Accounts (UN NA). UA NA data are obtained from the UN Statistical Data and Metadata eXchange (SDMX) and the UN Analysis of Main Aggregates (AMA). The former (SDMX) provides more disaggregated industry details than the latter.

(iii) Imputing Value-added Price Deflators for Three Sectors when Industry Details are Not Available

One issue with the UN NA data is that they do not offer industry level disaggregation detailed enough to be matched directly to the three broad sectors. For example, in the UN NA, ISIC Rev. 4 industries R (Arts, entertainment and recreation), S (Other service activities), T (Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use), and U (Activities of extraterritorial organizations and bodies) are reported in an aggregated fashion. Since industry R belongs to highly tradable services, and industries S, T, and U to barely tradable services, I need to separate the data items into the part coming from R and that from S, T, and U. In this case, I assume that the prices for R and those

Table O.C1: Availability of Price Deflators

		STAN (GO)		STAN (VA)		UN NA SDMX		UN NA AMA	
	Country	Start	End	Start	End	Start	End	Start	End
1	ARG							1995	2018
2	AUS					1995	2018	1995	2018
3	AUT	1995	2018	1995	2018	1995	2018	1995	2018
4	BEL	1995	2018	1995	2018	1995	2018	1995	2018
5	BGR					1995	2018	1995	2018
6	BRA					2000	2018	1995	2018
7	BRN							1995	2018
8	CAN					1997	2017	1995	2018
9	CHE	1997	2017	1997	2017	1997	2018	1995	2018
10	CHL					1996	2018	1995	2018
11	CHN					1995	2018	1995	2018
12	COL					2005	2018	1995	2018
13	CRI					1995	2018	1995	2018
14	CYP					1995	2018	1995	2018
15	CZE	1995	2018	1995	2018	1995	2018	1995	2018
16	DEU	1995	2018	1995	2018	1995	2018	1995	2018
17	DNK	1995	2018	1995	2018	1995	2018	1995	2018
18	ESP			1995	2018	1995	2018	1995	2018
19	EST	1995	2018	1995	2018	1995	2018	1995	2018
20	FIN	1995	2018	1995	2018	1995	2018	1995	2018
21	FRA	1995	2018	1995	2018	1995	2018	1995	2018
22	GBR			1995	2018	1995	2018	1995	2018
23	GRC	1995	2018	1995	2018	1995	2018	1995	2018
24	HKG							1995	2018
25	HRV					1995	2018	1995	2018
26	HUN	1995	2018	1995	2018	1995	2018	1995	2018
27	IDN					2010	2018	1995	2018
28	IND					2011	2017	1995	2018
29	IRL			1995	2018	1995	2018	1995	2018
30	ISL			1995	2018	1995	2018	1995	2018
31	ISR					1995	2018	1995	2018
32	ITA	1995	2017	1995	2018	1995	2018	1995	2018
33	JPN					1995	2018	1995	2018
34	KAZ							1995	2018
35	KHM							1995	2018
36	KOR					1995	2018	1995	2018
37	LAO							1995	2018
38	LTU			1995	2018	1995	2018	1995	2018
39	LUX	1995	2018	1995	2018	1995	2018	1995	2018
40	LVA	1995	2018	1995	2018	1995	2018	1995	2018
41	MAR							1995	2018
42	MEX	1995	2018	1995	2018	1995	2018	1995	2018

(Continued in the next page)

	Country	STAN (GO) Start	STAN (GO) End	STAN (VA) Start	STAN (VA) End	UN NA SDMX Start	UN NA SDMX End	UN NA AMA Start	UN NA AMA End
(Continued from the previous page)									
43	MLT					1995	2018	1995	2018
44	MMR							1995	2018
45	MYS							1995	2018
46	NLD	1995	2018	1995	2018	1995	2018	1995	2018
47	NOR	1995	2018	1995	2017	1995	2018	1995	2018
48	NZL					1995	2018	1995	2018
49	PER							1995	2018
50	PHL							1995	2018
51	POL	1995	2018	1995	2018	1995	2018	1995	2018
52	PRT	1995	2017	1995	2018	1995	2018	1995	2018
53	ROU					1995	2018	1995	2018
54	RUS					2011	2018	1995	2018
55	SAU					1995	2018	1995	2018
56	SGP							1995	2018
57	SVK	1995	2016	1995	2018	1995	2018	1995	2018
58	SVN			1995	2018	1995	2018	1995	2018
59	SWE	1995	2018	1995	2018	1995	2018	1995	2018
60	THA							1995	2018
61	TUN							1995	2018
62	TUR					1998	2018	1995	2018
63	TWN								
64	USA	1997	2018	1995	2018	1997	2018	1995	2018
65	VNM							1995	2018
66	ZAF					1995	2018	1995	2018

* Note: Price deflators for Taiwan are obtained from National Statistics of the Republic of China (Taiwan).

for S, T, and U are equal. To split the volumes of the aggregated industries (R to U) into two parts (S and T to U), I use nominal value-added outputs observed in the OECD ICIO as weights.

Despite this assumption, the imputed price deflators are good proxies for the actual price deflators. I show this by comparing imputed VAPDs from the UN data compares with actual VAPD from the OECD STAN for the countries where data are available in both datasets.

In this appendix, to compare the performance of imputed prices to actual prices, I utilize the following three measures. Let $\vec{P}^k_{ACT,i}$ and $\vec{P}^k_{IMP,i}$ denote the vector (time series) of actual and imputed prices for country i sector k.

