Trade Policy and Structural Change*

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May 31, 2025

Abstract

We examine how tariffs affect sectoral reallocation in an economy where preferences are nonhomothetic and sectors are complements—two key drivers of structural change. Beyond their conventional role in trade protection, tariffs influence sectoral composition by altering relative prices and income levels. We qualitatively characterize these mechanisms and use a quantitative dynamic model to show that a 20 percentage point increase in U.S. manufacturing tariffs since 2001 would have raised the manufacturing value-added share by one percentage point and increased welfare by 0.36 percent. However, if trading partners responded with equally high tariffs on manufacturing, U.S. welfare would decline by 0.12 percent.

JEL Classification: F11; F16; F43; O41

Keywords: Tariff; Ricardian model of trade; Structural transformation; Nonhomothetic preferences; Capital accumulation; Trade war

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*We would like to thank Cheng Chen, Terry Cheung, Jonathan Eaton, Markus Epp, Marten Hillebrand, Julian Hinz, Hirokazu Ishise, Danial Lashkari, Oliver Landmann, Andrea Lassman, Kiminori Matsuyama, Philip Sauré, Hang Yang, Joschka Wanner and seminar participants at Clark University, JGU Mainz, Bielefeld University, University of Freiburg, Nagoya University, College of the Holy Cross, Göttinger Workshop, Midwest Economic Association Annual Conference, Midwest International Trade Conference, CITP Conference, Kansai Macro Workshop, Yonsei University, Asia Trade Pacific Seminars, Academia Sinica, the German Council of Economic Experts, European Trade Study Group, FIW-Conference International Economics, Australasian Trade Workshop, and IEFS Japan for their helpful comments. This work is supported by the Project Research Grant (IERPK2321, IERPK2417), the Institute of Economic Research, Hitotsubashi University; the Japan Society for the Promotion of Science (JP20H01495); and Clark University Start-Up Research Fund. We are grateful to Edward Nyarko, Zeyi Qian, and Li Shen for the outstanding research assistance.

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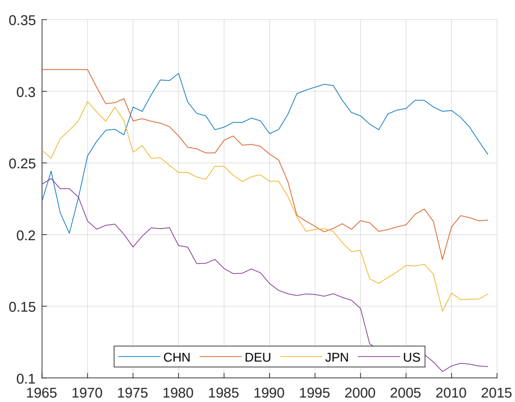
1 Introduction

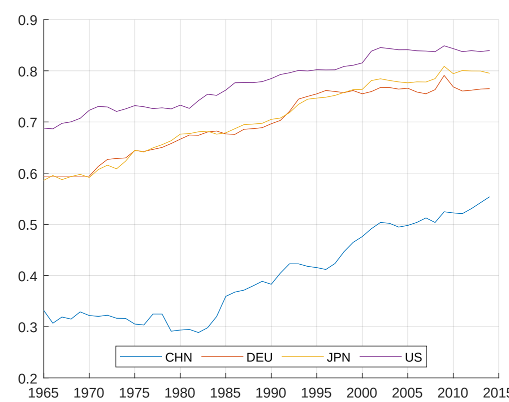
On February 1, 2025, U.S. President Donald Trump signed executive orders imposing a 25 percent additional tariff on most imports from Canada and Mexico, and a 10 percent additional tariff on imports from China.[1] These measures were part of the Trump administration's attempts to reshape trade relations in ways that favor American workers and manufacturers. The growing popularity of protectionism in the U.S. in recent years has been rooted in the decline of manufacturing presence and the rise of developing countries in the global market (Goldberg and Reed, 2023 for a survey).[2] However, declining manufacturing is not unique to the U.S., but is also observed in other developed countries such as Germany and Japan. Figure 1(a) shows similar declining trends of the manufacturing value-added share in the three countries from 1965 to 2014. From the viewpoint of structural change, the shift of resources from manufacturing to services, shown in Figure 1(b), will occur even in the absence of trade (Kuznets, 1973).

Figure 1: Value Added Share in GDP

(a) Manufacturing



(b) Service



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

[1]See the White House statement, "Fact Sheet: President Donald J. Trump Imposes Tariffs on Imports from Canada, Mexico, and China": https://www.whitehouse.gov/fact-sheets/2025/02/fact-sheet-president-donald-j-trump-imposes-tariffs-on-imports-from-canada-mexico-and-china/ (accessed May 13, 2025). The Trump administration's agenda is articulated in "America First Trade Policy,": https://www.whitehouse.gov/presidential-actions/2025/01/america-first-trade-policy/ (accessed May 13, 2025).

[2]In the context of the U.S., Mexico and China played a major role. For example, using U.S. Census data from 1990 to 2000, Hakobyan and McLaren (2016) find that the North American Free Trade Agreement (NAFTA) significantly reduced wage growth for blue-collar workers in industries and regions most exposed to Mexican import competition. Acemoglu et al. (2016) report 2.0 to 2.4 million U.S. manufacturing workers losing their jobs due to Chinese import competition over 1999 to 2011. See also Autor et al. (2013); and Pierce and Schott (2016).

Can tariffs successfully revitalize manufacturing in a country undergoing structural change? The impact of tariffs extends beyond merely protecting domestic industries from imports. Tariffs also interact with two key drivers of structural change: sectors being complements and nonhomothetic preferences. Tariffs on manufacturing raise its relative price compared to agriculture and services. If sectoral goods are gross complements in consumption, the higher relative price of manufacturing may bias expenditure toward the sector and shift resources away from agriculture and services. On the other hand, tariffs generate revenue and may raise overall income, shifting demand from less income-elastic sectors, such as agriculture and manufacturing, toward more income-elastic sectors like services. The effects of tariffs on manufacturing through changes in relative prices—the relative price effect—and through changes in income—the income effect—may work in opposite directions.

Our main goals are to qualitatively isolate these impacts of tariffs on industrial structure using a two country model, and to extend it to a fully dynamic multi-country model to quantitatively asses their magnitudes. Our static model features trade based on the Ricardian comparative advantage (Eaton and Kortum, 2002) and the (isoelastically) nonhomothetic constant elasticity of substitution (CES) preferences (Hanoch, 1975; Matsuyama, 2019; Comin et al., 2021). The nonhomothetic CES neatly delineates the relative price effect from the income effect of tariffs.[3] Suppose only the relative price effect operates under sector-specific tariffs and homothetic preferences. Then, a rise in tariffs increases the domestic consumption expenditure share, and thus the value-added share, of protected sectors. In contrast, suppose only the income effect operates under uniform tariffs across sectors and nonhomothetic preferences. Then, a rise in tariffs and tariff revenue reduces the expenditure share, and thus the value-added share, of sectors with lower income elasticity. The standard protective role of tariffs operates in both cases and even in their absence: reductions in imports of protected sectors improve their net exports, thereby increasing their value-added shares.

To quantitatively evaluate these roles of tariffs, we next 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 exact hat-algebra method (Dekle et al., 2008; Caliendo and Parro, 2015; Caliendo et al., 2019). We then conduct a counterfactual experiment of a 20 percent point increase in U.S. tariffs applied to all

[3]The nonhomothetic CES allows sector-specific parameters (ϵ^js) capturing income elasticity differences across sectors, while treating separately the parameter (σ) that captures the constant elasticity of substitution (Matsuyama, 2009).

countries starting in 2001.

We find that tariffs alter sectoral composition in a manner consistent with the standard trade protection argument and the relative price effect. Specifically, compared with the baseline values in the corresponding year, a 20 percentage point increase in the U.S. manufacturing tariffs since 2001 leads to a 6–10 percent (0.9–1.2 percentage point) increase in manufacturing value-added share, while 2.5–8.0 percent (9.5–1.5 percentage point) decrease in service share in 2001 to 2014. Although this results may sound cheering trade protectionists, the U.S. welfare increases only by 0.36 percent. The U.S. gains of course come at the cost of the other countries getting worse off. The biggest loser is Canada, reporting a 1.26 percent dynamic welfare loss. Moreover, if other countries retaliate with 20 percentage point higher tariffs, the U.S. welfare decreases by 0.12 percent.

We make contributions to a few strands of literature. First, our study relates to a large literature that quantitatively evaluate trade policies, import tariffs in particular (Ossa, 2016; Caliendo and Parro, 2022 for surveys). Many studies confirm the possibility of welfare gains from increasing tariffs from a low level, unless other countries retaliate (Costinot and Rodríguez-Clare, 2014; Ossa, 2014; Caliendo et al., 2023; Balistreri et al., 2024). For example, Costinot and Rodríguez-Clare (2014) report in their Table 4.2 that U.S. welfare gains from imposing a 40 percent tariff on all imports would be at most 0.63 percent, which is close in magnitude to our result (0.36 percent), despite differences in model setup. Most of these studies assume homothetic preferences and use the exact hat algebra. By incorporating nonhomothetic preferences and solving the model in levels, we aim to provide a better understanding of the effects of tariffs on sectoral composition and welfare.

We also contribute to the growing literature 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 in industrial structure 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. (2024) develops and applies the dynamic model of international trade to study structural change.[4] Our quantitative framework largely follows Sposi et al. (2024), but depart from them by explicitly introducing tariffs and tariff revenue 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 Ricardian trade and nonhomothetic preferences. 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

To highlight the role of tariffs in shaping a country's sectoral composition, we first present a simple trade model à la Eaton and Kortum (2002), incorporating essential features for structural change: nonhomothetic CES preferences and a less-than-unity elasticity of substitution across sectors. Consider a static economy with two countries, 1 and 2. There are three sectors, agriculture, manufacturing, and services.[5]

Demand side Let C_n be the aggregate consumption (or the utility) of country $n \in \{H, F\}$ and L_n the population there. The representative household minimizes its expenditure given a certain level of C_n, by choosing consumption for sectoral composite goods, C_n^j for $j \in \{a, m, s\}$,

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

[4]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.

[5]Sectors and industries are synonymous in this paper. Although we state Propositions in the case of three sectors, the analytical results of this section hold in the case of general J sectors. The general J sector case is studied in the Online Appendix.

where P_n^j is the price index of the sectoral 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 second line. The two key parameters governing structural change are $\epsilon^j > 0$ 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. If $\epsilon^j = 1$ for all j, the utility function reduces to a standard CES aggregator of sectoral composite goods, $C_n = \left[\sum_j (C_n^j)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$. If we let σ approaches one, the utility function further reduces to the Cobb-Douglas one, $C_n = \Pi_j (C_n^j/3)^{\frac{1}{3}}$.

Letting $E_n = \sum_j P_n^j C_n^j$ be the (minimized) total expenditure, 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 budget constraint, we solve for the expenditure function:

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

Letting $P_n \equiv E_n/C_n$ be an aggregate price index, we have

$$P_n = \left[\sum_{j=a,m,s} \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^j-1} P_n^j\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{3}$$

From these results, we can see the income and the relative price effects clearly. The income effect is highlighted by the non-constant income elasticity of sectoral demand:[6]

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

where $\bar{\epsilon}_n$ is an average of sector j's nonhomotheticity parameter ϵ^j weighted by the sectoral

[6] We rearrange (1) and take its log to obtain

$$\ln C_n^j = (1-\sigma)(1-\epsilon^j)\ln L_n - \sigma \ln P_n^j + \sigma \ln E_n + (1-\sigma)\epsilon^j \ln C_n.$$

To obtain the income elasticity of sectoral demand, we take the derivative of this with respect to E_n taking into account its effect on the real consumption (i.e., utility) by noting $\partial \ln C_n/\partial \ln E_n = 1/\bar{\epsilon}_n$ from (2).

expenditure share, ω_n^k:

$$\bar{\epsilon}_n \equiv \sum_{h=a,m,s} \omega_n^h \epsilon_n^h, \qquad \omega_n^h \equiv \frac{P_n^h C_n^h}{\sum_k P_n^k C_n^k} = \frac{(P_n^h)^{1-\sigma}(C_n/L_n)^{\epsilon^j(1-\sigma)}}{\sum_k (P_n^k)^{1-\sigma}(C_n/L_n)^{\epsilon^k(1-\sigma)}}. \tag{4}$$

In the case of CES preferences with $\epsilon^j = 1$ for all j, the sectoral demand elasticity becomes σ 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 ϵ^j captures the degree of income elasticity of demand.

The relative price effect results from the facts that the sectoral demands are gross complements:[7]

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

and that the elasticity of substitution across sectors is less than one if there is no income effect:

$$-\frac{\partial \ln(C_n^j/C_n^h)}{\partial \ln(P_n^j/P_n^h)} = \sigma \in (0,1) \qquad \text{if} \;\; \epsilon^j = 1 \text{ for all } j.$$

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

[7] Using $C_n \equiv E_n/P_n$, we have

$$\ln C_n^j = (1-\sigma)(1-\epsilon^j)\ln L_n - \sigma \ln P_n^j + [\sigma + (1-\sigma)\epsilon^j]\ln E_n - (1-\sigma)\epsilon^j \ln P_n.$$

Differentiating this with respect to P_n^h while keeping E_n fixed (i.e., C_n^j here being a Marshallian demand) yields the expression in the text. In doing so, we use $\partial \ln P_n / \partial \ln P_n^h = \omega_n^h/\bar{\epsilon}_n$ from (3).

distribution:

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

Here $\theta > 1$ and A_n^j are respectively the shape parameter and the location parameter of the Frechét distribution, 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. In this section, the productivity is the same across sectors, $A_n^j = A_n$ and $a_n^j = a_n$ for all j, to highlight the role of (potentially) sector-specific tariffs.

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

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

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

$$P_n^j = \left[\sum_{i=H,F}\left(w_i b_{ni}^j / A_i\right)^{-\theta}\right]^{-\frac{1}{\theta}}. \tag{5}$$

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

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

which we call the trade share of country i in country n.

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:

$$VA_n^j = w_n L_n^j = \sum_{i=H,F} \frac{X_{in}^j}{1+\tau_{in}^j} = \sum_{i=H,F} \frac{\pi_{in}^j P_i^j C_i^j}{1+\tau_{in}^j},$$

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:

$$w_n L_n = \sum_{j=a,m,s} \sum_{i=H,F} \frac{\pi_{in}^j P_i^j C_i^j}{1+\tau_{in}^j}. \tag{6}$$

One can check that this is equivalent with the trade balance condition.[8] The aggregate expenditure must be equal to the aggregate income consisting of labor income and tariff revenues, $\widetilde{T}_n$:

$$E_n = w_n L_n + \widetilde{T}_n, \tag{7}$$

where

$$\widetilde{T}_n \equiv \sum_{j=a,m,s} \widetilde{T}_n^j \equiv \sum_{j=a,m,s} \tau_{ni}^j IM_n^j, \qquad IM_n^j \equiv \frac{X_{ni}^j}{1+\tau_{ni}^j} = \frac{\pi_{ni}^j P_n^j C_n^j}{1+\tau_{ni}^j},$$

and $\widetilde{T}_n^j$ is country n's tariff revenues in sector j and IM_n^j is country n's imports from i in sector j. This completes the model. With a choice of numéraire such that $w_F = 1$, the equilibrium wage w_H and the aggregate consumption $\{C_i\}_{i=1,2}$ satisfy equilibrium conditions (1), (2), (5), (6), and (7).

2.1 Tariffs and real per capita consumption

Before examining the tariff impact on sectoral composition, let us first see how tariffs affect real per capita consumption, C_n/L_n.[9] In the following subsections, we assume that tariffs applied by Home to Foreign are uniform across sectors, $\tau_{HF}^j = \tau_{HF} \geq 0$ for all $j \in \{a, m, s\}$, and Foreign

[8] The trade balance condition is

$$\sum_{j=a,m,s} \frac{\pi_{HF}^j P_H^j C_H^j}{1+\tau_{HF}^j} = \sum_{j=a,m,s} \frac{\pi_{12}^j P_F^j C_F^j}{1+\tau_{12}^j}.$$

[9] As tariffs do not affect population L_n, the following discussion holds both in terms of aggregate and per capita consumption.

does not set tariffs, $\tau_{12}^j = 0$ for all j. We then consider a unilateral increase in Home's tariffs. For analytical convenience, in the case of nonhomothetic CES preferences ($0 < \epsilon^a < \epsilon^m = 1 < \epsilon^s$), the tariff increase is assumed to be uniform across sectors, $d\tau_{HF}^j = d\tau_{HF} > 0$ for all j. In the case of homothetic CES preferences ($\epsilon^j = 1$ for all j), however, the tariff increase can vary across sectors, $d\tau_{HF}^j = d\tau_{HF} > 0$ for some j and $d\tau_{HF}^h = 0$ for $h \neq j$. As will be seen clearly in the next subsection, the former highlights the income effect and the latter the relative price effect.

In both cases of nonhomothetic CES and homothetic CES, the real per capita consumption in Home is expressed as $C_H/L_H = (1+\mu_H)w_H/P_H$, and its logarithmic change is

$$d\ln\left(\frac{C_H}{L_H}\right) = \underbrace{d\ln w_H}_{>0} + \underbrace{\frac{\mu_H d\ln \mu_H}{1+\mu_H}}_{\gtrless 0} \underbrace{-d\ln P_H}_{\gtrless 0}, \tag{8}$$

where μ_H denotes the ratio of tariff revenue to labor income and is given by $\mu_H \equiv \widetilde{T}_H/(w_H L_H)$.[10] The sum of the first and the second terms, if positive, can be called terms-of-trade gains. An increase in tariffs in Home, τ_{HF}, reduces import demand there and raises Home's export price relative to its import price to maintain balanced trade. This leads to a higher relative wage in Home, making positive the first term in (8), $d\ln w_H > 0$.

In addition, if the tariff rises from a sufficiently low level, it increases the ratio of tariff revenue to labor income and makes positive the second term in (8), $\mu_H d\ln\mu_H/(1+\mu_H) > 0$). A further tariff increase, however, reduces Home's imports significantly, so that the second term turns from positive to negative at some point, $\mu_H d\ln\mu_H/(1+\mu_H) < 0$.

In the case of homothetic CES, the tariff effect on the aggregate price index (the third term in (8): $-d\ln P_H$) is always negative, for the obvious reason that tariff makes more expensive the imported intermediate varieties and thus raises the sectoral price indices constituting the aggregate price index. In the case of nonhomothetic CES, however, the tariff effect can be positive if the nonhomotheticity parameters ϵ^j take extreme values.[11]

As in the tariff-revenue-to-income ratio μ_H, we can show that rising tariffs first increase and

[10] Strictly speaking, the second term in (8), $d\ln\mu_H = d\mu_H/\mu_H$, is not defined at zero tariff (zero revenue). However, the discussion in the text also goes through in this case.

[11] If, for example, the sector in which tariff rises is extremely income elastic ($\epsilon^j << 1$), the Hicksian demand for the sectoral composite good decreases the aggregate expenditure so greatly that the aggregate price index may fall ($d\ln P_H < 0$ or $-d\ln P_H > 0$). To see this formally, the change in the aggregate price index in Home is given by

$$\begin{aligned} d\ln P_H &= \sum_{j=a,m,s} (\omega_H^j/\bar{\epsilon}_H) d\ln P_H^j + \sum_{j=a,m,s} (1-\epsilon^j/\bar{\epsilon}_H)\omega_H^j d\ln E_H \\ &= \sum_{j=a,m,s} \omega_H^j d\ln P_H^j + \sum_{j=a,m,s} (\epsilon^j - 1)\omega_H^j d\ln(C_H/L_H). \end{aligned}$$

then decrease the real per capita consumption C_H/L_H.[12] The qualitative feature of this result is independent of the nonhomotheticity parameters ϵ^js and the elasticity of substitution σ, so that the same result holds when preferences are Cobb-Douglas ($\sigma = 1$). The discussion is summarized in the following proposition. The proof and other results on w_H and μ_H are given in Online Appendix A.

Proposition 1. Tariffs and real per capita consumption

In a model with two asymmetric countries and three symmetric sectors, we consider a unilateral increase in Home's tariffs. If preferences are nonhomothetic CES, the tariff increase is assumed to be uniform across sectors; while if preferences are either homothetic CES or Cobb-Douglas, it can be sector specific. In both cases, the real per capita consumption in Home first rises and then falls: there exists a tariff level τ^*_{HF} below which $d(C_H/L_H)/d\tau_{HF} > 0$, and above which $d(C_H/L_H)/d\tau_{HF} < 0$.

2.2 Tariffs and expenditure share

Let us turn to the impact of tariffs on the sectoral expenditure share given in (4). The logarithmic change in Home's expenditure share of sector $j \in \{a, m, s\}$ is decomposed as

$$d \ln \omega^j_H = \underbrace{(1-\sigma)\left(d \ln P^j_H - \sum_{h=a,m,s} \omega^h_H d \ln P^h_H\right)}_{\text{Relative price effect}} + \underbrace{(1-\sigma)\left(\epsilon^j - \bar{\epsilon}_H\right) d \ln \left(\frac{C_H}{L_H}\right)}_{\text{Income effect}}, \tag{9}$$

where $\bar{\epsilon}_H \equiv \sum_h \omega^h_H \epsilon^h$.[13] The first set of terms in (9) is the relative price effect through changes in the relative price of sector j composite good. To highlight this, we assume homothetic CES preferences by setting $\epsilon^j = 1$ for all j, and consider an increase in sector j tariff only, $d\tau^j_{HF} = d\tau_{HF} > 0$. The tariff increase in a sector raises its price index relative to those in the other sectors by making more expensive the imported intermediate varieties to produce the sectoral composite good. With the elasticity of substitution between different sectors being less than unity, $\sigma \in (0, 1)$, the increased

In the case of homothetic CES with $\epsilon^j = 1$ for all j, the second term vanishes.

[12]This suggests a existence of level of tariff that maximizes welfare. We discuss this point in detail in Online Appendix A.

[13]The real sectoral expenditure share has a similar expression. Letting $\widetilde{\omega}^j_H \equiv C^j_H / \sum_h C^h_H$, we have

$$d \ln \widetilde{\omega}^j_H = -\sigma\left(d \ln P^j_H - \sum_{h=a,m,s} \omega^h_H d \ln P^h_H\right) + (1-\sigma)\left(\epsilon^j - \bar{\epsilon}_H\right) d \ln \left(C_H/L_H\right).$$

relative price of the sector's composite good raises the expenditure share in that sector and reduces the expenditure shares in the other sectors.

The second set of terms in (9) is the income effect through changes in the real per capita consumption. The income effect never operates in the case of homothetic CES preferences with $\epsilon^j = 1$ for all j. To highlight this, we assume nonhomothetic CES preferences with $\epsilon^a < \epsilon^m = 1 < \epsilon^s$ and consider a uniform increase in tariffs in all sectors, $d\tau^j_{HF} = d\tau_{HF} > 0$ for all j. In doing so, the price indices in all sectors rise proportionally, shutting down the relative price effect. The tariff increase, starting from a sufficiently low level, raises the real per capita consumption rises in the tariff-imposing Home (Proposition 1). Home then shifts expenditure away from the sectors with a lower income elasticity (smaller ϵ^j) toward the sectors with a higher income elasticity (greater ϵ^j). In our model of three sectors, we can show that the income effect is negative in agriculture, positive in services, and it can be negative or positive in manufacturing, depending on the value of ϵ^m.

Letting $\sigma = 1$, preferences reduce to Cobb-Douglas and the sectoral expenditures are fixed. Therefore, tariffs have no effect on the sectoral expenditure shares: (9) is always zero.

