# Trade Policy and Structural Change*

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**Abstract**

Recently, developed countries have seen manufacturing decline not only because of structural change forces, but also of emerging economies being integrated globally. Can they reverse this declining trend by resorting to tariffs? Tariffs may help manufacturing regain through the channel of relative price change in favor of manufacturing over service. However, tariffs may cause a further decline through the channel of income change under nonhomothetic preferences, brought about by terms-of-trade gains. Using a two-country model of Ricardian trade, we analytically show that tariffs may have ambiguous effects on the manufacturing expenditure/value-added share. We then extend it to a full-fledged multi-country dynamic model with capital accumulation and intermediate goods, and quantify the effect of a 20% point increase in US tariffs applied to all countries starting in 2001. We find that the tariff hike increases the US manufacturing share by 0.9–1.2% point, suggesting a stronger relative price effect. However, the dynamic gains in the US are only 0.2%, at the expense of all the other countries getting worse off, with Canada suffering the largest loss of 0.7%.

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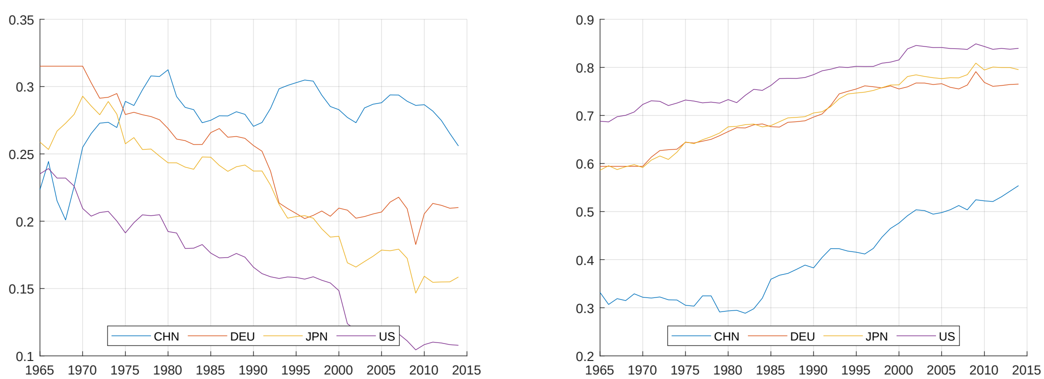
# 1 Introduction

Trade protectionist policies are gaining momentum. Shortly after his inauguration on January 2025, the US President Donald Trump announced his plan of a ten percent increase in tariffs on Chinese-made goods and a 25% tariff on imports from Canada and Mexico, with a view to regaining industries back to the US.[1] The growing popularity of protectionism in the US in recent years has been rooted in the decline of manufacturing presence and the rise of China in the global market (Goldberg and Reed, 2023 for a survey).[2] However, declining manufacturing is not unique to the US, but is also observed in other developed countries such as Germany and Japan. Figure 1(a) shows similar declining trends of the manufacturing share in value-added of the three countries from 1965 to 2014. From the viewpoint of structural change, the shifts of resources from manufacturing to services, shown in Figure 1(b), are inevitable even in the absence of trade.

Figure 1: Value Added Share in GDP

(a) Manufacturing (b) Service




*Notes*: The data is from the WIOD database. See Section 4 for details.

Are tariffs effective in reversing structural change forces? The consequences of tariffs on

[1] His remarks on tariffs are summarized in an article on *Guardian*: https://www.theguardian.com/business/2025/jan/22/trump-tariff-china-eu-levy-yuan-stocks (accessed on January 30, 2025).

[2] A number of studies find adverse effects of these events on industries in developed economies, in particular, their manufacturing employment. Looking at the impacts of China's growing trade, for example, Acemoglu et al. (2016) report 2.0 to 2.4 million US manufacturing workers losing their jobs due to Chinese import competition over 1999 to 2011. See also Autor et al. (2013); Acemoglu et al. (2016); Pierce and Schott (2016). The adverse effects of rising Chinese imports are observed in other developed countries, including Canada (Albouy et al., 2019), Denmark (Utar, 2018), France (Malgouyres, 2017), and Germany (Dauth et al., 2014). See also Autor et al. (2016) for a comprehensive review. We note, however, that not all studies find negative effects of rising Chinese imports on developed countries. Taniguchi (2019), for example, finds a positive effect of the China shock in Japan due to the complementary role of imported intermediate inputs.

sectoral composition, however, may not be as simple as it seems considering the two opposing effects. First, tariffs cannot be levied across all sectors in a uniform way simply because of the presence of services in trade. If a country raises tariffs on all goods, this increases the prices of goods relative to services. With the elasticity of substitution between sectors being less than one, this sector-biased price change may reverse structural change by shifting resources from services back to goods. Second, large countries such as the US can have an influence on the world price and thus may increase the real income by improving the terms of trade. As the real income rises, consumers with nonhomothetic preferences demand higher-income elastic services more than manufacturing, accelerating structural change.

We qualitatively make clear the roles of tariffs on sectoral composition, and quantitatively evaluate their magnitudes. More specifically, we first analytically isolate the two opposing effects of tariffs on sectoral composition using a three-sector two-country model of trade and structural change forces. Our model features trade based on Ricardian comparative advantage (Eaton and Kortum, 2002) and the nonhomothetic CES preferences (Hanoch, 1975; Matsuyama, 2019; Comin et al., 2021). The two results are particularly relevant. Supposing that only the income effect via nonhomothetic preferences is present, if tariffs increase uniformly across sectors, the real per capita income first rises and then declines, suggesting a optimal tariff. The expenditure share of manufacturing with an intermediate income-elasticity follows the same pattern. By contrast, supposing that only the relative price effect via tariffs applied to only goods (agriculture and manufacturing) is present, the manufacturing expenditure share rises. If the initial levels of tariff are low like many developed countries today, a tariff increase may increase manufacturing share through the income effect, but decrease it through the relative price effect.

To quantitatively evaluate which effects are dominant, we then extend the two-country static model to a multi-country dynamic one with capital accumulation and input-output linkages. We calibrate our model using the data for 24 countries over half the century, from 1965 to 2014. We calibrate the model's fundamentals, such as sectoral productivity and non-tariff trade barriers, which allows us to solve transition paths of the economy in terms of *level*, not in *relative change* known as the hat-algebra method (Dekle et al., 2008; Caliendo and Parro, 2015; Caliendo et al., 2019). We then conduct a counterfactual experiment of a 20% point increase in US tariffs applied to all countries starting in 2001.

We find that the sector-biased price change is the key driver of sectoral expenditure/value-added shares. Specifically, compared with the baseline values in the corresponding year, the US tariff increase since 2001 leads to a 6–10% (0.9–1.2% point) increase in manufacturing value-added share, while 2.5–8.0% (9.5–1.5% point) decrease in service share in 2001 to 2014. Although this results may sound cheering trade protectionists, the dynamic welfare impacts are minor; the US representative consumer can increase real consumption in every year only by 0.2%. The US gains of course come at the cost of the other countries getting worse off. The biggest loser is Canada, reporting a 0.6% dynamic welfare loss. Considering the possibility of retaliatory tariffs increases by others, the 20% tariff increase will lead to a much greater costs than benefits.

We contribute to the literature on on structural change and trade through both qualitative and qualitative approaches. Our analytical two-country model is complementary to Matsuyama (2019) in that trade in his model is based on increasing returns à la Krugman (1980), while trade in ours based on Ricardian comparative advantage à la Dornbusch et al. (1977); and Eaton and Kortum (2002). The focus of analysis is also different. Matsuyama (2019) is mainly concerned with the comparison between the rich and the poor countries along with reductions in symmetric trade costs (or productivity improvement), while our focus is on the effect of tariffs on the sectoral composition *within* the imposing country.

Our quantitative part is positioned in the recent literature on quantitative models of structural change embedding international trade (see Alessandria et al., 2023 for a survey). Those studies show a number of new insights such as the decomposition of different mechanisms for declining manufacturing share (Święcki, 2017; Smitkova, 2023), a systematic relationship between countries' intermediate-input intensities and their level of development (Sposi, 2019), and the negative effect of structural change on trade (Lewis et al., 2022). A more recent study by Sposi et al. (2021) develops and applies the dynamic model of international trade to study structural change.[3] Our quantitative framework largely follows Sposi et al. (2021), but depart from them by explicitly introducing tariffs and tariff revenues and distinguishing them from non-tariff barriers. Accordingly, we calibrate sector-specific non-tariff trade barriers using gravity models with tariff data.

The remainder of this paper is structured as follows. Section 2 presents a two-country model of trade and structural change forces. Section 3 extends it to a full-fledged quantitative model. Section 4 introduces the calibration of the model and solution algorithm. Section 5 presents the quantitative results, and the final section 6 concludes.

## 2 Two-Country Model of Structural Change, Trade, and Tariffs

To highlight the role of tariffs on sectoral composition in a country, we first present a simple trade model à la Eaton and Kortum (2002) with structural change forces, that is, the nonhomothetic CES preference and the sectoral elasticity of substitution being less than unity. Consider a static economy with two countries, 1 and 2. They have three sectors, agriculture,

[3] Another closely related study to ours is Święcki (2017) examining to what extent each elements of the model contributes to changes in sectoral composition. He finds that the most important element is the sector-biased productivity. We depart from his static model with non-tradable services by allowing for endogenous capital accumulation and tradable services. His finding might be due to his calibration based on the model without capital, because the estimates of sector-biased sectoral productivity potentially include the contribution by capital. We instead model capital explicitly and give more precise estimates of productivities.

manufacturing, and service.[4] If $\epsilon^j = 1$ for all $j$, the utility function reduces to a standard CES aggregator of sectoral composite goods, $C_n = \left[\sum_j (C_n^j)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$.

*Demand side* Let $C_n$ be the aggregate consumption of country $n \in \{1, 2\}$ and $L_n$ the population there. The representative consumer maximize her utility (or real per capita income), $C_n/L_n$, by choosing sectoral composite goods, $C_n^j$ for $j \in \{a, m, s\}$, subject to a budget constraint:

$$\max_{\{C_n^j\}_j} \; C_n/L_n,$$
$$\text{s.t.} \begin{cases} \sum_{j=a,m,s} P_n^j C_n^j \leq E_n, \\ \sum_{j=a,m,s} \left(\frac{C_n}{L_n}\right)^{\frac{\epsilon^j(1-\sigma)}{\sigma}} \left(\frac{C_n^j}{L_n}\right)^{\frac{\sigma-1}{\sigma}} = 1 \end{cases},$$

where $P_n^j$ is the price index of the composite good in sector $j$ in country $n$, and $E_n$ is the aggregate income. The aggregate consumption $C_n$ is *implicitly* defined by the equation in the third line. As will be clear shortly, the two key parameters governing structural change are $\epsilon^j > 0$ with $\epsilon^{j^*} = 1$ for some $j^*$ capturing the degree of the nonhomotheticity, and $\sigma \in (0, 1)$ measuring the elasticity of substitution between sectoral composite goods. We assume the parameter ranges such that $0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$ and $\sigma \in (0, 1)$ hold.

Rather than solving the utility maximization problem above, it is easier to work on the expenditure minimization, given the level of utility, $C_n/L_n$. With a slight abuse of notation $E_n$ (income), the Hicksian demand function for the sectoral composite good is obtained as

$$C_n^j = L_n (P_n^j)^{-\sigma} \left(\frac{E_n}{C_n}\right)^{\sigma} \left(\frac{C_n}{L_n}\right)^{\epsilon^j(1-\sigma)+\sigma}. \tag{1}$$

Substituting this into the balanced budget constraint, we obtain the expenditure function:

$$E_n = \sum_{j=a,m,s} L_n \left[\sum_{j=a,m,s} \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^j} P_n^j\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{2}$$

Letting us define an aggregate price index, $P_n$, by $P_n \equiv E_n/C_n$, we have

$$P_n = \left[\sum_{j=a,m,s} (P_n^j)^{1-\sigma} \left(\frac{C_n}{L_n}\right)^{(1-\sigma)(\epsilon^j-1)}\right]^{\frac{1}{1-\sigma}}.$$

[4]Sectors and industries are synonymous in this paper. As will be discussed, the analytical results of this section holds in the case of general $J$ sectors.

From these results, we can see two things. First, the sectoral demand elasticity with respect to the aggregate income is not constant:

$$\frac{\partial \ln C_n^j}{\partial \ln E_n} = \sigma + (1-\sigma)\frac{\epsilon^j}{\bar{\epsilon}_n} > 0,$$

where $\bar{\epsilon}_n$ is an average of the nonhomotheticity parameter $\epsilon^j$ weighted by the sectoral expenditure share, $\omega_n^k$:

$$\bar{\epsilon}_n \equiv \sum_{h=a,m,s} \omega_n^h \epsilon_n^h, \qquad \omega_n^h \equiv \frac{P_n^h C_n^h}{\sum_k P_n^k C_n^k}.$$

In the case of CES preference with $\epsilon^j = 1$ for all $j$, the sectoral demand elasticity becomes $\sigma$ and are independent of sectors. As we assume $0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$, agriculture has the the lowest elasticity, and services the highest one. The parameter $\epsilon^j$ captures the degree of income elasticity of demand.

Second, the sectoral demands are gross complements:

$$\frac{\partial \ln C_n^j}{\partial \ln P_n^h} = (\sigma - 1)\frac{\omega_n^h \epsilon^h}{\bar{\epsilon}_n} < 0.$$

This implies, for example, that a lower relative price of service to agriculture leads to a lower relative relative demand for the two sectors. We note that this second property holds in the case of homothetic CES preference with $\epsilon^j = 1$ for all $j$.

*Supply side* The production side follows Eaton and Kortum (2002). Producers of sectoral composite goods in sector $j$ in country $n$ are perfectly competitive and supply the amount of $Y_n^j$ using the technology of

$$Y_n^j = \left[\int_0^1 y_n^j(z)^{\frac{\eta-1}{\eta}} dz\right]^{\frac{\eta}{\eta-1}},$$

where $\eta > 0$ is the elasticity of substitution between sectors, and $y_n^j(z)$ is the amount of input variety $z$ used by the producers in sector $j$ in country $n$. While the sectoral composite goods are not tradable, the producers source tradable input varieties from the least expensive country.

The variety producers are also perfectly competitive and have a linear technology such that $y_n^j(z) = a_n^j(z) l_n^j(z)$, where $a_n^j(z)$ and $l_n^j(z)$ are respectively the labor productivity and the labor input in sector $j$ in country $n$ for producing variety $z$. The labor productivity follows the Frechét distribution:

$$\Pr[a_n^j \leq a] = \exp\left[-\left(\frac{a}{\widetilde{\gamma} A_n^j}\right)^{-\theta}\right].$$

Here $\theta$ and $A_n^j$ are the shape parameter and the location parameter of the Frechét distribution, respectively, and $\widetilde{\gamma} = [\Gamma((\theta + 1 - \eta)/\theta)]^{-\frac{1}{1-\eta}}$ is a normalizing constant, where $\Gamma(\cdot)$ is the Gamma function. We assume $\theta + 1 - \eta > 0$ to ensure that the expectation of prices is finite.

