Structural Change and Global Trade

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Abstract

Services, which are less traded than goods, rose from 58 percent of world expenditure in 1970 to 79 percent in 2015. In a trade model featuring nonhomothetic preferences and input-output linkages, we find that such structural change has restrained the growth in world trade to GDP by 16 percentage points over this period. This magnitude is similar to how much declining trade costs have boosted openness. Moreover, structural change dampens the measured gains from trade by incorporating endogenous responses of expenditure shares to the trade regime. Ongoing structural change implies declining openness, even absent rising protectionism.

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1 Introduction

International trade expanded substantially in the past 45 years, as the ratio of world trade to world GDP increased from 19 percent in 1970 to 48 percent in 2015. This remarkable growth in trade is primarily due to increased trade in goods; growth in services trade has been comparatively limited. Over the same time period, however, even as trade in goods skyrocketed, total spending on services rose from 58 percent of world expenditures in 1970 to nearly 80 percent in 2015. This phenomenon of "structural change" is thoroughly studied and well known to be a foundational component of economic growth and development. Less appreciated, however, are the implications of structural change on global trade flows and on the potential benefits from trade integration.

This paper studies the joint evolution of international trade flows and structural change and asks two related questions: (i) How much has structural change restricted the growth in world trade? (ii) To what extent has structural change affected the measured gains from trade? On the first question, we find that structural change since 1970 has dampened "openness"—an empirical measure of trade as a fraction of world GDP—by 16 percentage points by 2015. This magnitude is similar to how much declining trade costs have boosted openness over the same time period. In addition, this result highlights a mechanism by which openness can change without any change in trade costs.

On the second question, we find that the gains from trade estimated in our model are only about two-thirds of those implied by other models without structural change. The key insight is that structural change, as a result of price and income effects, determines what we consume, produce and trade. The data show that the services expenditure share increases with real income and with relative services prices, both of which are endogenous to the trade regime. As countries open up to trade, the relative price of services and real income rise, shifting expenditure to services and partially offsetting the benefits from more-integrated goods markets.

In order to fix ideas, we start with a reduced-form computation of counterfactual openness for a world without structural change. We assume that the sectoral expenditure share is fixed at its 1970 level, while each sector's trade-to-expenditure ratio—"sectoral openness"—rises as in the data. Under these assumptions, openness in 2015 would have been 81 percent, or 34 percentage points higher than in the data, which suggests that shifting toward less-tradable consumption substantially suppressed trade growth in the last five decades. At the same time, it is implausible to assume that sectoral openness would have evolved exactly as in the real world in the absence of structural change; endogenous prices and input-output linkages implied by fixed expenditure shares should have affected sectoral openness. The interactions between these factors call for a general equilibrium model to accurately measure the effect of structural change on trade.

We build a multi-country, multi-sector, Ricardian trade model that incorporates endogenous structural change and trade patterns over time, similar to Uy, Yi and Zhang (2013) and Sposi (2018). On the production side, a continuum of varieties in each sector are produced with labor and intermediates. Countries differ in their sectoral input-output linkages, productivity and trade barriers, forming the basis for comparative advantage. The evolution of productivity and bilateral trade costs at the sector level influences the patterns of production and trade over time. On the demand side, we adopt nonhomothetic preferences that allow total income and relative prices to shape sectoral expenditure shares, as in Comin, Lashkari and Mestieri (2015).

We calibrate the underlying structural parameters and time-varying processes of the model to relevant observables in 26 countries and a rest-of-world aggregate from 1970–2015. Using data on sectoral expenditure shares, sectoral prices, and employment levels, we estimate the key preference parameters, namely the elasticity of substitution between goods and services and the income elasticity of demand for both goods and services. Services have a higher income elasticity than goods, generating a higher services expenditure share with rising income, and goods and services are complements. Coupling these with input-output coefficients from the World Input-Output Database and bilateral trade data enables us to back out estimates of productivity and trade costs at the sector level from the structural equations of the model.

After calibrating and solving the baseline model, we conduct a counterfactual similar to the reduced-form one. We again deliver constant expenditure shares across time, this time by setting both the elasticity of substitution and the income elasticity to one. The model differs from the reduced-form calculation in that it allows for the counterfactual expenditure shares to impact prices for goods, services and labor, and trade flows, all of which affect sectoral openness. We show that the model-based counterfactual still implies a substantial increase in the global trade-to-expenditure ratio, 16 percentage points or 34 percent higher than in reality by 2015.

The model-based effect of structural change on world openness (16 percentage points) is smaller than the reduced-form one (34 percentage points). Why is this the case? The primary reason is that "goods openness"—the ratio of goods trade over goods expenditure—in the counterfactual is substantially lower than in the data. When fixing the expenditure shares at the 1970 level, the goods expenditure share rises relative to the data; however, as a result of input-output linkages weakening the overall effect, goods trade does not rise by the same degree.