Focusing on the case where tariffs increase real per capita consumption—that is, $\tau_{HF} \in (0, \tau^*_{HF}]$ from Proposition 1—we formally state the following proposition and relegate the proof to Online Appendix B.

Proposition 2. Tariffs and expenditure share

In a model with two asymmetric countries and three symmetric sectors, we consider an unilateral increase in Home's tariffs.

Assume preferences are nonhomothetic CES and the tariffs uniformly increase from $\tau_{HF} \in [0, \tau^*_{HF})$ in all sectors. Then the real per capita consumption in Home rises and the following holds:

(i) the agricultural expenditure share in Home falls ($d\omega^a_H/d\tau_{HF} < 0$), while the service expenditure share rises ($d\omega^s_H/d\tau_{HF} > 0$);

(ii) the manufacturing expenditure share falls if the income elasticity of manufacturing demand is sufficiently low ($d\omega^m_H/d\tau_{HF} < 0$ if $\epsilon^m < \bar{\epsilon}_H$), while it falls if the opposite holds ($d\omega^m_H/d\tau_{HF} > 0$ if $\epsilon^m > \bar{\epsilon}_H$).

Assume preferences are homothetic CES and the tariffs uniformly increases from $\tau_{HF} \in [0, \tau^*_{HF})$ in some sectors. Then the real per capita consumption in Home rises and the following holds:

(iii) the sectoral expenditure share in Home rises in the sectors where tariffs increase ($d\omega^j_H/d\tau^j_{HF} > 0$ for some j with $d\tau^j_{HF} > 0$), while it falls in the sectors where tariffs remain unchanged ($d\omega^h_H/d\tau^j_{HF} < 0$ for $h \neq j$ with $d\tau^h_{HF} = 0$).

If preferences are Cobb-Douglas, changes in tariffs have no effect on the sectoral expenditure shares.

From Proposition 2, we can infer how the manufacturing tariff affects the manufacturing expenditure shares in the presence of both nonhomothetic CES preferences and sector-specific tariffs. Suppose Home increases the manufacturing tariff from a sufficiently low level and that $\epsilon^m < \bar{\epsilon}_H$ holds. As the relative price of manufacturing rises, Home shifts expenditure from agriculture and services toward manufacturing. However, the tariff is also likely to increase Home's real per capita consumption, shifting expenditure from agriculture and manufacturing toward services.

In summary, the manufacturing expenditure share is positively affected by the manufacturing tariff through the relative price effect, but negatively affected through the income effect. We leave the question of which effect dominates to the full quantitative analysis in later sections.

2.3 Tariffs and value-added shares

The value-added of sector $j \in \{a, m, s\}$ in the tariff-imposing Home is the labor income in that sector, which is earned from sales in the domestic and the foreign markets:

$$\begin{aligned} VA^j_H = w_H L^j_H &= \sum_{i=H,F} \pi^j_{iH} P^j_i C^j_i \\ &= P^j_H C^j_H + NX^j_H - \widetilde{T}^j_H, \qquad NX^j_H \equiv EX^j_H - IM^j_H \equiv \pi^j_{FH} P^j_F C^j_F - \frac{\pi^j_{HF} P^j_H C^j_H}{1+\tau^j_{HF}}, \end{aligned}$$

where NX^j_H is Home's net exports, (gross) exports and (gross) imports in sector j. The sectoral value added in Home increases with domestic expenditure and net exports, but decreases with tariff revenue, since the revenue accrues from the value added generated by workers in Foreign.

The value-added share of sector j in Home is then $va^j_H \equiv VA^j_H/(w_H L_H)$. Its logarithmic change is given by[14]

$$d \ln va_H^j = \underbrace{\frac{P_H^j C_H^j}{w_H L_H^j}\left(d\ln\omega_H^j + \frac{\mu_H d\ln\mu_H}{1+\mu_H}\right)}_{\text{(a)Expenditure adj. by tariff revenue}} + \underbrace{\frac{NX_H^j}{w_H L_H^j} d\ln\left(\frac{NX_H^j}{w_H L_H}\right)}_{\text{(b)Net exports}} - \underbrace{\frac{\widetilde{T}_H^j}{w_H L_H^j} d\ln\left(\frac{\widetilde{T}_H^j}{w_H L_H}\right)}_{\text{(c)Tariff revenue}} \quad (10)$$

In autarky, the value-added shares and the expenditure shares always coincide: $va_H^j = \omega_H^j$. With international trade, however, they may differ.

The contribution of sectoral expenditure shares to value-added shares is captured by the first term (a) in (10). This expenditure channel also includes changes in aggregate tariff revenue relative to labor income ($\mu_H \equiv \widetilde{T}_H/(w_H L_H)$)—the second term within (a)—since higher revenue scales up consumption across all sectors. How the sectoral expenditure shares respond to tariffs—the first term within (a)—is already well understood from Proposition 2. If only the relative price effect operates in sector j under homothetic CES preferences and sector-specific tariffs, then $d\ln\omega_H^j > 0$ holds, contributing positively to $d\ln va_H^j$. In contrast, if only the income effect operates under nonhomothetic CES preferences with uniform tariffs across sectors, then $d\ln\omega_H^j < 0$ holds for a lower income elastic sector j, contributing negatively to $d\ln va_H^j$.

The last term (c) in (10) is a mechanical channel from the definition of va_H^j. When tariffs raise tariff revenue in a sector more than labor income, the share of contribution by Home's workers in that sector decreases.

The second term (b) in (10) captures the standard protective role of tariffs. As Home increases tariffs on a sector, imports in that sector decline and net exports improve, thereby expanding its value-added share. This net export channel (b) operates under Cobb-Douglas preferences, where neither the relative price effect nor the income effect is present.

To determine the sign of (10), we highlight the polar cases where either one of the income effect via nonhomothetic preferences or the relative price effect via sector-specific tariffs operates, as in Proposition 2. Under a little more restrictive conditions than in Proposition 2 (symmetric countries and an increase in tariffs from zero), we can formally show the following proposition, where the proof is relegated to Online Appendix C.

[14]The second term (b) is defined as

$$\frac{NX_H^j}{w_H L_H^j} d\ln\left(\frac{NX_H^j}{w_H L_H}\right) \equiv \frac{EX_H^j}{w_H L_H^j} d\ln\left(\frac{EX_H^j}{w_H L_H}\right) - \frac{IM_H^j}{w_H L_H^j} d\ln\left(\frac{IM_H^j}{w_H L_H}\right).$$

Proposition 3. Tariffs and value-added shares

In a model of two countries and three symmetric sectors, we consider a unilateral increase in tariffs in Home. Assume preferences are nonhomothetic CES; the two countries are symmetric; the income elasticity of manufacturing demand is low enough; and the tariff uniformly increases from zero in all sectors. Then the real per capita consumption in Home rises and the following holds:

(i) the sectoral value-added share in agriculture and manufacturing falls ($dva^j_H/d\tau_{HF} < 0$ for $j \in \{a, m\}$), while it rises in services ($dva^s_H/d\tau_{HF} > 0$),

and the sectoral expenditure shares exhibit the same pattern.

Assume preferences are homothetic CES; the two countries are asymmetric; and the tariff uniformly increases from $\tau_{HF} = 0$ in some sectors. Then the real per capital consumption in Home rises and the following holds:

(ii) the sectoral value-added share in Home rises in the sectors where tariffs increase ($dva^j_H/d\tau^j_{HF} > 0$ for some j with $d\tau^j_{HF} > 0$), while it falls in the sectors where tariffs remain unchanged ($dva^h_H/d\tau^j_{HF} < 0$ for $h \neq j$ with $d\tau^h_{HF} = 0$),

and the sectoral expenditure shares exhibit the same pattern.

If preferences are Cobb-Douglas, sectoral value-added shares exhibit the same pattern as under homothetic CES, while sectoral expenditure shares remain unchanged.

From Proposition 3, we can infer the effect of tariffs on sectoral value-added shares in the presence of both nonhomothetic CES preferences and sector-specific tariffs. Suppose Home increases tariffs from a sufficiently low level only in manufacturing sector with a lower income elasticity ($\epsilon^m < \bar{\epsilon}_H$), which seems plausible in many developed countries today. Then the effects of the manufacturing tariff on its value-added share mirror those on the manufacturing expenditure share, captured by the expenditure channel (a) in (10): the relative price effect is likely to contribute positively to the manufacturing value-added share, while the income effect is likely to contribute negatively. In addition, the replacement of expensive foreign manufactures with domestic ones—the net export channel in (10)—has an overall positive effect. We will quantify the magnitudes of these channels in later sections.

2.4 Toward a full dynamic model

To bridge to a fully quantitative dynamic model, we introduce capital into the two-country model and extend it to two periods. Using this extended model, we examine how a temporary and a permanent tariff shocks affect the representative household's consumption-saving decision. Letting $K_{n,t}$ and $I_{n,t}$ denote the capital stock and investment, respectively, in country $n \in \{H, F\}$ and period $t \in \{1, 2\}$, the law of motion of the capital stock is $K_{n,t+1} = I_{n,t}$, where capital in the last period fully depreciates. Capital is owned by the household and rented to domestic variety producers at the rate $r_{n,t}$. They employ a Cobb-Douglas production technology using capital and labor. The investment good is produced using the sectoral composite goods à la CES technology with the elasticity parameter $\sigma^K \in (0, 1)$ and is domestically traded at price $P^K_{n,t}$. The consumption-saving decision maximizes the discounted sum of utility derived from the aggregate consumption good: $u(C_{n,1}) + \beta u(C_{n,2})$.

2.4.1 Saving decisions and tariff shocks

In each period $t \in \{1, 2\}$, the representative household in country H earns labor and capital income, $w_{H,t}L_{H,t} + r_{H,t}K_{H,t}$, as well as tariff revenue, $\widetilde{T}_{H,t}$, and spends this on consumption, $E_{n,t}$, and investment, $P^K_{H,t}I_{n,t}$:

$$
\begin{aligned}
E_{H,t} + P^K_{n,t}I_{n,t} &= w_{n,t}L_{n,t} + r_{n,t}K_{n,t} + \widetilde{T}_{n,t} \\
&= (1 + \mu_{H,t})(w_{n,t}L_{n,t} + r_{n,t}K_{n,t}),
\end{aligned}
$$

where $\mu_{H,t} \equiv \widetilde{T}_{H,t}/(w_{H,t}L_{H,t} + r_{H,t}K_{H,t})$ is the ratio of tariff revenue to factor income. Assuming zero capital stock in the initial period, $K_{H,1} = 0$, we rearrange the intertemporal budget constraint in Home in period 1 to obtain

$$
I_{H,1} = \frac{P_{H,1}}{P^K_{H,1}} \left[\frac{(1 + \mu_{H,1})w_{H,1}L_{H,1}}{P_{H,1}} - C_{H,1} \right]. \tag{11}
$$

Investment occurs ($I_{H,1} > 0$) when part of aggregate real labor income is saved. This helps us understand how tariffs affect the consumption-saving decision in the following two scenarios.

Temporary tariff shock Let us consider an unanticipated, temporary tariff increase on manufacturing in Home during period 1. Upon the tariff increase from a sufficiently low level, both the aggregate real labor income ($(1 + \mu_{H,1})w_{H,1}L_{H,1}/P_{H,1}$) and the aggregate consumption ($C_{H,1}$) rise in period 1, but the aggregate consumption does not rise as much as the the real aggregate income, as the household with a smoothing motive saves a part of additional income in period 1 for consumption in period 2. If the manufacturing tariff does not significantly change the relative price of the consumption good to the investment good ($P_{H,1}/P^K_{H,1}$), we see from (11) that the investment (good) in period 1, $I_{H,1}$, increases. The household shits expenditure from consumption to investment in period 1.

Permanent tariff shock We next consider a permanent tariff increase on manufacturing that takes effect in both periods 1 and 2. The tariff increase in period 1 is an unanticipated shock, while that in period 2 is an anticipated one. In response to the tariff increase from a sufficiently low level in periods 1 and 2, the aggregate real labor income ($(1 + \mu_{H,t})w_{H,t}L_{H,t}/P_{H,t}$) and the aggregate consumption ($C_{H,t}$) rise in both periods. Compared to the case of a temporary shock, the household has a weaker incentive to save since future income is expected to rise. The investment in period 1, $I_{H,1}$, may decrease upon the permanent tariff shock.

In summary, how saving responds to tariff shocks depends on their duration. If the tariff shock is temporary, the household saves more today; whereas if the shock is permanent, it saves less. In the quantitative section, we will examine whether this intuition holds in the corresponding counterfactual exercises.

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 $\mathcal{N} = \{1, \cdots, N\}$, with the number of countries being N. Countries are generically indexed by i or n. We maintain three sectors as in the previous model: agriculture, manufacturing, and services.

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

$$\sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_{n,t} \frac{(C_{n,t}/L_{n,t})^{1-\psi}}{1-\psi}, \tag{12}$$

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

$$\sum_{j=a,m,s} (\Omega^j_{n,t})^{\frac{1}{\sigma}} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{\frac{\epsilon^j(1-\sigma)}{\sigma}} \left(\frac{C^j_{n,t}}{L_{n,t}}\right)^{\frac{\sigma-1}{\sigma}} = 1, \tag{13}$$

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, Ω^j is the demand shifter for sector j.[15]

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

$$E_{n,t} = L_{n,t} \left[\sum_{j=a,m,s} \Omega^j_{n,t} \left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t}\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{14}$$

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

$$C^j_{n,t} = L_{n,t}\Omega^j_{n,t} \left(\frac{P^j_{n,t}}{P_{n,t}}\right)^{-\sigma} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{(1-\sigma)\epsilon^j+\sigma}. \tag{15}$$

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

$$\omega^j_{n,t} = \frac{\Omega^j_{n,t}\left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^j} P^j_{n,t}\right\}^{1-\sigma}}{\sum_{j'=a,m,s} \Omega^{j'}_{n,t}\left\{\left(\frac{C_{n,t}}{L_{n,t}}\right)^{\epsilon^{j'}} P^{j'}_{n,t}\right\}^{1-\sigma}}. \tag{16}$$

[15] Besides this nonhomothetic CES period utility function, we consider a homothetic CES function (letting $\epsilon^j = 1$ for any j) and a Cobb-Douglas function $\prod_{j=a,m,s}\left(\frac{C^j_{n,t}}{\chi^j_{n,t}}\right)^{\chi^j_{n,t}}$ with $\sum_{j=a,m,s}\chi^j_{n,t} = 1$.

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

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

$$E_{n,t} + P^K_{n,t} I_{n,t} \leq (1 - \phi_{n,t}) \left(w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t} \right) + L_{n,t} T^P_t, \tag{17}$$

where $P^K_{n,t}$ 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^P_t 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

$$K_{n,t+1} = (1 - \delta_{n,t}) K_{n,t} + I^\lambda_{n,t} (\delta_{n,t} K_{n,t})^{1-\lambda}, \tag{18}$$

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

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

Take the derivatives of Φ with respect to the first and the second argument

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

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

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

$$\max \ (12)$$

subject to (14), (17), and (18). Solving this problem, we obtain the Euler equation

$$\begin{aligned}&\left(\frac{C_{n,t+1}/L_{n,t+1}}{C_{n,t}/L_{n,t}}\right)^{\psi-1}\frac{E_{n,t+1}\bar{\epsilon}_{n,t+1}}{E_{n,t}\bar{\epsilon}_{n,t}}\\=&\beta\frac{\zeta_{n,t+1}}{\zeta_{n,t}}\frac{L_{n,t+1}}{L_{n,t}}\frac{(1-\phi_{n,t+1})r_{n,t+1}-P^K_{n,t+1}\Phi_2(K_{n,t+2},K_{n,t+1};\delta_{n,t+1})}{P^K_{n,t}\Phi_1(K_{n,t+1},K_{n,t};\delta_{n,t})},\end{aligned}\tag{19}$$

where

$$\bar{\epsilon}_{n,t}=\sum_{h=a,m,s}\omega^h_{n,t}\epsilon^h.\tag{20}$$

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. (19) tells that this per-capita consumption ratio depends on the discount factor (β), 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

$$y^j_{n,t}(z)=a^j_{n,t}(z)\left(\frac{K^j_{n,t}(z)}{\gamma^j_{n,t}\alpha^j_{n,t}}\right)^{\gamma^j_{n,t}\alpha^j_{n,t}}\left(\frac{L^j_{n,t}(z)}{\gamma^j_{n,t}(1-\alpha^j_{n,t})}\right)^{\gamma^j_{n,t}(1-\alpha^j_{n,t})}\left(\frac{M^j_{n,t}(z)}{1-\gamma^j_{n,t}}\right)^{1-\gamma^j_{n,t}}.\tag{21}$$

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 (15), and σ^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

$$g_{n,t}^{j,j'} = \frac{P_{n,t}^{j'} M_{n,t}^{j,j'}}{\sum_{j''=a,m,s} P_{n,t}^{j''} M_{n,t}^{j,j''}} = \frac{\kappa_{n,t}^{j,j'} (P_{n,t}^{j'})^{1-\sigma^j}}{\sum_{j''=a,m,s} \kappa_{n,t}^{j,j''} (P_{n,t}^{j''})^{1-\sigma^j}}.$$

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

$$F_{n,t}^j(a) = \Pr[a_{n,t}^j \leq a] = \exp\left[- \left(\frac{a}{\widetilde{\gamma}^j A_{n,t}^j} \right)^{-\theta^j} \right].$$

Unlike the two-country model, θ^j varies across sectors, consequently so does $\widetilde{\gamma}^j = [\Gamma((\theta^j + 1 - \eta)/\theta^j)]^{-\frac{1}{1-\eta}}$. Productivity of varieties are independent within and across sectors, countries, and periods.

Solving the cost minimization problem for the production function (21), the cost for an input bundle is

$$\widetilde{c}_{n,t}^j = (r_{n,t})^{\gamma_{n,t}^j \alpha_{n,t}^j} (w_{n,t})^{\gamma_{n,t}^j (1-\alpha_{n,t}^j)} (\xi_{n,t}^j)^{1-\gamma_{n,t}^j}, \tag{22}$$

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

$$\xi_{n,t}^j = \left[\sum_{j'=a,m,s} \kappa_{n,t}^{j,j'} (P_{n,t}^{j'})^{1-\sigma^j} \right]^{\frac{1}{1-\sigma^j}}. \tag{23}$$

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

$$P_{n,t}^j = \left[\sum_{i \in \mathcal{N}} \left(\frac{\tilde{c}_{i,t}^j b_{ni,t}^j}{A_{i,t}^j} \right)^{-\theta^j} \right]^{-1/\theta^j}, \tag{24}$$

where $b_{ni,t}^j$ 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. $b_{ni,t}^j$ is expressed as

$$b_{ni,t}^j = d_{ni,t}^j (1 + \tau_{ni,t}^j), \tag{25}$$

where $d_{ni,t}^j$ 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 $\tau_{ni,t}^j$ 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 σ^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

$$P^K_{n,t} = \frac{1}{\kappa^K_{n,t}} \left(\sum_{j=s,m,s} \kappa^{K,j}_{n,t} (P^j_{n,t})^{1-\sigma^K} \right)^{\frac{1}{1-\sigma^K}}. \tag{26}$$

Let $X^j_{ni,t}$ 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 $X^j_{ni,t}$ across i, let $X^j_{n,t}$ be country n's spending on sector j goods (or services) in period t. Let $\pi^j_{ni,t} = X^j_{ni,t}/X^j_{n,t}$, that is, the share of goods from country i within country n's expenditure on sector j goods in period t. We call $\pi^j_{ni,t}$ as trade shares following the literature of quantitative trade models. Following Eaton and Kortum (2002), we have

$$\pi^j_{ni,t} = \frac{(\tilde{c}^j_{i,t} b^j_{ni,t} / A^j_{i,t})^{-\theta^j}}{\sum_{i' \in \mathcal{N}} (\tilde{c}^j_{i',t} b^j_{ni',t} / A^j_{i',t})^{-\theta^j}} = \frac{(\tilde{c}^j_{i,t} b^j_{ni,t} / A^j_{i,t})^{-\theta^j}}{(P^j_{n,t})^{-\theta^j}} \tag{27}$$

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

$$Y^j_{n,t} = \sum_{i \in \mathcal{N}} \frac{\pi^j_{in,t}}{\tilde{\tau}^j_{in,t}} X^j_{i,t}. \tag{28}$$

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

$$\begin{aligned} X^j_{n,t} &= P^j_{n,t} C^j_{n,t} + P^j_{n,t} M^{K,j}_n + \sum_{j'=a,m,s} (1-\gamma^{j'}_{n,t}) g^{j',j}_{n,t} Y^{j'}_{n,t} \\ &= \omega^j_{n,t} E_{n,t} + g^{K,j}_{n,t} P^K_{n,t} I_{n,t} + \sum_{j'=a,m,s} (1-\gamma^{j'}_{n,t}) g^{j',j}_{n,t} Y^{j'}_{n,t}. \end{aligned} \tag{29}$$

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

$$w_{n,t} L_{n,t} = \sum_{j=a,m,s} \gamma^j_{n,t} (1-\alpha^j_{n,t}) Y^j_{n,t}. \tag{30}$$

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

$$r_{n,t} K_{n,t} = \sum_{j=a,m,s} \gamma^j_{n,t} \alpha^j_{n,t} Y^j_{n,t}. \tag{31}$$

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

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

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

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

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

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

Solving this for T^P_t, we have

$$T^P_t = \frac{\sum_{n=1}^N \phi_{n,t} (w_{n,t} L_{n,t} + r_{n,t} K_{n,t} + \widetilde{T}_{n,t})}{\sum_{n=1}^N L_{n,t}}. \tag{32}$$

Definition 1 (Equilibrium)**.** Given the capital stocks in the initial period $\{K_{n,0}\}_{n \in \mathcal{N}}$, an equilibrium is a tuple of $\{w_{n,t}\}_{n \in \mathcal{N}, t=0,\cdots,\infty}$, $\{r_{n,t}\}_{n \in \mathcal{N}, t=0,\cdots,\infty}$, $\{E_{n,t}\}_{n \in \mathcal{N}, t=0,\cdots,\infty}$, $\{\tilde{c}^j_{n,t}\}_{n \in \mathcal{N}, t=0,\cdots,\infty, j=a,m,s}$,

$\{P^j_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{\pi^j_{ni,t}\}_{(n,i)\in\mathcal{N}\times\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{Y_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{X^j_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{\bar{\epsilon}_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{\omega^j_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty,j=a,m,s}$, $\{C_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{K_{n,t}\}_{n\in\mathcal{N},t=1,\cdots,\infty}$, $\{I_{n,t}\}_{n\in\mathcal{N},t=0,\cdots,\infty}$, $\{T^P_t\}_{t=0,\cdots,\infty}$ satisfying a system of equations (14), (16), (17), (18), (19), (20), (22), (24), (27), (28), (29), (30), (31), and (32).

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 $\{w_n\}_{n\in\mathcal{N}}$, $\{r_n\}_{n\in\mathcal{N}}$, $\{E_n\}_{n\in\mathcal{N}}$, $\{\tilde{c}^j_n\}_{n\in\mathcal{N},j=a,m,s}$, $\{P^j_n\}_{n\in\mathcal{N},j=a,m,s}$, $\{\pi^j_{ni}\}_{(n,i)\in\mathcal{N}\times\mathcal{N},j=a,m,s}$, $\{Y_n\}_{n\in\mathcal{N}}$, $\{X^j_n\}_{n\in\mathcal{N},j=a,m,s}$, $\{\omega^j_n\}_{n\in\mathcal{N},j=a,m,s}$, $\{C_n\}_{n\in\mathcal{N}}$, $\{K_n\}_{n\in\mathcal{N}}$ satisfying a system of equations, (14), (16), (22), (24), (27), (28), (29), (30), (32),

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

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

and

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

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

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	U.S.A

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 their products. Construction and utility supply (e.g., electricity, gas, and water supply) is classified as a service.[16] 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).[17]

4.2 Structural Parameters

We begin by discussing our calibration of the parameters in preferences. The discount factor β 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 complements, and, therefore, the relative price effect is at work. Values of ϵs indicate that the income effect works, too, i.e., agriculture is a necessity, service is a luxury, and manufacturing starts as a luxury and then becomes a necessity as the consumption expenditure rises.