*International trade* Trade in varieties are subject to tariffs, $\tau_{ni}^j \geq 0$ for $n \neq i \in \{1, 2\}$ and $\tau_{nn}^j = 1$, and non-tariff trade barriers, $d_{ni}^j \geq 1$ for $n \neq i \in \{1, 2\}$ and $d_{nn}^j = 1$. Thus, the total bilateral trade costs per shipment of a variety in sector $j$ from country $i$ to $n$ of

$$b_{ni}^j \equiv d_{ni}^j \left(1 + \tau_{ni}^j\right).$$

Thus, letting $w_n$ be the wage in country $n$, the unit cost of variety $z$ produced in country $n$ and shipped to $i$ is $w_n b_{ni}^j / a_n^j(z)$. As a result of the cost-minimization of sectoral composites producers, the price of the variety available in country $n$ becomes $p_n^j(z) = \min_i\{w_i b_{ni}^j / a_i^j(z)\}$. With these results and the Frechét productivity distribution, the price of the sectoral composite good is obtained by

$$P_n^j = \left[\sum_{i=1}^{2} \left(w_i b_{ni}^j / A_i^j\right)^{-\theta}\right]^{-\frac{1}{\theta}}. \tag{3}$$

Let $X_{ni}^j$ be sector-$j$ expenditure of country $n$ on varieties from $i$. The share of country $i$'s varieties in country $n$'s sectoral expenditure becomes

$$\frac{X_{ni}^j}{P_n^j C_n^j} = \pi_{ni}^j = \frac{\left(w_n b_{ni}^j / A_i^j\right)^{-\theta}}{\sum_{i'=1}^{2} \left(w_{i'} b_{ni'}^j / A_{i'}^j\right)^{-\theta}}.$$

*Market clearing* As labor is the only factor of production, the sectoral value added is the sectoral labor income, which comes from the sales from the domestic and the foreign markets:

$$\begin{aligned} VA_n^j &= w_n L_n^j \\ &= \sum_{i=1}^{2} \frac{X_{in}^j}{1 + \tau_{in}^j} = \sum_{i=1}^{2} \frac{\pi_{in}^j P_i^j C_i^j}{1 + \tau_{in}^j}, \end{aligned}$$

where $L_n^j$ is sector $j$ employment in country $n$ and the export sales are divided by gross tariff rate, $1 + \tau_{in}^j$. This is because the price index is a tariff-inclusive (c.i.f) one, while sales for producers are based on the tariff-exclusive (f.o.b.) price. Summing this condition over sectors gives the labor market clearing condition:

$$w_n L_n = \sum_{j=a,m,s} \sum_{i=1}^{2} \frac{\pi_{in}^j P_i^j C_i^j}{1+\tau_{in}^j}. \tag{4}$$

One can check that this is equivalent with the trade balance condition.[5] The total income consists of labor income and tariff revenues, $\widetilde{T}_n$:

$$E_n = w_n L_n + \widetilde{T}_n, \qquad \widetilde{T}_n \equiv \sum_{j=a,m,s} \frac{\tau_{ni}^j X_{ni}^j}{1+\tau_{ni}^j} = \sum_{j=a,m,s} \frac{\tau_{ni}^j \pi_{ni}^j P_n^j C_n^j}{1+\tau_{ni}^j}. \tag{5}$$

This completes the model. With a choice of numéraire such that $w_1 = 1$, the equilibrium wage $w_2$ and the aggregate consumption $\{C_i\}_{i=1,2}$ satisfy equilibrium conditions (1), (2), (3), (4), and (5).

## 2.1 Tariffs and real income

Before examining the tariff impact on sectoral composition, let us first see how tariffs affect real income. As tariffs do not affect population $L_n$, the following discussion holds for both (aggregate) real income and real per capita income. In general, our model has no analytical solution. We thus focus on two polar cases to highlight the roles of nonhomotheticity and sector-biased price change. In doing so, we allow for sectoral heterogeneity only in the degree of nonhomotheticity, $\epsilon^j$ or tariffs applied by country 2 to 1, $\tau_{21}^j$.

In the case of homothetic CES preferences with $\epsilon^j = 1$ for all $j$ and sector-specific tariffs $\tau_{21}^j \neq \tau_{21}^h$, the real per capita income is explicitly expressed as $C_2/L_2 = (1+\alpha_2)w_2/P_2$, and its log change as

$$d\ln\left(\frac{C_2}{L_2}\right) = \underbrace{d\ln w_2}_{>0} + \underbrace{\frac{\alpha_2}{1+\alpha_2} d\ln\alpha_2}_{\gtreqless 0} \underbrace{-d\ln P_2}_{<0},$$

where $\alpha_2$ represents the ratio of tariff revenues to labor income and is given by

$$\alpha_2 \equiv \frac{\sum_j \alpha_2^j}{1-\sum_j \alpha_2^j}, \qquad \alpha_2^j \equiv \frac{\tau_{21}^j \pi_{21}^j \omega_2^j}{1+\tau_{21}^j}.$$

[5]The trade balance condition is

$$\sum_{j=a,m,s} \frac{\pi_{21}^j P_2^j C_2^j}{1+\tau_{21}^j} = \sum_{j=a,m,s} \frac{\pi_{12}^j P_1^j C_1^j}{1+\tau_{12}^j}.$$

The first-two positive terms are terms-of-trade gains. A rise in tariffs in country 2 reduces import demand there and pushes the relative f.o.b. price of exports to imports upward, resulting in a higher relative wage of the imposing country 2 (first term). In addition, a rise in trade may increase tariff revenues unless this causes a significant decline in imports (second term). The third negative term shows the most apparent cost of tariffs, i.e., a higher c.i.f. price for consumers. As $\tau_{21}^j$ rises, country 2's imports monotonically decreases, so that the second term turns from positive to negative. We can indeed check that the real (per capita) income has an inverted U-shaped relationship with $\tau_{21}^j$.

In the case of nonhomothetic CES preferences with $0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$ and symmetric tariffs $\tau_{21}^j = \tau_{21}$, the real per capita income cannot be expressed explicitly. Using the demand function (1), the aggregate income (5) and the sectoral price index (3), we rewrite country 2's sectoral expenditure share $\omega_2^j = P_2^j C_2^j / E_2$ as

$$\omega_2^j = \left(\frac{(1+\alpha_2)w_2}{P_2^j}\right)^{\sigma-1}\left(\frac{C_2}{L_2}\right)^{\epsilon^j(1-\sigma)} = (1+\alpha_2)^{\sigma-1}\left(b_{21}^{-\theta}A_1^\theta w^\theta + A_2^\theta\right)^{\frac{\sigma-1}{\theta}}\left(\frac{C_2}{L_2}\right)^{\epsilon^j(1-\sigma)},$$

where $w \equiv w_2/w_1$ is country 2's relative wage and we note that due to tariff revenues, the labor income expands by $\alpha_2 \equiv \tau_{21}\pi_{21}/(1+\tau_{21}\pi_{22})$, that is, $E_2 = \alpha_2 w_2 L_2$. We also note $P_2^j = P_2$ for all $j$ as there is no sectoral heterogeneity in trade costs and productivity. Letting $u(x_2) \equiv C_2/L_2$, the real per capita income $u(x_2)$ is implicitly defined as

$$1 = \sum_{j=a,m,s}\omega_2^j = \sum_{j=a,m,s} x_2^{\frac{\sigma-1}{\theta}}[u(x_2)]^{\epsilon^j(1-\sigma)}, \qquad x_2 \equiv (1+\alpha_2)^\theta\left(b_{21}^{-\theta}A_1^\theta w^\theta + A_2^\theta\right).$$

It is clear from this expression and $\sigma \in (0,1)$ that $u(x_2)$ increases with an index $x_2$. To see this formally, we take the logarithm change of the above:

$$0 = \sum_{j=a,m,s} d\ln\omega_2^j = (1-\sigma)\sum_j x_2^{\frac{\sigma-1}{\theta}}[u(x_2)]^{\epsilon^j(1-\sigma)}\left[\epsilon^j\xi(x_2) - \frac{1}{\theta}\right]d\ln x_2,$$

where $\xi(x_2) \equiv x_2 u'(x_2)/u(x_2)$. If $\xi(x_2) < 0$, this inequality would never hold so that $\xi(x_2) > 0$ or $u'(x_2)$ must hold. As the index $x_2$ increases ($d\ln x_2 > 0$) and thus $u(x_2) = C_2/L_2$ does so, the sectoral expenditure share changes as

$$d\ln\omega_n^j \begin{cases} < 0 & \text{for } j = a, \\ > 0 & \text{for } j = s \end{cases}, \qquad d\ln\omega_n^m \begin{cases} \leq 0 & \text{if } \xi(x_2) \leq \epsilon^m/\theta, \\ > 0 & \text{if } \xi(x_2) > \epsilon^m/\theta. \end{cases}$$

We can check that $\xi(x_2)$ decreases with $x_2$. Thus, the manufacturing expenditure share has an inverted U-shaped relationship with $C_2/L_2$.

The index $x_2$ includes the relative wage $w = w_2/w_2$, which is endogenously determined by the labor market clearing condition (4). Using these, we can see

$$\frac{d\ln x_2}{d\ln \tau_{21}} \begin{cases} = 0 & \text{if } \tau_{21} \in \{0, \tau_{21}^*\} \\ > 0 & \text{if } \tau_{21} \in (0, \tau_{21}^*) \\ < 0 & \text{if } \tau_{21} \in (\tau_{21}^*, \infty) \end{cases},$$

where the optimum tariff to maximize $C_2/L_2$ is

$$\tau_{21}^* \equiv \frac{1}{\theta \pi_{11}}, \quad \pi_{11} = \left(\frac{w_1/A_1}{P_1}\right)^{-\theta} = \frac{w^\theta}{b_{21}^{-\theta} A^\theta + w^\theta}. \tag{6}$$

The same formula is studied in Caliendo and Parro (2022) in the case of CES preferences and a single sector. Three points are worth noting here. First, the optimal tariff increases with the trade elasticity $\theta$. This is because a decline in imports due to tariffs is smaller when productivity distribution is more dispersed (low $\theta$), which allows country 2 to set a higher tariff. Second, the optimal tariff decreases with the domestic expenditure share of country 1, $\pi_{11}$. If country 2 is very small relative to country 1 in the world market, $\pi_{11}$ approaches one. Smaller countries have less room for manipulating terms-of-trade than larger countries. Third, the degree of nonhomotheticity $\epsilon^j$ does not affect $\tau_{21}^*$, implying that the level of optimal tariff under the nonhomothetic CES preferences, not just the expressions, is the same as the one under the homothetic CES preferences. In the case of symmetric sectors here, tariffs affect prices and tariff revenues in all sectors in the same way, so that $\epsilon^j$ has no effect on the real income through changes in tariffs.

Let us turn to the other polar case where there is a full set of sectoral heterogeneity, $A_n^j$ and $b_{ni}^j = d_{ni}^j(1+\tau_{ni}^j)$ varying in $j \in \{a, m, s\}$, but preferences are homothetic, $\epsilon^j = 1$ for all $j$. This case will make clear the role of sector-biased price change.

We summarize the relationship between tariffs and real per capita income in the following proposition:

**Proposition 1. Tariffs and real income**

*Consider the two-country model described in the text. Then the following holds:*

(i) *Assume the homothetic CES preferences, $\epsilon^j = 1$ for all $j$, and sector-specific tariffs. A unilateral increase in tariffs in a sector first raises and then reduces the real per capita income of the imposing country.*

(ii) *Assume the nonhomothetic CES preferences such that $0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$, and uniform tariffs across sectors. Then a unilateral increase in tariffs has the same effect as in (i): the real per capita income first rises and then declines.*

*(iii) When tariffs are uniform across sectors, the levels of optimal tariffs that maximizes the real per capita income are the same in both the homothetic and nonhomothetic CES preferences.*

*Proof: See Appendix (to be added).*

## 2.2 Tariffs and expenditure share

Let us move to the impact of tariffs on sectoral expenditure share. Its log change is decomposed as

$$d\ln\omega_2^j = \underbrace{(1-\sigma)\left(d\ln P_2^j - \sum_h \omega_2^h d\ln P_2^h\right)}_{\text{Baumol effect}} + \underbrace{(1-\sigma)\left(\epsilon^j - \sum_h \omega_2^h \epsilon^h\right)d\ln\left(\frac{C_2}{L_2}\right)}_{\text{Income effect}}.$$

The first set of terms is the Baumol effect, or also called as the (relative) price effect, through changes in the relative price of sector-$j$'s composite. With the elasticity of substitution between different sectors being less than unity, $\sigma \in (0,1)$, an increase in the relative price of sector-$j$'s composite shifts expenditure on the sector despite the reductions in the volume of consumption. The second set of terms is the income effect through nonhomothetic preferences. As the real per capita income rises, the expenditure moves toward the sectors with a higher-income elasticity captured by $\epsilon^j$. This income effect never occurs in the case of homothetic CES preferences with $\epsilon^j = 1$ for all $j \in \{a, m, s\}$.

The Baumol effect is affected by changes in tariffs for the obvious reason that an increase in the sectoral tariffs directly raises the tariff-inclusive prices of imported varieties and thus the price index of that sector.[6] The tariff increase also affects the sectoral price index by changing the terms of trade in production factors. That is, the imposing country shrinks import demand and thus forces the relative price, determined by relative wage, to adjust in order to maintain the trade balance.

The income effect is also affected by changes in tariffs, as summarized in Proposition 1(ii). An increase in tariffs from zero will raise the real per capital income of the imposing country. This is because additional tariff revenues allow the country to consume more despite the increased tariff-inclusive prices, thanks to the improved terms-of-trade. A further increase

[6] To see this formally, we see changes in the sectoral price index:

$$d\ln P_2^j = \pi_{21}\left(\frac{\tau_{21}^j}{1+\tau_{21}^j}\underbrace{d\ln\tau_{21}^j}_{>0} + \underbrace{d\ln w_1}_{=0}\right) + \pi_{22}\underbrace{d\ln w_2}_{>0} > 0,$$

noting that the labor in country 1 is chosen as the numéraire, $w_1 = 1$.

in tariffs, however, will reduce the real per capita income since it will not bring enough tariff revenues.

The tariff effects on the sectoral expenditure share is summarized as follows. An increase in the sectoral tariff directly raises its price index, shifting expenditure toward that sector through the Baumol effect. If the initial tariff is very small (or large enough), the tariff increase expands (or shrinks) the real per capita income and thus shifts expenditure toward the sectors with a higher (or a lower) income elasticity through the income effect.

**Proposition 2. Tariffs and expenditure share**

*Consider the two-country model described in the text. Then the following holds:*

*(i) Assume the homothetic CES preferences, $\epsilon^j = 1$ for all $j$, and sector-specific tariffs. A unilateral increase in tariffs in a sector raises the expenditure share of the sector in the imposing country.*

*(ii) Assume the nonhomothetic CES preferences such that $0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$, and uniform tariffs across sectors. Along with a unilateral increase in tariffs, the expenditure share in agriculture (or services) in the imposing country declines (or rises), and the manufacturing expenditure share first rises and then declines, where its infection point is given by the level of optimal tariff (6).*

*Proof: See Appendix (to be added).*

### 2.3 Tariffs and value-added share

From the results in Section 2.1, the value-added of sector $j$ in country 2 is

$$\begin{aligned} VA_2^j &= w_2 L_2^j \\ &= \sum_{i=1}^{2} \frac{\pi_{i2}^j P_i^j C_i^j}{1+\tau_{i2}^j} \\ &= P_2^j C_2^j + NX_2^j - \widetilde{T}_2^j, \qquad NX_2^j \equiv \frac{\pi_{12}^j P_1^j C_1^j}{1+\tau_{12}^j} - \frac{\pi_{21}^j P_2^j C_2^j}{1+\tau_{21}^j}, \quad \widetilde{T}_2^j \equiv \frac{\tau_{21}^j \pi_{21}^j P_2^j C_2^j}{1+\tau_{21}^j}, \end{aligned}$$

where $NX_2^j$ is the net export value of country 2 in sector $j$ and $\widetilde{T}_2^j$ is the tariff revenue of country 2 in sector $j$. The sectoral value added increases as the domestic expenditure and the net exports expands, while it decreases with the tariff revenue since the tariff revenue is from the value added of foreign workers in country 1. We also note that the sectoral expenditure, $P_i^j C_i^j$, is always divided by one plus a tariff rate since the price index $P_i^j$ is a tariff-inclusive price while firms' production decision is based on tariff-exclusive prices.

The value-added share of sector $j$ in country 2, $va_2^j$, is given by the ratio of the sectoral value-added to aggregate value-added (or GDP), $VA_2 = \sum_{h=a,m,s} VA_2^h = w_2 L_2$:[7]

$$
\begin{aligned}
va_2^j \equiv \frac{VA_2^j}{VA_2} &= \frac{P_2^j C_2^j}{w_2 L_2} + \frac{NX_2^j}{w_2 L_2} - \frac{\widetilde{T}_2^j}{w_2 L_2} \\
&= \omega_2^j \left(1 + \frac{\widetilde{T}_2}{w_2 L_2}\right) + \frac{NX_2^j}{w_2 L_2} - \frac{\widetilde{T}_2^j}{w_2 L_2},
\end{aligned}
$$

where $\omega_2^j \equiv P_2^j C_2^j / E_2$ is the expenditure share of sector $j$ and $\widetilde{T}_2 \equiv \sum_{h=a,m,s} \widetilde{T}_2^h$ is the total tariff revenue in country 2. As discussed in the level of sectoral value-added, the sectoral value-added share increases with the domestic sectoral expenditure share and the share of sectoral net exports to total value-added, while it decreases with the share of sectoral tariff revenues. The contribution of domestic expenditure share is scaled up by the share of total tariff revenues, $\widetilde{T}_2/(w_2 L_2)$, due to the fact that more tariff revenues directly raise income and allow country 2 to consume more.