1. Correlation: $cor(\vec{P}^k_{ACT,i}, \vec{P}^k_{IMP,i})$
2. Root-mean-square error: $RMSE(\vec{P}^k_{ACT,i}, \vec{P}^k_{IMP,i}) \equiv \sqrt{\frac{1}{t_e - t_s + 1}\sum_{t=t_s}^{t_e}\left(P^k_{ACT,i,t} - P^k_{IMP,i,t}\right)^2}$, where t_s and

Table O.C2: Summary Statistics for the Three Metrics for VAPD (OECD STAN) vs Imputed VAPD from the UN SDMX and the UN AMA

			Correlation		RMSE		Reg. coef.	
	Ind	Stats	SDMX	AMA	SDMX	AMA	SDMX	AMA
1	G	Mean	0.99	0.98	0.01	0.02	1.00	1.01
2	G	Q1	1.00	0.97	0.00	0.01	1.00	1.00
3	G	Q2	1.00	1.00	0.00	0.01	1.00	1.00
4	G	Q3	1.00	1.00	0.01	0.02	1.00	1.01
5	HTS	Mean	1.00	0.99	0.01	0.03	1.00	1.02
6	HTS	Q1	1.00	0.99	0.00	0.02	1.00	1.00
7	HTS	Q2	1.00	1.00	0.00	0.03	1.00	1.02
8	HTS	Q3	1.00	1.00	0.01	0.04	1.00	1.03
9	BTS	Mean	1.00	1.00	0.01	0.03	1.00	1.00
10	BTS	Q1	1.00	1.00	0.00	0.02	1.00	0.99
11	BTS	Q2	1.00	1.00	0.00	0.02	1.00	1.00
12	BTS	Q3	1.00	1.00	0.01	0.03	1.00	1.02

* Note: "Correlation-SDMX" denotes the summary statistics for the correlation between the VAPD from OECD STAN and VAPD from the UN SDMX. Other columns follow symmetric definitions. For column "Ind", G, HTS, and BTS denote goods, highly tradable services, and barely tradable services, respectively. Q1, Q2, and Q3 denote first, second, and third quartiles, respectively.

t_e represent the start and end years of the time series, respectively.

3. Regression coefficient β_1 from regressing $\vec{P}^k_{ACT,i}$ on $\vec{P}^k_{IMP,i}$ (Note: Regressions are done without intercepts.)

Higher correlation, lower RMSE, and the regression coefficient closer to one imply higher performance as a proxy. Correlation captures the directional movements, and RMSE and the regression coefficients complement the correlation measure by examining the level-wise similarity across two price sequences. Table O.C2 illustrates the performance of imputed VAPD from the UN NA.

(iv) Construction of Gross-Output Price Deflators

I construct GOPD through the following procedures.

1. For country-sector-years where GOPD data is available from OECD STAN, use GOPD.
2. For country-sector-years without GOPD data, impute GOPD from VAPD.

3. After obtaining GOPD in local currencies from data and imputation, adjust for the nominal exchange rate fluctuations.

To impute GOPD from VAPD, it is necessary to first discuss the double deflation method. To construct VAPD, U.S. Bureau of Economic Analysis (BEA) uses the method, where they deflate outputs using output prices and inputs using input prices (Mayerhauser and Strassner 2010). Half of the G20 countries use the double deflation method, and it provides a more accurate measure of value-added prices than the single deflation method (see Alexander et al. (2017) for details).

Since the double deflation method calculates the price and volume of value added from the price and volume data on gross output, I use the inverse of the deflation method to derive GOPD from VAPD and the volume data on value added and gross outputs. I apply this strategy to countries that use double deflation method and only report VAPD—as for countries that use single deflation, their VAPD and GOPD are equal by definition.

The double deflation method in the three sector setting, assuming the additivity of prices, is given by the following. For $k \in \mathcal{S} \equiv \{g, hts, bts\}$, the price deflator for intermediate inputs,

$$P^k_{INT,i,t} = \frac{\sum_{h\in\mathcal{S}} X^{hk}_{i,t}}{\sum_{h\in\mathcal{S}} Q^{hk}_{i,t}}, \tag{O.C1}$$

where $X^{hk}_{i,t}$ and $Q^{hk}_{i,t}$ denote nominal and real sector-h intermediate usage in sector-k production. (Note that $X^{hk}_{i,t} = P^h_{i,t} Q^{hk}_{i,t}$.) Then, the quantity index for the sector-k value added,

$$Q^k_{VA,i,t} = \frac{X^k_{i,t}}{P^k_{i,t}} - \frac{X^k_{INT,i,t}}{P^k_{INT,i,t}}, \tag{O.C2}$$

where $X^k_{INT,i,t} = \sum_{h\in\mathcal{S}} X^{hk}_{i,t}$, and $X^k_{i,t}$ and $P^k_{i,t}$ denote the nominal output and gross-output price of sector k. From the value-added quantity, $Q^k_{VA,i,t}$ and nominal value added, $X^k_{VA,i,t}$, one can derive the VAPD, $P^k_{VA,i,t}$.

In Equations (O.C1) and (O.C2), data observables are $\{X^{hk}_{i,t}\}_{h,k\in\mathcal{S}}$, $\{X^k_{i,t}\}_{k\in\mathcal{S}}$ (from the input-output tables) and $\{Q^k_{VA,i,t}\}_k$ (quantity derived from value-added volume and VAPD), and I find $\{P^k_{i,t}\}_{k\in\mathcal{S}}$ and $\{Q^{hk}_{i,t}\}_{h,k\in\mathcal{S}}$ that are consistent with the equations. In essence, this is deriving three GOPDs from three VAPDs using three equations.

I demonstrate that the imputed GOPD returns reasonable estimates for the actual GOPD. Furthermore, I show that VAPD is not a good proxy for GOPD and propose imputed GOPD as an alternative proxy that quantitatively offers a good fit with actual GOPD. I use the data from 22 countries that report both GOPD and VAPD in the OECD STAN database to study the performance of the imputed GOPD. I utilize the three measures defined earlier: correlation, RMSE, and the regression coefficient. Let $\vec{P}^k_{GO,i}$, $\vec{P}^k_{VA,i}$ and $\vec{P}^k_{IMP,i}$ denote the time series of GOPD, VAPD, and imputed GOPD for country i sector k. I compute $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{VA,i})$, $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{IMP,i})$, $RMSE(\vec{P}^k_{GO,i}, \vec{P}^k_{VA,i})$, $RMSE(\vec{P}^k_{GO,i}, \vec{P}^k_{IMP,i})$, regression coefficient β_1 from regressing $\vec{P}^k_{GO,i}$ on $\vec{P}^k_{VA,i}$, and β_2 from regressing $\vec{P}^k_{GO,i}$ on $\vec{P}^k_{IMP,i}$.