Value-added shares in the production function $\gamma^j_{n,t}$ are directly observed in the IO table. Capital shares within value-added $\alpha^j_{n,t}$ are 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

[16] 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. (2024), 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.

[17] 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

$\sigma^j = 0.38$ 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. (2024). Lower-than-one elasticity of substitution indicates that the relative price effect works both in the production of goods and services and investment goods. Shape parameters of the Fréchet distribution are calibrated based on the estimates of Caliendo and Parro (2015). We choose $\theta^a = 8.11$ and $\theta^m = 4.55$. For the service trade elasticity, we follow Gervais and Jensen (2019) and set $\theta^s = 0.75 \cdot \theta^m$.

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.

Calibration of fundamentals. We calibrate the sequences of iceberg trade costs $\{d^j_{ni,t}\}$, productivity $\{A^j_{n,t}\}$, and cost shifters $\{g^i_{n,t}\}$ and $\{g^K_{n,t}\}$ exploiting the standard gravity equation, sectoral price indices across countries provided by the WIOD, and some other data provided by the PWT. Demand shifters $\{\Omega^j_{n,t}\}$ in nonhomothetic CES preferences (13) are such that the consumption expenditure shares $\{\omega^j_{n,t}\}$ are matched between the data and the baseline equilibrium. See Appendix

E for details.

4.3 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 (19) 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

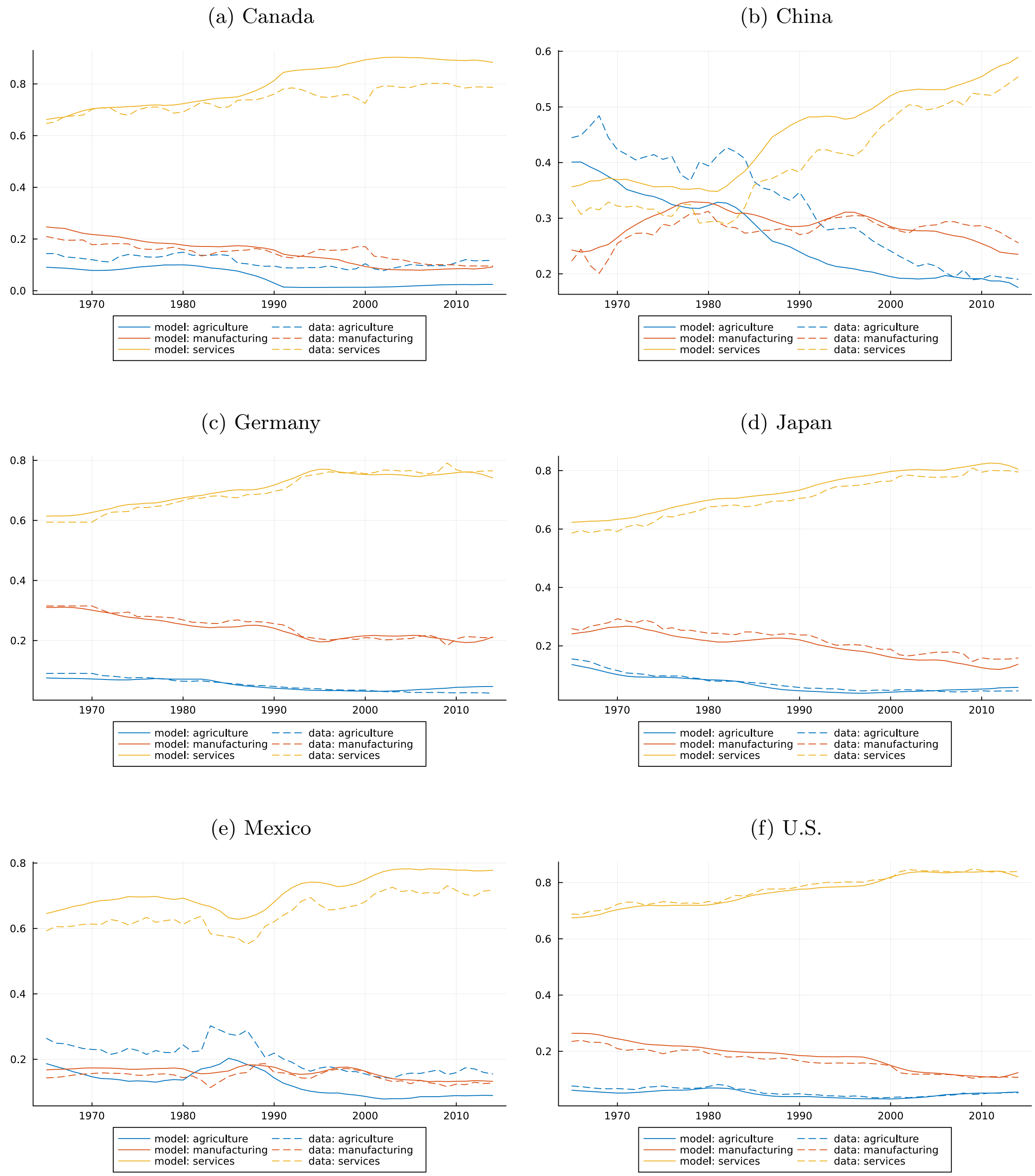
This section presents the quantitative results of the calibrated model.

5.1 Fit of the Baseline Model

We first show the baseline results. To examine the model's ability to match the data, Figure 2 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 U.S. 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 U.S., while in the other three countries, the model overestimates the service share and underestimates the agricultural share, despite the overall trend being captured.

Next, Figure 3 demonstrates the model fit of sectoral expenditure shares in final consumption, $\omega^j_{n,t}$. 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 2. The model captures the

Figure 2: Model Fit: Sectoral Value Added Share in GDP

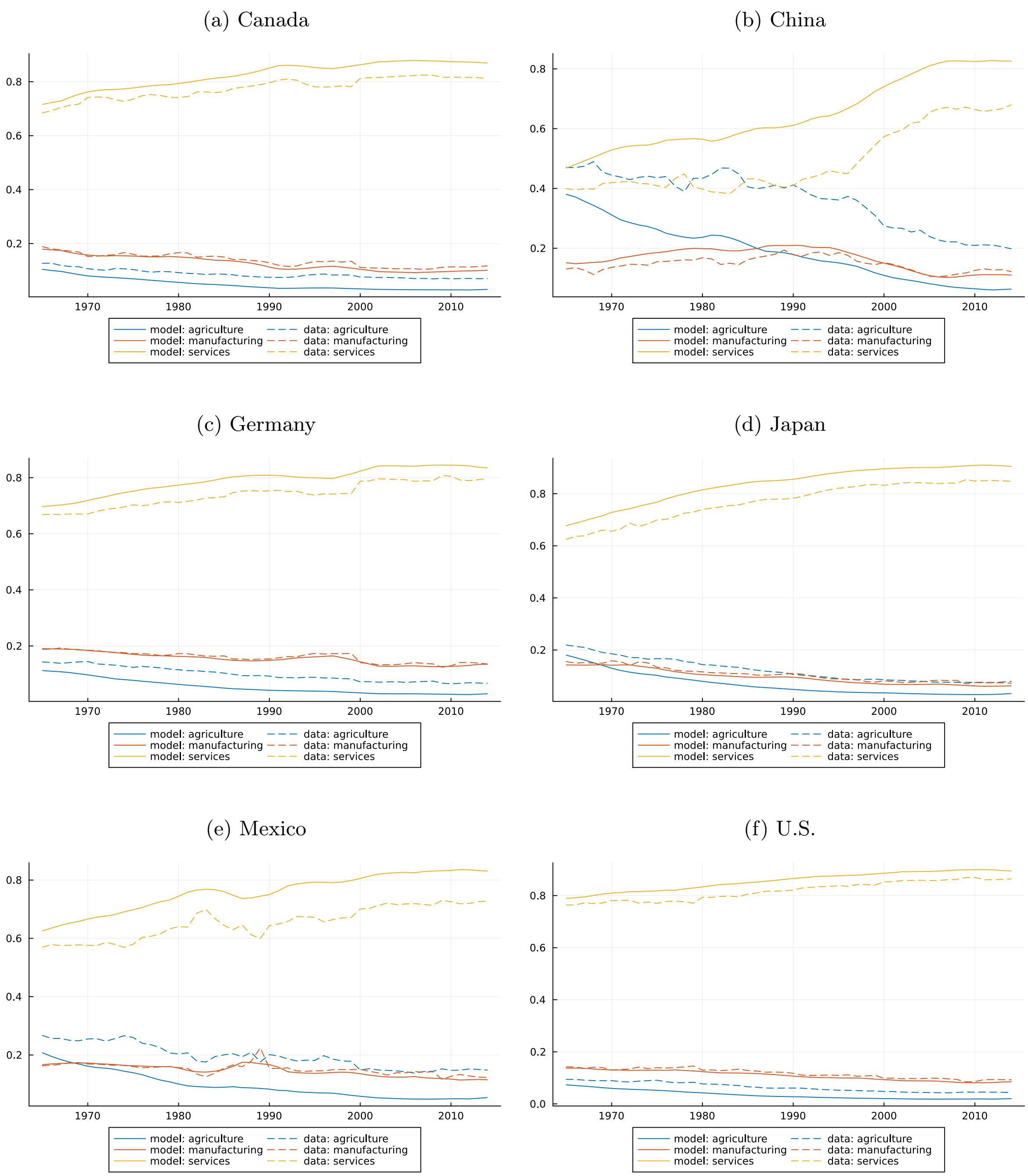


shift of final expenditure from agriculture to manufacturing, and then to services over time. In all countries, the model tends to overpredict the service expenditure and underestimate the agriculture expenditure. As in the case of the value added share, the fit of the model is better for the advanced economies, Canada, Germany, Japan, and the U.S., compared to the emerging economies, China and

Mexico. In Appendix J, 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 outperforms the homothetic counterpart in matching the data.

In Appendix J.1, we present the model fit of saving rates.

Figure 3: Model Fit: Sectoral Expenditure Share in Final Consumption



5.2 Counterfactuals

Now, we will use the model to examine the impacts of a temporary and a permanent 20% point unilateral increases in U.S. tariffs applied to manufacturing goods from all countries since 2001. We choose the year 2001 becausethe U.S. manufacturing value-added share sharply decreased and has never returned since then. This exercise serves as 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, in particular, for revitalizing manufacturing. In this exercise, we keep the levels of non-tariff trade barriers fixed to single out the pure effect of tariffs.

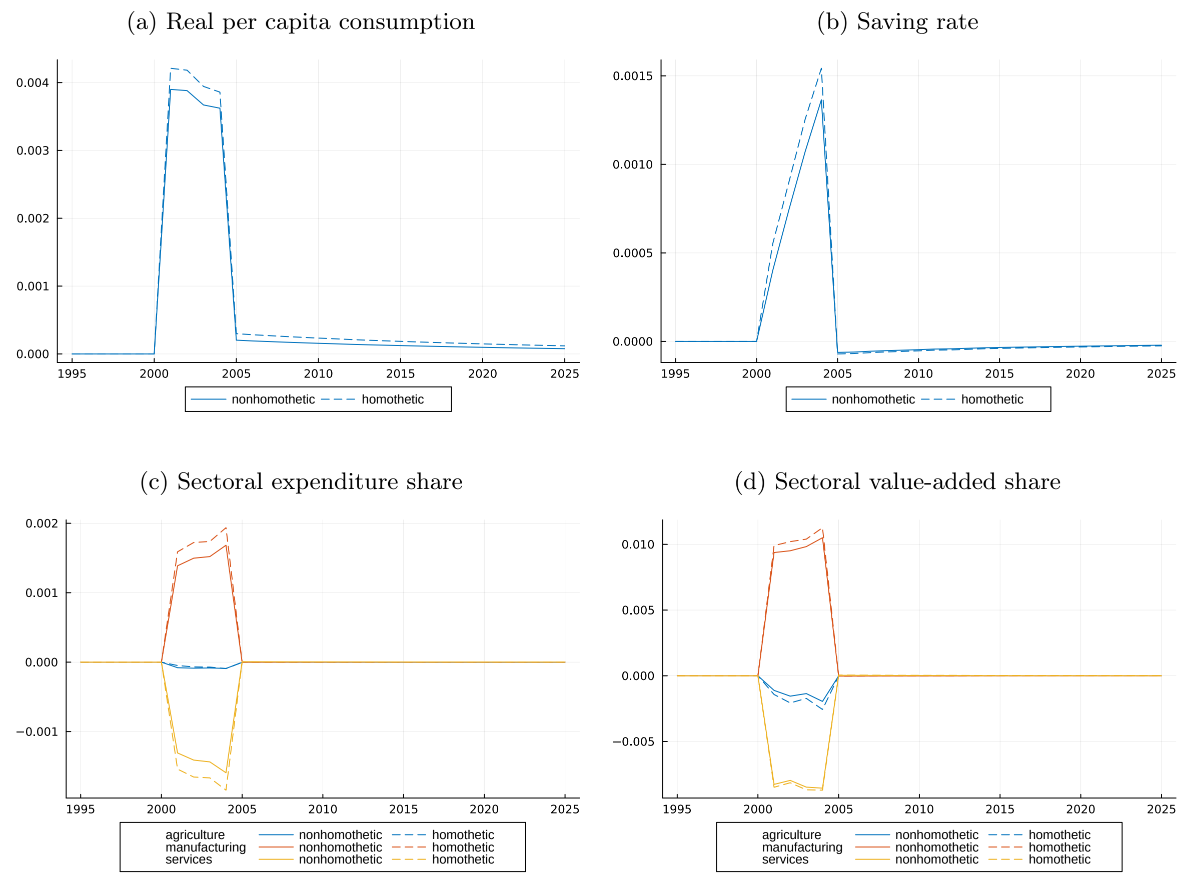
5.2.1 Temporary tariff shock

First, we delineate the effect of such tariffs implemented for four years from 2001 to 2004. We suppose that the tariff hike is a surprise, i.e., every agent in all countries suddenly realizes the policy in 2001. Yet, they all anticipate that the U.S. will lift the additional tariffs in 2005. In this setting, as described in footnote 15, we consider three different period utility functions: (i) nonhomothetic CES in (13), (ii) homothetic CES, (iii) Cobb-Douglas. Figure 4 shows the impacts of a 4-year, 20 percent increase in U.S. manufacturing tariffs on 4 economic variables in the U.S. Figure 4 reports results under nonhomothetic and homothetic CES preferences. In Appendix K, Figure A8 presents results under homothetic CES and Cobb-Douglas preferences.

Real per capita consumption and saving Panel (a) shows the percent changes in real per capita consumption $C_{n,t}/L_{n,t}$ from the baseline to this counterfactual equilibrium. In relation to Proposition 1 in our static two-country model in Section 2.1, these results confirm that the U.S. in 2001 was indeed in the increasing part of the tariff-consumption schedule. For both nonhomothetic and homothetic CES preferences, the consumption is about 0.4 percent higher in the counterfactual than in the baseline for the four years of the high tariffs. Even after the high tariff period, the consumption in the counterfactual is slightly higher than the one in the baseline.

The higher-than-baseline real consumption is due to the consumption smoothing. To see this, let us move on to Panel (b) of Figure 4. Panel (b) shows the percentage point changes in saving rates from the baseline to the counterfactual. In the four years of the high tariffs, the saving rates are higher than in the baseline. After the high tariff period, the saving rates are slightly lower than in

Figure 4: Impacts of a 4 year, 20 percentage point increase in U.S. manufacturing tariffs applied to all countries: Nonhomothetic and homothetic CES



Notes: This figure shows the impacts of a 20 percentage point increase in U.S. manufacturing tariffs applied to all the other countries between 2001 and 2004. Each panel is based on the time series of transition paths of respective variables indicated by its title. For real per capita consumption, the vertical axes represent percent changes from the baseline to the counterfactual equilibrium. For sectoral expenditure shares, sectoral value-added shares, and saving rates, the vertical axes represent percentage point changes.

the baseline. And the saving rate eventually converges to the baseline level. In 2001, U.S. households realize that the high tariffs are implemented and they will end in four years. Therefore, they do not fully spend temporarily increased tariff revenues on consumption and save a fraction of such temporary income, which confirms the intuition obtained from the two-country two-period model in Section 2.4. After four years, U.S. households dissave the piled-up temporal income. Moreover, during the high-tariff period, the discrepancy in the saving rates between the counterfactual and the baseline increases over time.[18]

[18]This is because U.S. households have an incentive to front-load their consumption. Figure A7 confirms that real per capita consumption increases over time. The lifetime utility function (12) weights population over time, and the higher population growth may motivate individuals to save. Yet, given the U.S. population growth rate of less

Before moving on, let us briefly review our theoretical predictions about the effects of tariffs on sectoral shares. As explored in Section 2.2, how the expenditure shares respond to tariffs is governed by the relative price effect and the income effect.[19] Under homothetic CES preferences and tariffs specific to a sector, only the relative price effect operates, and therefore, equation (9) (i.e., $d \ln \omega_H^j$) and Proposition 2 provided a clear prediction for this case; the expenditure share on the protected sector becomes higher. Under nonhomothetic CES preferences and sector-specific tariffs, however, the income effect counteracts the relative price effect. The same patterns hold for the sectoral value-added shares and an additional standard channel of trade protection emerges, as summarized in equation (10) (i.e., $d \ln va_H^j$) and Proposition 3 in Section 2.3. We quantify the magnitudes of these counteracting effects.

Sectoral expenditure share Panel (c) reports the percentage point changes in the consumption expenditure shares from the baseline to the counterfactual. The dashed lines in Panel (c) are under homothetic CES preferences. Since the tariffs raise U.S. manufacturing prices relative to agriculture and service prices, the expenditure shares on manufacturing goods become higher. Under nonhomothetic CES preferences, however, the higher consumption dampens the shift of expenditures to manufacturing due to the income effect, resulting in smaller changes as depicted by the solid lines. The income effect is not large enough to overturn the relative price effect, and the 20 percentage point higher tariffs make the manufacturing expenditure share higher under nonhomothetic preferences, too. For both homothetic and nonhomothetic CES preferences, the expenditure shares quickly go back to the baseline levels after the high-tariff period.

Sectoral value-added share Panel (d) represents the percentage point changes in the sectoral value-added shares. A 20 percentage point additional tariff on the U.S. manufacturing import will lead to approximately 1 percentage point increase in the manufacturing value-added share. The value-added share of the other two sectors would be lower, but most of the increase in the manufacturing value-added share is accounted for by the lower service share. As in the expenditure shares, the value-added shares in the counterfactual quickly go back to the baseline level as soon as

than 100 percent from 1965 to 2014, the consumption-smoothing motive will be dominating. Therefore, when U.S. households receive temporary income for four years, they consume a larger fraction in earlier years and shift toward more saving in later years during the high-tariff period.

[19]As Proposition 2 states, neither of these two effects is at play under Cobb-Douglas preferences. See Figure A8 in Appendix K.

the tariffs are lifted.

To better interpret Panel (d), we make a couple of remarks. Unlike our models in Sections 2 and 3, if we consider a closed-economy model without intermediate inputs such as the one of Comin et al. (2021),[20] expenditure shares and value-added shares would be exactly the same. The separation of sectoral expenditure shares and sectoral value-added shares is only possible if we model either intermediate inputs or international trade or both. Comparing Panels (c) and (d), the manufacturing expenditure share is less than 0.2 percentage points higher, whereas the manufacturing value-added share is about 1 percentage point higher. In our quantitative model, the effect of tariffs on the value-added shares is much larger than the effect on the expenditure shares.

Next, we compare the effects of the tariffs on the sectoral value-added shares across different preferences. Panel (d) of Figure A8 in Appendix K shows the percent changes in the sectoral value-added shares under homothetic CES and Cobb-Douglas preferences. In the high tariff period, the manufacturing value-added share under homothetic CES preferences is higher than the one for Cobb-Douglas preferences. This is because the relative price effect operates only under homothetic CES preferences among the two kinds of preferences. Going back to Panel (d) of Figure 4, in the high tariff period, the manufacturing value-added share under nonhomothetic CES preferences is lower than the one under homothetic CES preferences. This is because the income effect operates only under nonhomothetic CES preferences. Comparing Panel (d)s between Figure A8 and Figure 4, however, we observe that the primary driver of the effects of the high tariffs on the value-added share is not the changes in the consumption expenditure shares, but those in the net exports (corresponding to the term (b) in (10): $d \ln va_H^j$).

Welfare Overall, if the U.S. imposes a 20 percentage point higher manufacturing tariffs for four years since 2001, the U.S. welfare (measured by consumption equivalent from the viewpoint as of 2001) increases by 0.058 percent.[21] All other countries are worse off. Mexico and India have the first and second largest welfare losses: 0.27 percent and 0.23 percent, respectively. For these two countries, the export value to the U.S. is the largest among their trade partners. As such, the disruption caused by the higher tariffs costs them the most. More specifically, these two countries are large manufacturing exporters to the U.S., and U.S. imports from these two countries decline when

[20] They consider value-added production functions for agriculture, manufacturing, services and "the investment sector."In contrast, we consider gross production functions combining production factors and sectoral intermediate inputs.

[21] See Appendix D for the welfare formula.

tariffs are imposed. However, the fixed net export to GDP ratio for any country (see $\phi_{n,t}$ in (17)) requires the two countries having the lower factor prices to keep selling their goods internationally and domestically. As the price of tradeable goods do not decline as much in these two countries, the real income declines in these two countries, and so does the consumption and welfare. See the columns noted "4 years" in Table 3 for the welfare changes of all sample countries.