To see the determinants of sectoral value-added share more clearly, we derive its logarithmic change as

$$
d\ln va_2^j = \underbrace{\frac{P_2^j C_2^j}{w_2 L_2^j} d\ln \omega_2^j}_{\text{Expenditure}} + \underbrace{\frac{NX_2^j}{w_2 L_2^j} d\ln\left(\frac{NX_2^j}{w_2 L_2}\right)}_{\text{Trade}} + \underbrace{\frac{\omega_2^j \widetilde{T}_2 - \widetilde{T}_2^j}{w_2 L_2^j} d\ln\left(\frac{\widetilde{T}_2}{w_2 L_2}\right)}_{\text{Tariff-revenue}}.
$$

We know from Section 2.2 how the first term works as tariffs change. Considering that sector $j$'s tariff in country 2 always reduces its sectoral net exports ($d\ln[NX_2^j/(w_2 L_2)] < 0$), the second term has a positive effect on the sectoral value-added share if country 2 runs trade deficits in the sector ($NX_2^j < 0$). The workings of the third term are more nuanced.

Overall, the tariff effects on sectoral value-added share are similar to those on sectoral expenditure share. The directions in which the effects diverge depend on the sectoral trade positions.

## 3 Quantitative Model

We extend the two-country model to a dynamic multi-country model with capital accumulation and sectoral input-output linkages. Time is discrete $t = 0, 1, \cdots$. The set of countries is $\mathcal{N} = \{1, 2, \cdots, N\}$, with the cardinality of $\mathcal{N}$ being $N$. Countries are generically indexed by $i$ or $n$. We maintain three sectors as in the previous model: agriculture, manufacturing, and

[7]Since there is no capital (depreciation), the definitions of (net) value-added and the gross value-added are the same.

services.

The representative household in country $n$ as of period 0 maximizes the lifetime utility function

$$\sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_{n,t} \frac{(C_{n,t}/L_{n,t})^{1-\psi}}{1-\psi}, \tag{7}$$

where $\beta \in (0,1)$ is the discount factor, $\psi > 1$ is the intertemporal elasticity of substitution, $\zeta_{n,t}$ is the demand shifter in country $n$ and period $t$, and $L_{n,t}$ is the population of country $n$ and period $t$. The aggregate consumption in country $n$ and period $t$, $C_{n,t}$, is *implicitly* defined by

$$\sum_{j=a,m,s} (\Omega^j)^{\frac{1}{\sigma}} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{\frac{\epsilon^j(1-\sigma)}{\sigma}} \left(\frac{C^j_{n,t}}{L_{n,t}}\right)^{\frac{\sigma-1}{\sigma}} = 1,$$

where, for $j \in \{a, m, s\}$, $C^j_{n,t}$ is the composite good of sector $j$ which the representative household in country $n$ and period $t$ consumes, $\Omega^j$ is the demand shifter for sector $j$.

Solving the intratemporal expenditure minimization problem given $C_{n,t}$, the expenditure of country $n$ in period $t$ is

$$E_{n,t} = L_{n,t} \left[ \sum_{j=a,m,s} \Omega^j_{n,t} \left\{ \left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t} \right\}^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{8}$$

where $P^j_{n,t}$ is the price of the composite good of sector $j$ in country $n$ and period $t$. Define $P_{n,t}$ by $P_{n,t} = E_{n,t}/C_{n,t}$. Then we have

$$P_{n,t} = \left[ \sum_{j=a,m,s} \Omega^j_{n,t} (P^j_{n,t})^{1-\sigma} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{(1-\sigma)(\epsilon^j-1)} \right]^{\frac{1}{1-\sigma}}.$$

The consumption of the composite good of sector $j$ is

$$C^j_{n,t} = L_{n,t} \Omega^j_{n,t} \left(\frac{P^j_{n,t}}{P_{n,t}}\right)^{-\sigma} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{(1-\sigma)\epsilon^j+\sigma}. \tag{9}$$

Let $\omega^j_{n,t}$ be country $n$'s expenditure share on sector $j$ in period $t$, that is, $\omega^j_{n,t} = E^j_{n,t}/E_{n,t}$, where $E^j_{n,t}$ denotes country $n$'s expenditure on sector $j$ goods (or services) in period $t$. Then we have

$$\omega^j_{n,t} = \frac{\Omega^j_{n,t} \left\{ \left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t} \right\}^{1-\sigma}}{\sum_{j'=a,m,s} \Omega^{j'}_{n,t} \left\{ \left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^{j'}} P^{j'}_{n,t} \right\}^{1-\sigma}}. \tag{10}$$

By definition, we have $\sum_{j=a,m,s} \omega_{n,t}^{j} = 1$.

The representative household in country $n$ is the sole owner of labor and capital there. The budget constraint of country $n$ in period $t$ is

$$E_{n,t} + P_{n,t}^{K} I_{n,t} \leq (1-\phi_{n,t}) \left( w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t} \right) + L_{n,t} T_{t}^{P}, \tag{11}$$

where $P_{n,t}^{K}$ is the capital good price index which will be defined later, $I_{n,t}$ is the quantity of investment, $\phi_{n,t}$ is the fraction of the aggregate income accrued to the global portfolio, and $T_{t}^{P}$ is the payment from the global portfolio to each person of country $n$ in period $t$, and $\widetilde{T}_{n,t}$ is the tariff revenues in country $n$ and period $t$. $\phi_{n,t}$ is an exogenous parameter.

Let $K_{n,t}$ be the quantity of capital in country $n$ and period $t$. Then capital dynamics are

$$K_{n,t+1} = (1-\delta_{n,t}) K_{n,t} + I_{n,t}^{\lambda} (\delta_{n,t} K_{n,t})^{1-\lambda}, \tag{12}$$

where $\delta_{n,t}$ is the capital depreciation rate in country $n$ and period $t$ and $\lambda \in [0,1]$ is a parameter governing capital adjustment costs. Solving this for $I_{n,t}$ and viewing it as a function of $K_{n,t}$, $K_{n,t+1}$, and $\delta_{n,t}$, we have

$$I_{n,t} = \Phi(K_{n,t+1}, K_{n,t}; \delta_{n,t}) = \delta_{n,t}^{1-\frac{1}{\lambda}} K_{n,t} \left( \frac{K_{n,t+1}}{K_{n,t}} - (1-\delta_{n,t}) \right)^{\frac{1}{\lambda}}.$$

Take the derivatives of $\Phi$ with respect to the first and the second argument

$$\Phi_1(K_{n,t+1}, K_{n,t}; \delta_{n,t}) = \frac{\partial \Phi}{\partial K_{n,t+1}} (K_{n,t+1}, K_{n,t}; \delta_{n,t}) = \frac{1}{\lambda} \delta_{n,t}^{1-\frac{1}{\lambda}} \left( \frac{K_{n,t+1}}{K_{n,t}} - (1-\delta_{n,t}) \right)^{\frac{1}{\lambda}-1},$$

$$\Phi_2(K_{n,t+1}, K_{n,t}; \delta_{n,t}) = \frac{\partial \Phi}{\partial K_{n,t}} (K_{n,t+1}, K_{n,t}; \delta_{n,t}) = \Phi_1(K_{n,t+1}, K_{n,t}; \delta_{n,t}) \cdot \left( (\lambda-1) \frac{K_{n,t+1}}{K_{n,t}} - \lambda(1-\delta_{n,t}) \right).$$

The dynamic optimization problem of the representative household in country $n$ and period 0 is

$$\max \ (7)$$

subject to (8), (11), and (12). Solving this problem, we obtain the Euler equation

$$\left( \frac{C_{n,t+1}/L_{n,t+1}}{C_{n,t}/L_{n,t}} \right)^{\psi-1} \frac{E_{n,t+1} \bar{\epsilon}_{n,t+1}}{E_{n,t} \bar{\epsilon}_{n,t}} = \beta \frac{\zeta_{n,t+1}}{\zeta_{n,t}} \frac{L_{n,t+1}}{L_{n,t}} \frac{(1-\phi_{n,t+1}) r_{n,t+1} - P_{n,t+1}^{K} \Phi_2(K_{n,t+2}, K_{n,t+1}; \delta_{n,t+1})}{P_{n,t}^{K} \Phi_1(K_{n,t+1}, K_{n,t}; \delta_{n,t})}, \tag{13}$$

where

$$\bar{\epsilon}_{n,t} = \sum_{h=a,m,s} \omega_{n,t}^{h} \epsilon^{h}. \tag{14}$$

Both $E_{n,t+1}/E_{n,t}$ and $\bar{\epsilon}_{n,t+1}/\bar{\epsilon}_{n,t}$ are both increasing in $\frac{C_{n,t+1}/L_{n,t+1}}{C_{n,t}/L_{n,t}}$. Since $\psi > 1$, therefore, the left-hand side is just an increasing function of the ratio in per-capita consumption between periods $t+1$ and $t$. Eq. (13) tells that this per-capita consumption ratio depends on the discount factor ($\beta$), the ratio in the intertemporal demand shifters ($\zeta_{n,t+1}/\zeta_{n,t}$), the ratio in populations ($L_{n,t+1}/L_{n,t}$), and the real return to capital

$$\frac{(1-\phi_{n,t+1})r_{n,t+1} - P^K_{n,t+1}\Phi_2(K_{n,t+2}, K_{n,t+1}; \delta_{n,t+1})}{P^K_{n,t}\Phi_1(K_{n,t+1}, K_{n,t}; \delta_{n,t})}.$$

We have described households' behavior thus far. We move on to producers' behavior. The production function of variety $z \in [0,1]$ of sector $j$ in country $n$ and period $t$ is

$$y^j_{n,t}(z) = a^j_{n,t}(z)\left(\frac{K^j_{n,t}(z)}{\gamma^j_{n,t}\alpha^j_{n,t}}\right)^{\gamma^j_{n,t}\alpha^j_{n,t}}\left(\frac{L^j_{n,t}(z)}{\gamma^j_{n,t}(1-\alpha^j_{n,t})}\right)^{\gamma^j_{n,t}(1-\alpha^j_{n,t})}\left(\frac{M^j_{n,t}(z)}{1-\gamma^j_{n,t}}\right)^{1-\gamma^j_{n,t}}. \tag{15}$$

Here $y^j_{n,t}(z)$ is the quantity of output, $a^j_{n,t}(z)$ is the productivity which will be expressed as a realization of a random variable, $K^j_{n,t}(z)$ is the capital, $L^j_{n,t}(z)$ is the labor, $\gamma^j_{n,t} \in (0,1)$ is the value-added share, that is, the cost share on production factors (labor and capital), not on intermediate inputs, $\alpha^j_{n,t} \in (0,1)$ is the cost share on capital *within production factors*, $M^j_{n,t}(z)$ is the CES aggregate of sectoral intermediate goods used for production of variety $z$, that is,

$$M^j_{n,t}(z) = \left(\sum_{j'=a,m,s}(\kappa^{j,j'}_{n,t})^{\frac{1}{\sigma^j}}(M^{j,j'}_{n,t}(z))^{\frac{\sigma^j-1}{\sigma^j}}\right)^{\frac{\sigma^j}{\sigma^j-1}},$$

where $\kappa^{j,j'}_{n,t}$ is the shifter for sector $j$'s demand for sector-$j'$ goods, $M^{j,j'}_{n,t}(z)$ is the input of sector-$j'$ good for production of variety $z$ of sector $j$ and is produced using the same CES composite in (9), and $\sigma^j$ is the elasticity of substitution across sectoral goods for production of sector $j$ goods. In production of sector-$j$ goods, the cost share on sector-$j'$ goods *within intermediate-good costs* is

$$g^{j,j'}_{n,t} = \frac{P^{j'}_{n,t}M^{j,j'}_{n,t}}{\sum_{j''=a,m,s}P^{j''}_{n,t}M^{j,j''}_{n,t}} = \frac{\kappa^{j,j'}_{n,t}(P^{j'}_{n,t})^{1-\sigma^j}}{\sum_{j''=a,m,s}\kappa^{j,j''}_{n,t}(P^{j''}_{n,t})^{1-\sigma^j}}.$$

The productivity of variety $z$ of sector $j$ in country $n$ and period $t$, $a^j_{n,t}$, follows the Frechét distribution such that

$$F^j_{n,t}(a) = \Pr[a^j_{n,t} \le a] = \exp\left[-\left(\frac{a}{\widetilde{\gamma}^j A^j_{n,t}}\right)^{-\theta^j}\right].$$

Unlike the two-country model, we allow $\theta^j$ to vary in sectors, which makes the normalizing constant sector specific: $\widetilde{\gamma}^j = [\Gamma((\theta^j+1-\eta)/\theta^j)]^{-\frac{1}{1-\eta}}$. Productivity of varieties are independent within and across sectors, countries, and periods.

Solving the cost minimization problem for the production function (15), the cost for an input bundle is

$$\widetilde{c}^j_{n,t} = (r_{n,t})^{\gamma^j_{n,t}\alpha^j_{n,t}}(w_{n,t})^{\gamma^j_{n,t}(1-\alpha^j_{n,t})}(\xi^j_{n,t})^{1-\gamma^j_{n,t}}, \tag{16}$$

where $\xi^j_{n,t}$ is the CES price index for the composite intermediate good for production of sector-$j$ goods

$$\xi^j_{n,t} = \left[\sum_{j'=a,m,s} \kappa^{j,j'}_{n,t}(P^{j'}_{n,t})^{1-\sigma^j}\right]^{\frac{1}{1-\sigma^j}}. \tag{17}$$

The price index (or the price of the composite good) of sector $j$ in country $n$ and period $t$ is

$$P^j_{n,t} = \left[\sum_{i\in\mathcal{N}} \left(\frac{\tilde{c}^j_{i,t} b^j_{ni,t}}{A^j_{i,t}}\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{18}$$

where $b^j_{ni,t}$ is the total trade costs including tariffs and non-tariff trade barriers for goods or services of sector $j$ from country $i$ to country $n$. $b^j_{ni,t}$ is expressed as

$$b^j_{ni,t} = d^j_{ni,t}(1+\tau^j_{ni,t}), \tag{19}$$

where $d^j_{ni,t}$ is the iceberg trade cost for sector-$j$ goods from country $i$ to country $n$ in period $t$ including phisical trade costs and non-tariff barriers, and $\tau^j_{ni,t}$ is country $n$'s tariffs against sector-$j$ goods from country $i$ in period $t$. For later use, define gross tariffs $\tilde{\tau}^j_{ni,t}$ by $\tilde{\tau}^j_{ni,t} = 1+\tau^j_{ni,t}$.