Among the 66 country-sectors (22 countries and 3 sectors), the imputed GOPD outperformed VAPD in 48, 51, and 45 country-sectors in terms of correlation, RMSE, and the regression coefficients, respectively. Table O.C3 lists summary statistics for the comparisons in the three metrics. The superior performance of imputed GOPD is most prominent for goods prices. Since value-added shares are typically lower for goods production, VAPD is not a good proxy for GOPD, as evidenced by the summary statistics, whereas the imputed GOPD shows significantly better performance. To further illustrate the point, in Table O.C4, I show the result for the country-sectors whose VAPD's performance is one of the top-10 worst in each of the three metrics. Slovakia's goods prices provide a graphical illustration (Figure O.C1).

(v) From Price Deflators to Price Levels

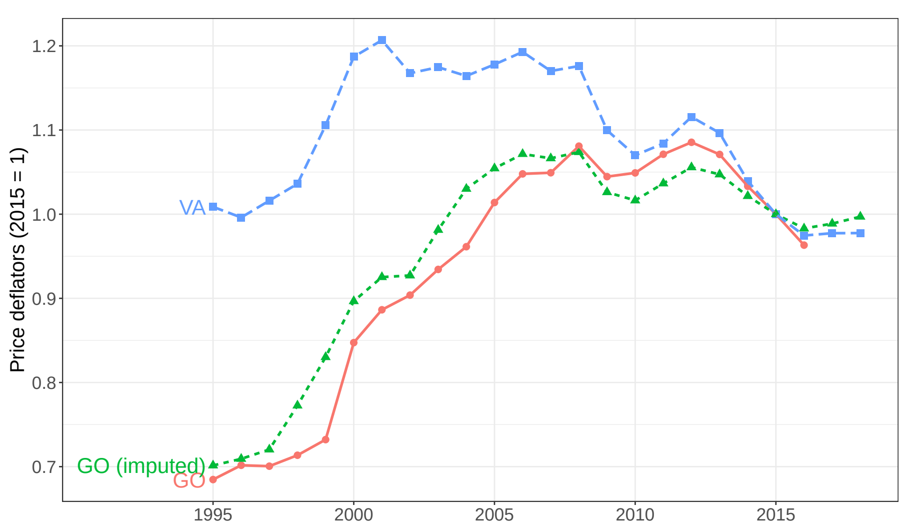
Through the procedures laid out previously, I obtained within-country over-time changes in sectoral prices. To have full price level sequences, I use the 2005 cross-country sectoral price-level data from the Productivity Level Database 2005 Benchmark (PLD 2005, Inklaar and Timmer 2014) of Groningen Growth and Development Centre (GGDC). It provides price-level information for 42 countries and 35 industries. The 35 industries are mapped into three aggregate sectors (goods, highly tradable services, and barely tradable services). For 42 countries, sectoral price levels exhibit a strong linear relationship with the income levels of countries (Figure O.C2). Using this relationship, I impute sectoral price levels for 24 countries that are not in the dataset. Specifically, for each sector, I regress price levels of the 42 countries on their log GDP per capita. Then, using the regression result and GDP per capita for the remaining 24 countries, I impute their sectoral prices.

Table O.C3: Summary Statistics for the Three Metrics for GOPD vs VAPD and GOPD vs Imputed GOPD

			Correlation		RMSE		Reg. coef.	
	Ind	Stats	VA	IMP	VA	IMP	VA	IMP
1	G	Mean	0.78	0.94	0.07	0.05	0.99	1.01
2	G	Q1	0.79	0.92	0.04	0.03	0.96	0.98
3	G	Q2	0.95	0.97	0.06	0.05	0.99	1.00
4	G	Q3	0.99	0.99	0.09	0.06	1.02	1.02
5	HTS	Mean	0.99	1.00	0.02	0.02	1.00	1.00
6	HTS	Q1	0.99	0.99	0.01	0.01	0.99	0.99
7	HTS	Q2	1.00	1.00	0.02	0.02	1.00	1.00
8	HTS	Q3	1.00	1.00	0.03	0.03	1.01	1.01
9	BTS	Mean	1.00	1.00	0.03	0.02	1.01	1.00
10	BTS	Q1	1.00	1.00	0.01	0.01	1.00	0.99
11	BTS	Q2	1.00	1.00	0.03	0.01	1.01	1.00
12	BTS	Q3	1.00	1.00	0.04	0.02	1.03	1.01

* Note: Columns "Correlation-VA" and "Correlation-IMP" denote the summary statistics for $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{VA,i})$ and $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{IMP,i})$, respectively. Other columns follow symmetric definitions. For column "Ind", G, HTS, and BTS denote goods, highly tradable services, and barely tradable services, respectively. Q1, Q2, and Q3 denote first, second, and third quartiles, respectively.

Figure O.C1: Price Deflators for Goods in Slovakia: GOPD vs VAPD vs imputed GOPD



* Note: GO, VA, GO (imputed) denote GOPD, VAPD, imputed GOPD, respectively. GOPD is not available for the last two years.