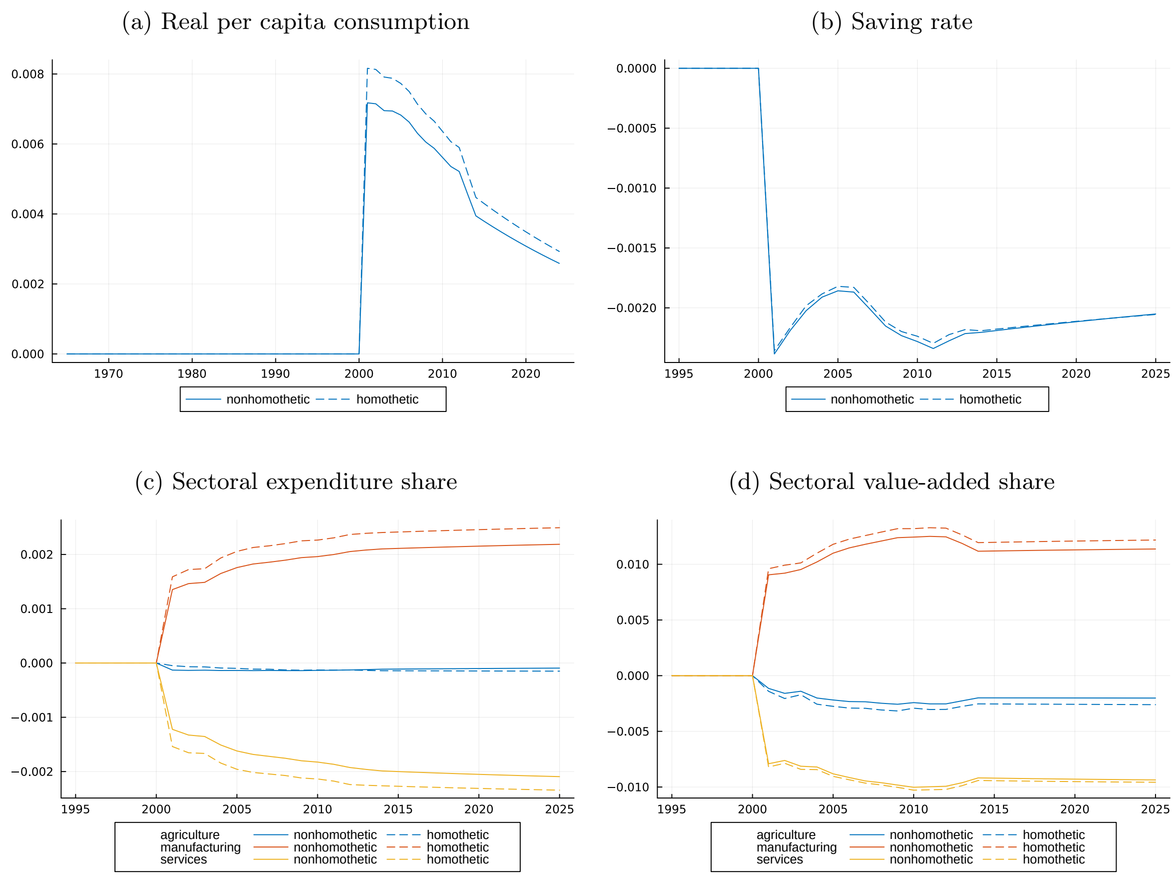
5.2.2 Permanent tariff shock

Next, we turn to the effect of a 20 percent hike in U.S. manufacturing tariffs, which is implemented in 2001 and in effect forever. As in the previous exercise, the tariff hike is a surprise shock for all individuals, and they realize that this is a permanent shock. Figure 5 shows the impacts of such a tariff increase.

Real per capita consumption and saving Panel (a) reports the percent change in real per capita consumption from the baseline to this counterfactual. Since the real income becomes higher permanently, the real consumption also becomes higher than in the baseline equilibrium. The magnitude of the hike in the consumption is about twice as large as in the case of the 4-year temporal hike (see Panel (a) of Figure 4), reflecting the larger change in permanent income under the permanent tariff scenario compared to the temporary one. Yet, the discrepancy between the baseline and the counterfactual consumption is the largest in the first year after the shock, and declines over time. This is, again, because households want to front-load consumption. The lump-sum transfer of tariff revenues disincentivizes U.S. households from saving, as highlighted by our two-period model in Section 2.4. Therefore, as shown in Panel (b), the saving rate in the counterfactual is lower than in the baseline. This is a stark contrast to the temporary tariff scenario depicted in Panel (b) of Figure 4, where U.S. households save during the high-tariff period and dissave afterward.

Sectoral expenditure and value-added shares, and welfare Panels (c) and (d) of Figure 5 show the percentage point changes in the sectoral expenditure shares and the sectoral value-added shares, respectively. The values from 2001 to 2004 are similar to those in the case of the 4-year tariffs (see Panels (c) and (d) of Figure 4). In the case of the permanent tariffs, both the expenditure share and the value-added share of manufacturing are permanently higher than in the baseline equilibrium. Now, we discuss the welfare implications of the U.S. permanent tariffs under nonhomothetic CES preferences. See the columns indexed by "Permanent" in Table 3. The U.S. welfare is 0.36 percent

Figure 5: Impacts of a permenent, 20% point increase in U.S. manufacturing tariffs applied to all countries: Nonhomothetic and homothetic CES



Notes: This figure shows the impacts of a 20% point increase in U.S. manufacturing tariffs applied to all the other countries since 2001. Each panel is based on the time series of transition paths of respective variables indicated by its title. For real per capita consumption, the vertical axes represent percent changes from the baseline to the counterfactual equilibrium. For sectoral expenditure shares, sectoral value-added shares, and saving rates, the vertical axes represent percentage point changes.

higher than in the baseline equilibrium under nonhomothetic CES preferences. All other countries are worse off. India and Mexico have the first and second largest welfare losses of 0.74 and 0.64 percent, respectively.

Table 3: Welfare changes: U.S. tariffs

	Nonhomothetic CES		Homothetic CES	
	4 years	Permanent	4 years	Permanent
Australia	-0.012	-0.026	-0.014	-0.024
Austria	-0.022	-0.126	-0.027	-0.151
Belgium	-0.013	-0.095	-0.016	-0.110
Brazil	-0.046	-0.177	-0.051	-0.195
Canada	-0.186	-1.260	-0.238	-1.605
China	-0.125	-0.361	-0.158	-0.424
Germany	-0.015	-0.085	-0.018	-0.094
Denmark	-0.010	-0.048	-0.013	-0.058
Spain	-0.017	-0.096	-0.021	-0.112
Finland	-0.024	-0.141	-0.030	-0.171
France	-0.012	-0.069	-0.014	-0.080
U.K.	-0.012	-0.064	-0.015	-0.073
Greece	-0.023	-0.157	-0.027	-0.182
India	-0.227	-0.744	-0.255	-0.791
Ireland	-0.016	-0.074	-0.021	-0.088
Italy	-0.023	-0.103	-0.028	-0.120
Japan	-0.010	-0.070	-0.012	-0.083
Korea	-0.030	-0.166	-0.037	-0.197
Mexico	-0.267	-0.640	-0.315	-0.715
Netherland	-0.018	-0.089	-0.021	-0.104
Portugal	-0.021	-0.132	-0.026	-0.156
Sweeden	-0.021	-0.108	-0.026	-0.129
Taiwan	-0.037	-0.212	-0.044	-0.250
U.S.	0.058	0.357	0.067	0.408
Rest of the World	-0.043	-0.128	-0.050	-0.144

Notes: This tables shows welfare changes from the baseline equilibrium to the 4 year or permanent 20 percentage point higher U.S. manufacturing tariffs since 2001 for nonhomothetic or homothetic CES preferences. The numbers are percent changes. For example, 0.058 (U.S., 4 years, nonhomothetic CES) means that the U.S. welfare is 0.058 percent higher in this counterfactual than in the baseline.

5.2.3 Trade war

If the U.S. imposes tariffs against other countries, it is very likely that the other countries will retaliate. Therefore, we consider the situation where the other countries also impose 20 percentage point higher tariffs on U.S. manufacturing goods. We consider the 4-year and permanent trade wars starting in 2001. As before, these trade wars come as a surprise. In this case, all countries are worse off. We report the welfare changes under nonhomothetic CES preferences, but those under homothetic CES preferences are similar in Table 4. For both the 4-year and permanent trade wars, all countries are worse off than in the baseline equilibrium.

In the case of the 4-year trade war, the U.S. has the smallest welfare loss of 0.006 percent across the world, as it is the largest economy. Mexico has the largest welfare loss of 0.288 percent. If the the trade war is permanent, the U.S. welfare loss is 0.121 percent, which is larger than the welfare losses of most European countries and Japan. Canada has the largest welfare loss of 1.078 percent. Comparing Table 3 and Table 4, we realize that in Canada, Mexico, and the U.S., the welfare losses from the permanent trade war are larger than the welfare losses from the permanent U.S. unilateral tariffs. In contrast, in large manufacturers such as China, Germany, and Japan, the welfare losses from the permanent U.S. unilateral tariffs are larger than the welfare losses from the U.S. unilateral tariffs. If the U.S. unilaterally imposes tariffs, the trade values from China, Germany, and Japan to the U.S. become lower. But, because the net export to GDP ratios, $\phi_{n,t}$, are fixed, the factor prices must fall for those three countries, resulting in a welfare loss. If China, Germany, and Japan also impose tariffs against the U.S., they will receive larger tariff revenues. Moreover, the import value from the US to these countries declines, so the higher factor prices can satisfy the net export to GDP ratios. Therefore, the trade war is better than the U.S. unilateral tariffs for these three countries. However, since Canada and Mexico are so much reliant on the U.S. economy as both the largest export destination and the largest import source, Canada and Mexico are worse off if all the other countries punish the U.S. with retaliatory tariffs.

Table 4: Welfare changes: Trade war

	Nonhomothetic CES		Homothetic CES	
	4 years	Permanent	4 years	Permanent
Australia	-0.011	-0.048	-0.014	-0.055
Austria	-0.018	-0.092	-0.022	-0.109
Belgium	-0.012	-0.075	-0.015	-0.088
Brazil	-0.035	-0.130	-0.040	-0.146
Canada	-0.177	-1.078	-0.230	-1.385
China	-0.077	-0.220	-0.096	-0.255
Germany	-0.012	-0.060	-0.014	-0.068
Denmark	-0.009	-0.041	-0.011	-0.050
Spain	-0.014	-0.073	-0.018	-0.086
Finland	-0.020	-0.101	-0.025	-0.122
France	-0.010	-0.051	-0.011	-0.059
U.K.	-0.009	-0.044	-0.011	-0.051
Greece	-0.021	-0.126	-0.025	-0.145
India	-0.138	-0.442	-0.153	-0.465
Ireland	-0.017	-0.067	-0.022	-0.081
Italy	-0.019	-0.076	-0.023	-0.088
Japan	-0.007	-0.046	-0.009	-0.053
Korea	-0.023	-0.134	-0.029	-0.157
Mexico	-0.288	-0.716	-0.342	-0.817
Netherland	-0.014	-0.072	-0.017	-0.084
Portugal	-0.020	-0.109	-0.025	-0.129
Sweeden	-0.017	-0.078	-0.021	-0.093
Taiwan	-0.029	-0.150	-0.035	-0.176
U.S.	-0.006	-0.121	-0.009	-0.165
Rest of the World	-0.027	-0.078	-0.031	-0.087

Notes: This tables shows welfare changes from the baseline equilibrium to the 4-year or permanent trade war since 2001 for nonhomothetic or homothetic CES preferences. The trade war means that the U.S. imposes 20 percentage point higher manufacturing tariffs on all other countries, and all other countries impose 20 percentage point higher tariffs on the U.S. The numbers are percent changes. For example, -0.006 (U.S., 4 years, nonhomothetic CES) means that the U.S. welfare is 0.058 percent higher in this counterfactual than in the baseline.

6 Conclusion

This paper qualitatively and quantitatively examined the effects of tariffs on sectoral composition and welfare, in the presence of economic forces that drive structural change—sectors being complements and nonhomothetic preferences—as well as the standard protective role of tariffs. We asked whether tariffs could help manufacturing regain its share in sectoral consumption expenditure and value added.

Using a two-country model, we show that an increase in tariffs from a low level raises income and shifts demand from manufacturing to services through the income effect driven by nonhomothetic preferences. However, tariffs targeting manufacturing shift demand in the opposite direction via the relative price effect, given an elasticity of substitution less than one. In addition to these consumption-driven effects, tariffs replace foreign manufactures with domestic ones, increasing the manufacturing value-added share.

To quantitatively assess these effects, we extend 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 calibrating 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 percent increase in U.S. manufacturing tariffs on all trading partners beginning in 2001. Our findings favors the relative price effect and the trade protection effect over the income effect. Specifically, U.S. manufacturing's value-added share rises by about one percentage point, while the service sector declines by 0.9 percentage point between 2001 and 2014. Despite these shifts supporting protectionist objectives, the welfare impact is minor: the U.S. is better off only by 0.36 percent. However, other countries, particularly Canada, experience welfare losses, with Canada facing a 1.3 percent decline. If the other countries retaliate with 20 percentage point higher tariffs, all countries are worse off with the U.S. welfare loss being 0.12 percent.

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Online Appendices for "Trade Policy and Structural Change"

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May, 2025

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A Proof of Proposition 1

In the proofs of Propositions 1 to 3, we allow for an arbitrary number of sectors, $j \in \{1, \dots, J\}$. In the case of nonhonmothetic CES preferences, the nonhomotheticity parameters are common in the two countries and ordered in a way that $0 < \epsilon^1 < \cdots < \epsilon^J$ and there exists a sector j such that $\epsilon^j = 1$. In the case of homothetic CES preferences, the nonhomotheticity parameters are common in both countries and sectors, $\epsilon^j = 1$ for all $j \in \{1, \dots, J\}$.

Nonhomothetic CES case We assume that preferences are nonhomothetic CES and allow productivity A_n, population L_n, non-tariff trade barriers d_{ni}, and tariffs τ_{ni} to be country (pair) specific, but not to be sector specific. We here look at the effect of tariff applied by Home to 1 uniform across sectors, $\tau_{HF}^j = \tau_{HF}$ for all j.

We first show there exists a unique equilibrium wage. The trade balance condition requires

$$\sum_{j=1}^{J} \frac{\pi_{HF}^j \omega_H^j (1+\mu_H) w_H L_H}{1+\tau_{HF}} = \sum_{j=1}^{J} \frac{\pi_{FH}^j \omega_F^j (1+\mu_F) w_F L_F}{1+\tau_{FH}},$$

where

$$\begin{aligned}
\pi_{HF}^j &= \left(\frac{w_F b_{HF}/A_F}{P_H^j} \right)^{-\theta} = \frac{(A_F/b_{HF})^\theta}{(A_F/b_{HF})^\theta + (A_H/w)^\theta} = \frac{(w/b_{HF})^\theta}{(w/b_{HF})^\theta + A^\theta} \equiv \pi_{HF}, && \forall j \\
\pi_{FH}^j &= \left(\frac{w_H b_{FH}/A_H}{P_F^j} \right)^{-\theta} = \frac{(A_H/b_{FH})^\theta w^{-\theta}}{A_F^\theta + (A_H/b_{FH})^\theta w^{-\theta}} = \frac{(A/b_{FH})^\theta}{w^\theta + (A/b_{FH})^\theta} \equiv \pi_{FH}, && \forall j \\
\mu_n^j &= \frac{\tau_{ni}\pi_{ni}^j \omega_n^j}{1+\tau_{ni}} = \frac{\tau_{ni}\pi_{ni}\omega_n^j}{1+\tau_{ni}}, && n \neq i \in \{H, F\}, \ \forall j \\
\mu_n &= \frac{\sum_j \mu_n^j}{1 - \sum_j \mu_n^j} = \frac{\frac{\tau_{ni}\pi_{ni}}{1+\tau_{ni}}}{1 - \frac{\tau_{ni}\pi_{ni}}{1+\tau_{ni}}} = \frac{\tau_{ni}\pi_{ni}}{1+\tau_{ni}\pi_{nn}}, && \forall n \\
b_{ni} &\equiv d_{ni}(1+\tau_{ni}), \quad w \equiv w_H/w_F = w_H, \quad A \equiv A_H/A_F,
\end{aligned}$$

noting $\sum_j \omega_n^j = \sum_j P_n^j C_n^j / E_n = 1$ and $w_F = 1$ due to the choice of numéraire; and $\pi_{ni} + \pi_{nn} = 1$. As there are no sectoral heterogeneity except for the nonhomotheticity parameter ϵ^j, the sectoral price indices and the trade shares are all the same across sectors, $\pi_{ni}^j = \pi_{ni}$ and $P_n^j = P_n$ for all j.

Using $\sum_j \omega_n^j = 1$, we rearrange the trade balance condition to obtain

$$\frac{\pi_{HF}(1+\mu_H)w_H L_H}{1+\tau_{HF}} = \frac{\pi_{FH}(1+\mu_F)w_F L_F}{1+\tau_{FH}},$$
$$\Leftrightarrow \frac{L_H}{L_F} = \frac{\pi_{FH}}{w\pi_{HF}}\left(\frac{1+\mu_F}{1+\mu_H}\right)\left(\frac{1+\tau_{HF}}{1+\tau_{FH}}\right) = \frac{\pi_{FH}}{w\pi_{HF}}\frac{\frac{1+\tau_{FH}}{1+\tau_{FH}\pi_{FF}}}{\frac{1+\tau_{HF}}{1+\tau_{HF}\pi_{HH}}}\left(\frac{1+\tau_{HF}}{1+\tau_{FH}}\right) = \frac{\pi_{FH}}{w\pi_{HF}}\left(\frac{1+\tau_{HF}\pi_{HH}}{1+\tau_{FH}\pi_{FF}}\right).$$

Finally, we have

$$\frac{L_H}{L_F} = \frac{(A/b_{FH})^\theta\left[(w/b_{HF})^\theta + (1+\tau_{HF})A^\theta\right]}{b_{HF}^{-\theta}w^{1+\theta}\left[(1+\tau_{FH})w^\theta + (A/b_{FH})^\theta\right]}.$$

We can conclude that this equation has a unique solution of w by checking that (i)the right-hand side approaches infinity as w goes to zero; (ii)it approaches zero as w goes to infinity; and (iii)it decreases with w.

Two comments are in order. First, the trade balance condition above does not include ϵ^j nor σ, implying that the equilibrium (relative) wage is the same in both the nonhomothetic and homothetic CES cases. Second, the equilibrium (relative) wage in the imposing Home increases with its tariff. Taking the derivative of the trade balance condition with respect to τ_{HF} gives

$$d\ln\pi_{HF} + \frac{d\mu_H}{1+\mu_H} + d\ln w - \frac{d\tau_{HF}}{1+\tau_{HF}} = d\ln\pi_{FH} + \frac{d\mu_F}{1+\mu_F} - \frac{d\tau_{FH}}{1+\tau_{FH}},$$

where, for example, $d\ln w \equiv dw/w$ and

$$\begin{aligned}
&d\ln b_{HF} = d\ln d_{HF}(1+\tau_{HF}) = \frac{d\tau_{HF}}{1+\tau_{HF}} > 0, \qquad d\ln b_{FH} = \frac{d\tau_{FH}}{1+\tau_{FH}} = 0, \\
&d\ln P_F^j = \pi_{FH}\left(d\ln b_{FH} + d\ln w\right), \qquad d\ln P_H^j = \pi_{HF}d\ln b_{HF} + \pi_{HH}d\ln w, && \forall j \\
&d\ln\pi_{HF} = -\theta\left(d\ln b_{HF} - d\ln P_H^j\right) = -\theta\pi_{HH}\left(d\ln b_{HF} - d\ln w\right), && \forall j \\
&d\ln\pi_{FH} = -\theta\left(d\ln b_{FH} + d\ln w - d\ln P_F^j\right) = -\theta\pi_{FF}\left(d\ln b_{FH} + d\ln w\right), && \forall j \\
&d\mu_n = \begin{cases} \pi_{ni}d\tau_{ni} & \text{if } \tau_{ni} = 0 \\ \frac{\tau_{ni}\pi_{ni}}{(1+\tau_{ni}\pi_{nn})^2}\left[d\ln\tau_{ni} + (1+\tau_{ni})d\ln\pi_{ni}\right] & \text{if } \tau_{ni} > 0 \end{cases}, && n \neq i \in \{H, F\}
\end{aligned}$$

We set $\tau_{FH} = 0$ in what follows. Solving the equations for $d\ln w$ yields

$$\frac{d\ln w}{d\tau_{HF}} = \Gamma^{-1}(1+\theta)A^\theta\left[w^\theta + (A/b_{FH})^\theta\right] > 0,$$

where $\Gamma > 0$ is a bundle of variables.

Using (1) and $E_H = (1+\mu_H)w_H L_H$, we write the expenditure share on the sector j composite good in Home, $\omega_H^j = P_H^j C_H^j / E_H$, as

$$\omega_H^j = \left(\frac{(1+\mu_H)w_H}{P_H^j}\right)^{\sigma-1}\left(\frac{C_H}{L_H}\right)^{\epsilon^j(1-\sigma)} = (1+\mu_H)^{\sigma-1}\left[(A_F w/b_{HF})^\theta + A_H^\theta\right]^{\frac{\sigma-1}{\theta}}\left(\frac{C_H}{L_H}\right)^{\epsilon^j(1-\sigma)},$$

Summing this over sectors yields

$$1 = \sum_{j=1}^{J}\omega_H^j = \sum_{j=1}^{J} x_H^{\frac{\sigma-1}{\theta}}\left(\frac{C_H}{L_H}\right)^{\epsilon^j(1-\sigma)}, \quad x_H \equiv (1+\mu_H)^\theta\left[(A_F w/b_{HF})^\theta + A_H^\theta\right]. \tag{A1}$$

This equation implicitly defines the real per capita income (or utility), C_H/L_H, as a function of index x_H (see Lemma 1 in Appendix B for details). To highlight this, we write $u(x_H) = C_H/L_H$. With $\sigma \in (0,1)$, we can see that $u(x_H)$ increases with x_H. Therefore, the optimal level of tariff that achieves the highest $u(x_H)$ maximizes x_H. Taking the derivative of x_H with respect to τ_{HF} gives

$$\frac{d\ln x_H}{d\tau_{HF}} = \frac{(1+\theta)(\theta w^\theta)^2(A/b_{HF})^\theta}{\Gamma(1+\tau_{HF})[(w/b_{HF})^\theta + A^\theta]}\left(\frac{1}{\theta\pi_{FF}} - \tau_{HF}\right)\begin{cases}\geq 0 & \text{if } \tau_{HF} \leq (\theta\pi_{FF})^{-1} \text{ or } \tau_{HF} \leq \tau_{HF}^* \\ < 0 & \text{if } \tau_{HF} > (\theta\pi_{FF})^{-1} \text{ or } \tau_{HF} > \tau_{HF}^*\end{cases},$$

where $\Gamma > 0$ is the same bundle of variables as the one in $d\ln w/d\tau_{HF}$. At $\tau_{HF} = 0$, we have $d\ln x_H/d\tau_{HF} > 0$. Letting $f(\tau_{HF}) \equiv \tau_{HF} - (\theta\tau_{FF})^{-1} = \tau_{HF} - \theta^{-1}\left[(A/(wb_{FH}))^\theta - 1\right]$, the condition $\tau_{HF} \leq (\theta\pi_{FF})^{-1}$ is equal to $f(\tau_{HF}) \leq 0$. We can check that $f(\tau_{HF})$ increases with τ_{HF} so that $f(\tau_{HF}) = 0$ holds at some point $\tau_{HF} = \tau_{HF}^*$. This implies that the condition $\tau_{HF} \leq (\theta\pi_{FF})^{-1}$ is equivalent to $\tau_{HF} \leq \tau_{HF}^*$. The index x_H and thus the real per capita income $u(x_H)$ is maximized at $\tau_{HF} = (\theta\pi_{FF})^{-1}$ or $\tau_{HF} = \tau_{HF}^*$.

The optimal tariff is given by

$$\tau_{HF}^* \equiv \frac{1}{\theta\pi_{FF}}, \quad \pi_{FF} = \left(\frac{w_F/A_F}{P_F}\right)^{-\theta} = \frac{w^\theta}{w^\theta + (A/b_{HF})^\theta},$$

The same expression is obtained in Caliendo and Parro (2022) in a single sector model with homothetic CES preferences. Three points are worth noting here. First, the optimal tariff increases with the trade elasticity θ. This is because imports are less responsive to changes in tariffs when productivity distribution is more dispersed (low θ), which allows Home to set a higher tariff. Second, the optimal tariff decreases with the share of domestic expenditure in Foreign, π_{11}. If Home is very small relative to Foreign in the world market, π_{11} approaches one. Smaller countries have less room for manipulating terms-of-trade than larger countries. Third, the degree of nonhomotheticity ϵ^j does not affect τ^*_{HF}, implying that the level of optimal tariff under the nonhomothetic CES preferences is the same as the one under the homothetic CES preferences, which we will see shortly. The optimal tariff is independent of ϵ^j because we restrict changes in tariffs to be uniform across sectors.