The production function of capital (investment) goods in country $n$ and period $t$ is

$$I_{n,t} = \kappa^K_{n,t}\left(\sum_{j=a,m,s}(\kappa^{K,j}_{n,t})^{\frac{1}{\sigma^K}}(M^{K,j}_{n,t})^{\frac{\sigma^K-1}{\sigma^K}}\right)^{\frac{\sigma^K}{\sigma^K-1}},$$

where $\kappa^K_{n,t}$ is the productivity, $M^{K,j}_{n,t}$ is the sector-$j$ goods used for production of capital goods, and $\sigma^K$ is the elasticity of substitution across sectoral intermediate goods for production of capital goods. Then the cost share on sector-$j$ goods

$$g^{K,j}_{n,t} = \frac{P^j_{n,t}M^{K,j}_{n,t}}{\sum_{j'=a,m,s}P^{j'}_{n,t}M^{K,j'}_{n,t}} = \frac{\kappa^{K,j}_{n,t}(P^j_{n,t})^{1-\sigma^K}}{\sum_{j'=a,m,s}\kappa^{K,j'}_{n,t}(P^{j'}_{n,t})^{1-\sigma^K}}.$$

The ideal price index of capital goods is

$$P_{n,t}^{K}=\frac{1}{\kappa_{n,t}^{K}}\left(\sum_{j=s,m,s}\kappa_{n,t}^{K,j}(P_{n,t}^{j})^{1-\sigma^{K}}\right)^{\frac{1}{1-\sigma^{K}}}. \tag{20}$$

Let $X_{ni,t}^{j}$ be country $n$'s spending on sector-$j$ goods (or services) from country $i$ in period $t$. This includes spending for consumption, investment, and intermediate inputs. Summing $X_{ni,t}^{j}$ across $i$, let $X_{n,t}^{j}$ be country $n$'s spending on sector $j$ goods (or services) in period $t$. Let $\pi_{ni,t}^{j}=X_{ni,t}^{j}/X_{n,t}^{j}$, that is, the share of goods from country $i$ within country $n$'s expenditure on sector $j$ goods in period $t$. We call $\pi_{ni,t}^{j}$ as trade shares following the literature of quantitative trade models. Following Eaton and Kortum (2002), we have

$$\pi_{ni,t}^{j}=\frac{(\tilde{c}_{i,t}^{j}b_{ni,t}^{j}/A_{i,t}^{j})^{-\theta^{j}}}{\sum_{i'\in\mathcal{N}}(\tilde{c}_{i',t}^{j}b_{ni',t}^{j}/A_{i',t}^{j})^{-\theta^{j}}}=\frac{(\tilde{c}_{i,t}^{j}b_{ni,t}^{j}/A_{i,t}^{j})^{-\theta^{j}}}{(P_{n,t}^{j})^{-\theta^{j}}} \tag{21}$$

Let $Y_{n,t}^{j}$ be the gross production of sector $j$ in country $n$ and period $t$. It is value not quantity. We have

$$Y_{n,t}^{j}=\sum_{i\in\mathcal{N}}\frac{\pi_{in,t}^{j}}{\tilde{\tau}_{in,t}^{j}}X_{i,t}^{j}. \tag{22}$$

Country $n$'s spending on sector-$j$ goods in period $t$ consists of the final consumption, the input for production of capital goods, and the input for production of goods and services of various sectors

$$\begin{aligned}X_{n,t}^{j}&=P_{n,t}^{j}C_{n,t}^{j}+P_{n,t}^{j}M_{n}^{K,j}+\sum_{j'=a,m,s}(1-\gamma_{n,t}^{j'})g_{n,t}^{j',j}Y_{n,t}^{j'}\\&=\omega_{n,t}^{j}E_{n,t}++g_{n,t}^{K,j}P_{n,t}^{K}I_{n,t}+\sum_{j'=a,m,s}(1-\gamma_{n,t}^{j'})g_{n,t}^{j',j}Y_{n,t}^{j'}.\end{aligned} \tag{23}$$

In country $n$ and period $t$, the aggregate labor income must be equal to the aggregate labor cost

$$w_{n,t}L_{n,t}=\sum_{j=a,m,s}\gamma_{n,t}^{j}(1-\alpha_{n,t}^{j})Y_{n,t}^{j}. \tag{24}$$

Similarly, the aggregate capital income must be equal to the aggregate capital cost

$$r_{n,t}K_{n,t}=\sum_{j=a,m,s}\gamma_{n,t}^{j}\alpha_{n,t}^{j}Y_{n,t}^{j}. \tag{25}$$

The trade deficit, $D_{n,t}$, is the imports minus the exports

$$D_{n,t} = \underbrace{\sum_{j=a,m,s} \sum_{i=1}^{N} X_{n,t}^{j} \frac{\pi_{ni,t}^{j}}{\tilde{\tau}_{ni,t}^{j}}}_{\text{imports}} - \underbrace{\sum_{j=a,m,s} \sum_{i=1}^{N} X_{i,t}^{j} \frac{\pi_{in,t}^{j}}{\tilde{\tau}_{in,t}^{j}}}_{\text{exports}}.$$

Country $n$'s trade deficit must be equal to its net payment to the global portfolio

$$D_{n,t} = L_{n,t} T_t^P - \phi_{n,t}(w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t}).$$

We move on to the budget balance of the global portfolio. The sum of the net payments from all countries to the global portfolio must be zero

$$\sum_{n=1}^{N} \left\{ \phi_{n,t}(w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t}) - L_{n,t} T_t^P \right\} = 0.$$

Solving this for $T_t^P$, we have

$$T_t^P = \frac{\sum_{n=1}^{N} \phi_{n,t}(w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t})}{\sum_{n=1}^{N} L_{n,t}}. \tag{26}$$

**Definition 1** (Equilibrium)**.** Given the capital stocks in the initial period $\{K_{n,0}\}_{n\in\mathcal{N}}$, an equilibrium is a tuple of $\{w_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{r_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{E_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{\tilde{c}_{n,t}^{j}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{P_{n,t}^{j}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{\pi_{ni,t}^{j}\}_{(n,i)\in\mathcal{N}\times\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{Y_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{X_{n,t}^{j}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{\bar{\epsilon}_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{\omega_{n,t}^{j}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{C_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{K_{n,t}\}_{n\in\mathcal{N},t=1,\cdots,\infty}$, $\{I_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{T_t^P\}_{t=0,\cdots,\infty}$ satisfying a system of equations (8), (10), (11), (12), (13), (14), (16), (18), (21), (22), (23), (24), (25), and (26).

We compute transition paths, that is, equilibria converging to steady states. For this purpose, we define steady states of this model.

**Definition 2** (Steady state)**.** A steady state is an equilibrium in which relevant endogenous variables are time-invariant. Specifically, a steady state is a tuple of $\{w_n\}_{n\in\mathcal{N}}$, $\{r_n\}_{n\in\mathcal{N}}$, $\{E_n\}_{n\in\mathcal{N}}$, $\{\tilde{c}_n^{j}\}_{n\in\mathcal{N},j=a,m,s}$, $\{P_n^{j}\}_{n\in\mathcal{N},j=a,m,s}$, $\{\pi_{ni}^{j}\}_{(n,i)\in\mathcal{N}\times\mathcal{N},j=a,m,s}$, $\{Y_n\}_{n\in\mathcal{N}}$, $\{X_n^{j}\}_{n\in\mathcal{N},j=a,m,s}$, $\{\omega_n^{j}\}_{n\in\mathcal{N},j=a,m,s}$, $\{C_n\}_{n\in\mathcal{N}}$, $\{K_n\}_{n\in\mathcal{N}}$ satisfying a system of equations, (8), (10), (16), (18), (21), (22), (23), (24), (26),

$$r_n K_n = \frac{\alpha}{1-\alpha} w_n L_n,$$

$$r_n = \frac{1-\beta(1-\lambda\delta_n)}{\beta(1-\phi_n)\lambda} P_n^K,$$

Table 1: List of Countries

| | | | | | |
|---|---|---|---|---|---|
| Australia | Canada | Spain | Greece | Japan | Portugal |
| Austria | China | Finland | India | Korea | Sweden |
| Belgium | Germany | France | Ireland | Mexico | Taiwan |
| Brazil | Denmark | UK | Italy | Netherlands | USA |

and

$$E_n = (1 - \phi_n)\left(w_n L_n + r_n K_n + \widetilde{T}_n\right) - \delta_n P_n^K K_n + L_n T^P,$$

dropping time subscripts $t$ from all the equations.

# 4 Calibration and Solution Algorithm

We bring the model to the data for the global economy. We first describe our main data sources and then discuss the calibration of the structural parameters. We then present the solution algorithm for computing transition paths.

## 4.1 Data

Our primary data source is the World Input-Output Database (WIOD) Release 2016 and the Long-Run WIOD (Woltjer et al., 2021; Timmer et al., 2015), which allows us to observe the intermediate input uses across different countries and sectors of both origins and destinations. By merging the two datasets, we constructed a database that covers half a century, 1965–2014. Our empirical exercise encompasses 24 countries (see Table 1) and the rest of the world (RoW). They are the listed countries in the Long-Run WIOD, and we moved Hong Kong to the RoW. We aggregate the ISIC industries into three categories as in Table 2. We label D15-D16 Food, Beverages, and Tobacco as agriculture instead of manufacturing due to the nature of its products. Construction and utility supply (e.g., electricity, gas, and water supply) is classified as a service.[8] We complement the WIOD data with the Penn World Table (PWT) 10.0 (Feenstra et al., 2015) and CEPII Gravity database (Mayer and Zignago, 2011). Bilateral tariffs on good sectors are sourced from the World Integrated Trade Solution (WITS).[9]

[8]Whether the construction and utilities are classified as manufacturing, services, or an independent sector differs across previous studies. For example, Sposi (2019); Sposi et al. (2021), Uy et al. (2013), Smitkova (2023), Lewis et al. (2022) include construction in the service sector, while Święcki (2017), García-Santana et al. (2021), Herrendorf et al. (2014, 2021), and Betts et al. (2017) include it in the manufacturing sector.

[9]As the bilateral tariffs are specified on each Harmonized System (HS) product, we first group the HS products to the ISIC industries using the concordance table provided by the WITS and then compute the simple average for agriculture and manufacturing sectors.

Table 2: Three Sectors and Corresponding ISIC3 Codes

| Sector | ISIC3 | Description |
|---|---|---|
| Agriculture | A to B | Agriculture, Hunting, Forestry and Fishing |
| | C | Mining and Quarrying |
| | D15 to 16 | Food, Beverages and Tobacco |
| Manufacturing | D17 to 19 | Textiles, Textile, Leather and Footwear |
| | D21 to 22 | Pulp, Paper, Printing and Publishing |
| | D23 | Coke, Refined Petroleum and Nuclear Fuel |
| | D24 | Chemicals and Chemical Products |
| | D25 | Rubber and Plastics |
| | D26 | Other Non-Metallic Mineral |
| | D27 to 28 | Basic Metals and Fabricated Metal |
| | D29 | Machinery, Nec |
| | D30 to 33 | Electrical and Optical Equipment |
| | D34 to 35 | Transport Equipment |
| | D n.e.c. | Manufacturing, Nec; Recycling |
| Service | E | Electricity, Gas and Water Supply |
| | F | Construction |
| | G | Wholesale and Retail Trade |
| | H | Hotels and Restaurants |
| | I60 to 63 | Transport and Storage |
| | I64 | Post and Telecommunications |
| | J | Financial Intermediation |
| | K | Real Estate, Renting and Business Activities |
| | L to Q | Community Social and Personal Services |

## 4.2 Structural Parameters

We begin with discussing our calibration of the parameters in preferences. The discount factor $\beta$ is set at 0.96 following the literature on macroeconomics. We set the inter-temporal elasticity of substitution $\psi = 2$ following Ravikumar et al. (2019). For parameters in the period utility, we choose the elasticities of substitution across sectors $\sigma = 0.5$, and the degree of nonhomotheticity $\epsilon^a = 0.05$ in agriculture, $\epsilon^m = 1$ in manufacturing, and $\epsilon^s = 1.2$ for services following Comin et al. (2021). $\sigma < 1$ implies that sectoral goods are compliments, and, therefore, the Baumol effect is at work. Values of $\epsilon$s suggest that agriculture is a necessity, service is a luxury, and manufacturing goods start as a luxury and then become a necessity as the consumption expenditure rises.

Value-added shares in production function $\gamma^j_{n,t}$ is directly observed in the IO table. Capital shares within value-added $\alpha^j_{n,t}$ is calibrated as one minus labor shares, which are obtained from the PWT. Since the PWT does not provide the sectoral labor share, we apply the common value across sectors for each year and country. We set the elasticity of substitution across intermediate inputs $\sigma^j = 0.38$ for all $j$ following Atalay (2017). For the capital goods production, we set the elasticity of substitution $\sigma^K = 0.29$ following Sposi et al. (2021). Shape parameters of the Fréchet distribution, i.e., trade elasticities, are chosen as $\theta^a = 8.11$ and $\theta^m = 4.55$. For the service trade elasticity, we follow Gervais and Jensen (2019) and set $\theta^s = 0.75 \cdot \theta^m$. Elasticities for the good sectors are calibrated based on the estimates of Caliendo and Parro (2015). We will discuss the calibration of productivity and exogenous demand shifters below.

We set the adjustment cost elasticity in the low of motion for capital $\lambda = 0.75$ following Eaton et al. (2016) and the depreciation rate of capital $\delta_{n,t}$ is obtained from the PWT.

### 4.3 Path of Fundamentals

We calibrate the iceberg trade costs (including tariffs and non-tariff barriers), $b^j_{nt}$, and average productivity, $A^j_{n,t}$, basically following Levchenko and Zhang (2016). Apart from Levchenko and Zhang (2016), we use information from price indices on WIOD to make sequences of productivity $A^j_{n,t}$ which are comparable across countries and over time within each sector. To begin with, we express the trade share normalized by its own trade share as follows:

$$\frac{\pi^j_{ni,t}}{\pi^j_{nn,t}} = \frac{\left(\frac{\tilde{c}^j_{i,t} b^j_{ni,t}}{A^j_{i,t}}\right)^{-\theta^j}}{\left(\frac{\tilde{c}^j_{n,t}}{A^j_{n,t}}\right)^{-\theta^j}} = \left(\tilde{c}^j_{i,t}/A^j_{i,t}\right)^{-\theta^j} \times \left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j} \times \left(b^j_{ni,t}\right)^{-\theta^j}.$$

Taking the log of both sides yields

$$\ln\left(\frac{\pi^j_{ni,t}}{\pi^j_{nn,t}}\right) = \ln\left(\tilde{c}^j_{i,t}/A^j_{i,t}\right)^{-\theta^j} + \ln\left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j} - \theta^j \ln\left(b^j_{ni,t}\right).$$

According to (19), the total trade costs $b^j_{ni,t}$ can be decomposed into tariffs and non-tariff barriers, we can express the above expression as,

$$\ln\left(\frac{\pi^j_{ni,t}}{\pi^j_{nn,t}}\right) = \ln\left(\tilde{c}^j_{i,t}/A^j_{i,t}\right)^{-\theta^j} + \ln\left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j} - \theta^j \ln\left(d^j_{ni,t}\right) - \theta^j \ln\left(\tilde{\tau}^j_{ni,t}\right),$$

where and $\tilde{\tau}^j_{ni,t} = 1 + \tau^j_{ni,t}$, and then express the log of non-tariff barriers $d^j_{ni,t}$ with the set of bilateral observables used in the gravity estimation:

$$\ln\left(d^j_{ni,t}\right) = \mathrm{dist}^j_{k(ni)} + \mathrm{CB}^j_{ni,t} + \mathrm{CU}^j_{ni,t} + \mathrm{RTA}^j_{ni,t} + ex^j_{i,t} + \nu^j_{ni,t},$$

where $\text{dist}^j_{k(ni),t}$ is the contribution to trade costs of the distance between $n$ and $i$ being in a certain interval[10], $\text{CB}^j_{ni,t}$ is the indicator if the two countries $n$ and $i$ share the border, $\text{CU}^j_{ni,t}$ indicates if they are in a currency union, $\text{RTA}^j_{ni,t}$ indicates if they are in a regional trade agreement (WTO definition), $ex^j_{it}$ is the exporter fixed effects, and $\nu^j_{ni,t}$ is the bilateral error term. Note that each component in the bilateral trade cost is indexed by $t$ and we estimate them as the fixed effects interacted with years. This implies that, for instance, the contribution of distance to trade costs can vary over time due to the technological progress of transportation (e.g., reduction in container shipping costs). Exporter fixed effects are included to allow asymmetry in trade costs in the spirits of Waugh (2010). We plug this into the trade share equation (21) and estimate the following using the Pseudo Poisson Maximum Likelihood (PPML) for each sector $j$ while pooling all sampled countries and years:

$$\ln\left(\frac{\tilde{\pi}^j_{ni,t}}{\pi^j_{nn,t}}\right) = \underbrace{\left(\ln\left(\tilde{c}^j_{i,t}/A^j_{i,t}\right)^{-\theta^j} - \theta^j ex^j_{it}\right)}_{\text{exporter-year F.E.}} + \underbrace{\ln\left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j}}_{\text{importer-year F.F.}}$$
$$\underbrace{-\theta^j\left(\text{dist}^j_{k(ni),t} + \text{CB}^j_{ni,t} + \text{CU}^j_{ni,t} + \text{RTA}^j_{ni,t}\right)}_{\text{Bilateral observables}} - \theta^j \nu^j_{ni,t}.$$

where $\ln\left(\frac{\tilde{\pi}^j_{ni,t}}{\pi^j_{nn,t}}\right) = \ln\left(\frac{\pi^j_{ni,t}}{\pi^j_{nn,t}}\right) + \theta^j \ln\left(\tilde{\tau}^j_{ni,t}\right)$. Estimating the gravity equation above allows us to identify the technology-cum-unit-cost term, $\ln\left(\tilde{c}^j_{n,t}/A^j_{i,t}\right)^{\theta^j}$, for each county and year as an importer-year fixed effect, relative to the reference country and year (US in 1965), which we denote by $S^j_{nt} = \left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j} / \left(\tilde{c}^j_{US,1965}/A^j_{US,1965}\right)^{\theta^j}$. We can then tease out the term $(-\theta^j ex^j_{it})$ from the exporter-year fixed effects. By combining all the terms in the bilateral trade costs, we can recover the asymmetric bilateral trade costs.