Our estimates of the gains from trade are lower than those estimated using otherwise similar models that ignore structural change because we consider endogenous responses of expenditure shares to changing trade regimes. In a typical multi-sector framework, the gains from trade—the percent change in consumption when moving from autarky to open trade—are an expenditure-weighted average of the sectoral gains, which are governed by domestic absorption shares and the trade elasticity at the sector level. Since goods are traded more intensively than services with lower domestic absorption shares, the sectoral gains are larger for goods than for services. In our model of structural change, opening up to trade shifts expenditure shares from goods to services, through (i) a decline in the relative price of goods and (ii) an increase in aggregate income. In contrast to the prior literature where expenditure shares are treated as exogenous, this endogenous shift of expenditures dampens the measured gains from trade. Consequently, as structural change persists over time, the measured gains from trade will be increasingly suppressed. Finally, emerging economies, which tend to have higher goods expenditure shares, also tend to have higher gains from trade compared to advanced economies.

Projecting our model into the future, assuming constant trade costs and continued technical progress, demonstrates that openness has peaked and will decline to below 40 percent by 2030. Importantly, the projected downward trend in trade relative to GDP is driven by the effects of increased services consumption. At the same time, there is little evidence that the slowdown in international trade growth that started in 2011 is due to forces distinct to that time; that is, structural change has been a drag on trade growth for decades, and the drag has not been stronger in recent years.

To the extent that structural change reflects the efficient, long-run response of expenditures and production to asymmetric technological progress and aggregate income growth, it would not prove prudent to design policies that restrict the expansion of the service sector. Furthermore, trade policy has become increasingly restrained in its ability to further boost trade in goods, as tariffs are currently low. This means that modern trade policy should focus on liberalizing trade in services in order to foster the growth in world trade and to stimulate the benefits therein.

This paper contributes to a broad literature on how global trade grows relative to GDP. In an early theoretical contribution, Markusen (1986) includes nonhomothetic preferences in a trade model to be consistent with empirical evidence of a relationship between income and trade volumes. Rose (1991) shows that increases in income and international reserves along with declining tariff rates help explain the differences in trade growth across countries over three decades. Krugman, Cooper and Srinivasan (1995) analyze the growth in world trade since World War II and potential consequences for labor markets. Baier and Bergstrand (2001) find that income growth explains nearly two-thirds of the increase in global trade, with tariffs explaining an additional one-quarter. Imbs and Wacziarg (2003) document a U-shaped pattern of specialization as countries become richer; they first diversify across industries and only later specialize as they grow. Yi (2003) shows how vertical specialization—the splitting of production stages across borders—can amplify gross trade relative to value-added trade and help explain the large increases in trade-to-GDP ratios. Our paper provides an additional reason why the trade-to-GDP ratio is an imperfect measure of true openness, and given our projection exercise, a decline in this ratio does not necessarily reflect a less-open world with increasing protectionism.

A well-established literature documents how international trade and openness affect structural change. Matsuyama (2009) emphasizes that trade can alter patterns of structural change and that using closed-economy models may be insufficient. Uy et al. (2013) find that rapid productivity growth in South Korea's manufacturing sector contributed to a rise in manufacturing employment share due to improved comparative advantage. In a closed economy, the same productivity growth would have produced a decline in the manufacturing share. Betts, Giri and Verma (2017) explore the effects of South Korea's trade policies on structural change, finding that these policies raised the industrial employment share and hastened industrialization in general. Teignier (2016) finds that international trade in agricultural goods affected structural change in the United Kingdom even more than in South Korea. We show in this paper that structural change may in fact be more consequential for international trade than trade is for explaining structural change in many countries.

More broadly, our findings point to structural change as being an important link between international trade and economic development. McMillan and Rodrik (2011) find that the effect of structural change on growth depends on a country's export pattern, specifically the degree to which a country exports natural resources. Cravino and Sotelo (2017) show that structural change originating from greater manufacturing trade increases the skill premium, particularly in developing countries. Sposi (2018) documents how the input-output structures of advanced economies are systematically different from those of developing economies, which contributes to systematic differences in resource allocations between rich and poor countries. Markusen (2013) shows how including nonhomothetic preferences into a Hecksher-Ohlin model can help explain why we observe less trade than predicted by models without nonhomotheticities.

Some analysis suggests that international trade plays only a small role in explaining structural change. Kehoe, Ruhl and Steinberg (2017) find that relatively faster growth in manufacturing productivity was the primary cause for reduced employment in the goods-producing sector in the United States, with a smaller role for trade deficits. Święcki (2017) also finds differential productivity growth is more important than other mechanisms, including international trade, in explaining structural change. Nonetheless, even if international trade only contributes a small portion to structural change, we show that structural change plays a large role in the growth of world trade.