Finally, we can check that the revenue to labor-income ratio, μ_H, also has an inverted U-shaped relationship with τ_{HF}. Using the previous results, we again take the derivative of x_H while preserving μ_H to obtain

$$
\begin{aligned}
&\frac{d\ln x_H}{d\tau_{HF}} = \theta\left(\frac{1}{1+\mu_H}\frac{d\mu_H}{d\tau_{HF}} + \frac{d\ln w}{d\tau_{HF}} - \frac{d\ln P_H^j}{d\tau_{HF}}\right),\\
\Leftrightarrow\ &\frac{(1+\theta)(\theta w^\theta)^2(A/b_{HF})^\theta}{\Gamma(1+\tau_{HF})[(w/b_{HF})^\theta + A^\theta]}\left(\frac{1}{\theta\pi_{FF}} - \tau_{HF}\right) = \\
&\qquad \frac{\theta}{1+\mu_H}\frac{d\ln\mu_H}{d\tau_{HF}} - \frac{\theta\pi_{HF}w^\theta\left[(1+\theta)(w/b_{HF})^\theta + A^\theta\left(\theta(1+\tau_{HF}) + (b_{HF}b_{FH})^{-\theta}\right)\right]}{\Gamma(1+\tau_{HF})},\\
\Leftrightarrow\ &\frac{\theta}{1+\mu_H}\frac{d\mu_H}{d\tau_{HF}} = \frac{(1+\theta)(\theta w^\theta)^2(A/b_{HF})^\theta}{\Gamma(1+\tau_{HF})[(w/b_{HF})^\theta + A^\theta]}\left(\frac{1}{\theta\pi_{FF}} + \Gamma' - \tau_{HF}\right)\\
&\qquad = \begin{cases}\geq 0 & \text{if } \tau_{HF} \leq (\theta\pi_{FF})^{-1} + \Gamma' \text{ or } \tau_{HF} \leq \tau^{**}_{HF}\\ < 0 & \text{if } \tau_{HF} > (\theta\pi_{FF})^{-1} + \Gamma' \text{ or } \tau_{HF} > \tau^{**}_{HF}\end{cases},
\end{aligned}
$$

where $\Gamma' > 0$ is another bundle of parameters. Letting $g(\tau_{HF}) \equiv \tau_{HF} - (\theta\pi_{FF})^{-1} - \Gamma'$, the condition $\tau_{HF} \leq (\theta\pi_{FF})^{-1} + \Gamma'$ is equal to $g(\tau_{HF}) \leq 0$. We can check that $g(\tau_{HF})$ increases with τ_{HF} so that $g(\tau_{HF}) = 0$ holds at some point $\tau_{HF} = \tau^{**}_{HF}$. The condition $\tau_{HF} \leq (\theta\pi_{FF})^{-1} + \Gamma'$ is equivalent to $\tau_{HF} \leq \tau^{**}_{HF}$. The revenue to labor-income ratio is maximized at $\tau_{HF} = (\theta\pi_{FF})^{-1} + \Gamma'$ or $\tau_{HF} = \tau^{**}_{HF}$.

Analogously, the real per capita income in Foreign is implicitly defined as

$$
\begin{aligned}
&1 = \sum_{j=1}^{J}\omega_F^j = \sum_{j=1}^{J}\left(\frac{(1+\mu_F)w_F}{P_F^j}\right)^{\sigma-1}\left(\frac{C_F}{L_F}\right)^{\epsilon^j(1-\sigma)} = \sum_{j=1}^{J} x_F^{\frac{\sigma-1}{\theta}}\left(\frac{C_F}{L_F}\right)^{\epsilon^j(1-\sigma)},\\
&x_F \equiv (1+\mu_F)^\theta\left[A_F^\theta + (A_H/(wb_{FH}))^\theta\right].
\end{aligned}
$$

As in Home, we see that C_F/L_F positively depends on x_F and thus write $u(x_F) = C_F/L_F$.

$$
\frac{d\ln x_F}{d\tau_{HF}} = -\Gamma^{-1}\theta(1+\theta)\left(A^2/b_{FH}\right)^{-\theta} < 0,
$$

where $\Gamma > 0$ is the same bundle of variables as the one in $d\ln w/d\tau_{HF}$. □

Homothetic CES case We set $\epsilon^j = 1$ for all j and consider Home's unilateral uniform tariff change in some sectors $j \in \mathcal{J}$ with $\mathcal{J}$ being the set of sectors that increase tariffs and $\mathcal{J}^c$ being its complement set,

$d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}$ and $d\tau_{HF}^h = 0$ for $h \in \mathcal{J}^c$. We still assume that initial tariffs before the change are symmetric in sector, $\tau_{HF}^j = \tau_{HF}$ for all j, and Foreign never sets tariffs, $\tau_{FH}^j = 0$ for all j. As in the case of nonhomothetic CES, the change in the (relative) wage in Home is derived by differentiating the change in the trade balance condition:

$$\sum_{j=1}^{J} \frac{1}{J}\left(d\ln\pi_{FH}^j + d\ln\omega_F^j + \frac{d\mu_F}{1+\mu_F}\right) = \sum_{j=1}^{J} \frac{1}{J}\left(d\ln\pi_{HF}^j + d\ln\omega_H^j + \frac{d\mu_H}{1+\mu_H} + d\ln w - \frac{d\tau_{HF}^j}{1+\tau_{HF}}\right),$$

where

$$d\ln b_{HF}^j = d\ln d_{HF}\left(1+\tau_{HF}^j\right) = \frac{d\tau_{HF}^j}{1+\tau_{HF}} = \frac{d\tau_{HF}}{1+\tau_{HF}} > 0, \qquad j \in \mathcal{J}$$

$$d\ln b_{HF}^h = \frac{d\tau_{HF}^h}{1+\tau_{HF}} = 0, \qquad h \in \mathcal{J}^c$$

$$d\ln P_F^j = \pi_{FH} d\ln w, \qquad \pi_{FH} = \left(\frac{w b_{FH}/A_H}{P_F}\right)^{-\theta} = \frac{(A/b_{FH})^\theta}{w^\theta + (A/b_{FH})^\theta} = 1 - \pi_{FF}, \qquad \forall j$$

$$d\ln P_H^j = \pi_{HF} d\ln b_{HF}^j + \pi_{HH} d\ln w, \qquad \pi_{HF} = \left(\frac{b_{HF}/A_F}{P_H}\right)^{-\theta} = \frac{(w/b_{HF})^\theta}{(w/b_{HF})^\theta + A^\theta} = 1 - \pi_{HH}, \qquad \forall j$$

$$d\ln\pi_{HF}^j = -\theta\left(d\ln b_{HF}^j - d\ln P_H^j\right) = -\theta\pi_{HH}\left(d\ln b_{HF}^j - d\ln w\right), \qquad \forall j$$

$$d\ln\pi_{FH}^j = -\theta\left(d\ln w - d\ln P_F^j\right) = -\theta\pi_{FF} d\ln w, \qquad \forall j$$

$$d\ln\omega_n^j = (1-\sigma)\left(d\ln P_n^j - \sum_{h=1}^{J}\omega_n^h d\ln P_n^h\right), \qquad \omega_n^j = \frac{(P_n^j)^{1-\sigma}}{\sum_{h=1}^{J}(P_n^h)^{1-\sigma}} = \frac{1}{J}, \qquad \forall (n,j)$$

$$d\mu_F = \sum_{j=1}^{J} d\mu_F^j = \sum_{j=1}^{J} \pi_{FH}\omega_F^j d\tau_{FH}^j = 0,$$

$$d\mu_H = \begin{cases} \sum_j^J d\mu_H^j = \sum_j^J \pi_{HF}\omega_F^j d\tau_{HF}^j = \sum_j^J \pi_{HF} J^{-1} d\tau_{HF}^j & \text{if } \tau_{HF} = 0 \\ \dfrac{\mu_H(1+\tau_{HF})}{1+\tau_{HF}\pi_{HH}} \sum_j^J \omega_H^j d\ln\mu_H^j = \dfrac{\tau_{HF}\pi_{HF}(1+\tau_{HF})}{J(1+\tau_{FH}\pi_{HF})^2} \sum_j^J \left(\dfrac{d\ln\tau_{HF}^j}{1+\tau_{HF}} + d\ln\pi_{HF}^j + d\ln\omega_H^j\right) & \text{if } \tau_{HF} > 0 \end{cases},$$

noting $w \equiv w_H/w_F = w_H$; $A \equiv A_H/A_F$; and $P_n^j = P_n^h$ for $j \neq h$ because of no sectoral asymmetry in parameters. We solve the trade balance condition for $d\ln w$ to obtain

$$\frac{d\ln w}{d\tau_{HF}^j} = |\mathcal{J}|(J\Gamma)^{-1}(1+\theta)A^\theta\left[w^\theta + (A/b_{FH})^\theta\right] > 0, \qquad j \in \mathcal{J}$$

where $|\mathcal{J}|$ is the number of sectors that increase tariffs and Γ where $\Gamma > 0$ is the same bundle of variables as the one in the nohomothetic CES case.

Similarly, the revenue to wage-income ratio and the real per capita income in Home respond as

$$\frac{d\mu_H}{d\tau_{HF}^j} = \frac{|\mathcal{J}|(1+\mu_H)(1+\theta)w^{2\theta}(A/b_{HF})^\theta}{J\Gamma(1+\tau_{HF})[(w/b_{HF})^\theta + A^\theta]}\left(\frac{1}{\theta\pi_{FF}} + \Gamma' - \tau_{HF}\right) = \begin{cases} \geq 0 & \text{if } \tau_{HF} \leq (\theta\pi_{FF})^{-1} + \Gamma' \text{ or } \tau_{HF} \leq \tau_{HF}^{**} \\ < 0 & \text{if } \tau_{HF} > (\theta\pi_{FF})^{-1} + \Gamma' \text{ or } \tau_{HF} > \tau_{HF}^{**} \end{cases},$$

$$\frac{d}{d\tau_{HF}^j}\left(\frac{C_H}{L_H}\right) = \frac{|\mathcal{J}|\theta(1+\theta)w^{2\theta}(A/b_{HF})^\theta}{J\Gamma(1+\tau_{HF})[(w/b_{HF})^\theta + A^\theta]}\left(\frac{1}{\theta\pi_{FF}} - \tau_{HF}\right)\begin{cases} \geq 0 & \text{if } \tau_{HF} \leq (\theta\pi_{FF})^{-1} \text{ or } \tau_{HF} \leq \tau_{HF}^{*} \\ < 0 & \text{if } \tau_{HF} > (\theta\pi_{FF})^{-1} \text{ or } \tau_{HF} > \tau_{HF}^{*} \end{cases},$$

for $j \in \mathcal{J}$, where the parameters such as Γ, Γ', τ_{HF}^* and τ_{HF}^{**} are the same as those in the nohomothetic CES case. □

B Proof of Proposition 2

For later reference, we first prove the following two lemmas.

Lemma 1: *Define a probability function $f(j;x) : \{H, F, .., J\} \to [0,1]$ by*

$$f(j;x) \equiv \frac{[u(x)]^{\epsilon^j(1-\sigma)}}{\sum_{h=1}^J [u(x)]^{\epsilon^h(1-\sigma)}},$$

where $u(x) > 0$ is a positive value function of $x \in (0,\infty)$ and satisfies $x^{\frac{\sigma-1}{\theta}}[u(x)]^{\epsilon^j(1-\sigma)} = \omega^j \in (0,1)$ and $\sum_{j=1}^J \omega^j = 1$; $\{\epsilon^j\}_{j=1}^J$ are parameters such that $0 < \epsilon^1 < ... < \epsilon^J$ with a sector j such that $\epsilon^j = 1$; and $\sigma \in (0,1)$. Then, its distribution function, defined by $F(k;x) \equiv \sum_{j=1}^k f(j;x)$, decreases with x.

Proof of Lemma 1: Differentiating $F(k;x)$ with respect to x yields

$$\begin{aligned} \frac{d\ln F(k;x)}{d\ln x} &= \frac{(1-\sigma)\xi(x)}{\sum_{j=1}^k \omega^j}\left[\sum_{j=1}^k \epsilon^j\omega^j - \left(\sum_{j=1}^J \epsilon^j\omega^j\right)\left(\sum_{j=1}^k \omega^j\right)\right] \\ &= \frac{(1-\sigma)\xi(x)}{\sum_{j=1}^k \omega^j}\sum_{h=1}^k \omega^h \sum_{j=k+1}^J \left(\epsilon^h - \epsilon^j\right)\omega^j, \qquad k \in \{1,\ldots,J-1\} \end{aligned}$$

where $\xi(x) \equiv xu'(x)/u(x)$, which we saw in Appendix A. From the first to the second line, we use the mathematical induction. Specifically, we can check the equality holds at $k=1$; by assuming it holds at $k = k' \in \{2,\ldots,J-1\}$, we can prove it holds at $k = k'+1$.

The function $\xi(x)$ is positive because we rewrite $1 = \sum_j \omega^j = \sum_j x^{\frac{\sigma-1}{\theta}}[u(x)]^{\epsilon^j(1-\sigma)}$ given in (A1) as $x^{\frac{1-\sigma}{\theta}} = \sum_j^J [u(x)]^{\epsilon^j(1-\sigma)}$ and differentiate it with respect to x to obtain

$$\frac{1}{\xi(x)} = \theta\sum_{j=1}^J \epsilon^j x^{\frac{\sigma-1}{\theta}}[u(x)]^{\epsilon^j(1-\sigma)} > 0.$$

From this and the assumptions that $1-\sigma > 0$ and $\epsilon^h - \epsilon^j < 0$ for $h < j$, we can conclude that the derivative is negative: $d\ln F(k;x)/d\ln x < 0$ for $k \in \{1,\dots,J\}$. $\square$

Lemma 2: *The function $\xi(x) \equiv xu'(x)/u(x)$ defined in Lemma 1 decreases with x.*

Proof of Lemma 2: Again we differentiate $x^{\frac{1-\sigma}{\theta}} = \sum_j^J [u(x)]^{\epsilon^j(1-\sigma)}$ with respect to x to obtain

$$\frac{1}{\xi(x)} = \theta \sum_{j=1}^{J} \epsilon^j \cdot \frac{[u(x)]^{\epsilon^j(1-\sigma)}}{\sum_{h=1}^J [u(x)]^{\epsilon^h(1-\sigma)}} = \theta \sum_{j=1}^{J} \epsilon^j f(j;x).$$

What we need to show is that if $x_F < x_H$, $\xi(x_F) > \xi(x_H)$ holds. From Lemma 1, the distribution function $F(j;x)$ exhibits the first-order stochastic dominance in the discrete case (Courtault et al., 2006). That is, if $x_F < x_H$, $F(k;x_H) \equiv \sum_{j=1}^k f(j;x_H) < F(k;x_F) \equiv \sum_{j=1}^k f(j;x_F)$ holds for all $k \in \{1,2,\dots,J-1\}$. Then, Proposition 1 in Courtault et al. (2006) implies $1/\xi(x_H) = \theta\sum_{j=1}^J \epsilon^j f(j;x_H) > 1/\xi(x_F) = \theta\sum_{j=1}^J \epsilon^j f(j;x_F)$, or equivalently $\xi(x_F) > \xi(x_H)$. $\square$

Nonhomothetic CES case As in Proposition 1, we assume productivity A_n, population L_n, non-tariff trade barriers d_{ni}, and tariffs τ_{ni} are country (pair) specific, but not sector specific. We consider an uniform increase in Home's tariffs across all sectors, $d\tau_{HF}^j = d\tau_{HF} > 0$ for all j.

We derive the derivative of x_H given in (A1) with respect to τ_{HF}:

$$\begin{aligned} 0 = \sum_{j=1}^{J} \frac{d\omega_H^j}{d\tau_{HF}} &= (1-\sigma)\sum_{j=1}^{J} x_H^{\frac{\sigma-1}{\theta}} [u(x_H)]^{\epsilon^j(1-\sigma)} \left[\epsilon^j \xi(x_H) - \frac{1}{\theta}\right] \frac{d\ln x_H}{d\tau_{HF}} \\ &= (1-\sigma)\sum_{j=1}^{J} \omega_H^j \left[\epsilon^j \xi(x_H) - \frac{1}{\theta}\right] \frac{d\ln x_H}{d\tau_{HF}}. \end{aligned}$$

Since $d\ln x_H/d\tau_{HF} \neq 0$ in general, the equation above implies $\sum_j^J \omega_H^j \epsilon^j \xi(x_H) = 1/\theta$. Substituting this back into $d\omega_H^j/d\tau_{HF}$ yields

$$\begin{aligned} \frac{d\omega_H^j}{d\tau_{HF}} &= (1-\sigma)\omega_H^j \left[\epsilon^j \xi(x_H) - \frac{1}{\theta}\right] \frac{d\ln x_H}{d\tau_{HF}} \\ &= (1-\sigma)\omega_H^j \left[\epsilon^j \xi(x_H) - \sum_{h=1}^{J} \omega_H^h \epsilon^h \xi(x_H)\right] \frac{d\ln x_H}{d\tau_{HF}}, \\ \Leftrightarrow \frac{d\ln \omega_H^j}{d\tau_{HF}} &= (1-\sigma)\left(\epsilon^j - \bar{\epsilon}_H\right) \frac{d\ln u(x_H)}{d\tau_{HF}}, \end{aligned}$$

where $\bar{\epsilon}_H \equiv \sum_h^J \omega_H^h \epsilon^h$. The equation in the last line was studied in Section 2.2. in the text. An equivalent condition of, for example, $\epsilon^j - \bar{\epsilon}_H > 0$ is $\epsilon^j \xi(x_H) - 1/\theta > 0$.

Suppose that τ_{HF} is in $[0, \tau_{HF}^*)$ so that Home is in the increasing part of the tariff real-income schedule: $d\ln x_H/d\tau_{HF} > 0$. Given the ordering of $\{\epsilon^j\}_j$, for the above equation to hold, we must have (i)$\epsilon^1\xi(x_H) - 1/\theta < 0$; (ii)$\epsilon^J\xi(x_H) - 1/\theta > 0$; and (iii)there exists a cutoff sector j_H such that $\epsilon^{j_H}\xi(x_H) - 1/\theta \le 0$ and

$\epsilon^{j_H+1}\xi(x_H) - 1/\theta \geq 0$ hold where the exact equality, if any, only holds in either $\epsilon^{j_H}\xi(x_H) - 1/\theta = 0$ or $\epsilon^{j_H+1}\xi(x_H) - 1/\theta = 0$. The index of the cutoff sector, j_H, depends on x_H and thus on τ_{HF}. These results imply

$$\frac{d\ln\omega_H^j}{d\tau_{HF}} \begin{cases} < 0 & \text{for } j \in \{1, \ldots, j_H\} \\ > 0 & \text{for } j \in \{j_H + 1, \ldots, J\} \end{cases},$$

except for the rare cases in which the exact equality holds, $\epsilon^{j_H}\xi(x_H) - 1/\theta = 0$ or $\epsilon^{j_H+1}\xi(x_H) - 1/\theta = 0$.

For the sake of completeness, suppose that τ_{HF} is in (τ_{HF}^*, ∞) and thus $d\ln x_H/d\tau_{HF} < 0$ holds. We have

$$\frac{d\ln\omega_H^j}{d\tau_{HF}} \begin{cases} > 0 & \text{for } j \in \{1, \ldots, j_H\} \\ < 0 & \text{for } j \in \{j_H + 1, \ldots, J\} \end{cases},$$

except for the rare cases in which the exact equality holds, $\epsilon^{j_H}\xi(x_H) - 1/\theta = 0$ or $\epsilon^{j_H+1}\xi(x_H) - 1/\theta = 0$.

Analogously, we can derive the tariff effect on the sectoral expenditure share in the tariff-imposed Foreign. Considering $d\ln x_F/d\tau_{HF} < 0$ for any $\tau \in [0, \infty)$, we can conclude

$$\frac{d\ln\omega_F^j}{d\tau_{HF}} = \left[\epsilon^j\xi(x_F) - \frac{1}{\theta}\right]\frac{d\ln x_F}{d\tau_{HF}} \begin{cases} > 0 & \text{for } j \in \{1, \ldots, j_F\} \\ < 0 & \text{for } j \in \{j_F + 1, \ldots, J\} \end{cases},$$

where j_F is the index of the cut-off sector and satisfies $\epsilon^{j_F}\xi(x_F) - 1/\theta < 0$ (or equivalently, $\epsilon^{j_F} - \bar{\epsilon}_F < 0$) and $\epsilon^{j_F+1}\xi(x_F) - 1/\theta > 0$ (or equivalently, $\epsilon^{j_F+1} - \bar{\epsilon}_F > 0$) except when either of the two conditions holds with equality. $\square$

Using Lemma 2, we can also see how the sectoral expenditure share evolves as tariff rises. In the low income-elastic sectors with $\epsilon^j\xi(x_H) - 1/\theta < 0$ for any $\tau_{HF} \in (0, \infty)$, an increase in τ_{HF} first reduces and then raises ω_H^j. In the high income-elastic sectors with $\epsilon^j\xi(x_H) - 1/\theta > 0$ for any $\tau_{HF} \in (0, \infty)$, the tariff increase first raises and then reduces ω_H^j. In the middle income-elastic sectors, we see $\epsilon^j\xi(x_H) - 1/\theta \geq 0$ for $\tau_{HF} \in (0, \tau_{HF}^c]$ and $\epsilon^j\xi(x_H) - 1/\theta < 0$ for $\tau_{HF} \in (\tau_{HF}^c, \infty)$, and the tariff increase from a sufficiently low level raises ω_H^j but the tariff increase from a sufficiently high level reduces ω_H^j.

Homothetic CES case We allow for sector-specific tariff changes, while maintaining sectoral symmetry in all the other parameters and shutting down nonhomotheticity, $\epsilon^j = 1$ for all j. We here consider Home's unilateral uniform tariff increase in some sectors $j \in \mathcal{J}$ with $\mathcal{J}$ being the set of sectors that increase tariffs, $d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}$, and $\mathcal{J}^c$ being the complement set, $d\tau_{HF}^j = d\tau_{HF} = 0$ for $j \in \mathcal{J}^c$.