To back out productivity, we need a few preliminary steps. First, following Shikher (2013), we recover the sectoral price indices as follows. We define the own trade share relative to the ones of the reference country and year:

$$\frac{\pi^j_{nn,t}}{\pi^j_{US,US,1965}} = \frac{\left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{-\theta^j}}{\left(\tilde{c}^j_{US,1965}/A^j_{US,1965}\right)^{-\theta^j}} \left(\frac{P^j_{n,t}}{P^j_{US,1965}}\right)^{\theta^j} = \frac{1}{S^j_{nt}} \left(\frac{P^j_{n,t}}{P^j_{US,1965}}\right)^{\theta^j}.$$

[10] We follow Eaton and Kortum (2002) and intervals are defined, in miles, $[0, 350]$, $[350, 750]$, $[750, 1500]$, $[1500, 3000]$, $[3000, 6000]$, $[6000, \max]$

Hence, for given trade elasticity $\theta^j$, we have,[11]

$$\frac{P^j_{n,t}}{P^j_{US,1965}} = \left( \frac{\pi^j_{nn,t}}{\pi^j_{US,US,1965}} S^j_{nt} \right)^{1/\theta^j}. \tag{27}$$

It is important to note that, for each sector and year, $S^j_{nt}$ is only identified up to normalization. This implies that the sequence of prices given by equation (27) is only comparable across countries but not over time. To see this point clearly, consider a sequence of any positive scalar $\{a^j_t\}^j_t$. It is easy to show that the two sequences, $\{S^j_{nt}\}$ and $\{a^j_t S^j_{nt}\}$, generate the same trade share $\{\pi^j_{ni}\}$. Therefore, without correctly rescaling the sequence of $S^j_{nt}$ by identifying $\{a^j_t\}$, the calibrated productivity cannot measure the productivity which is comparable across countries and years.[12] Choose the United States as a reference country and assume $S^j_{US,t} = 1$ for any $t$ and $j$.

To identify the shifters $\{a^j_t\}$, we take advantage of the gross output price index provided by the WIOD Socio Economic Accounts. Let $\{P^j_{US,t,Data}\}$ be the gross output price index of sector $j$ in the United States and year $t$. Note that $\{P^j_{US,t,Data}\}_t$ are comparable over time within sector $j$. Since the sequence $\{a^j_t\}_t$ is defined for each sector, we will use the gross price index for the three sectors in the US and back out $\{a^j_t\}$ according to:

$$\begin{aligned} P^j_{US,t} &= (a^j_t)^{1/\theta^j} \left[ \sum_{n\in\mathcal{N}} S^{-1}_{n,t} b^{-\theta^j}_{US,n,t} \right]^{-1/\theta^j} \\ \Leftrightarrow a^j_t &= \left( P^j_{US,t,Data} \right)^{\theta^j} \left[ \sum_{n\in\mathcal{N}} S^{-1}_{n,t} b^{-\theta^j}_{US,n,t} \right] \end{aligned}$$

Now redefine $S^j_{n,t}$ by $a^j_t S^j_{n,t}$. Such redefined $\{S^j_{n,t}\}_{n,t}$ are comparable over time and across countries within sector $j$.

Being armed with the sectoral price indices after rescaling the sequence of $\{S^j_{nt}\}$, we next back out the exogenous demand shifters for intermediate inputs, $\kappa^{jh}_{n,t}$, by solving the system of equations for each $j$, $n$, and $t$:

$$g^{j,h}_{n,t} = \frac{\kappa^{j,h}_{n,t} (P^h_{n,t})^{1-\sigma^j}}{\sum_{h'=a,m,s} \kappa^{j,h'}_{n,t} (P^{h'}_{n,t})^{1-\sigma^j}}.$$

by restricting $\sum_{h'} \kappa^{j,h'}_{n,t} = 1$ for each $j$, $n$, and $t$. The left-hand side of the equation, $g^{j,h}_{n,t}$, is the share of expenditure spent on input from sector $h$ in total input costs of $j$, which is directly observed in the IO table. After obtaining $\kappa^{j,h}_{n,t}$, we can recover the CES price index for the

[11] Note that the price indices are recovered relative to the US in 1965 for each sector, implying that the US price index is 1 for all sectors in 1965.

[12] Even after rescaling the sequence of $\{S^j_{nt}\}$, productivity of the US in 1965 is normalized to 1 for all sectors.

composite intermediate good $\xi^j_{n,t}$ according to (17).

We analogously back out the exogenous demand shifter in the capital goods production function, $\kappa^{Kh}_{n,t}$, by solving the system of equations for each $n$ and $t$:

$$g^{K,h}_{n,t} = \frac{\kappa^{K,h}_{n,t}(P^h_{n,t})^{1-\sigma^K}}{\sum_{h'=a,m,s}\kappa^{K,h'}_{n,t}(P^{h'}_{n,t})^{1-\sigma^K}}.$$

by restricting $\sum_{h'}\kappa^{K,h'}_{n,t} = 1$. This gives the price index of investment $P^K_{n,t}$ good over time, following (20).

In order to obtain the factor prices, we next construct the sequence of capital stock over time for each country. Starting from the initial capital stock in 1965 for each country provided by the PWT, we use the gross fixed capital formation from the WIOD and follow (12) to construct the nationwide capital stock. Since, in the model, capital stock is measured as the real variable, we need to obtain the initial period capital stock in the current USD[13] and then divide the nominal value by the price index of the investment good obtained in the previous step.[14] We then compute the real investment in each year by dividing the gross fixed capital formation (in current USD) by the investment good price index (obtained above) and accumulate the capital stock as implied by the model.

Using the value-added from the WIOD, we apply the labor share from the PWT to obtain the wage bill and the return to capital. The wage bill and the total number of employment give the wage, $w_{n,t}$, and the return to capital and the capital stock give the rental price of capital, $r_{n,t}$.

Together with the composite intermediate input price index, $\xi^j_{n,t}$, and factor prices, $r_{n,t}, w_{n,t}$, we can compute the cost of the input bundle according to (16). Finally, we can recover the productivity $A^j_{n,t}$ by:[15]

$$\frac{A^j_{n,t}}{A^j_{US,1965}} = (S^j_{n,t})^{1/\theta^j}\left(\frac{\tilde{c}^j_{n,t}}{-\tilde{c}^j_{US,1965}}\right).$$

Using the sectoral price indices computed above, we calibrated the sectoral demand shifter $\Omega^j_{n,t}$ as follows. First, we guess the vector of $\{\Omega^j_{n,t}\}$. Given the data on consumption expenditure $E_{n,t}$ from the WIOD, population $L_{n,t}$ from the PWT, sectoral prices $P^j_{n,t}$, and guessed values of $\Omega^j_{n,t}$, solve the consumption index $C^j_{n,t}$ according to (8). Using the computed consumption index, we can find the unique vector of $\Omega^j_{n,t}$ (up to normalization for each $n$ and $t$) by applying the Perron-Frobenius theorem to (10). We then use the value of $\Omega^j_{n,t}$ as the new guess and repeat the steps until we find the fixed points.

The intertemporal demand shifter $\zeta_{n,t}$ is backed out sequentially according to (13). Using

[13] We use the capital stock at current PPP multiplied by the price level of capital stock to obtain the initial capital stock.

[14] The underlying assumption is that the capital stock in period $t$ is priced at $P^K_{n,t}$.

[15] By construction, sectoral productivity takes 1 for the US in 1965 in all sectors.

the consumption index $C_{n,t}$ obtained above, we can construct the series of $\zeta_{n,t}$ for each country with normalizing the one in the last sample year $\zeta_{n,2014}$ to be unity.

We also calibrated the sectoral demand shifter $\Omega^{j}_{n,t}$ and the interdemporal demand shifter $\zeta_{n,t}$ under the homothetic CES preference (i.e., $\epsilon^{j} = 1$ for all $j$).

### 4.4 Values of Fundamentals

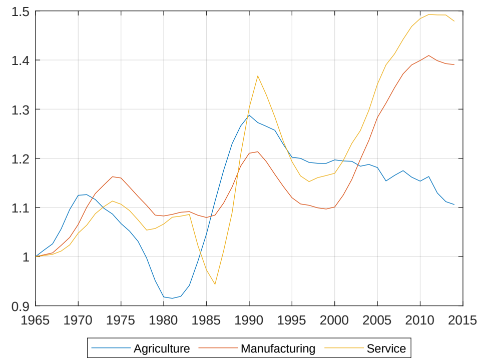
Before moving on to the quantitative results, we summarize the baseline fundamentals we calibrated above. Figure 2 shows the evolution of sectoral productivity in six countries, Canada, China, Germany, Japan, Mexico, and the US. We normalize the productivity in 1965 to be 1 and take the moving average over 5 years to remove the noise. In every country other than Canada, after the 1980s, the productivity of the manufacturing sector grows more than that of the service sector. In the US, the manufacturing productivity increased by a factor of 2.2 while the service sector productivity increased by a factor of 1.5. The productivity growth biased toward manufacturing implies that the expenditure share on manufacturing may drop due to the Baumol effect, even if we do not take into account impacts of international trade and non-homotheticity preferences-driven demand changes. Canada exhibits the opposite pattern, i.e., the productivity of the service sector grows faster than that of the manufacturing sector.

Figure 3 shows the evolution of trade costs in the six countries. For each country and year, we compute the simple arithmetic average of the bilateral tariff rate (inward and outward) with all its trading partners. The source of the tariff data is the WITS, which provides the bilateral tariff after the late 1980s for the major countries. For the period prior to the year when the tariffs are reported for its first time, we apply the tariff rates in the first year. The figure confirms that the tarriffs are continuously falling after 1990s for manufacturing sector in most of the countries. It is also worth noting that China's export tariffs drop more significantly in the late 1990s than in the 2000s when China joined the WTO.

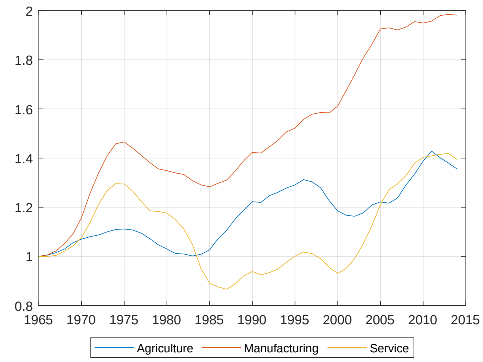
Figure 4 exhibits the evolution of non-tariff barriers in the six countries, measuerd as the simple average of inward and outward iceberg trade costs. First, we see the fall in non-tariff barriers is more significant in magnitude compared to the tariff barriers. For instance, in the US, the non-tariff barriers in the US dropped from 400% to 300% over the five decades while the tariff barriers droppped from 5% to 3%. Second, the non-tariff barriers for the service sector are much higher in level than the good sectors, but exhibits a significant drop over time. While the service trade is often overlooked in the quantitative trade analysis, the result suggests that the falling service trade cost is a crucial factor in understading the sectoral reallocation in the global context.

Figure 2: Productivity Evolution (1965=1)