Table O.C4: Comparison between Imputed GOPD and VAPD for Select Country-sectors

			Correlation			RMSE			Reg. coef.		
	Country	Ind	VA	IMP	Improve	VA	IMP	Improve	VA	IMP	Improve
1	BEL	G	0.77	0.96	Y	0.13	0.07	Y	0.91	0.96	Y
2	CHE	BTS	0.99	1.00	Y	0.05	0.01	Y	1.04	1.01	Y
3	CHE	G	0.91	0.86	N	0.02	0.03	N	1.02	1.03	N
4	CZE	G	0.66	0.92	Y	0.06	0.03	Y	0.99	1.00	Y
5	DEU	G	0.92	0.92	Y	0.04	0.03	Y	0.99	1.00	Y
6	FIN	G	-0.49	0.67	Y	0.11	0.05	Y	0.94	0.99	Y
7	FRA	G	-0.08	0.89	Y	0.10	0.06	Y	0.95	0.97	Y
8	GRC	G	0.94	0.96	Y	0.07	0.06	Y	1.05	1.03	Y
9	HUN	G	0.99	0.99	Y	0.09	0.09	Y	1.09	1.08	Y
10	LUX	G	0.98	0.97	N	0.07	0.09	N	1.06	1.09	N
11	NOR	G	0.99	1.00	Y	0.07	0.05	Y	0.97	0.98	Y
12	PRT	G	0.87	0.90	Y	0.05	0.04	Y	1.03	1.02	Y
13	SVK	BTS	1.00	0.99	N	0.05	0.02	Y	1.04	1.01	Y
14	SVK	G	0.37	0.97	Y	0.21	0.04	Y	0.85	0.98	Y
15	SWE	G	0.48	0.87	Y	0.09	0.06	Y	0.96	0.98	Y
16	USA	G	0.97	0.97	Y	0.08	0.06	Y	0.96	0.99	Y

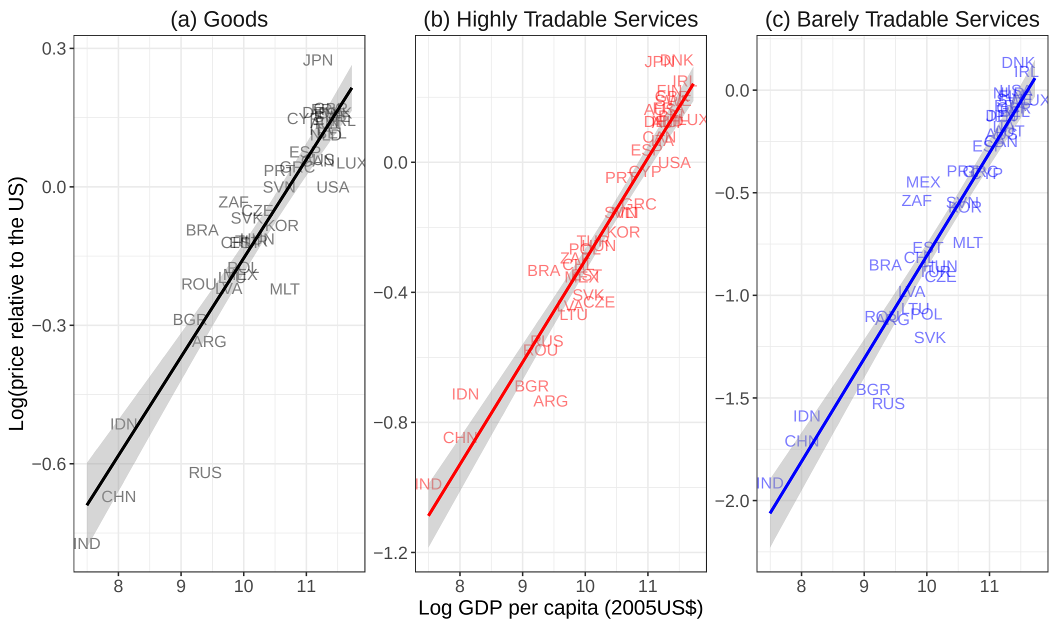
* Note: Columns "Correlation-VA" and "Correlation-IMP" denote $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{VA,i})$ and $cor(\vec{P}^k_{GO,i}, \vec{P}^k_{IMP,i})$, respectively. Column "Correlation-Improve" denotes whether the imputed GOPD outperforms the VAPD as a proxy for the actual GOPD in terms of correlation. Other columns follow symmetric definitions. For column "Ind", G and BTS denote goods and barely tradable services.

Using the 2005 cross-country sectoral price-level data and the within-country cross-time sectoral price deflator data, I construct the full sequence of prices. Note that the quantitative results of the paper are robust to this price-level conversion, because it is possible to run counterfactual exercises without price-level information following the Exact Hat Algebra of Dekle, Eaton, and Kortum (2008) (Online Appendix O.D).

(vi) Imputing Prices for the Rest-of-the-world Aggregate

Since I do not have price data for the rest-of-the-world aggregate (ROW) that accounts for approximately 7% of world GDP and 8% of world total export, I impute its prices. For each sector, I regress the logarithm of country-years' prices on the logarithm of countries' GDP per capita with a year fixed effects. Using the regres-

Figure O.C2: Sectoral Price Levels and Per-capita Income



sion result and data on ROW's GDP per capita, I impute the prices for the ROW. ROW's GDP and population are obtained from the OECD ICIO and the PWT, respectively. For ROW's population, I subtracted the population of 66 countries from the population of all sample countries in the PWT.

O.D Counterfactuals through Exact Hat Algebra

This section illustrates how I can derive the dynamics of trade costs and the structural transformation patterns in the counterfactual equilibria through the Exact Hat Algebra of Dekle, Eaton, and Kortum (2008). This approach does not require the cross-country sectoral price level data from the PLD 2005 of the GGDC. The purpose of this exercise is to mitigate concerns related to possible measurement issues in the cross-country price levels.

To briefly introduce the method, from the equilibrium conditions, (a) changes in equilibrium prices and allocations of interest are expressed in terms of (b) changes in the data observables. Then, from (b), we can infer (a). The hat notations are used to denote changes, hence the namesake. The key benefit of this method is that there is no need to obtain levels of the model primitives, relieving the data collection burden of researchers. The measurement issues related to levels can be avoided as well. These are the reasons why it is widely used in running counterfactual exercises with quantitative spatial models.