Since the relative wage is determined by the trade balance condition, the change in the (relative) wage in

Home is derived by differentiating the change in the trade balance condition:

$$\sum_{j=1}^{J}\frac{1}{J}\left(d\ln\pi_{FH}^{j}+d\ln\omega_{F}^{j}+\frac{d\mu_F}{1+\mu_F}\right)=\sum_{j=1}^{J}\frac{1}{J}\left(d\ln\pi_{HF}^{j}+d\ln\omega_{H}^{j}+\frac{d\mu_H}{1+\mu_H}+d\ln w-\frac{d\tau_{HF}^{j}}{1+\tau_{HF}}\right),$$

where

$$\begin{aligned}
&d\ln b_{HF}^{j}=d\ln d_{HF}\left(1+\tau_{HF}^{j}\right)=\frac{d\tau_{HF}^{j}}{1+\tau_{HF}}=\frac{d\tau_{HF}}{1+\tau_{HF}}>0, && j\in\mathcal{J}\\
&d\ln b_{HF}^{h}=\frac{d\tau_{HF}^{h}}{1+\tau_{HF}}=0, && h\in\mathcal{J}^c\\
&d\ln b_{FH}^{j}=\frac{d\tau_{FH}^{j}}{1+\tau_{FH}}=0, && \forall j\\
&d\ln P_{F}^{j}=\pi_{FH}d\ln w,\qquad \pi_{FH}=\left(\frac{wb_{FH}/A_H}{P_F}\right)^{-\theta}=\frac{(A/b_{FH})^{\theta}}{w^{\theta}+(A/b_{FH})^{\theta}}=1-\pi_{FF}, && \forall j\\
&d\ln P_{H}^{j}=\pi_{HF}d\ln b_{HF}^{j}+\pi_{HH}d\ln w,\qquad \pi_{HF}=\left(\frac{b_{HF}/A_F}{P_H}\right)^{-\theta}=\frac{(w/b_{HF})^{\theta}}{(w/b_{HF})^{\theta}+A^{\theta}}=1-\pi_{HH}, && \forall j\\
&d\ln\pi_{HF}^{j}=-\theta\left(d\ln b_{HF}^{j}-d\ln P_{H}^{j}\right)=-\theta\pi_{HH}\left(d\ln b_{HF}^{j}-d\ln w\right), && \forall j\\
&d\ln\pi_{FH}^{j}=-\theta\left(d\ln w-d\ln P_{F}^{j}\right)=-\theta\pi_{FF}d\ln w, && \forall j\\
&d\ln\omega_{n}^{j}=(1-\sigma)\left(d\ln P_{n}^{j}-\sum_{h=1}^{J}\omega_{n}^{h}d\ln P_{n}^{h}\right),\qquad \omega_{n}^{j}=\frac{(P_{n}^{j})^{1-\sigma}}{\sum_{h=1}^{J}(P_{n}^{h})^{1-\sigma}}=\frac{1}{J}, && \forall(n,j)\\
&d\mu_F=\sum_{j=1}^{J}d\mu_{F}^{j}=\sum_{j=1}^{J}\pi_{FH}\omega_{F}^{j}d\tau_{FH}^{j}=0,\\
&d\mu_H=\begin{cases}\sum_{j}^{J}d\mu_{H}^{j}=\sum_{j}^{J}\pi_{HF}\omega_{F}^{j}d\tau_{HF}^{j}=\sum_{j}^{J}\pi_{HF}J^{-1}d\tau_{HF}^{j} & \text{if } \tau_{HF}=0\\ \frac{\mu_H(1+\tau_{HF})}{1+\tau_{HF}\pi_{HH}}\sum_{j}^{J}\omega_{H}^{j}d\ln\mu_{H}^{j}=\frac{\tau_{HF}\pi_{HF}(1+\tau_{HF})}{J(1+\tau_{FH}\pi_{HF})^{2}}\sum_{j}^{J}\left(\frac{d\ln\tau_{HF}^{j}}{1+\tau_{HF}}+d\ln\pi_{HF}^{j}+d\ln\omega_{H}^{j}\right) & \text{if } \tau_{HF}>0\end{cases},
\end{aligned}$$

noting $w\equiv w_H/w_F=w_H$; $A\equiv A_H/A_F$; and $P_n^j=P_n^h$ for $j\neq h$ because of no sectoral asymmetry in parameters. We solve the trade balance condition for $d\ln w$ and substitute this back into $d\ln\omega_n^j$ to obtain

$$\begin{aligned}
&\frac{d\ln\omega_{H}^{j}}{d\tau_{HF}}=\frac{(J-|\mathcal{J}|)(1-\sigma)}{J(1+\tau_{HF})\left[(b_{HF}A/w)^{\theta}+1\right]}>0, && j\in\mathcal{J}\\
&\frac{d\ln\omega_{H}^{j}}{d\tau_{HF}}=-\frac{|\mathcal{J}|(1-\sigma)}{J(1+\tau_{HF})\left[(b_{HF}A/w)^{\theta}+1\right]}<0, && j\in\mathcal{J}^c\\
&\frac{d\ln\omega_{H}^{j}}{d\tau_{HF}}=0. && \forall j
\end{aligned}$$

Due to the relative price effect, Home shifts their expenditure to the sectors with increasing tariff. Foreign does not change their expenditure pattern simply because changes in relative wage due to tariff affect sectoral price indices in Foreign proportionally and thus the relative price effect does not manifest there. □

C Proof of Proposition 3

We assume here that at the initial situation before tariff changes, the initial tariffs are zero, $\tau_{HF}^j = \tau_{FH}^j = 0$ for all j, and the sectors are symmetric (except for $\{\epsilon^j\}_j^J$ in the case of nonhomothetic CES) in all aspects such as productivity $A_n^j = A_n$ and non-tariff trade barriers $d_{ni}^j = d_{ni}$. The value-added share of sector j in country n is given by

$$\begin{aligned} va_n^j &\equiv \frac{VA_n^j}{\sum_{h=1}^J VA_n^h} = \frac{w_n L_n^j}{\sum_{h=1}^J w_n L_n^h} \\ &= \frac{P_n^j C_n^j}{w_n L_n} + \frac{NX_n^j}{w_n L_n} - \frac{\widetilde{T}_n}{w_n L_n} = \frac{P_n^j C_n^j}{E_n}\frac{E_n}{w_n L_n} + \frac{NX_n^j}{w_n L_n} - \frac{\widetilde{T}_n}{w_n L_n} \\ &= \omega_n^j (1+\mu_n) + \frac{NX_n^j}{w_n L_n} - \frac{\widetilde{T}_n}{w_n L_n}. \end{aligned}$$

As in the text, its marginal change is given by

$$d\ln va_n^j = \underbrace{\frac{P_n^j C_n^j}{w_n L_n^j}\left(d\ln \omega_n^j + \frac{d\mu_n}{1+\mu_n}\right)}_{\text{(a) Expenditure adjusted by tariff revenue}} + \underbrace{\frac{NX_n^j}{w_n L_n^j} d\ln\left(\frac{NX_n^j}{w_n L_n}\right)}_{\text{(b) Net exports}} \underbrace{- \frac{1}{va_n^j} d\left(\frac{\widetilde{T}_n^j}{w_n L_n}\right)}_{\text{(c) Tariff revenue}}, \tag{C1}$$

noting that we write $d\mu_H$ and $d[\widetilde{T}_n^j/(w_n L_n)]$ in terms of changes in level since $\mu_n \equiv \widetilde{T}_n/(w_n L_n)$ and $\widetilde{T}_n^j$ are zero at the initial situation. We can tell from Propositions 1 and 2 how $d\ln\omega_n^j$ and $d\mu_n$ adjust after tariffs change.

In the case of Home, the change in net exports, term (b) in (C1), is further decomposed as

$$\begin{aligned} \frac{NX_H^j}{w_H L_H^j} d\ln\left(\frac{NX_H^j}{w_H L_H}\right) &= \frac{EX_H^j}{w_H L_H^j} d\ln\left(\frac{EX_H^j}{w_H L_H}\right) - \frac{IM_H^j}{w_H L_H^j} d\ln\left(\frac{IM_H^j}{w_H L_H}\right) \\ &= \frac{1}{va_H^j}\frac{EX_H^j}{w_H L_H} d\ln\left(\frac{EX_H^j}{w_H L_H}\right) - \frac{1}{va_H^j}\frac{IM_H^j}{w_H L_H} d\ln\left(\frac{IM_H^j}{w_H L_H}\right) \\ &= \frac{1}{va_H^j}\left[\frac{\pi_{FH}^j \omega_F^j}{wL}\left(d\ln\pi_{FH}^j + d\ln\omega_F^j - d\ln w\right) - \pi_{HF}^j\omega_H^j\left(d\mu_H + d\ln\pi_{HF}^j + d\ln\omega_H^j - d\tau_{HF}^j\right)\right], \end{aligned}$$

noting $w \equiv w_H/w_F$; $L \equiv L_H/L_F$; and $\tau_{HF}^j = \tau_{FH}^j = 0$ (thus $\mu_H = \mu_F = 0$). An analogous expression holds for Foreign. Changes in tariffs by Home affect their net exports to Foreign in three channels. First, tariffs directly make Foreign's composite good more expensive, and hence reduce Home's imports and raise their net exports, which is captured by the very last term in the equation above, $d\tau_{HF}^j$. Second, as is clear from $d\ln\omega_n^j$ and $d\mu_H^j$, tariffs affect the demand for sector j composite good in both countries by changing their sectoral expenditure shares and Home's tariff revenue. Finally, tariffs affect the trade shares, $d\ln\pi_{ni}^j$, by changing the relative cost of production, i.e., the comparative advantage of the two countries.

Similarly, the change in tariff revenue, term (c) in (C1), is rewritten as

$$-\frac{1}{va_H^j}d\left(\frac{\widetilde{T}_H^j}{w_H L_H}\right) = -\frac{1}{va_H^j}d\left(\frac{\tau_{HF}^j IM_H^j}{w_H L_H}\right) = -\frac{1}{va_H^j}\pi_{HF}^j\omega_H^j d\tau_{HF}^j.$$

Given $d\tau_{HF}^j \geq 0$, this is always non-positive.

Nonhomothetic CES case In addition to the symmetry in sectors except for $\{\epsilon^j\}_j^J$, we also assume symmetric countries, $A_H = A_F$, $L_H = L_F$, and $d_{HF} = d_{FH} = d$. We here consider the effect of tariff applied by Home to 1 uniform across sectors, $d\tau_{HF}^j = d\tau_{HF} > 0$ for all j.

The tariff effects on (a)expenditure, (b)net exports, and (c)tariff revenue are

$$\begin{aligned}
&\frac{P_H^j C_H^j}{w_H L_H^j}\left(d\ln\omega_H^j + \frac{d\mu_H}{1+\mu_H}\right) = \pi_{HF}d\tau_{HF} + d\ln\omega_H^j \begin{cases} \gtreqless 0 & \text{if } j \in \{1,\ldots,j_*\} \\ > 0 & \text{if } j \in \{j_*+1,\ldots,J\} \end{cases}, \\
&\frac{NX_H^j}{w_H L_H^j}d\ln\left(\frac{NX_H^j}{w_H L_H}\right) = \pi_{HF}\left(d\ln\omega_F^j - d\ln\omega_H^j\right)\begin{cases} > 0 & \text{if } j \in \{1,\ldots,j_*\} \\ < 0 & \text{if } j \in \{j_*+1,\ldots,J\} \end{cases}, \\
&-\frac{1}{va_H^j}d\left(\frac{\widetilde{T}_H^j}{w_H L_H}\right) = -\pi_{HF}d\tau_{HF} < 0, \qquad\qquad \forall j
\end{aligned}$$

where the symmetry of countries and sectors implies $w_H = w_F$, $x_H = x_F$, $E_H = E_F$, $\pi_{HF}^j = \pi_{HF} = \pi_{FH}^j = \pi_{FH}^j = 1/(1+b^\theta)$ for all j, and $\omega_H^j = \omega_F^j$ for all j. Coupled these with Proposition 2, we see that $d\ln\omega_H^j < 0$ for $j \in \{1,\ldots,j_*\}$ and $d\ln\omega_H^j > 0$ for $j \in \{j_*+1,\ldots,J\}$, while $d\ln\omega_F^j > 0$ for $j \in \{1,\ldots,j_*\}$ and $d\ln\omega_F^j < 0$ for $j \in \{j_*+1,\ldots,J\}$, where $j_* = j_F = j_H$ is the cut-off sector common between the two countries such that $\epsilon^{j_*}\xi(x_n) - 1/\theta < 0$ (or equivalently, $\epsilon^{j_*} - \bar{\epsilon}_n < 0$) and $\epsilon^{j_*+1}\xi(x_n) - 1/\theta > 0$ (or $\epsilon^{j_*+1} - \bar{\epsilon}_n > 0$) hold. In general, the effects on expenditure and net exports go in the opposite way. Home's sectoral expenditure share directly contributes the sector's value-added share, but raises Home's imports and thus reduces their net exports.

Combining the three effects, we have

$$d\ln va_H^j = \pi_{HF}d\ln\omega_F^j + \pi_{HH}d\ln\omega_H^j = \frac{b^\theta - 1}{1+b^\theta}\left[\epsilon^j\xi(x_H) - \frac{1}{\theta}\right]\frac{d\ln x_H}{d\tau_{HF}}\begin{cases} < 0 & \text{if } j \in \{1,\ldots,j_*\} \\ > 0 & \text{if } j \in \{j_*+1,\ldots,J\} \end{cases},$$

where $b_{HF} = b_{FH} = b = d > 1$, $b^\theta > 1$, and $d\ln x_H/d\tau_{HF} = -d\ln x_F/d\tau_{HF} > 0$. The signs are the same as those of $d\ln\omega_H^j$, meaning that changes in the sectoral value-added share in a country are largely shaped by those in the domestic sectoral expenditure share.

Analogously, the tariff effects in Foreign are

$$\frac{P_F^j C_F^j}{w_F L_F^j} d\ln\omega_F^j = d\ln\omega_F^j \begin{cases} >0 & \text{if } j\in\{1,\ldots,j_*\} \\ <0 & \text{if } j\in\{j_*+1,\ldots,J\} \end{cases},$$

$$\frac{NX_F^j}{w_F L_F^j} d\ln\left(\frac{NX_F^j}{w_F L_F}\right) = \pi_{FH}\left(d\ln\omega_H^j - d\ln\omega_F^j\right) \begin{cases} <0 & \text{if } j\in\{1,\ldots,j_*\} \\ >0 & \text{if } j\in\{j_*+1,\ldots,J\} \end{cases},$$

$$-\frac{1}{va_F^j} d\left(\frac{\widetilde{T}_F^j}{w_F L_F}\right) = 0, \qquad\qquad j\in\{1,\ldots,J\}$$

$$d\ln va_F^j = \pi_{FF} d\ln\omega_F^j + \pi_{FH} d\ln\omega_H^j = \frac{1-b^\theta}{1+b^\theta}\left[\epsilon^j\xi(x_F) - \frac{1}{\theta}\right]\frac{d\ln x_F}{d\tau_{HF}} \begin{cases} >0 & \text{if } j\in\{1,\ldots,j_*\} \\ <0 & \text{if } j\in\{j_*+1,\ldots,J\} \end{cases},$$

where $d\mu_F = 0$ and $d[\widetilde{T}_F^j/(w_F L_F)] = 0$ since Foreign does not change tariffs from zero, $d\tau_{FH} = 0$. The results are a mirror image of those in Home. Tariffs by Home change Foreign's domestic sectoral expenditure and net exports in reverse. The tariff effect on sectoral value-added share is largely governed by that of the sectoral domestic expenditure share. The results are summarized in A1. $\square$

Table A1: The effect of unilateral tariff increase under the nonhomothetic CES preferences

Country n	Sector j	$d\tau_{ni}$	$d\ln\omega_n^j$	(a)Exp$_n^j$	(b)NX$_n^j$	(c)Tariff rev$_n^j$	$d\ln va_n^j$: (a) + (b) + (c)
H	$\{1,\ldots,j_*\}$	+	−	+/−	+	−	−
H	$\{j_*+1,\ldots,J\}$	+	+	+	−	−	+
F	$\{1,\ldots,j_*\}$	0	+	+	+	−	+
F	$\{j_*+1,\ldots,J\}$	0	−	+/−	−	−	−

Notes: This table shows the effects of a unilateral increase in uniform tariff across sectors by Home ($d\tau_{HF}^j = d\tau_{HF} > 0$ for all j). Except for the degree of nonhomotheticity $\{\epsilon^j\}_j^J$, the two countries and the J sectors are symmetric in all respects at the initial situation: technology, population, non-tariff trade barriers, and (zero) tariffs. The cut-off sector is denoted by j_*, and $\epsilon^{j_*}\xi(x) - 1/\theta < 0$ and $\epsilon^{j_*+1}\xi(x) - 1/\theta > 0$ hold. Each of the three effects, (a)expenditure adjusted by tariff revenue, (b)net exports, and (c)tariff revenue, corresponds to a distinct term in (C1).

Homothetic CES case Unlike the case of nonhomothetic CES, we allow for country asymmetry, but keep sector symmetry and shut down nonhomotheticity by setting $\epsilon^j = 1$ for all j. We here consider the effect of Home's unilateral uniform tariff increase in some sectors $j \in \mathcal{J}$ with $\mathcal{J}$ being the set of sectors that increase tariffs and $\mathcal{J}^c$ being its complement set, $d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}$, and $d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}^c$.

The tariff effects in Home are

$$\frac{P_H^j C_H^j}{w_H L_H^j}\left(d\ln\omega_H^j + \frac{d\mu_H}{1+\mu_H}\right) = \begin{cases} \left[1-\sigma\left(1-\frac{|\mathcal{J}|}{J}\right)\right]\pi_{HF}d\tau_{HF}^j > 0 & \text{if } j\in\mathcal{J} \\ \frac{|\mathcal{J}|}{J}\sigma\pi_{HF}d\tau_{HF}^j > 0 & \text{if } j\in\mathcal{J}^c \end{cases},$$

$$-\frac{1}{va_H^j}d\left(\frac{\widetilde{T}_H^j}{w_H L_H}\right) = \begin{cases} -\pi_{HF}d\tau_{HF}^j < 0 & \text{if } j\in\mathcal{J} \\ 0 & \text{if } j\in\mathcal{J}^c \end{cases},$$

$$\frac{NX_H^j}{w_H L_H^j}d\ln\left(\frac{NX_H^j}{w_H L_H}\right) = \begin{cases} \frac{\pi_{HF}(J-|\mathcal{J}|)[\sigma(w/b_{HF})^\theta + (1+\theta)A^\theta]}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j > 0 & \text{if } j\in\mathcal{J} \\ -\frac{\pi_{HF}|\mathcal{J}|[\sigma(w/b_{HF})^\theta + (1+\theta)A^\theta]}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j < 0 & \text{if } j\in\mathcal{J}^c \end{cases},$$

$$d\ln va_H^j = \begin{cases} \frac{\pi_{HF}(J-|\mathcal{J}|)A^\theta(\theta+1-\sigma)}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j > 0 & \text{if } j\in\mathcal{J} \\ -\frac{\pi_{HF}|\mathcal{J}|A^\theta(\theta+1-\sigma)}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j < 0 & \text{if } j\in\mathcal{J}^c \end{cases}.$$

Although the expenditure shares in the sectors that do not change their tariffs decrease, $d\ln\omega_H^j < 0$ for $j\in\mathcal{J}^c$, the overall tariff effect on expenditures in those sectors is positive due to an increase in tariff revenues, $d\ln\omega_H^j + d\mu_H/(1+\mu_H) > 0$ for $j\in\mathcal{J}^c$.

Similarly, the tariff effects in Foreign are

$$\frac{P_F^j C_F^j}{w_F L_F^j}d\ln\omega_F^j = 0, \qquad -\frac{1}{va_F^j}d\left(\frac{\widetilde{T}_F^j}{w_F L_F}\right) = 0, \qquad \forall j$$

$$d\ln va_F^j = \frac{NX_F^j}{w_F L_F^j}d\ln\left(\frac{NX_F^j}{w_F L_F}\right) = \begin{cases} -\frac{\pi_{FH}(J-|\mathcal{J}|)[\sigma(w/b_{HF})^\theta + (1+\theta)A^\theta]}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j < 0 & \text{if } j\in\mathcal{J} \\ \frac{\pi_{FH}|\mathcal{J}|[\sigma(w/b_{HF})^\theta + (1+\theta)A^\theta]}{J[(w/b_{HF})^\theta + A^\theta]}d\tau_{HF}^j > 0 & \text{if } j\in\mathcal{J}^c \end{cases},$$

where $d\mu_F = 0$ and $d\widetilde{T}_F^j = 0$ since Foreign does not change tariffs from zero, $d\tau_{FH} = 0$. The results are summarized in A2.

Table A2: The effect of unilateral tariff increase under the homothetic CES preferences

Country n	Sector j	$d\tau_{ni}^j$	$d\ln\omega_n^j$	(a)Exp$_n^j$	(b)NX$_n^j$	(c)Tariff rev$_n^j$	$d\ln va_n^j$: (a) + (b) + (c)
H	$j \in \mathcal{J}$	+	+	+	+	−	+
H	$j \in \mathcal{J}^c$	0	−	+	−	0	−
F	$j \in \mathcal{J}$	0	0	0	−	0	−
F	$j \in \mathcal{J}^c$	0	0	0	+	0	+

Notes: This table shows the effects of Home's unilateral uniform tariff increase in some sectors $j \in \mathcal{J}$ with $\mathcal{J}$ being the set of sectors that increase tariffs and $\mathcal{J}^c$ being the complement set ($d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}$ and $d\tau_{HF}^j = d\tau_{HF} = 0$ for $j \in \mathcal{J}^c$). Sectors are symmetric in all respects at the initial situation including the degree of nonhomotheticity, productivity, non-tariff trade barriers, and zero tariffs, while countries are asymmetric in terms of productivity, population, and non-tariff trade barriers. Each of the three, (a)expenditure adjusted by tariff revenue, (b)net exports, and (c)tariff revenue, corresponds to a distinct term in (C1).

Cobb-Douglas case For the sake of illustration, we provide the results under the Cobb-Douglas preferences. The non/homothetic CES preferences are reduced to the Cobb-Douglas ones if σ is set to one. In this case, neither the income effect nor the relative price effect work, meaning that the sectoral expenditure share does not respond to tariff changes at all, $d\ln\omega_n^j = 0$. Except for this, the tariff effects on the other variables are the same as those in the homothetic CES case. The results are summarized in A3.

Table A3: The effect of unilateral tariff increase under the Cobb-Douglas preferences

Country n	Sector j	$d\tau_{ni}^j$	$d\ln\omega_n^j$	(a)Exp$_n^j$	(b)NX$_n^j$	(c)Tariff rev$_n^j$	$d\ln va_n^j$: (a) + (b) + (c)
H	$j \in \mathcal{J}$	+	0	+	+	+	+
H	$j \in \mathcal{J}^c$	0	0	+	−	0	−
F	$j \in \mathcal{J}$	0	0	0	−	0	−
F	$j \in \mathcal{J}^c$	0	0	0	+	0	+

Notes: This table shows the effects of Home's unilateral uniform tariff increase in some sectors $j \in \mathcal{J}$ with $\mathcal{J}$ being the set of sectors that increase tariffs and $\mathcal{J}^c$ being the complement set ($d\tau_{HF}^j = d\tau_{HF} > 0$ for $j \in \mathcal{J}$ and $d\tau_{HF}^j = d\tau_{HF} = 0$ for $j \in \mathcal{J}^c$). Preferences are Cobb-Douglas, $\sigma = 1$. Sectors are symmetric in all respects at the initial situation including the degree of nonhomotheticity, productivity, non-tariff trade barriers, and zero tariffs, while countries are asymmetric in terms of productivity, population, and non-tariff trade barriers. Each of the three, (a)expenditure adjusted by tariff revenue, (b)net exports, and (c)tariff revenue, corresponds to a distinct term in (C1).