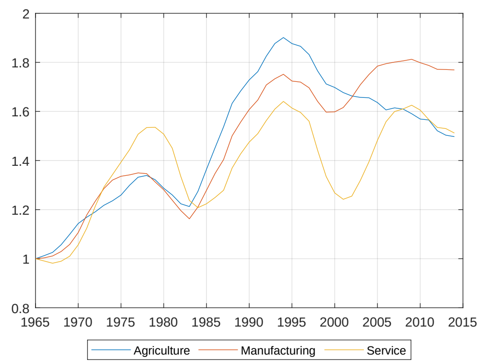
(a) Canada



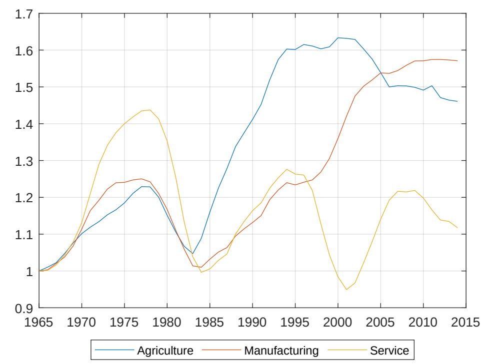

(b) China



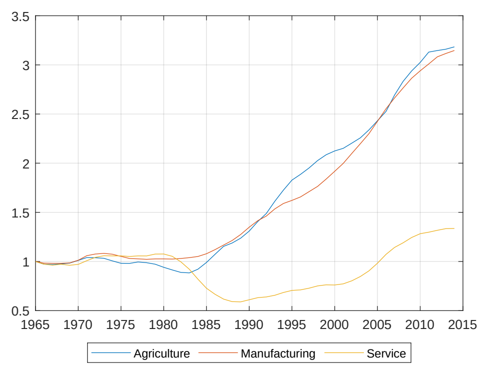

(c) Germany




(d) Japan




(e) Mexico




(f) United States

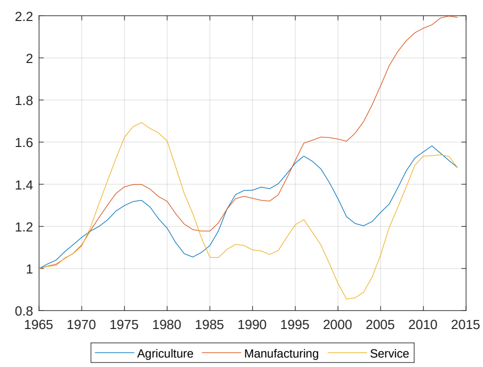


Figure 3: Evolution of Average Tariff

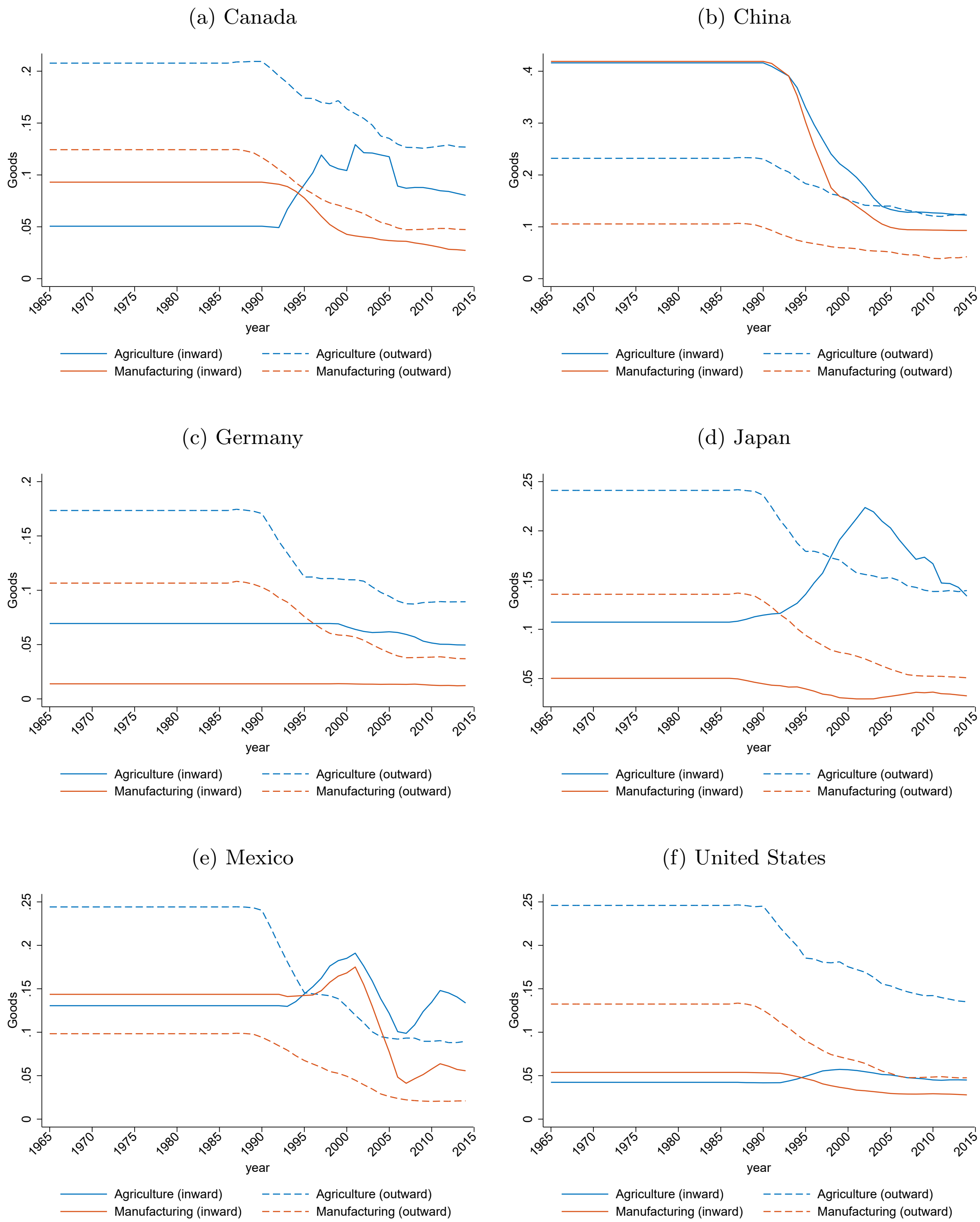
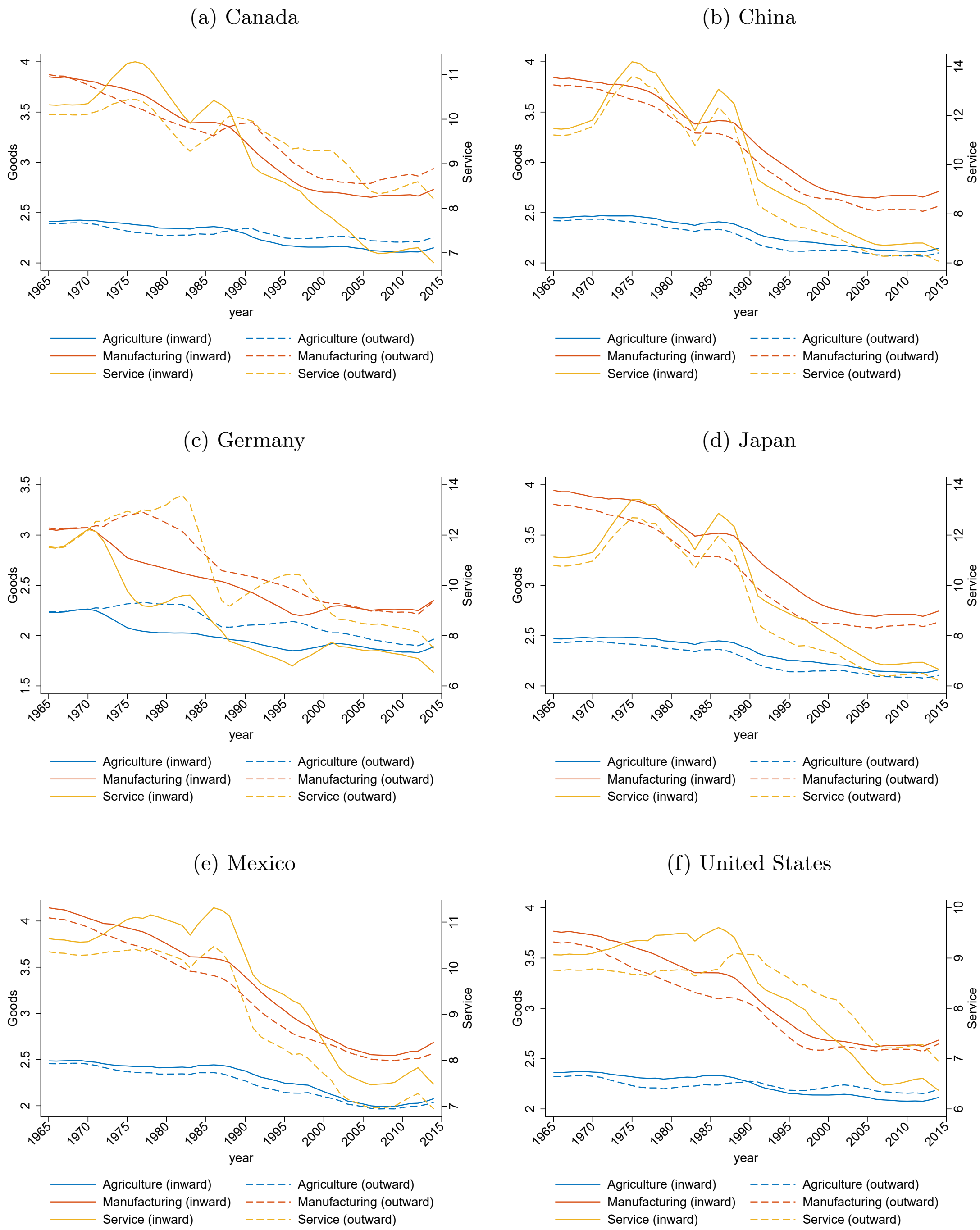


Figure 4: Evolution of Average Non-Tariff Barrier



### 4.5 Solution Algorithm

We solve the equilibrium transition path backward. We first solve the model for the steady state according to Definition 2, assuming the 2014 fundamentals (e.g., productivity, trade costs, exogenous demand shifters, etc) last forever. We then suppose that the economy will reach the steady state in 450 years after 2014. The solution algorithm for the transition path has two loops: the outer loop finds the sequence of investment (saving) rate $\{\rho_{n,t}\}_{n,t}$ that satisfies the dynamic optimality condition governed by the Euler equation (13) and the inner loop solves the intra-temporal optimization for each period (i.e., solving the sectoral prices and factor prices that satisfy the equilibrium conditions listed in Definition 1). More specifically, For the given sequence of $\{\rho_{n,t}\}_{n,t}$ and the initial period capital stock, we first solve the static equilibrium period-by-period sequentially from 1965 to 2464. After we solve the periodic equilibria up to the year 2464, we update $\rho_{n,t}$ backward from 2464 to 1965 according to the Euler equation. More details are in Appendix (see also Ravikumar et al., 2019 for the details of the outer loop iteration).

## 5 Quantitative Results

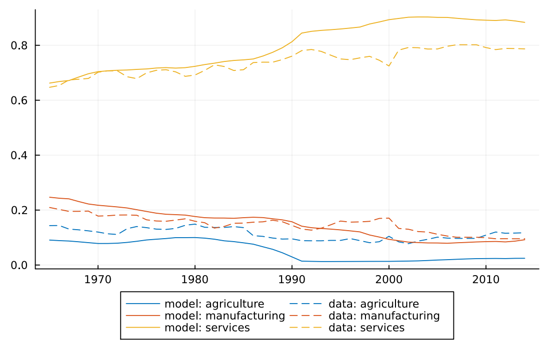
This section presents the quantitative results of the calibrated model.

### 5.1 Fit of the Baseline Model

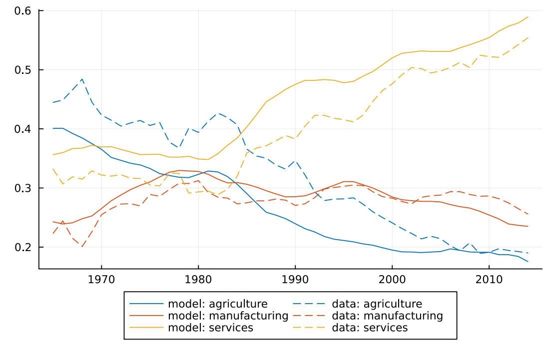
We first show the baseline results. To examine the model's ability to match the data, Figure 5 compares the model-implied (solid lines) value-added shares in three sectors (yellow for agriculture, orange for manufacturing, and blue for services) with the data counterparts (dashed lines) for six selected coutries, Canada, China, Germany, Japan, Mexico, and the US. In the six countries, the model captures the overall trend of falling manufacturing and rising services over time. The fit of the model is particularly better for Germany, Japan and the US, while in the other three countries, the model overestimates the service share and underestimates the agricultural share, despite the overall trend being captured.

Figure 5: Model Fit: Sectoral Value Added Share in GDP

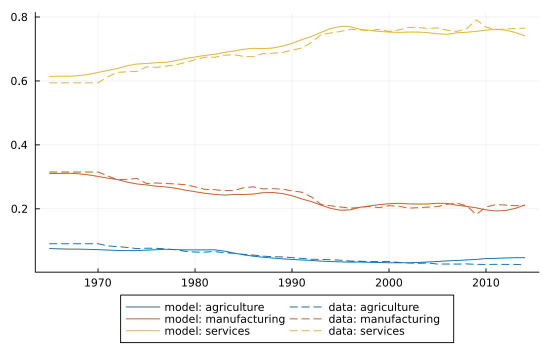
(a) Canada



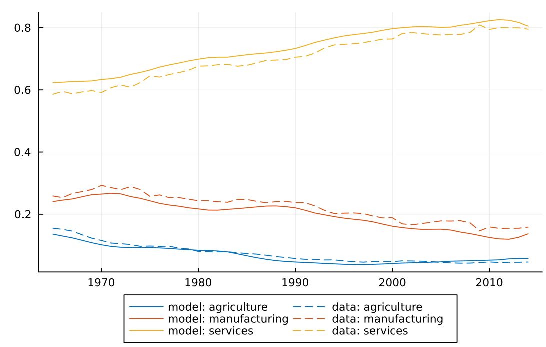

(b) China



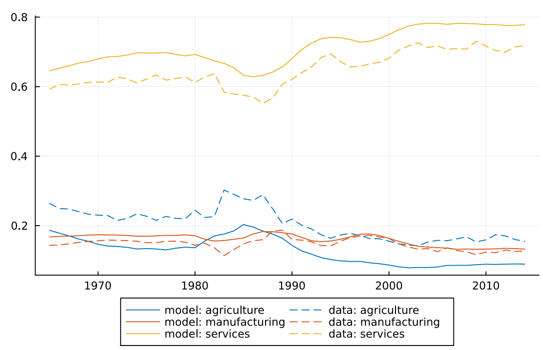

(c) Germany



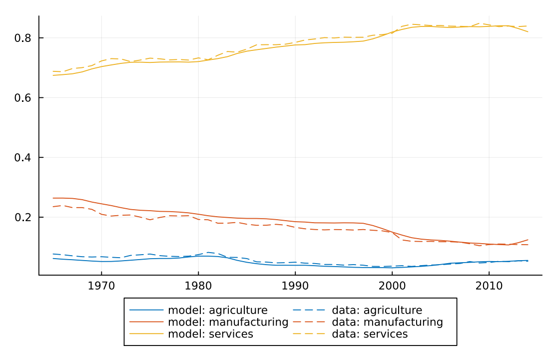

(d) Japan




(e) Mexico

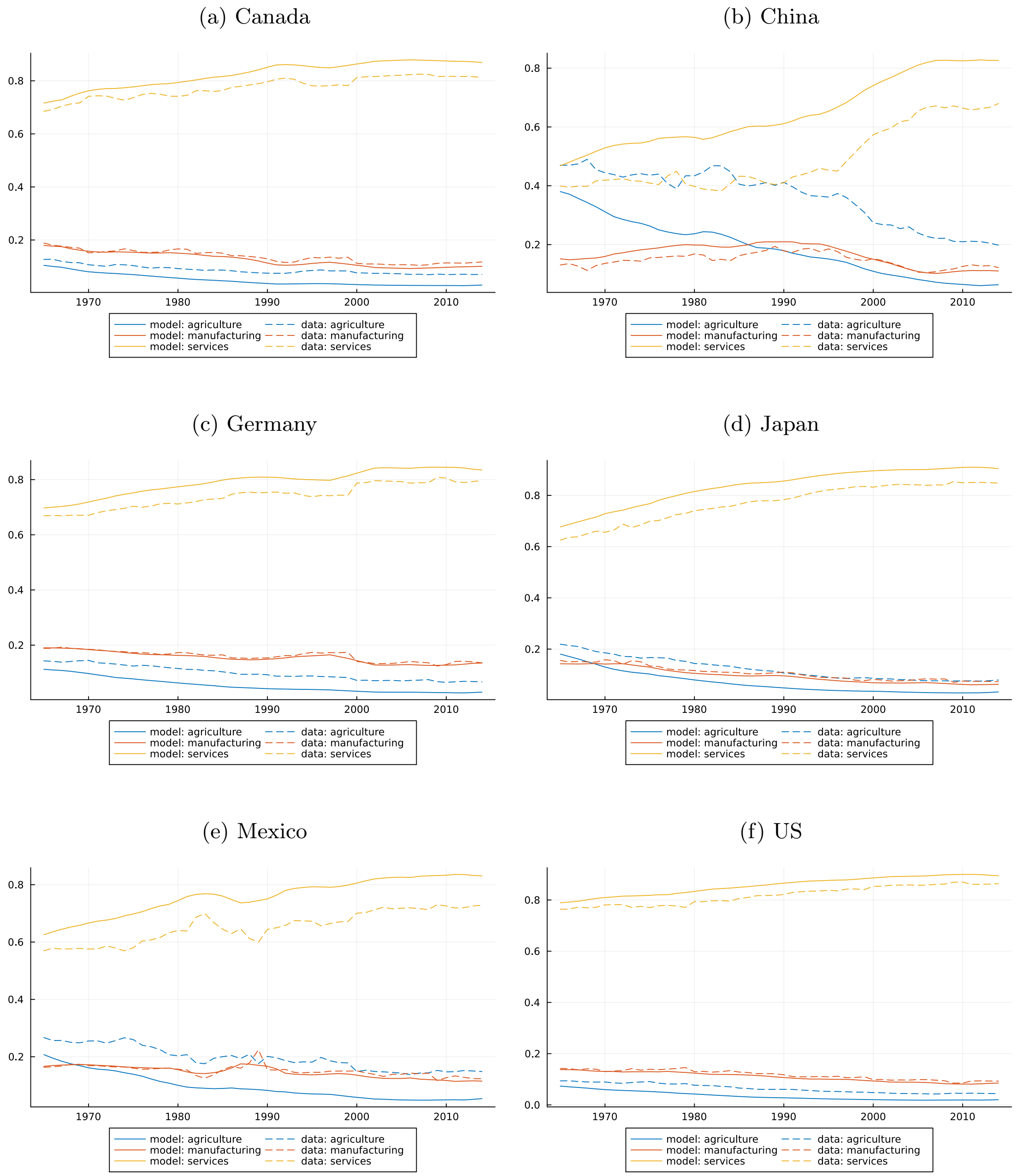



(f) US




Next, Figure 6 demonstrate the model fit of the sectoral expenditure shares in final consumption, $\omega_{n,t}^{j}$. The model-implied expenditure shares are shown in solid lines, while the data counterparts are shown in dashed lines, and the colors are the same as in Figure 5. The model captures the shigt of final expenditure from agriculture to manufacturing, and then to service over time. In all countries, the model tends to overpredict the service expenditure and underestimate the agriculture expenditure. As in the case of the value added share, the fit of the model is better for the advanced economies, Canada, Germany, Japan, and the US, compared to the emerging economies, China and Mexico. In Appendix C, we provide additional figures demonstrating the comparison of the model fit under the nonhomothetic and homothetic CES preferences. The results show that the model with nonhomothetic CES preferences outperform the homothetic counterpart in matching the data.

Figure 6: Model Fit: Sectoral Expenditure Share in Final Consumption




Finally, Figure 7 compares the saving rates in the baseline equilibrium to the data. In all six countries, the model predicts a higher saving rate than the data counterpart in earlier years. The model-implied saving rate gradually falls and converges to the levels close to the data.

Figure 7: Model Fit: Saving Rate


## 5.2 Counterfactuals

Now, we will use the model to examine the impacts of a 20% point unilateral increase in US tariffs applied to all countries since 2001. We choose the year 2001 because since then the US manufacturing value-added share sharply decreased and never returned. This exercise is a quantitative assessment of our qualitative arguments. Given the conflicting roles of tariffs on structural change, it is not clear if tariffs are effective for stopping structural change, manufacturing decline in particular. In this exercise, we keep the levels of non-tariff trade barriers fixed to single out the pure effect of tariffs.