Despite these benefits, I chose to collect the price level information and fully solved the model à la Alvarez and Lucas (2007), because the level information allows me to study the globalization patterns in both levels and changes. This was how I could document the trade-cost asymmetry.

Before applying the Exact Hat Algebra, it is important to note the following two points. First, cross-country price levels do not affect the estimates of the elasticities in Section 4.1. This is because the independent and dependent variables of the estimating equations are all expressed in relative terms. In contrast, price levels do affect the estimates of utility weights ($\{\phi_i^k\}_{k\in\mathcal{S}}$) and input weights ($\{\psi_i^{Lk}, \{\psi_i^{hk}\}_{h\in\mathcal{S}}\}_{k\in\mathcal{S}}$). However, the weights do not affect the solution derived from the Exact Hat Algebra.

Second, the definition of an equilibrium (Appendix A) is not parsimonious. Since Equations (Eq.F.2), (Eq.F.3), (Eq.H.3), and (Eq.M.1) imply Equation (Eq.G.3), and Equation (Eq.G.3) implies Equation (Eq.G.4), Equations (Eq.G.3) and (Eq.G.4) are redundant for characterizing an equilibrium. Therefore, the two conditions are excluded.

The solution method is described below. To economize on notations, absorptions and revenues for country-sectors are defined as follows.

$$B_{i,t}^k \equiv P_{i,t}^k Y_{i,t}^k, \quad V_{i,t}^k \equiv \sum_{j\in\mathcal{I}} \pi_{ij,t}^k B_{j,t}^k.$$

For an arbitrary variable x_t, let $\hat{x}$ denote the change in the variable from $t = 0$ to $t = 1$, i.e., $\hat{x} \equiv \frac{x_1}{x_0}$. (Although I am using $t = 1$ and $t = 0$ to simplify notations, this method applies to any two time periods.) Now, I express the equilibrium conditions in changes.

(Absorption)
$$\widehat{B_i^k} = \widehat{P_i^k}\widehat{Y_i^k}, \quad \forall i \in \mathcal{I},\ k \in \mathcal{S}. \tag{N1}$$

(Revenue)
$$\widehat{V_i^k} = \frac{\pi_{ij,0}^k B_{j,0}^k}{V_{i,0}^k}\widehat{\pi_{ij}^k}\widehat{B_j^k}, \quad \forall i \in \mathcal{I},\ k \in \mathcal{S}. \tag{N2}$$

(Sectoral demand)
$$\frac{\widehat{P_i^k}\widehat{C_i^k}}{\widehat{P_i}\widehat{U_i}} = \left(\frac{\widehat{P_i^k}}{\widehat{P_i}}\right)^{1-\sigma} \left(\widehat{U_i}\right)^{(1-\sigma)(\epsilon^k-1)}, \quad \forall i \in \mathcal{I},\ \forall k \in \mathcal{S}. \tag{H1'}$$

(Price index) $$\widehat{P}_i = \left\{ \sum_{k \in S} \frac{P^k_{i,0} C^k_{i,0}}{P_{i,0} U_{i,0}} (\widehat{P^k_i})^{1-\sigma} \widehat{U}_i^{(1-\sigma)(\epsilon^k - 1)} \right\}^{\frac{1}{1-\sigma}}, \quad \forall i \in \mathcal{I}. \tag{H2'}$$

(Budget constraint) $$\widehat{P}_i \widehat{U}_i = \frac{W_{i,0}}{W_{i,0} - NX_{i,0}} \widehat{W}_i + \frac{-NX_{i,0}}{W_{i,0} - NX_{i,0}} \widehat{NX_i}, \quad \forall i \in \mathcal{I}. \tag{H3'}$$

(Unit cost) $$\widehat{R^k_i} = \left(\frac{W_{i,0} L^k_{i,o}}{V^k_{i,o}} \widehat{W}_i^{1-\rho^k} + \sum_{h \in S} \frac{P^h_{i,0} Q^{hk}_{i,0}}{V^k_{i,0}} \left(\widehat{P^h_i} \right)^{1-\rho^k} \right)^{\frac{1}{1-\rho^k}}, \quad \forall i \in \mathcal{I}, \ \forall k \in \mathcal{S}. \tag{F1'}$$

(Value-added share) $$\widehat{W}_i \widehat{L^k_i} = \frac{\widehat{W}_i^{1-\rho^k}}{\left(\widehat{R^k_i} \right)^{1-\rho^k}} \widehat{V^k_i}, \quad \forall i \in \mathcal{I}, \ \forall k \in \mathcal{S}. \tag{F2'}$$

(Intermediate share) $$\widehat{P^h_i} \widehat{Q^{hk}_i} = \frac{\left(\widehat{P^h_i} \right)^{1-\rho^k}}{\left(\widehat{R^k_i} \right)^{1-\rho^k}} \widehat{V^k_i}, \quad \forall i \in \mathcal{I}, \ \forall h, k \in \mathcal{S}. \tag{F3'}$$

(Price of aggregates) $$\widehat{P^k_i} = \left\{ \sum_{j \in \mathcal{I}} \pi^k_{ji,0} \left(\frac{\widehat{\tau^k_{ji}} \widehat{R^k_j}}{\widehat{A^k_j}} \right)^{-\theta^k} \right\}^{-\frac{1}{\theta^k}}, \quad \forall i \in \mathcal{I}, \ \forall k \in \mathcal{S}. \tag{G1'}$$

(Import share) $$\widehat{\pi^k_{ji}} = \frac{\left(\frac{\widehat{\tau^k_{ji}} \widehat{R^k_j}}{\widehat{A^k_j}} \right)^{-\theta^k}}{\left(\widehat{P^k_i} \right)^{-\theta^k}}, \quad \forall i, j \in \mathcal{I}, \ \forall k \in \mathcal{S}. \tag{G2'}$$