D Welfare

To measure changes in welfare moving from the baseline to a counterfactual situation, we calculate a constant fraction λ_n of per-capita consumption that would be paid to the country n's representative consumer in in each year in the baseline to achieve the same utility in the counterfactual. Letting $\{C_{n,t}\}_t$ and $\{C^*_{n,t}\}_t$ be the consumption streams in country n in the baseline and in the counterfactual respectively, this fraction λ_n is given by

$$\sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_{n,t} \frac{(C^*_{n,t}/L_{n,t})^{1-\psi}}{1-\psi} = \sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_{n,t} \frac{\left(\left(1+\frac{\lambda_n}{100}\right) C_{n,t}/L_{n,t}\right)^{1-\psi}}{1-\psi},$$

$$\Leftrightarrow \lambda_n = 100 \times \left[\left\{\frac{\sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_t (C^*_{n,t}/L_{n,t})^{1-\psi}}{\sum_{t=0}^{\infty} \beta^t \zeta_{n,t} L_t (C_{n,t}/L_{n,t})^{1-\psi}}\right\}^{\frac{1}{1-\psi}} - 1\right].$$

In addition, our economy reaches the steady state at $t = T$. Letting the variables without the time subscript represent the steady state values, the formula can be rewritten as

$$\lambda_n = 100 \times \left[\left\{\frac{\sum_{t=0}^{T} \beta^t \zeta_{n,t} L_{n,t} \left(\frac{C^*_{n,t}}{L_{n,t}}\right)^{1-\psi} + \frac{\beta^{T+1}}{1-\beta} \zeta_n L_n \left(\frac{C^*_n}{L_n}\right)^{1-\psi}}{\sum_{t=0}^{T} \beta^t \zeta_{n,t} L_{n,t} \left(\frac{C_{n,t}}{L_{n,t}}\right)^{1-\psi} + \frac{\beta^{T+1}}{1-\beta} \zeta_n L_n \left(\frac{C_n}{L_n}\right)^{1-\psi}}\right\}^{\frac{1}{1-\psi}} - 1\right],$$

where $L_{n,t} = L_n$ and $\xi_{n,t} = \xi_n$ are time invariant after T and are common in both the baseline and the counterfactual scenarios. We also note

$$\sum_{t=T+1}^{\infty} \beta^t \zeta_n L_n \left(\frac{C^*_n}{L_n}\right)^{1-\psi} = \beta^{T+1} \zeta_n L_n \left(\frac{C^*_n}{L_n}\right)^{1-\psi} \sum_{t=0}^{\infty} \beta^t = \beta^{T+1} \zeta_n L_n \left(\frac{C^*_n}{L_n}\right)^{1-\psi} \frac{1}{1-\beta}.$$

E Calibration of Fundamentals

We calibrate the iceberg trade costs (including tariffs and non-tariff barriers), b^j_{nt}, and average productivity, $A^j_{n,t}$, 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 (25), the total trade costs $b^j_{ni,t}$ can be decomposed into tariffs and non-tariff barriers,

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

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

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

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[22], $\text{CB}^j_{ni,t}$ 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. Exporter fixed effects are included to allow asymmetry in trade costs in the spirit of Waugh (2010). We plug this into the trade share equation (27) and estimate the following using the Pseudo Poisson Maximum Likelihood (PPML) for each sector j while pooling all sampled countries and years:

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

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 (U.S. in 1965), which we denote by $S^j_{nt} = \left(\tilde{c}^j_{n,t}/A^j_{n,t}\right)^{\theta^j} / \left(\tilde{c}^j_{U.S.,1965}/A^j_{U.S.,1965}\right)^{\theta^j}$. 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

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

the sectoral price indices as follows. We define the own trade share relative to that of the reference country and year:

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

Hence, for given trade elasticity θ^j, we have,[23]

$$\frac{P^j_{n,t}}{P^j_{U.S.,1965}} = \left(\frac{\pi^j_{nn,t}}{\pi^j_{U.S.,U.S.,1965}} S^j_{nt}\right)^{1/\theta^j}. \tag{E1}$$

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 (E1) 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, we need to rescaling the sequence of S^j_{nt} by identifying $\{a^j_t\}$ to measure the productivity growth over time.

To identify the shifters $\{a^j_t\}$, we take advantage of the gross output price index provided by the WIOD Socio Economic Accounts. Let $\{P^j_{U.S.,t,Data}\}$ be the gross output price index of sector j in the United States and year t. Note that $\{P^j_{U.S.,t,Data}\}_t$ 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 U.S. and back out $\{a^j_t\}$ according to:

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

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.

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

After obtaining $\kappa^{j,h}_{n,t}$, we can recover the CES price index for the composite intermediate good $\xi^j_{n,t}$ according to (23).

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 (26).

In order to obtain the factor prices, we 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 (18) to construct the nationwide capital stock. Since capital stock is measured as the real variable in the model, we need to obtain the initial period capital stock in the current U.S. Dollars[24] and then divide the nominal value by the price index of the investment good obtained in the previous step.[25] We then compute the real investment in each year by dividing the gross fixed capital formation (in current U.S. Dollars) by the investment good price index 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 (22). Finally, we can recover the productivity $A^j_{n,t}$ by:[26]

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

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 (14). 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 (16). 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 (19). Using the consumption index $C_{n,t}$ obtained above, we can construct the series of $\zeta_{n,t}$ for each country by normalizing the one in the last sample year $\zeta_{n,2014}$ to be unity.

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

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

[26]By construction, sectoral productivity takes 1 for the U.S. in 1965 in all sectors.

We also calibrated the sectoral demand shifter $\Omega^j_{n,t}$ and the intertemporal demand shifter $\zeta_{n,t}$ under the homothetic CES preference (i.e., $\epsilon^j = 1$ for all j). See Appendix I for such calibrated productivity as well as average tariff rates.

F 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 $w_{U.S.} = 1$.
   (a) Compute r_n as follows.
      i. Guess rental rates across countries, $\{r_n\}_n \in \mathbb{R}^N$.
         A. Compute P^j_n as follows.
            - Guess sectoral price indices across countries, $\{P^j_n\}_{n,j} \in \mathbb{R}^{NJ}$.
               – Compute ξ^j_n using (F1).
               – Compute $\widetilde{c}^j_n$ using (F2).
               – Compute P^j_n using (F3).
            - Check if P^j_n obtained in the last step is close to P^j_n initially guessed. If it does, stop. Otherwise, update $\{P^j_n\}_{n,j}$ and return to the first step.
         B. Compute P^K_n 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 π^j_{ni} using (F6).
   (c) Compute K_n using (F7).
   (d) Compute $g^{j,j'}_n$ using (F8).
   (e) Compute $g^{K,j}_n$ using (F9).
   (f) Compute X^j_n as follows.
      - Guess sectoral spending across countries, $\{X^j_n\}_{n,j} \in \mathbb{R}^{NJ}$.
         – 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 ω^j_n 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 $w_{U.S.}$ to one. Otherwise, update $\{w_n\}_n$ and return to step 1.

Table A4: 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)	$P_n^j = \left[\sum_i^N \left(\dfrac{\widetilde{c}_i^j b_{n,i}^j}{A_i^j}\right)^{-\theta^j}\right]^{-\frac{1}{\theta^j}}$	$\forall(n,j)$
(F4)	$P_n^K = \dfrac{1}{\kappa_n^K} \left[\sum_j \kappa_n^{K,j} (P_n^j)^{1-\sigma^K}\right]^{\frac{1}{1-\sigma^K}}$	$\forall(n)$
(F5)	$r_n = \dfrac{1-\alpha_n(1-\lambda\delta_n)}{\alpha_n(1-\phi_n)\lambda} P_n^K$	$\forall(n)$
(F6)	$\pi_{ni}^j = \left(\dfrac{\widetilde{c}_i^j b_{ni}^j}{A_i^j P_n^j}\right)^{-\theta^j}$	$\forall(n,i,j)$
(F7)	$K_n = \dfrac{\alpha_n}{1-\alpha_n} \dfrac{w_n L_n}{r_n}$	$\forall(n)$
(F8)	$g_n^{j,j'} = \dfrac{\kappa_n^{j,j'} (P_n^{j'})^{1-\sigma^j}}{\sum_{j''} \kappa_n^{j,j''} (P_n^{j''})^{1-\sigma^j}}$	$\forall(n,j,j')$
(F9)	$g_n^{K,j} = \dfrac{\kappa_n^{K,j} (P_n^{K,j})^{1-\sigma^K}}{\sum_{j'} \kappa_n^{K,j'} (P_n^{K,j'})^{1-\sigma^K}}$	$\forall(n,j)$
(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)	$E_n = L_n \left[\sum_j \Omega_n^j \left\{\left(\dfrac{C_n}{L_n}\right)^{\epsilon^j} P_n^j\right\}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$	$\forall(n)$
(H4)	$\omega_n^j = \dfrac{\Omega_n^j \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^j} P_n^j\right\}^{1-\sigma}}{\sum_{j'} \Omega_n^{j'} \left\{\left(\frac{C_n}{L_n}\right)^{\epsilon^{j'}} P_n^{j'}\right\}^{1-\sigma}} \quad \left(= \dfrac{P_n^j C_n^j}{E_n}\right)$	$\forall(n,j)$
(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)	$\widetilde{T}_n = \sum_j \sum_i^N \tau_{ni}^j X_{n,t}^j \dfrac{\pi_{ni}^j}{\widetilde{\tau}_{ni}^j}$	$\forall(n)$
(M2)	$T^P = \sum_i^N \phi_i (w_i L_i + r_i K_i + \widetilde{T}_i) \big/ \sum_i^N L_i$	
(M3)	$Y_n^j = \sum_i^N X_i^j \dfrac{\pi_{in}^j}{\widetilde{\tau}_{in}^j}$	$\forall(n,j)$
(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.

G 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 $w_{U.S.,t} = 1$.
         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 $\tilde{c}^j_{n,t}$ 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 $w_{U.S.,t}$ 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. Update $\rho_{n,t}$ backward in time from period $t = T$ as $\rho_{n,t}(1 + \eta Z_{n,t})$ using (H6) "Euler equation residual"$Z_{n,t}$ with a dampening parameter η 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 A5: 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)	$\Phi_1(K_{n,t+2}, K_{n,t+1}) = \frac{\delta^{1-\frac{1}{\lambda}}_{n,t+1}}{\lambda} \left(\frac{K_{n,t+2}}{K_{n,t+1}} - (1-\delta_{n,t+1})\right)^{\frac{1-\lambda}{\lambda}}$	$\forall(n,t)$
(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: $b^j_{ni,t} \equiv d^j_{ni,t}\widetilde{\tau}^j_{ni,t}$ and $\widetilde{\tau}^j_{ni,t} \equiv 1 + \tau^j_{ni,t}$. Roughly, (F*) is a condition for firms/production; (H*) for household; (M*) for market clearing. An alternative expression of (H5) is
$X^j_{n,t} = \omega^j_{n,t} E_{n,t} + g^{K,j}_{n,t} P^K_{n,t} I_{n,t} + \sum_{j'} (1-\gamma^{j'}_{n,t}) g^{j',j}_{n,t} \sum_i^N \pi^j_{in,t} X^j_{i,t} / \widetilde{\tau}^j_{in,t}$.

H Applying the Newton Method

In the system of steady state and equilibrium conditions, most of economic variables are *explicitly* expressed. Therefore they are directly computable given parameters and other economic variables. Only one variable that is only *implicitly* expressed is aggregate consumption $C_{n,t}$ (in steady state, C_n). See equation (H3) in Table A5 (in steady state, Table A4. In the following, we describe the computational method for transition paths, but a similar argument applies for steady states). Given parameters σ, ϵ^j, $\Omega^j_{n,t}$, $L_{n,t}$, and economic variables $P^j_{n,t}$, we need to solve this equation for $C_{n,t}$. We apply the Newton–Raphson method to numerically solve this equation.

Observe that equation

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

is equivalent to (H3). Based on this equation, define real-valued function Δ by

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

$C_{n,t}$ is such that $\Delta(C_{n,t}) = 0$. The derivative of Δ is

$$\Delta'(x_{n,t}) = (1-\sigma) \sum_{j=a,m,s} \Omega^j_{n,t} (L_{n,t})^{-\epsilon^j(1-\sigma)} (P^j_n)^{1-\sigma} \epsilon^j x_n^{\epsilon^j(1-\sigma)-1}.$$

Using these expressions, we compute $C_{n,t}$ in the following iterative way.

Make an initial guess $x^0_{n,t} > 0$. The superscript of x keeps track of the number of updates in iteration. Then compute the updated value

$$x^1_{n,t} = x^0_{n,t} - \frac{\Delta(x^0_{n,t})}{\Delta'(x^0_{n,t})}.$$

If $x^1_{n,t}$ is close enough to $x^0_{n,t}$, we got the solution. Otherwise, use $x^1_{n,t}$ as a new guess, and compute $x^2_{n,t}$ and compare these two. Repeat this process until $x^k_{n,t}$ and $x^{k+1}_{n,t}$ for some k.

I Baseline Parameter Values

We summarize the baseline fundamentals we calibrated in Subsection E. Figure A1 shows the evolution of sectoral productivity in six countries, Canada, China, Germany, Japan, Mexico, and the U.S. 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 U.S., 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 A2 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 A3 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 U.S., the non-tariff barriers in the U.S. 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.

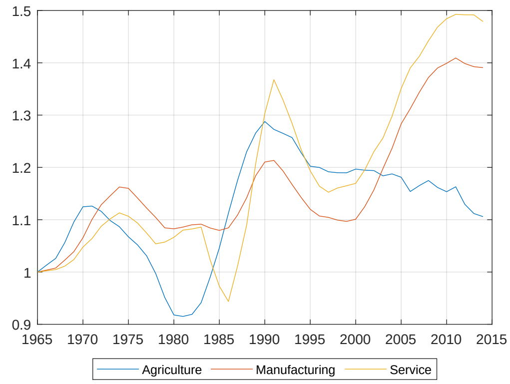
J Model Fit and Baseline Results

J.1 Saving Rates

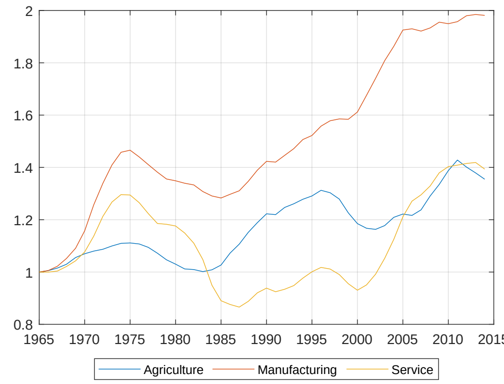
Figure A4 compares the saving rates in the baseline equilibrium to the data. In all six countries, the model predicts a higher saving rate than the data counterpart in earlier years. The model-implied saving rate gradually falls and converges to the levels close to the data.

Figure A1: Productivity Evolution (1965=1)

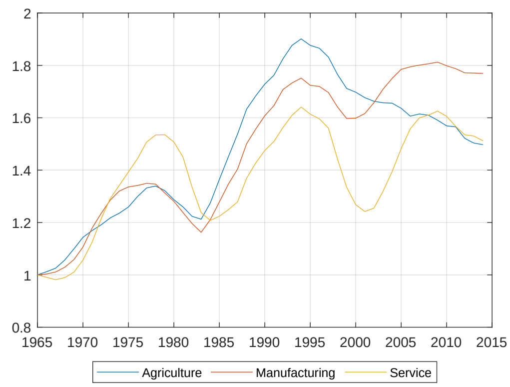
(a) Canada



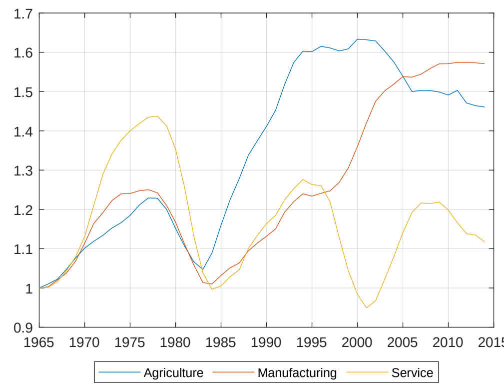
(b) China



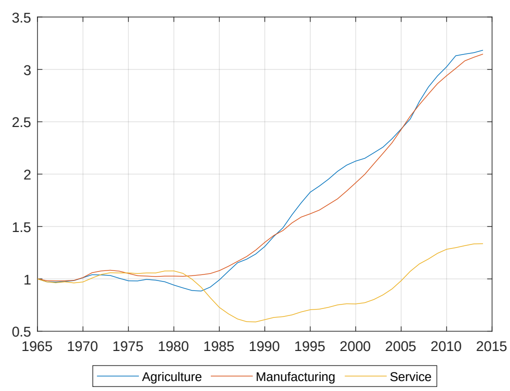
(c) Germany



(d) Japan



(e) Mexico



(f) United States

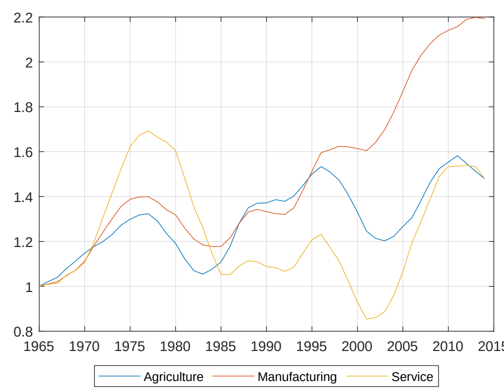


Figure A2: Evolution of Average Tariff

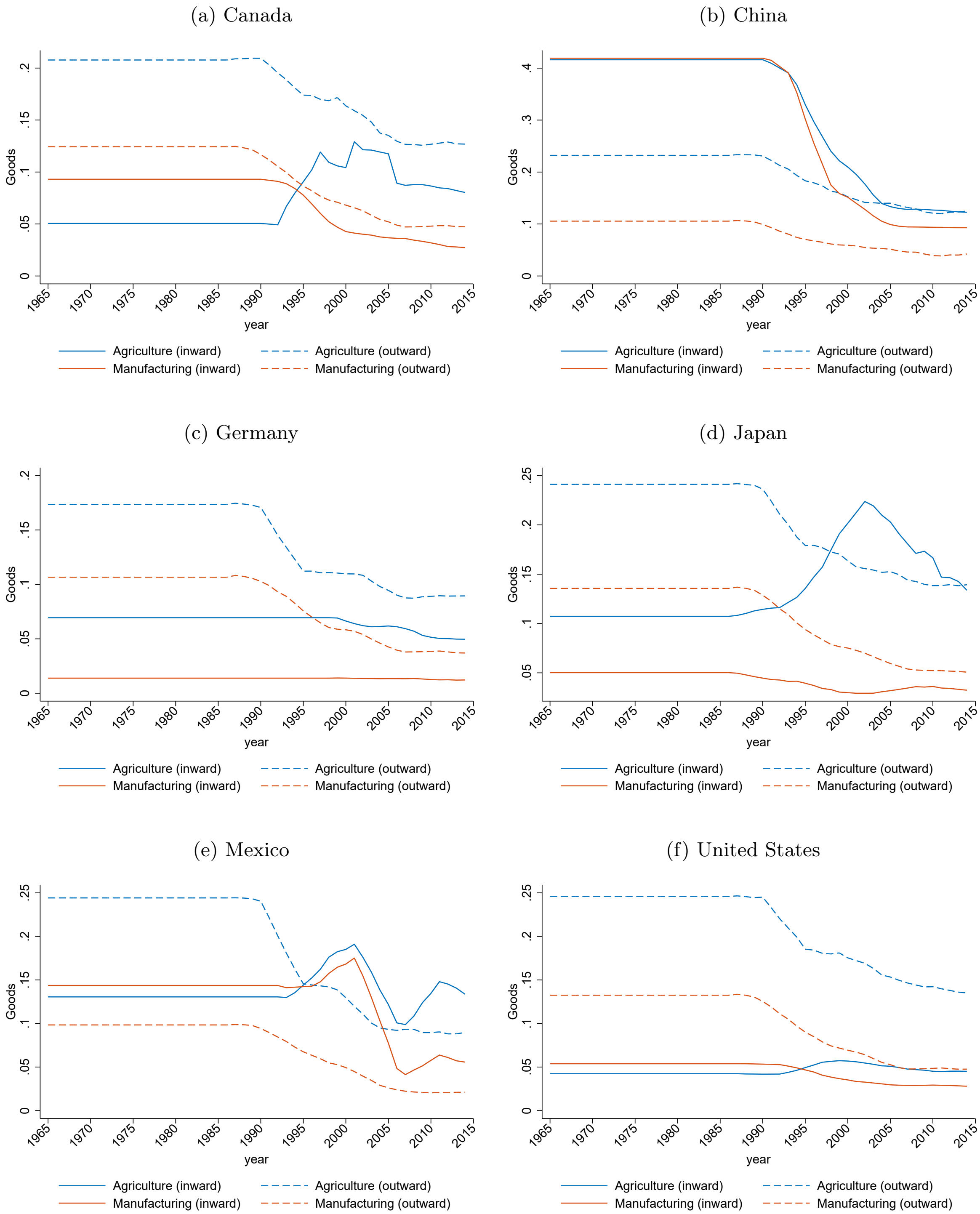
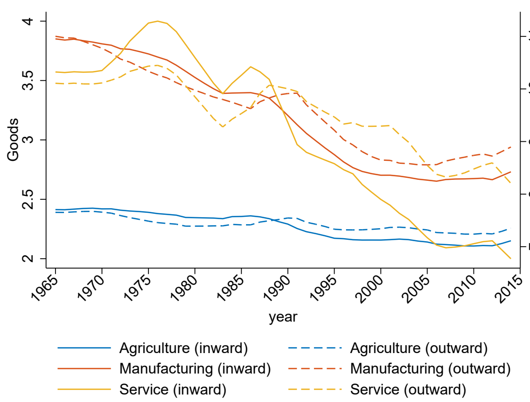
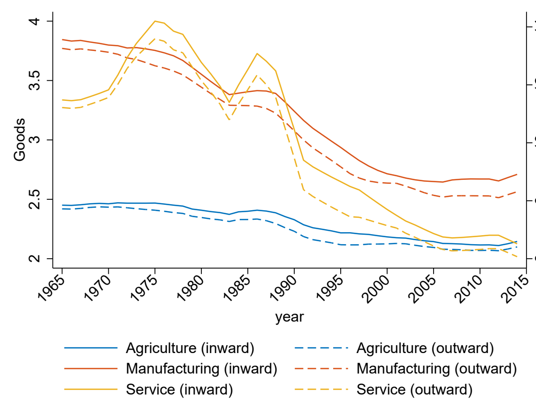


Figure A3: Evolution of Average Non-Tariff Barrier

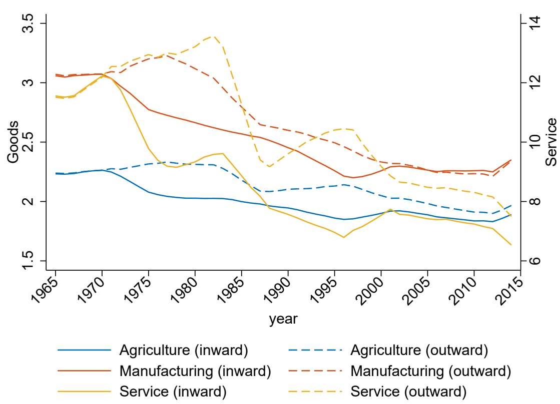
(a) Canada



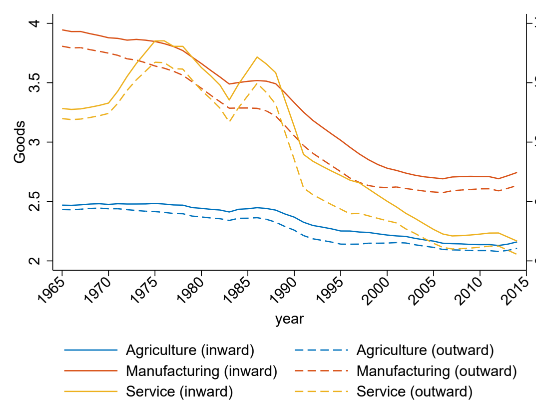
(b) China



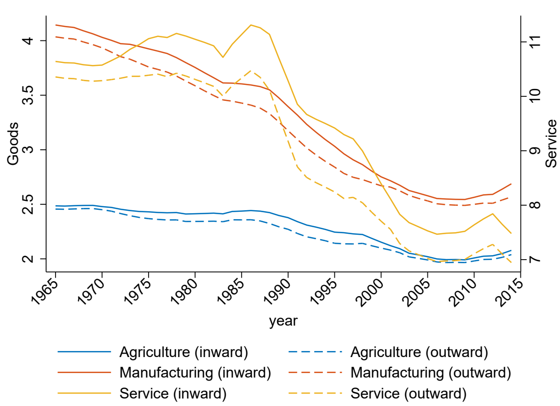
(c) Germany



(d) Japan



(e) Mexico



(f) United States

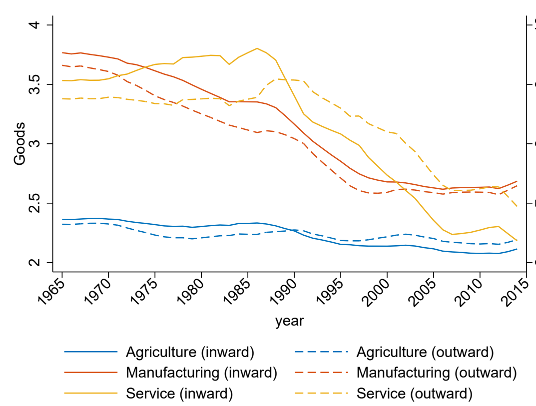
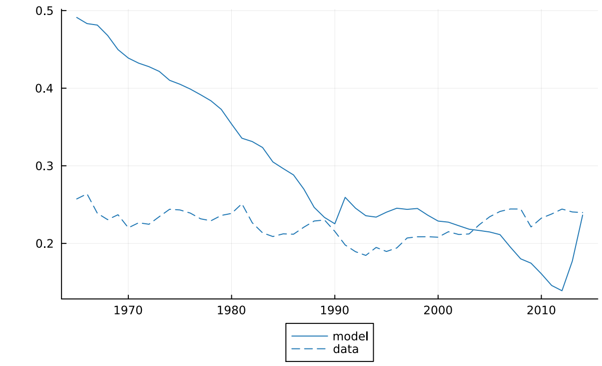
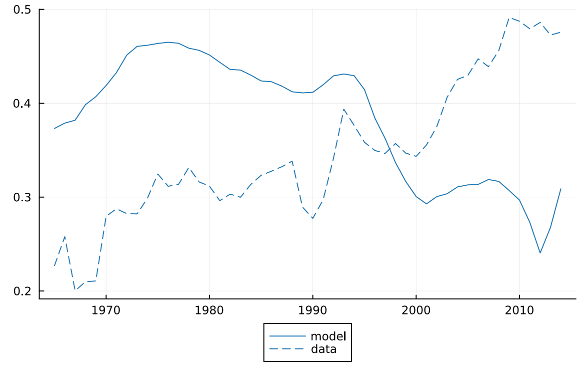