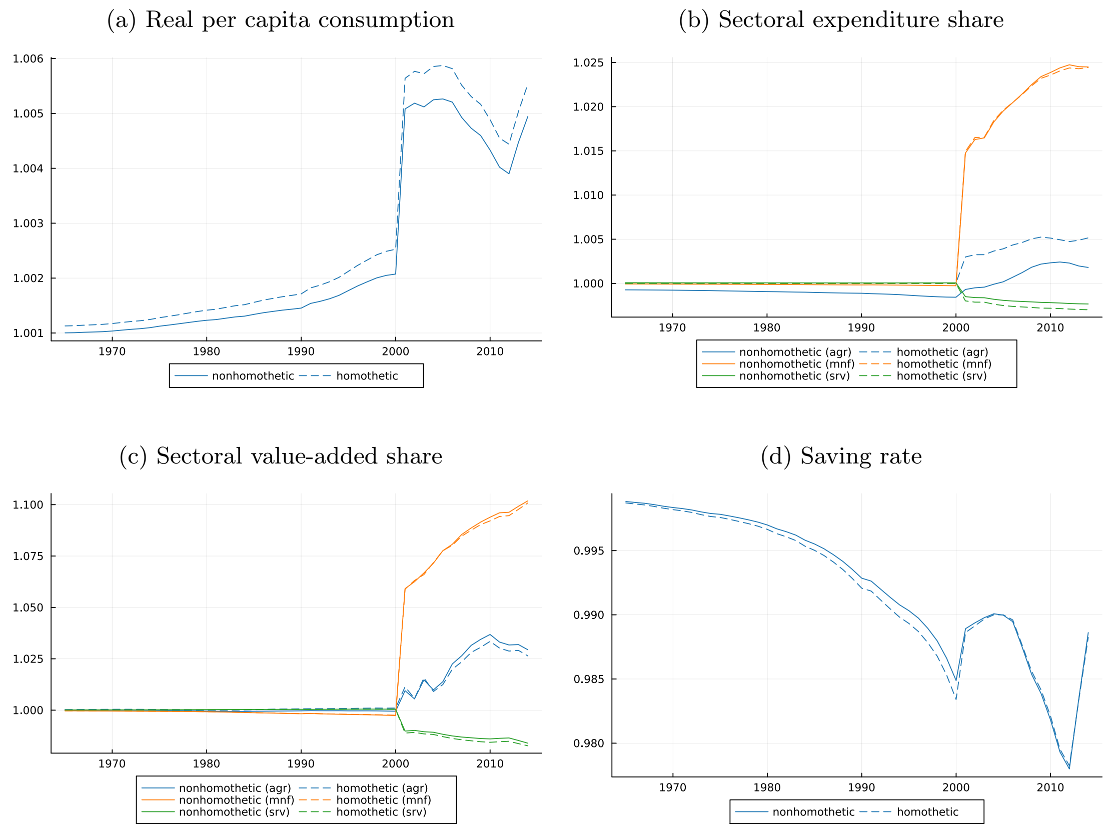
Figure 8 presents the time series of the ratio of the counterfactual value to the baseline value for key variables in the US. The solid (or dashed) curves are the results under nonhomothetic (or homothetic) preferences. First, the real per capita consumption, a rough welfare measure in each point in time, increases gradually since the initial year and spikes in 2001, as shown in panel (a). As we saw in the two-country model, a rise in tariffs from zero is good for the imposing country. This is indeed the case in the US, where the average tariffs in agriculture and manufacturing were respectively 6% and 4% in 2001. The forward-looking household increases their consumption in each period well before the 20% point tariff change comes out. The trends are very similar in both the nonhomothetic and the homothetic cases, which is in line with our analytical results summarized in Proposition 1. As a flip side of this, the saving rate, shown in panel (d), behaves in the opposite way.

From the role of tariffs as a driver of sector-biased price change in favor of goods, we expect expenditure patterns to shift from service to agriculture and manufacturing. This is true in the homothetic CES case, as shown in panel (c) of Figure 8. The dashed curves of agriculture and manufacturing expenditure share sharply increase in 2001, while that of services drops in 2001. On the other hand, we also expect an opposite change in expenditure patterns due to nonhomothetic preferences. This is reflected in the fact that the solid curves since 2001 are closer to zero than the dashed ones, indicating that the income effect weakens the Baumol effect from the sector-biased price change. The sectoral value-added shares, shown in panel (c) of Figure 8, largely follow the same patterns as the sectoral expenditure shares.

The magnitudes in both the nonhomothetic and the homothetic CES cases are summarized as follows. Compared with the baseline values, the US tariff hike starting in 2014 increases the manufacturing (or agricultural) value-added share by 0.9–1.2% point (or 0.1–0.3% point), and decreases the service one by 0.8–1.4% point in 2001 to 2014. The real per capita consumption increases by 0.04–0.06%. In terms of dynamic gains expressed as the consumption equivalent, the US gains by 0.2%.[16] This number is considerably small compared with the growth rate of sectoral manufacturing share of 6.0–10%. Moreover, the US trade protectionist policy comes at a cost of all the other countries in our sample getting worse off. The biggest loser is Canada, with dynamic loss being 0.7%. Considering the possibility of retaliatory actions by others, trade protectionist policies will not pay off at least in the US.

[16]This is computed as the hypothetical growth rate of real per capita consumption that equates the lifetime utilities between the counterfactual and the baseline cases.

Figure 8: Impact of a 20% point increase in US tariffs applied to all countries




*Notes*: This figure shows the impacts of a 20% point increase in US tariffs applied to all the other countries since 2001. Each panel shows the US time series in 1965 to 2014 of transition paths of respective variables indicated by its title. The vertical axis measures the ratio of the counterfactual value to the baseline value in the same year.

# 6 Conclusion

This paper presented both qualitative and quantitative analyses on the effects of tariffs on sectoral composition and welfare in the presence of structural change forces. Our central question is whether tariffs accelerate or reverse structural change. Our analytical results show that an increase in tariffs from near zero will shift demand from manufacturing to services through the income effect, while it will shit resources in the opposite way through the relative price effect.

To quantitatively assess which effect dominates, we extends the model to a multi-country dynamic framework with capital accumulation and input-output linkages. Using data from 24 countries spanning 1965 to 2014 and calibrated fundamentals such as sectoral productivity and non-tariff trade barriers, we compute transition paths in terms of economic levels rather than relative changes. The model is used to simulate a 20% increase in US tariffs on all trading partners beginning in 2001. Our findings favor the relative price effect over the income effect. Specifically, US manufacturing's value-added share rises by 6–10%, while the service sector declines by 2.5–8% between 2001 and 2014. Despite these shifts supporting protectionist objectives, the dynamic welfare impact is minor, with US consumers only able to increase real consumption by 0.2% annually. However, other countries, particularly Canada, experience welfare losses, with Canada facing a 0.6% decline. Retaliatory tariffs could impose far greater economic costs than the minor benefits observed for the US, suggesting that aggressive tariff policies are unlikely to yield long-term welfare improvements.

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# Appendix

## A Computation of Steady States

We compute steady states in the following way. As such, we drop the time subscript from the variables.

1. Guess wages across countries, $\{w_n\}_n \in \mathbb{R}^N$, normalized such that $w_{US} = 1$.
   (a) Compute $r_n$ as follows.
      i. Guess rental rates across countries, $\{r_n\}_n \in \mathbb{R}^N$.
         A. Compute $P_n^j$ as follows.
            - Guess sectoral price indices across countries, $\{P_n^j\}_{n,j} \in \mathbb{R}^{NJ}$.
              – Compute $\xi_n^j$ using (F1).
              – Compute $\widetilde{c}_n^j$ using (F2).
              – Compute $P_n^j$ using (F3).
            - Check if $P_n^j$ obtained in the last step is close to $P_n^j$ initially guessed. If it does, stop. Otherwise, update $\{P_n^j\}_{n,j}$ and return to the first step.
         B. Compute $P_n^K$ using (F4).
         C. Compute $r_n$ using (F5).
      ii. Check if $r_n$ obtained in the last step is close to $r_n$ initially guessed. If it does, stop. Otherwise, update $\{r_n\}_n$ and return to step i.
   (b) Compute $\pi_{ni}^j$ using (F6).
   (c) Compute $K_n$ using (F7).
   (d) Compute $g_n^{j,j'}$ using (F8).
   (e) Compute $g_n^{K,j}$ using (F9).
   (f) Compute $X_n^j$ as follows.
      - Guess sectoral spending across countries, $\{X_n^j\}_{n,j} \in \mathbb{R}^{NJ}$.
        – Compute $\widetilde{T}_n$ using (M1).
        – Compute $T^P$ using (M2).
        – Compute national income $NI_n$ using (H1).
        – Compute $E_n$ using (H2).
        – Compute $C_n$ applying the Newton method to (H3).
        – Compute $\omega_n^j$ using (H4).
        – Compute $F_n^j$ using (H5).
        – Compute $Y_n^j$ using (M3).

- Compute $X_n^j$ using (H6).

- Check if $X_n^j$ obtained in the last step is close to $X_n^j$ initially guessed. If it does, stop. Otherwise, update $\{X_n^j\}_{n,j}$ and return to the first step.

(g) Compute $w_n$ using (M4).

2. Check if $w_n$ obtained in the last step is close to $w_n$ initially guessed. If it does, stop and normalize $w_{US}$ to one. Otherwise, update $\{w_n\}_n$ and return to step 1.

Table 3: Equilibrium conditions at steady state

| | | |
|---|---|---|
| (F1) | $\xi_n^j = \left[\sum_{j'} \kappa_n^{j,j'} (P_n^{j'})^{1-\sigma^j}\right]^{\frac{1}{1-\sigma^j}}$ | $\forall(n,j)$ |
| (F2) | $\widetilde{c}_{n,t}^j = (r_n)^{\gamma_n^j \alpha_n} (w_n)^{\gamma_n^j (1-\alpha_n)} (\xi_n^j)^{1-\gamma_n^j}$ | $\forall(n,j)$ |
| (F3) | $P_n^j = \left[\sum_i^N \left(\frac{\widetilde{c}_i^j b_{n,i}^j}{A_i^j}\right)^{-\theta^j}\right]^{-\frac{1}{\theta^j}}$ | $\forall(n,j)$ |
| (F4) | $P_n^K = \frac{1}{\kappa_n^K} \left[\sum_j \kappa_n^{K,j} (P_n^j)^{1-\sigma^K}\right]^{\frac{1}{1-\sigma^K}}$ | $\forall(n)$ |
| (F5) | $r_n = \frac{1-\beta(1-\lambda\delta_n)}{\beta(1-\phi_n)\lambda} P_n^K$ | $\forall(n)$ |
| (F6) | $\pi_{ni}^j = \left(\frac{\widetilde{c}_i^j b_{ni}^j}{A_i^j P_n^j}\right)^{-\theta^j}$ | $\forall(n,i,j)$ |
| (F7) | $K_n = \frac{\alpha_n}{1-\alpha_n} \frac{w_n L_n}{r_n}$ | $\forall(n)$ |
| (F8) | $g_n^{j,j'} = \frac{\kappa_n^{j,j'} (P_n^{j'})^{1-\sigma^j}}{\sum_{j''} \kappa_n^{j,j''} (P_n^{j''})^{1-\sigma^j}}$ | $\forall(n,j,j')$ |
| (F9) | $g_n^{K,j} = \frac{\kappa_n^{K,j} (P_n^{K,j})^{1-\sigma^K}}{\sum_{j'} \kappa_n^{K,j'} (P_n^{K,j'})^{1-\sigma^K}}$ | $\forall(n,j)$ |
| (H1) | $NI_n = (1-\phi_n)(r_n K_n + w_n L_n + \widetilde{T}_n) + L_n T^P$ | $\forall(n)$ |
| (H2) | $E_n = NI_n - P_n^K \delta_n K_n$ | $\forall(n)$ |
| (H3) | $E_n = L_n \left[\sum_j \Omega_n^j \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^j} P_n^j\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ | $\forall(n)$ |
| (H4) | $\omega_n^j = \frac{\Omega_n^j \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^j} P_n^j\right\}^{1-\sigma}}{\sum_{j'} \Omega_n^{j'} \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^{j'}} P_n^{j'}\right\}^{1-\sigma}} \quad \left(= \frac{P_n^j C_n^j}{E_n}\right)$ | $\forall(n,j)$ |
| (H5) | $F_n^j = \omega_n^j E_n + g_n^{K,j} P_n^K \delta_n K_n$ | $\forall(n,j)$ |
| (H6) | $X_n^j = F_n^j + \sum_{j'} (1-\gamma_n^{j'}) g_n^{j',j} Y_n^{j'}$ | $\forall(n,j)$ |
| (M1) | $\widetilde{T}_n = \sum_j \sum_i^N \tau_{ni}^j X_{n,t}^j \frac{\pi_{ni}^j}{\widetilde{\tau}_{ni}^j}$ | $\forall(n)$ |
| (M2) | $T^P = \sum_i^N \phi_i (w_i L_i + r_i K_i + \widetilde{T}_i) / \sum_i^N L_i$ | |
| (M3) | $Y_n^j = \sum_i^N X_i^j \frac{\pi_{in}^j}{\widetilde{\tau}_{in}^j}$ | $\forall(n,j)$ |
| (M4) | $w_n = (1-\alpha_n) \sum_j \gamma_n^j Y_n^j / L_n$ | $\forall(n,j)$ |

*Notes*: $b_{ni}^j = d_{ni}^j \widetilde{\tau}_{ni}^j$ and $\widetilde{\tau}_{ni}^j = 1 + \tau_{ni}^j$. Roughly, (F*) is a condition for firms/production; (H*) for household; (M*) for market clearing.

## B Computation of Transition Paths

We compute transition paths in the following way. Let $T+1$ be the terminal period, $N$ the number of countries, and $J$ the number of sectors.

1. Give pre-determined values (data in our case) to the initial capital stock, $\{K_{n,1}\}_n$, and arbitrary values to the other variables at the initial period 1.

2. Give the steady-state values to variables at the terminal period $T+1$ including $\{K_{n,T+1}, K_{n,T+2}\}_n$, $\{C_{n,T+1}\}_n$, $\{\bar{\epsilon}_{n,T+1}\}_n$, $\{E_{n,T+1}\}_n$, $\{r_{n,T+1}\}_n$, and $\{P^K_{n,T+1}\}_n$. Note that $K_{n,t}$ is a pre-determined variable at period $t$. Therefore, $K_{n,T+2}$ is determined at period $T+1$ given the steady-state value of $K_{n,T+1}$ at the same period.

3. Guess nominal investment rates across countries and time, $\{\rho_{n,t}\}_{n,t} \in \mathbb{R}^{N(T+1)}$.

4. Compute variables forward in time from $t=1$ including $\{w_{n,t}\}_{n,t} \in \mathbb{R}^{N(T+1)}$, $\{I_{n,t}\}_{n,t} \in \mathbb{R}^{N(T+1)}$, $\{K_{n,t}\}_{n,t} \in \mathbb{R}^{N(T+2)}$, $\{\bar{\epsilon}_{n,t}\}_{n,t} \in \mathbb{R}^{N(T+1)}$, and others in the sub-steps below.

   (a) Compute $w_{n,t}$ in each period $t$ as follows, noting that in period $t$ capital stock across countries, $\{K_{n,t}\}_n \in \mathbb{R}^N$ are predetermined.

      i. Guess wages across countries in period $t$, $\{w_{n,t}\}_n \in \mathbb{R}^N$, normalized such that $w_{US,t} = 1$.

         A. Compute $r_{n,t}$ using (F5).

         B. Compute $P^j_{n,t}$ as follows.

            - Guess sectoral price indices across countries in period $t$, $\{P^j_{n,t}\}_{n,j} \in \mathbb{R}^{NJ}$.
               - Compute $\xi^j_{n,t}$ using (F1).
               - Compute $\widetilde{c}^j_{n,t}$ using (F2).
               - Compute $P^j_{n,t}$ using (F3).
            - Check if $P^j_{n,t}$ obtained in the last step is close to $P^j_{n,t}$ initially guessed. If it does, stop. Otherwise, update $\{P^j_{n,t}\}_{n,j}$ and return to the first step.

         C. Compute $P^K_{n,t}$ using (F4).

         D. Compute $\pi^j_{ni,t}$ using (F6).

         E. Compute $g^{j,j'}_{n,t}$ using (F7).

         F. Compute $g^{K,j}_{n,t}$ using (F8).

         G. Compute $X^j_{n,t}$ as follows.

            - Guess sectoral spending across countries in period $t$, $\{X^j_{n,t}\}_{n,j} \in \mathbb{R}^{NJ}$.
               - Compute $\widetilde{T}_{n,t}$ using (M1).
               - Compute $T^P$ using (M2).
               - Compute national income $NI_{n,t}$ using (H1).