(Aggregate goods) $$\widehat{B^k_i} = \frac{L_{i,0} P^k_{i,0} C^k_{i,0}}{B^k_{i,0}} \widehat{L}_i \widehat{P^k_i} \widehat{C^k_i} + \sum_{h \in S} \frac{P^k_{i,0} Q^{kh}_{i,0}}{B^k_{i,0}} \widehat{P^k_i} \widehat{Q^{kh}_i}, \quad \forall i \in \mathcal{I}, \ \forall k \in \mathcal{S}. \tag{M1'}$$

(Labor market) $$\widehat{L}_i = \sum_{k \in S} \frac{L^k_{i,0}}{L_{i,0}} \widehat{L^k_i}, \quad \forall i \in \mathcal{I}. \tag{M2'}$$

Since one market clearing condition is redundant by Walras' Law (summing over Equation (Eq.M.1) and summing over Equation (Eq.H.3) yields the same equation), there are $\{(I \times S \times S) + (I \times I \times S) + 7(I \times S) + 3(I) - 1\}$ equations. Excluding changes in the model primitives $\left(\left\{ \widehat{A^k_i} \right\}_{i \in \mathcal{I}, k \in \mathcal{S}} \right)$, $\left(\left\{ \widehat{\tau^k_{ij}} \right\}_{i,j \in \mathcal{I}, k \in \mathcal{S}} \right)$, $\left(\left\{ \widehat{NX_i} \right\}_{i \in \mathcal{I}} \right)$, and $\left(\left\{ \widehat{L}_i \right\}_{i \in \mathcal{I}} \right)$, there are the same number of unknowns: $\left\{ \widehat{Q^{hk}_i} \right\}_{i \in \mathcal{I}, h, k \in \mathcal{S}}$, $\left\{ \widehat{\pi^k_{ij}} \right\}_{i,j \in \mathcal{I}, k \in \mathcal{S}}$, $\{ \widehat{V^k_i}, \widehat{B^k_i}, \widehat{P^k_i}, \widehat{Y^k_i}, \widehat{C^k_i}, \widehat{R^k_i}, \widehat{L^k_i} \}_{i \in \mathcal{I}, k \in \mathcal{S}}$, and $\left\{ \widehat{U}_i, \widehat{P}_i, \widehat{W}_i \right\}_{i \in \mathcal{I}}$ minus one numeraire. Note that the "non-hat" objects (e.g., $\frac{\pi^k_{ij,0} B^k_{j,0}}{V^k_{i,0}}$) are shares that can be readily calculated from data.

Historical changes in the primitives can be derived from data. From Equation (11),

$$\widehat{\tau^k_{ij}} = \left(\frac{\widehat{\pi^k_{ij}}}{\widehat{\pi^k_{ii}}}\right)^{-\frac{1}{\theta^k}} \frac{\widehat{P^k_j}}{\widehat{P^k_i}} \quad \forall i, j \in \mathcal{I}, \forall k \in \mathcal{S}.$$

From Equation (12),

$$\widehat{A^k_i} = \left(\widehat{P^k_i}\right)^{-1} \widehat{R^k_i} \left(\widehat{\pi^k_{ii}}\right)^{\frac{1}{\theta^k}} \quad \forall i \in \mathcal{I}, \forall k \in \mathcal{S}, \text{ where}$$

$\widehat{R^k_i}$ can be calculated from Equation (F1'). $\widehat{NX}_i$ and $\widehat{L}_i$ can be directly obtained from data.

To illustrate how the Exact Hat Algebra works, suppose that one wants to calculate production shares in a counterfactual economy in 2018 if trade costs were fixed at the 1995 level. With $\widehat{\tau^k_{ij}} = \frac{\tau^k_{ij,1995}}{\tau^k_{ij,2018}}$, $\widehat{A^k_i} = 0$, $\widehat{NX_i} = 0$, $\widehat{L}_i = 0$, $\forall i, j \in \mathcal{I},\ k \in \mathcal{S}$, one can solve for $\{(I \times S \times S) + (I \times I \times S) + 7(I \times S) + 3(I)$ - $1\}$ unknowns using the same number of equations. Utilizing $\widehat{L^k_i}$, one can calculate the counterfacutal production shares.

One last thing to note is that the Exact Hat Algebra assumes that the model fits the data perfectly for each year. Therefore, it yields the same result as robustness analysis (iii) in Online Appendix O.E.

O.E Robustness Analyses

For the robustness analyses, I repeat the main exercise of this paper (Figure 8).

(i) Trade Elasticities for Services

Trade elasticities matter for the results for two reasons. First, in the model inversion, i.e., Equations (11) and (12), trade elasticities govern how sensitive calculated trade costs and productivities are to import shares. For example, in Equation (11), trade elasticities govern the relative contribution of import shares and relative price levels to the identification of trade costs. With low trade elasticities, inferred changes in trade costs will be more governed by changes in import share terms than by changes in relative prices. Therefore, it is possible that different trade elasticities for services can significantly affect the identification of the dynamics of services trade costs.

Second, in the model, they determine how sensitive prices and import shares are to the productivities and trade costs (Equations (Eq.G.1) and (Eq.G.2)). Due to this circular structure of model inversion and model simulation, it is ex-ante unclear how trade elasticities affect the quantitative result. Therefore, I explore the cases where trade elasticities for services (θ^{hts} and θ^{bts}) are lower at 2 and higher at 6.

Figure O.E1 illustrates that with any of the trade elasticities for services, the pattern of decreasing asymmetry for highly tradable services robustly holds. Figures O.E2 and O.E3 demonstrate that the main result of the paper holds under the alternative elasticities.