Figure A4: Model Fit: Saving Rate

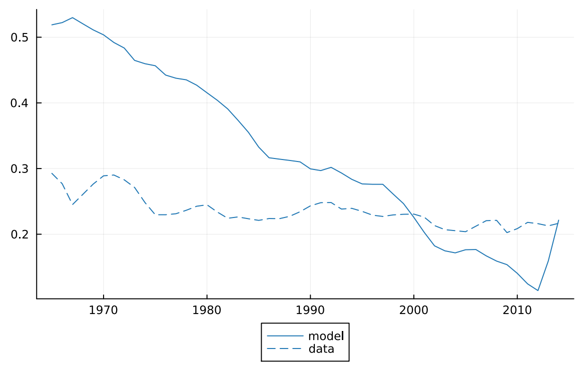
(a) Canada



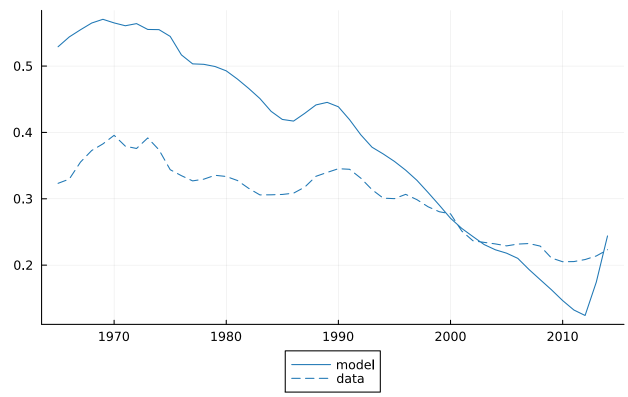
(b) China



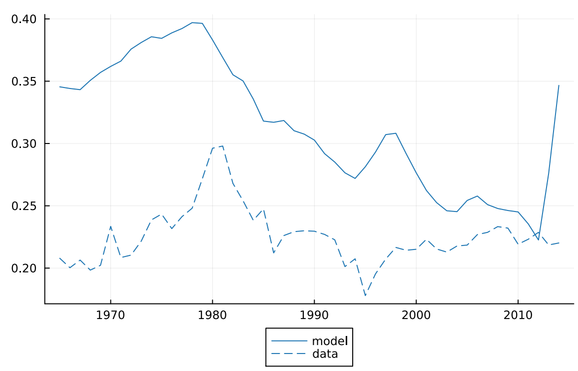
(c) Germany



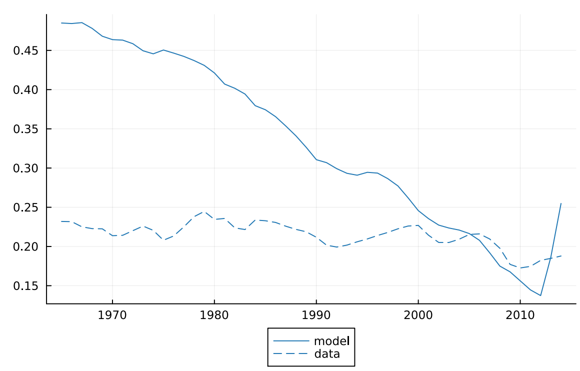
(d) Japan



(e) Mexico



(f) U.S.



J.2 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 A5: Model Fit Comparison (Nonhomothetic vs Homothetic): Expenditure Share

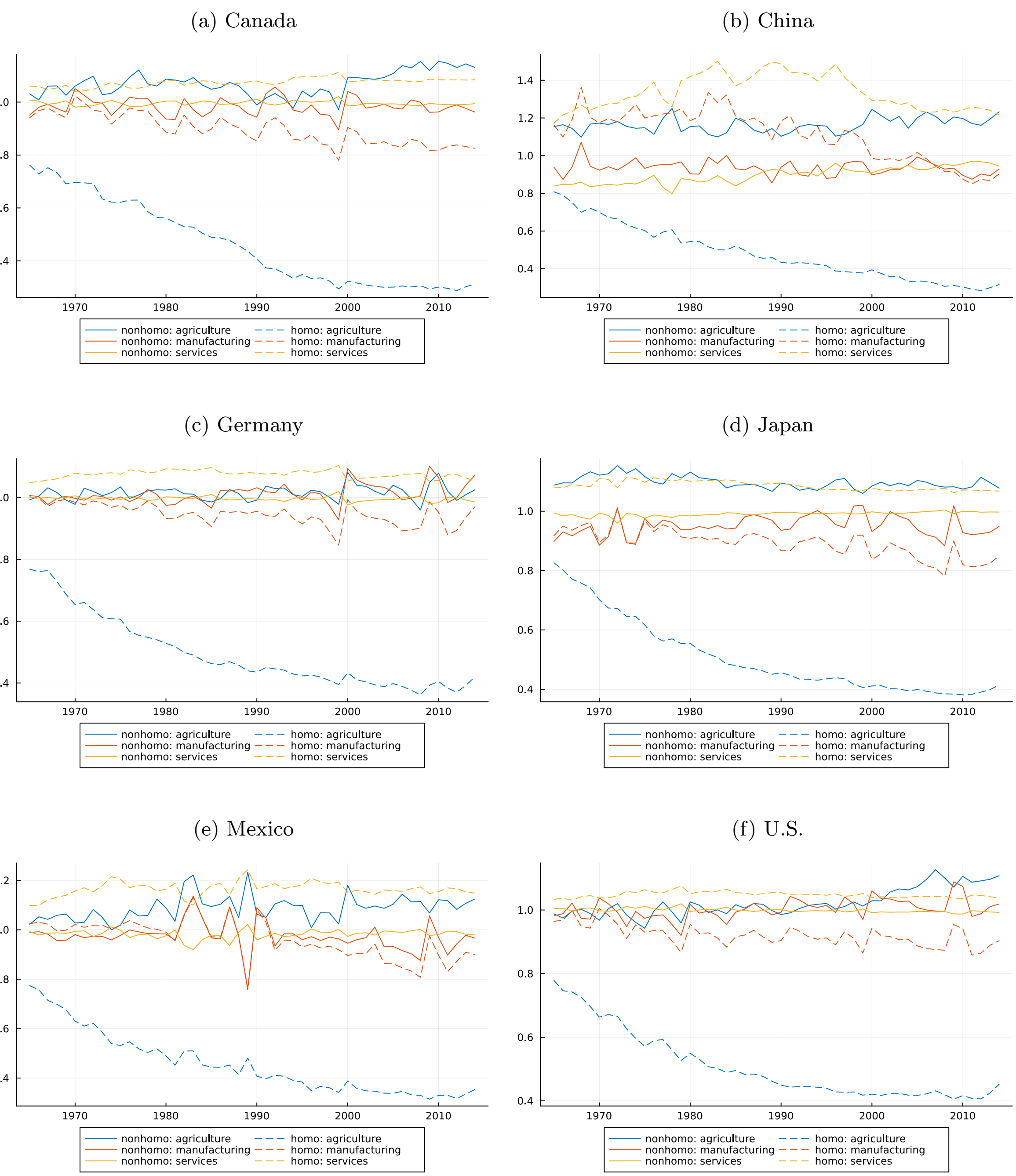
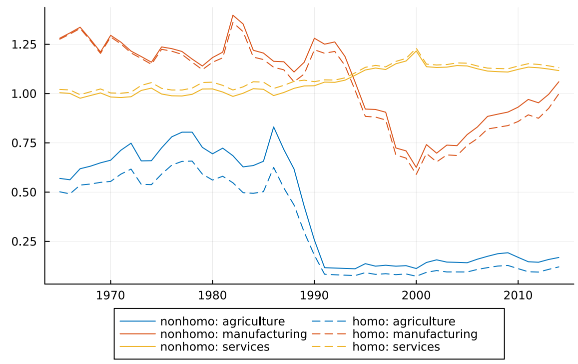
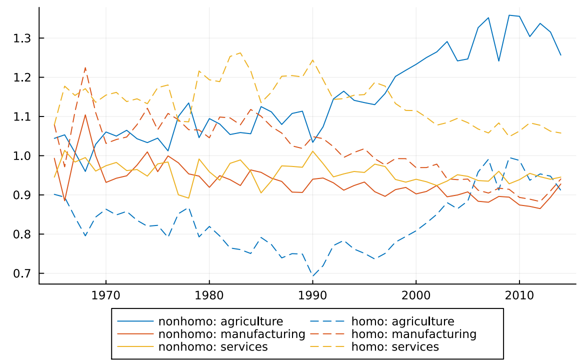


Figure A6: Model Fit Comparison (Nonhomothetic vs Homothetic): Value-Added Share

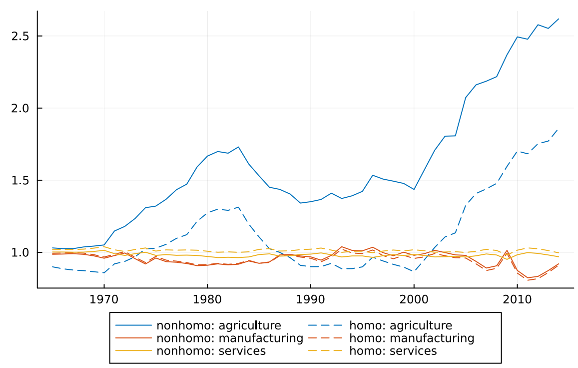
(a) Canada



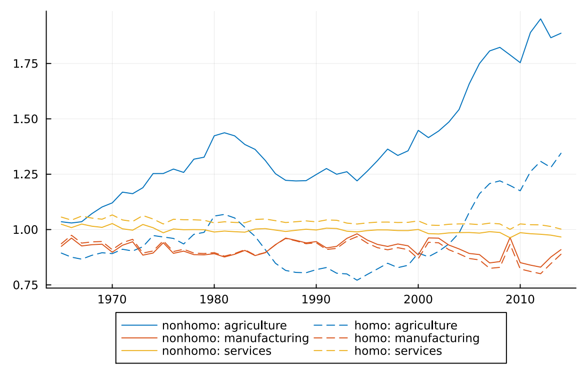
(b) China



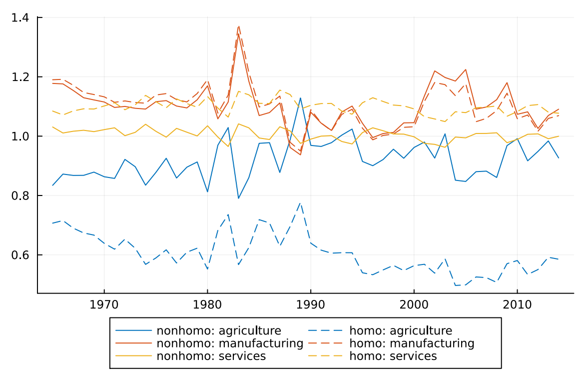
(c) Germany



(d) Japan



(e) Mexico



(f) U.S.

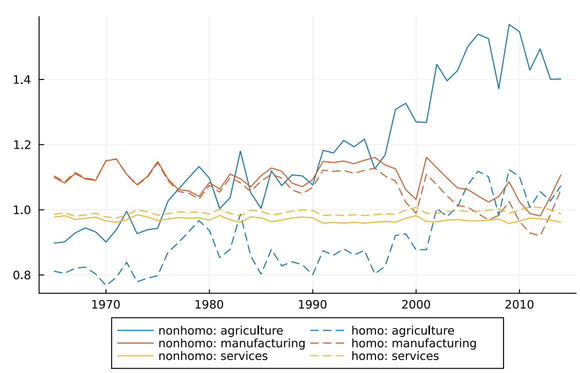
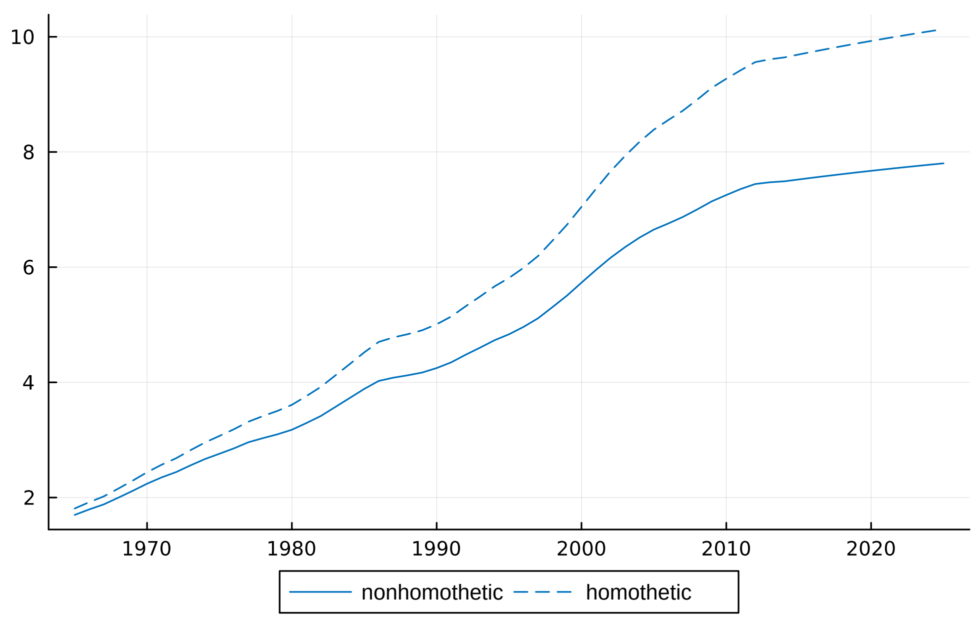


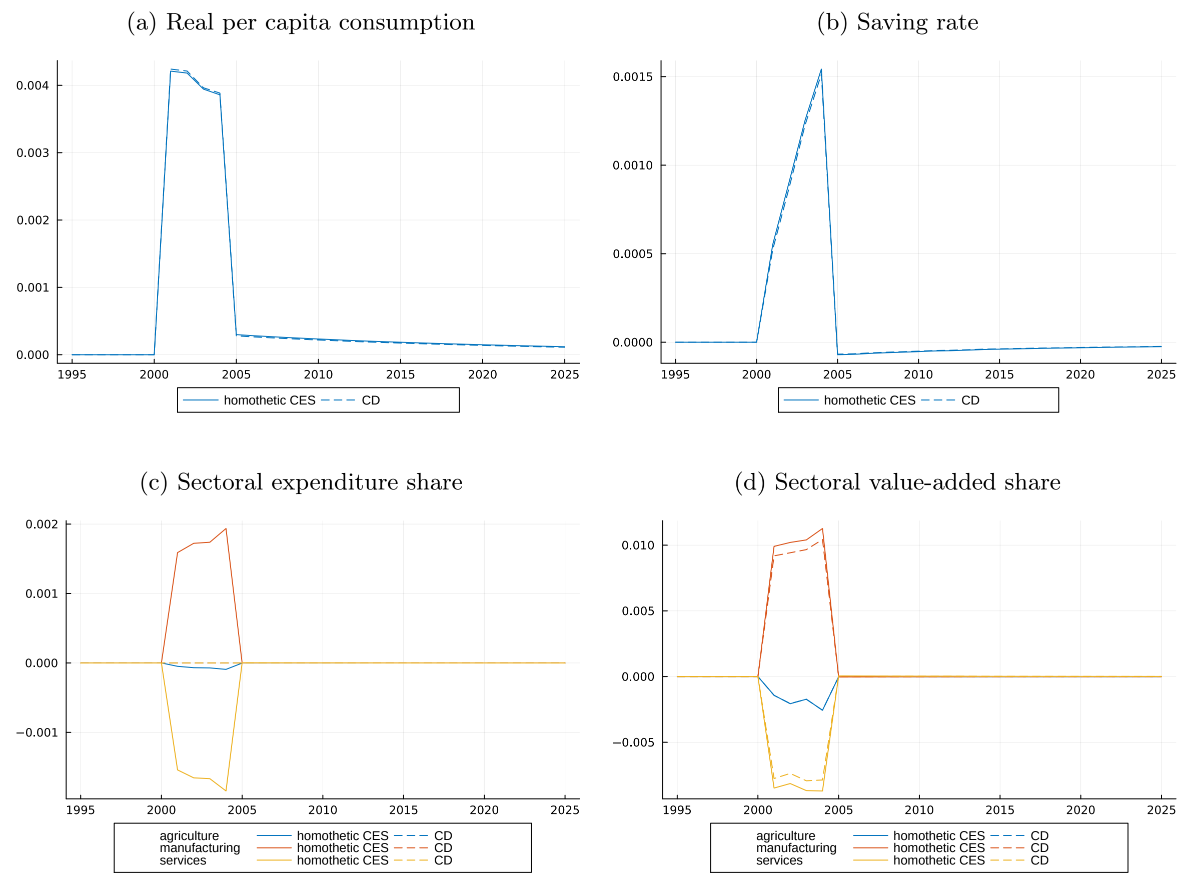
Figure A7: U.S. Per Capita Consumption



Notes: The per-capita consumption (period utility) of the U.S. in the baseline equilibrium.

K More on Counterfactual Results

Figure A8: Impacts of a 4 year, 20 percentage point increase in U.S. manufacturing tariffs applied to all countries: Homethetic CES and Cobb-Douglas



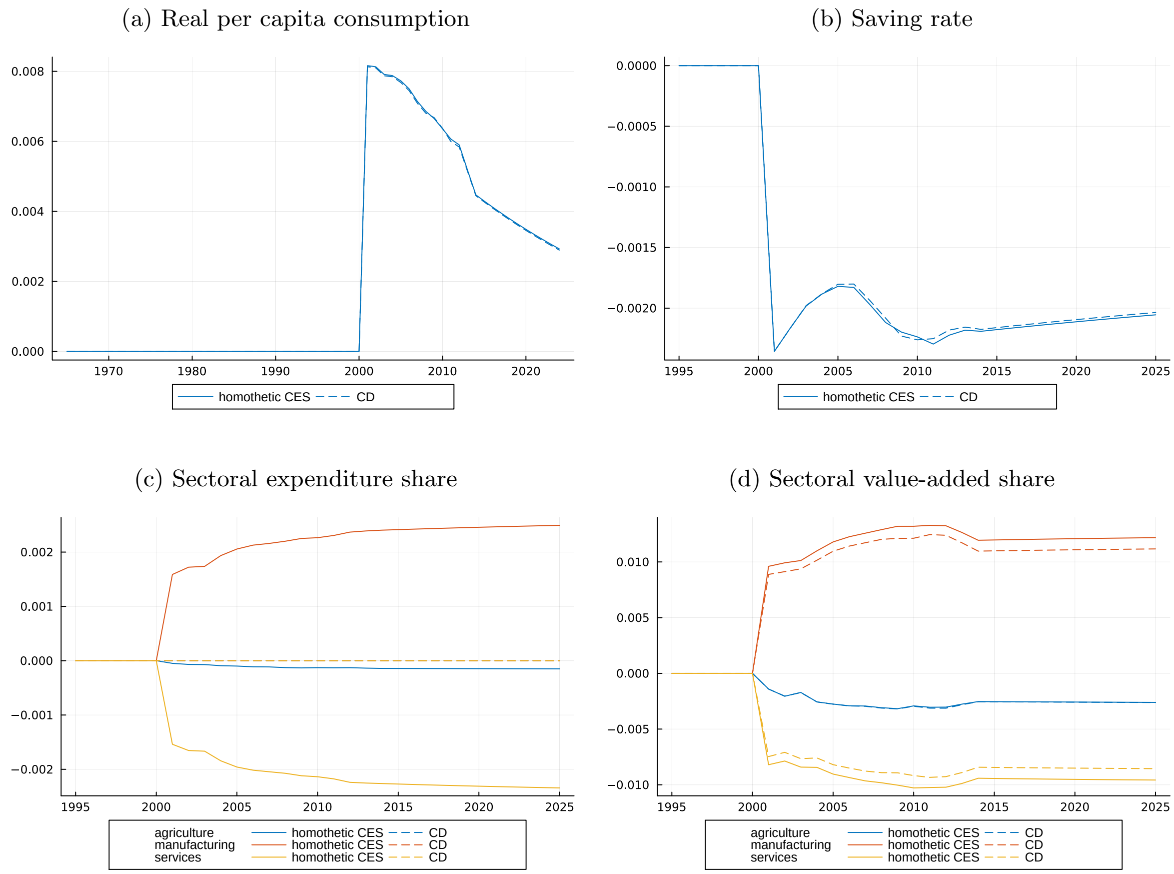
Notes: This figure shows the impacts of a 20% point increase in U.S. manufacturing tariffs applied to all the other countries since 2001. Each panel is based on the time series of transition paths of respective variables indicated by its title. For real per capita consumption, the vertical axes represent percent changes from the baseline to the counterfactual equilibrium. For sectoral expenditure shares, sectoral value-added shares, and saving rates, the vertical axes represent percentage point changes.

References

Caliendo, L., and Parro, F. (2022). Trade policy. In Gopinath, G., Helpman, E., and Rogoff, K., editors, *Handbook of International Economics*, volume 5, chapter 4, pages 219–295. Elsevier

Courtault, J. M., Crettez, B., and Hayek, N. (2006). Characterization of stochastic dominance for discrete random variable. Working paper: halshs-00446413f

Figure A9: Impacts of a permanent, 20 percentage point increase in U.S. manufacturing tariffs applied to all countries: Homethetic CES and Cobb-Douglas



Notes: This figure shows the impacts of a 20% point increase in U.S. manufacturing tariffs applied to all the other countries since 2001. Each panel is based on the time series of transition paths of respective variables indicated by its title. For real per capita consumption, the vertical axes represent percent changes from the baseline to the counterfactual equilibrium. For sectoral expenditure shares, sectoral value-added shares, and saving rates, the vertical axes represent percentage point changes.