- Compute $E_{n,t}$ using (H2).
- Compute $C_{n,t}$ applying the Newton method to (H3).
- Compute $\omega^j_{n,t}$ using (H4).
- Compute $Y^j_{n,t}$ using (M3).
- Compute $X^j_{n,t}$ using (H5).

• Check if $X^j_{n,t}$ obtained in the last step is close to $X^j_{n,t}$ initially guessed. If it does, stop. Otherwise, update $\{X^j_{n,t}\}_{n,j}$ and return to the first step.

H. Compute $w_{n,t}$ using (M4).

ii. Check if $w_{n,t}$ obtained in the last step is close to $w_{n,t}$ initially guessed. If it does, stop and normalize $w_{US,t}$ to one. Otherwise, update $\{w_{n,t}\}_n$ and return to step i.

(b) Compute $I_{n,t} = \rho_{n,t} NI_{n,t}/P^K_{n,t}$.

(c) Compute $K_{n,t+1} = (1 - \delta_{n,t})K_{n,t} + I^{\lambda}_{n,t}(\delta_{n,t}K_{n,t})^{1-\lambda}$.

(d) Compute $\bar{\epsilon}_{n,t} = \sum_j \omega^j_{n,t}\bar{\epsilon}^j_{n,t}$.

5. Compute $\rho_{n,t}$ backward in time from period $t = T$ from $\rho_{n,t}(1+\eta Z_{n,t})$ using (H6) "Euler equation residual" $Z_{n,t}$ with a dampening parameter $\eta$ and associated functions (H7) and (H8). Note that we restrict the updated $\rho_{n,t}$ to be in $(0, 1)$.

6. Check if $\rho_{n,t}$ obtained in step 5 is close to $\rho_{n,t}$ initially guessed. If it does, stop. Otherwise, update $\{\rho_{n,t}\}_{n,t}$ and return to step 3.

Table 4: Equilibrium conditions

| | | |
|---|---|---|
| (F1) | $\xi^j_{n,t} = \left[\sum_{j'} \kappa^{j,j'}_{n,t} (P^{j'}_{n,t})^{1-\sigma^j}\right]^{\frac{1}{1-\sigma^j}}$ | $\forall(n,j,t)$ |
| (F2) | $\widetilde{c}^j_{n,t} = (r_{n,t})^{\gamma^j_{n,t}\alpha_{n,t}} (w_{n,t})^{\gamma^j_{n,t}(1-\alpha_{n,t})} (\xi^j_{n,t})^{1-\gamma^j_{n,t}}$ | $\forall(n,j,t)$ |
| (F3) | $P^j_{n,t} = \left[\sum_i^N \left(\frac{\widetilde{c}^j_{i,t} b^j_{ni,t}}{A^j_{i,t}}\right)^{-\theta^j}\right]^{-\frac{1}{\theta^j}}$ | $\forall(n,j,t)$ |
| (F4) | $P^K_{n,t} = \frac{1}{\kappa^K_{n,t}} \left[\sum_j \kappa^{K,j}_{n,t} (P^j_{n,t})^{1-\sigma^K}\right]^{\frac{1}{1-\sigma^K}}$ | $\forall(n,t)$ |
| (F5) | $r_{n,t} = \frac{\alpha_{n,t}}{1-\alpha_{n,t}} \frac{w_{n,t} L_{n,t}}{K_{n,t}}$ | $\forall(n,t)$ |
| (F6) | $\pi^j_{ni,t} = \left(\frac{\widetilde{c}^j_{i,t} b^j_{ni,t}}{A^j_{i,t} P^j_{n,t}}\right)^{-\theta^j}$ | $\forall(n,i,j,t)$ |
| (F7) | $g^{j,j'}_{n,t} = \frac{\kappa^{j,j'}_{n,t} (P^{j'}_{n,t})^{1-\sigma^j}}{\sum_{j''} \kappa^{j,j''}_n (P^{j''}_{n,t})^{1-\sigma^j}}$ | $\forall(n,j,j',t)$ |
| (F8) | $g^{K,j}_{n,t} = \frac{\kappa^{K,j}_{n,t} (P^{K,j}_{n,t})^{1-\sigma^K}}{\sum_{j'} \kappa^{K,j'}_{n,t} (P^{K,j'}_{n,t})^{1-\sigma^K}}$ | $\forall(n,j,t)$ |
| (H1) | $NI_{n,t} = (1-\phi_{n,t})(r_{n,t}K_{n,t} + w_{n,t}L_{n,t} + \widetilde{T}_{n,t}) + L_{n,t}T^P_t$ | $\forall(n,t)$ |
| (H2) | $E_{n,t} = (1-\rho_{n,t}) NI_{n,t}$ | $\forall(n,t)$ |
| (H3) | $E_{n,t} = L_{n,t} \left[\sum_j \Omega^j_{n,t} \left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t}\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ | $\forall(n,t)$ |
| (H4) | $\omega^j_{n,t} = \frac{\Omega^j_{n,t}\left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t}\right\}^{1-\sigma}}{\sum_{j'} \Omega^{j'}_{n,t}\left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^{j'}} P^{j'}_{n,t}\right\}^{1-\sigma}} \quad \left(= \frac{P^j_{n,t} C^j_{n,t}}{E_{n,t}}\right)$ | $\forall(n,j,t)$ |
| (H5) | $X^j_{n,t} = [\omega^j_{n,t}(1-\rho_{n,t}) + g^{K,j}_{n,t}\rho_{n,t}] NI_{n,t} + \sum_{j'} (1-\gamma^{j'}_{n,t}) g^{j',j}_{n,t} \sum_i^N \pi^j_{in,t} X^j_{i,t} / \widetilde{\tau}^j_{in,t}$ | $\forall(n,j,t)$ |
| (H6) | $Z_{n,t} = \left[\beta \frac{\zeta_{n,t+1}}{\zeta_{n,t}} \frac{L_{n,t+1}}{L_{n,t}} \frac{E_{n,t}}{E_{n,t+1}} \frac{\bar{\epsilon}_{n,t}}{\bar{\epsilon}_{n,t+1}} \frac{\left[(1-\phi_{n,t+1}) r_{n,t+1} - P^K_{n,t+1} \Phi_2(K_{n,t+2}, K_{n,t+1})\right]}{P^K_{n,t} \Phi_1(K_{n,t+1}, K_{n,t})}\right]^{\frac{1}{\psi-1}} - \frac{C_{n,t+1}}{C_{n,t}} \frac{L_{n,t}}{L_{n,t+1}}$ | $\forall(n,t)$ |
| (H7) | $\Phi_1(K_{n,t+2}, K_{n,t+1}) = \frac{\delta_{n,t+1}^{1-\frac{1}{\lambda}}}{\lambda} \left(\frac{K_{n,t+2}}{K_{n,t+1}} - (1-\delta_{n,t+1})\right)^{\frac{1-\lambda}{\lambda}}$ | $\forall(n,t)$ |
| (H8) | $\Phi_2(K_{n,t+2}, K_{n,t+1}) = \Phi_1(K_{n,t+2}, K_{n,t+1}) \left[(\lambda-1)\frac{K_{n,t+2}}{K_{n,t+1}} - \lambda(1-\delta_{n,t+1})\right]$ | $\forall(n,t)$ |
| (M1) | $\widetilde{T}_{n,t} = \sum_j \sum_i^N \tau^j_{ni,t} X^j_{n,t} \frac{\pi^j_{ni,t}}{\widetilde{\tau}^j_{ni,t}}$ | $\forall(n,t)$ |
| (M2) | $T^P_t = \sum_i^N \phi_{i,t}(w_{i,t}L_{i,t} + r_{i,t}K_{i,t} + \widetilde{T}_{i,t}) / \sum_i^N L_{i,t}$ | $\forall(t)$ |
| (M3) | $Y^j_{n,t} = \sum_i^N X^j_{i,t} \frac{\pi^j_{in,t}}{\widetilde{\tau}^j_{in,t}}$ | $\forall(n,j,t)$ |
| (M4) | $w_{n,t} = (1-\alpha_{n,t}) \sum_j \gamma^j_{n,t} Y^j_{n,t} / L_{n,t}$ | $\forall(n,j,t)$ |

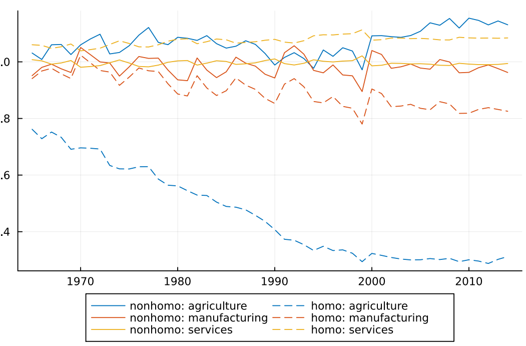
*Notes*: $b^j_{ni,t} = d^j_{ni,t}\widetilde{\tau}^j_{ni,t}$ and $\widetilde{\tau}^j_{ni,t} = 1 + \tau^j_{ni,t}$. Roughly, (F*) is a condition for firms/production; (H*) for household; (M*) for market clearing. An alternative expression of (H5) is
$X^j_{n,t} = \omega^j_{n,t} E_{n,t} + g^{K,j}_{n,t} P^K_{n,t} I_{n,t} + \sum_{j'} (1-\gamma^{j'}_{n,t}) g^{j',j}_{n,t} \sum_i^N \pi^j_{in,t} X^j_{i,t} / \widetilde{\tau}^j_{in,t}$.

# C Comparison of Model Fit

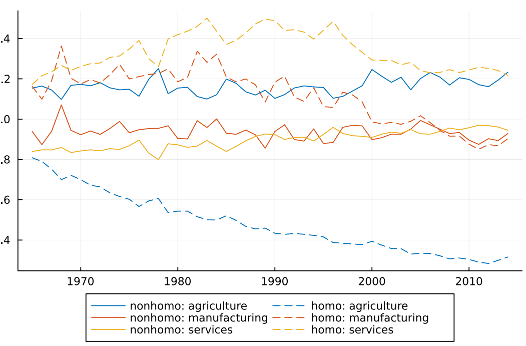
The figures below compare the ability of the model to match the data in terms of the sectoral value-added shares and the expenditure shares in final consumption under the different preferences. In the figure belows, we display the fit of the model to the data in terms of relative difference, i.e., the ratio of the model implied value to the data counterpart. By construction, the value takes 1 if the model perfectly fits the data, and the values greater (smaller) than 1 implies the overprediction (underprediction).

Figure 9: Model Fit Comparison (Nonhomothetic vs Homothetic): Expenditure Share

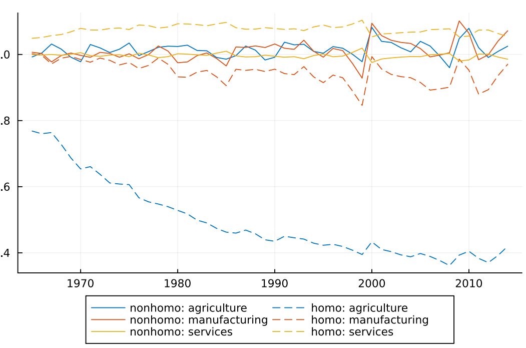
(a) Canada



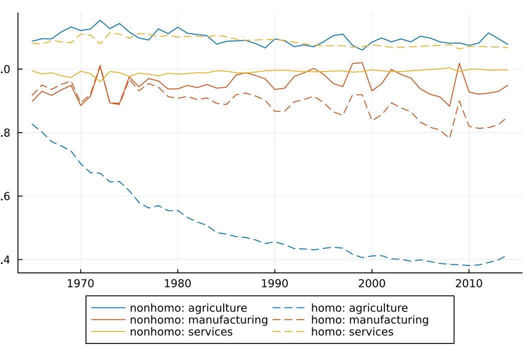

(b) China



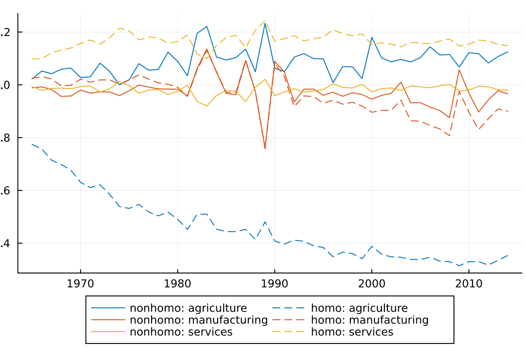

(c) Germany




(d) Japan




(e) Mexico




(f) US

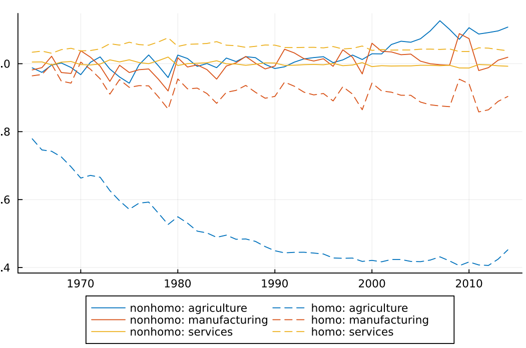
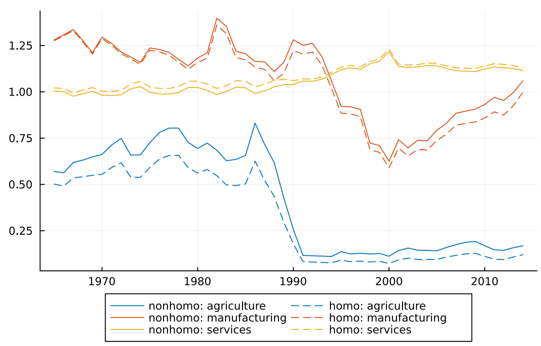
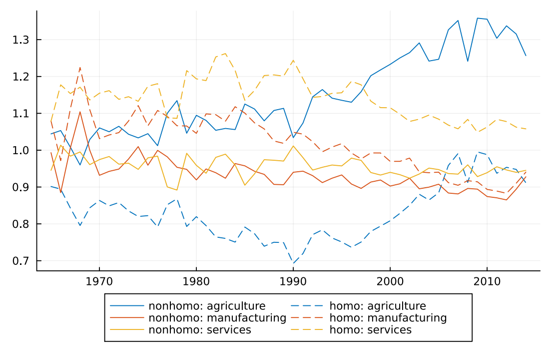


Figure 10: Model Fit Comparison (Nonhomothetic vs Homothetic): Value-Added Share

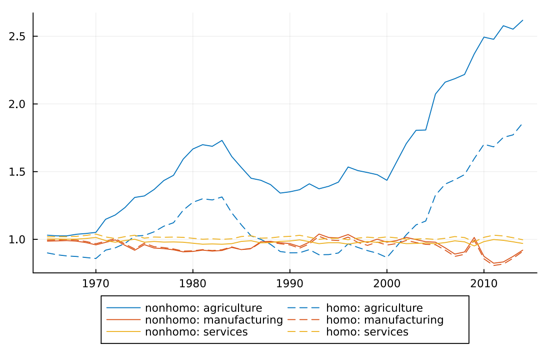
(a) Canada



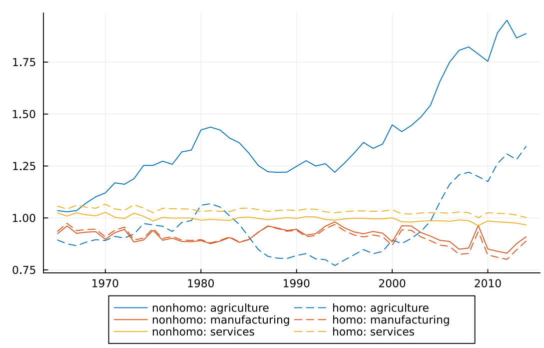

(b) China



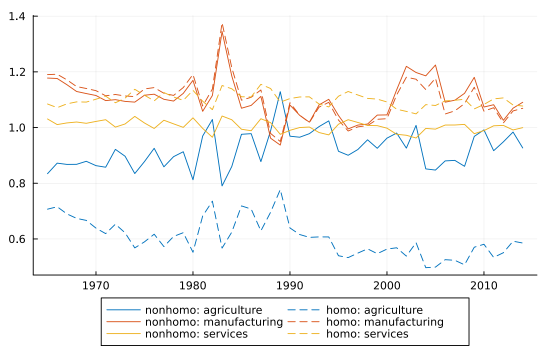

(c) Germany




(d) Japan




(e) Mexico




(f) US