(ii) Non-tradable Barely Tradable Services

To illustrate that trade costs for barely tradable services—which are almost non-tradable by definition—have minimal impact on the results, I explore the case where barely tradable services are non-tradable throughout the period, i.e., $\tau_{ij,t}^{bts} = \infty \; \forall i \neq j \in \mathcal{I},\; t \in \mathcal{T}$. The results are provided in Figure O.E4.

(iii) Exact Model Fit

As mentioned in Section 4.3, since the utility weights $\left(\left\{\phi_i^k\right\}_{i\in\mathcal{I},k\in\mathcal{S}}\right)$ and production weights $\left(\{\psi_i^{Lk}, \{\psi_i^{hk}\}_{h\in\mathcal{S}}\}_{k\in\mathcal{S}}\right)$ are time invariant, and trade costs $\left(\left\{\tau_{ij,t}^k\right\}_{i,j\in\mathcal{I},k\in\mathcal{S},t\in\mathcal{T}}\right)$ were assumed to be greater than or equal to one and to be finite, the baseline model does not fit the data perfectly. In Figure O.E5, I provide the result for when I assume that utility and production weights are time-varying and allow for trade costs to fall below one or to be infinite so that the model fits the data perfectly.

(iv) Nested CES Production Function

The baseline model assumes the following production function:

$$y_i^k(z) = A_i^k \alpha_i^k(z) \left\{ \left(\psi_i^{Lk}\right)^{\frac{1}{\rho^k}} \left(L_i^k(z)\right)^{\frac{\rho^k-1}{\rho^k}} + \sum_{h\in\mathcal{S}} \left(\psi_i^{hk}\right)^{\frac{1}{\rho^k}} \left(Q_i^{hk}(z)\right)^{\frac{\rho^k-1}{\rho^k}} \right\}^{\frac{\rho^k}{\rho^k-1}}.$$

To show that this functional-form assumption that labor is aggregated with the intermediate inputs under the same degree of substitutability is innocuous, I test another functional form, a nested CES production function:

$$
\begin{aligned}
& y_i^k(z) \\
=& A_i^k \alpha_i^k(z) \left[\left(\chi_i^{Lk}\right)^{\frac{1}{\mu^k}} \left(L_i^k(z)\right)^{\frac{\mu^k-1}{\mu^k}} + \left(1-\chi_i^{Lk}\right)^{\frac{1}{\mu^k}} \left\{ \sum_{h\in\mathcal{S}} \left(\psi_i^{hk}\right)^{\frac{1}{\rho^k}} \left(Q_i^{hk}(z)\right)^{\frac{\rho^k-1}{\rho^k}} \right\}^{\frac{\rho^k}{\rho^k-1}\frac{\mu^k-1}{\mu^k}} \right]^{\frac{\mu^k}{\mu^k-1}} .
\end{aligned}
$$

I re-estimate the parameters and show that the results are close to the baseline (Figure O.E6).

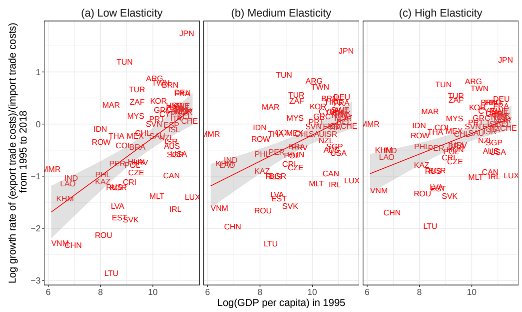
(v) Balanced-trade Assumption

The baseline model assumes that the net transfer of a country is exogenously given. The result of the paper remains robust when I assume balanced trade by setting $NX_{i,t} = 0 \ \forall i \in \mathcal{I},\ t \in \mathcal{T}$ (Figure O.E7).

(vi) Two-sector Economy

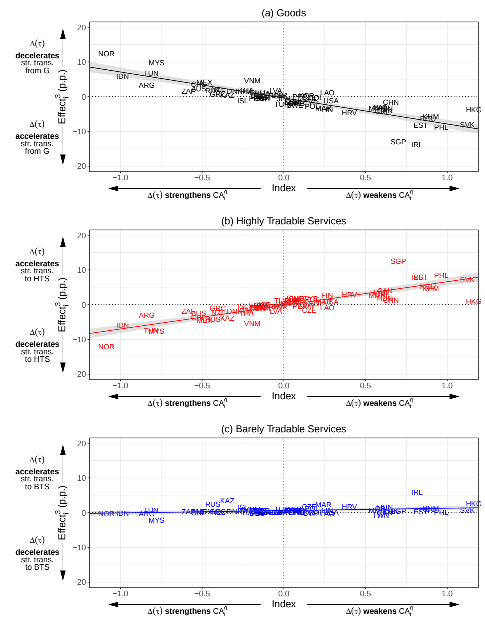
I explore the case of a two-sector setup (goods and services). The elasticities of the model are re-estimated. The results are in Figure O.E8.

Figure O.E1: GDP per Capita and the Growth Rate of Relative Export Trade Costs (Different Trade Elasticities for Services)



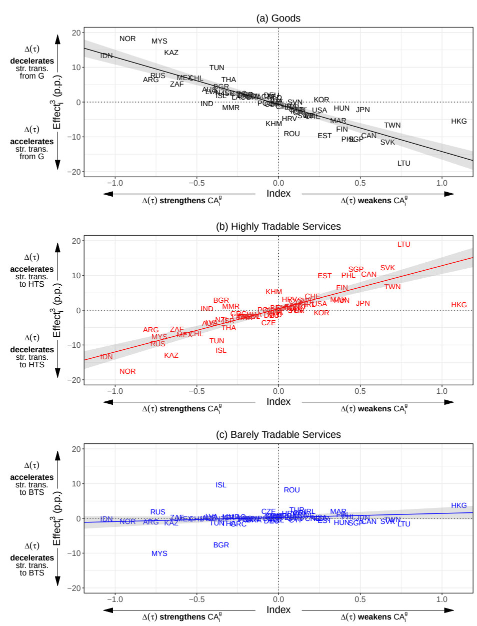
* Note: Low, medium, and high elasticities represent θ^{hts} with values two, four, and six, respectively.