Nonhomothetic preferences are important in understanding other aspects of international trade as well. Fieler (2011) finds that nonhomothetic preferences can explain why trade grows with income per capita but not population. Simonovska (2015) shows that nonhomothetic preferences can match the pattern found in the data that higher-income countries have higher prices of tradable goods. Matsuyama (2015) and Matsuyama (2017) show that nonhomothetic preferences combined with home market effects can lead to high-income countries producing and exporting higher income elasticity goods without assuming they have an exogenous comparative advantage in such goods.

The remainder of the paper proceeds as follows. Section 2 describes the reduced-form counterfactual, and Section 3 sets up the model. Section 4 describes the calibration and solution of the model, and Section 5 presents the quantitative results. Section 6 concludes.

2 Empirics and a Reduced-Form Counterfactual

The ratio of global trade to GDP rose from about 20 percent to 50 percent between 1970 and 2010 before flattening through 2015. How would this trend have differed without the significant shift in expenditures from goods to services over that time? This section presents a direct and simplified answer to the question by holding each country's expenditure share on goods and services fixed at its 1970 level and tracing out a counterfactual path for the global trade-to-GDP ratio. This approach will provide a preliminary idea of how structural change affected global trade growth.

2.1 Data

We begin by laying out the key concepts for our exercise and describing how we capture them in the data. First, some definitions: *Expenditure* refers to final demand: consumption, investment, and government spending. *Structural change* refers to changes in the expenditure of goods and services as a share of total expenditure over time. And *openness* is defined as total trade (imports plus exports) as a share of expenditure, with *sectoral openness* defined analogously at the sector (either goods or services) level.

For every country (and for the world as a whole), we can decompose openness in period t as

$$\frac{Trade_t}{Exp_t} = \frac{Trade_{gt}}{Exp_{gt}} \frac{Exp_{gt}}{Exp_t} + \frac{Trade_{st}}{Exp_{st}} \frac{Exp_{st}}{Exp_t}, \tag{1}$$

where g and s denote goods and services. Clearly, changes in sectoral openness $\frac{Trade_{kt}}{Exp_{kt}}$, and sectoral expenditure shares $\frac{Exp_{kt}}{Exp_t}$, shape the aggregate openness measure over time.

We gather data needed to do the breakdown in equation (1) for 26 countries and a rest-of-world aggregate over the period 1970–2015.[1] In UN nomenclature, we take the goods sector to consist of "agriculture, hunting, forestry, fishing" and "mining, manufacturing, utilities," while services includes "construction," "wholesale, retail trade, restaurants, and hotels," "transport, storage, and communication," and "other activities". The World Input-Output Database (WIOD) contains data on sectoral trade and expenditure for the years 1995–2011—we build around this subset of years to generate data for all other years in our sample.

Extending the trade data is straightforward. As detailed in Appendix A, we take longer-running country-level sectoral trade data from various data sources and then generate a splicing factor between it and WIOD data in overlapping years. Using this splicing factor on the longer-running data, we can then extend the series back to 1970–1994 and forward to 2012–2015.

The procedure for generating sectoral expenditure data is more involved, as there is no widely-available companion data available for our sample to splice with the WIOD. As a workaround, we take a long time series of data on sectoral value added from the United Nations Main Aggregates Database and convert it into sectoral gross output using average value-added-to-gross-output ratios from the WIOD. Then, subtracting sectoral net exports (coming from our trade data described above) from sectoral gross output generates *sectoral absorption*, which is equal to final demand for

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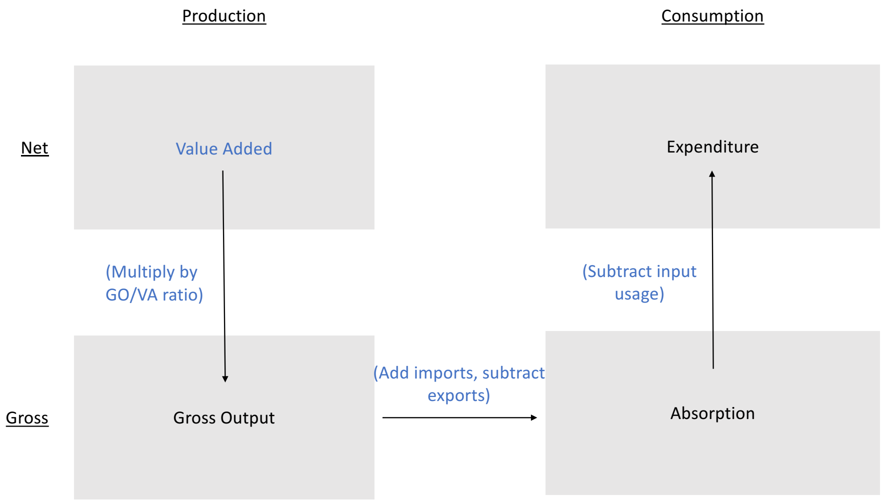
[1] The full list of countries is listed in Appendix A.