Figure O.E2: Robustness (Low Trade Elasticities for Services)



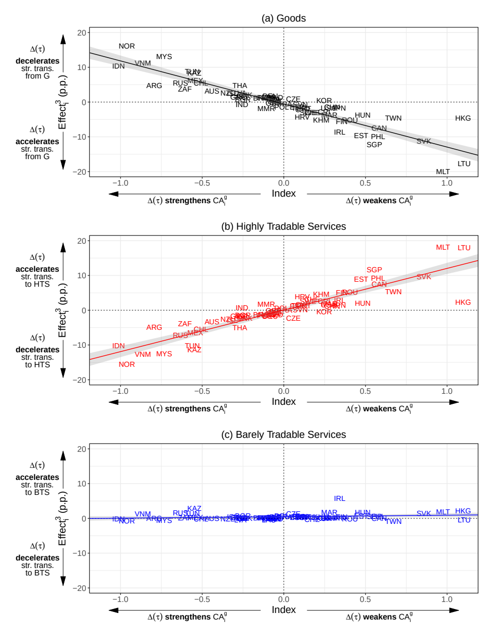
* Note: Outlier countries (Brunei, Luxembourg, Saudi Arabia, Hong Kong, Lithuania, and Malta) are not plotted.

Figure O.E3: Robustness (High Trade Elasticities for Services)



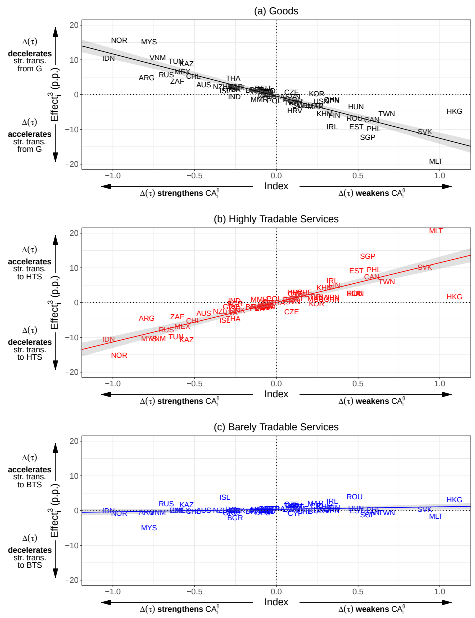
* Note: Outlier countries (Brunei, Luxembourg, Saudi Arabia, Malta, and Vietnam) are not plotted.

Figure O.E4: Robustness (Non-tradable Barely Tradable Services)



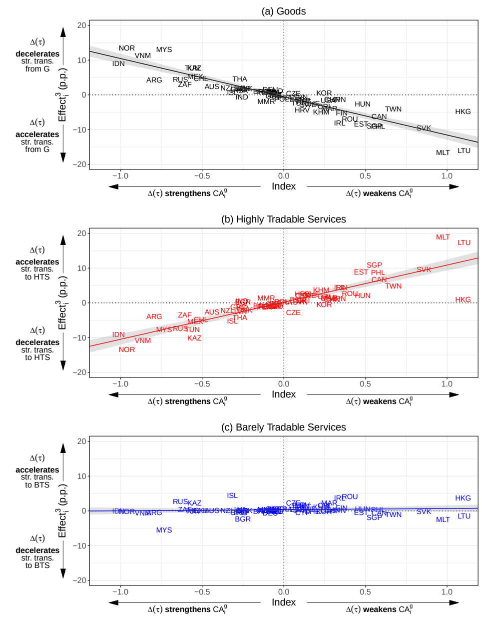
* Note: Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.

Figure O.E5: Robustness (Perfect Model Fit)



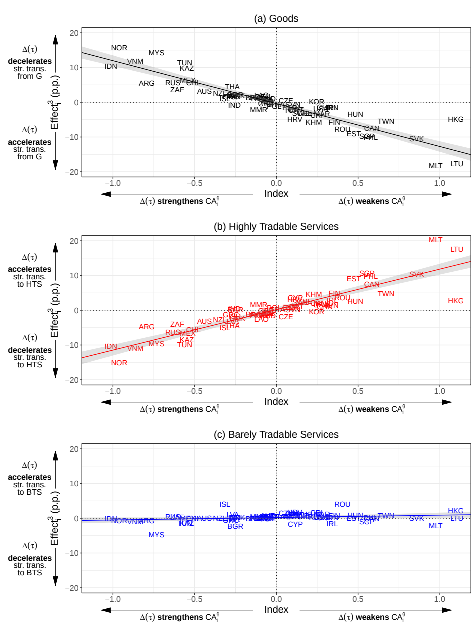
* Note: Outlier countries (Brunei, Luxembourg, Saudi Arabia, and Lithuania) are not plotted.

Figure O.E6: Robustness (Nested CES Production Function)



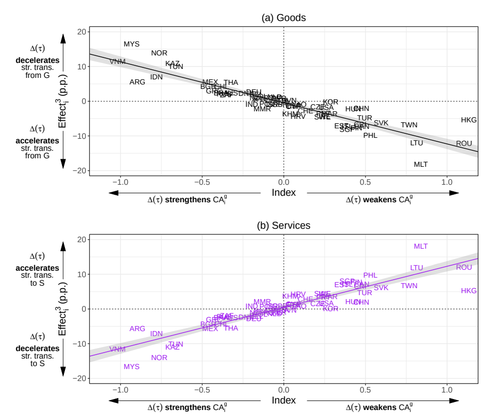
* Note: Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.

Figure O.E7: Robustness (Balanced Trade)



* Note: Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.

Figure O.E8: Robustness (Two-sector Economy)



* Note: Outlier countries (Brunei, Luxembourg, and Saudi Arabia) are not plotted.