a sector (i.e. sectoral expenditure) plus all usage of that sector as an intermediate input. In other words, domestic usage of that sector is absorbed either by consumers or by firms. Finally, using average input-output coefficients from the WIOD, we can calculate what fraction of sectoral absorption went to intermediate usage.[2] The remaining amount corresponds to sectoral expenditure. A stylized depiction of this calculation is in figure 1.[3]

Figure 1: Deriving sectoral expenditures from sectoral value added



Note: Categories in blue represent publicly available data, while categories in black represent imputed moments.

2.2 Openness and Structural Change

We now present key motivating facts for the relationship between openness and structural change. Panel (a) of figure 2 shows the trend in openness, which was 19 percent in 1970 and reached 55 percent by 2008. Openness grew substantially during much of the period, accelerating in the late 1990s and 2000s. Since 2011, the ratio has been nearly flat at about 50 percent. Over the same period, world consumption shifted prominently from goods to services. Panel (b) plots the expenditure shares for goods and services from 1970 to 2015. The services share increased steadily over the period by a total of 21 percentage points, from 58 percent in 1970 to 79 percent in 2015.

If these two sectors were both traded internationally with similar intensities, the impact of structural change on openness would be small. In the data, however, openness significantly differs between the two sectors. Panel (c) of figure 2 plots the ratio of sectoral trade to sectoral expenditure over 1970-2015. Clearly, goods are much more open than services; the ratio of trade to expenditure was about 5 percent for services compared to 37 percent for goods in 1970. Over time, trade open-

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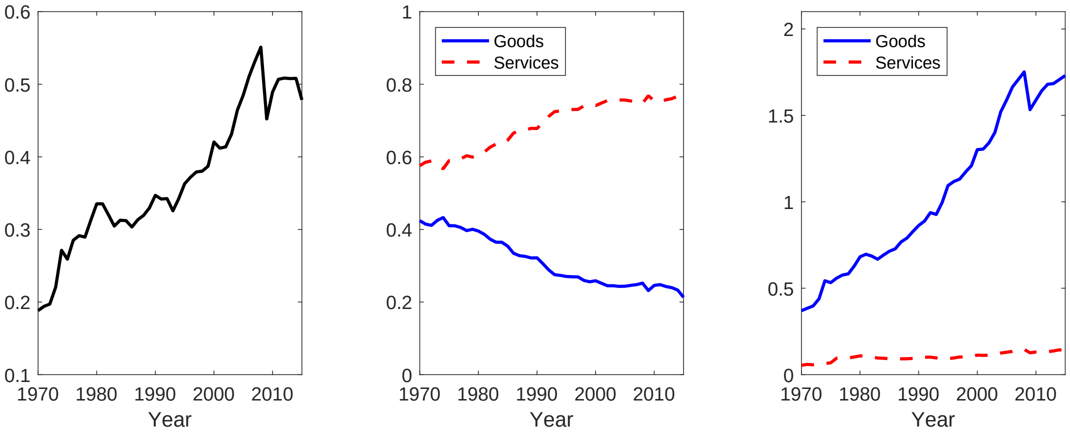
[2] More detail on this step can be found in Sposi (2018).

[3] Note that this procedure exactly replicates the sectoral expenditure data in the WIOD for 1995 through 2011.

ness increased for both sectors but was much more pronounced for goods. By the end of the period, the trade-expenditure ratio was about 14 percent for services and 170 percent for goods.[4]

Figure 2: Openness and structural change



(a) Openness (b) Sectoral Expenditure Shares (c) Sectoral Openness

Considering these three figures together presents a puzzle of sorts: How could trade grow so quickly while a relatively less-traded sector gained expenditure share? Trade grew spectacularly *in spite of* the ongoing transition to services in the world economy, meaning structural change prevented even greater increases in trade. This dynamic becomes apparent when calculating the correlation between the growth rates of openness and the services expenditure share. For the world, the correlation is -0.77 meaning that periods of faster openness growth feature a slower-growing service share. This relationship also exists at the country level. Table 1 shows the results of regressing the country-level growth rate of openness on the country-level growth rate of the service share for our sample. Again, we find strong evidence of a negative correlation; when a country featured higher growth in its service expenditure share, it experienced lower growth in openness, even accounting for its level of per capita income. In the next subsection, we present reduced-form evidence of how much structural change held back global trade growth.

2.3 A Reduced-Form Counterfactual

To gauge the contribution of structural change to openness, we return to equation (1), but freeze the expenditure shares at the 1970 levels. We compute a counterfactual measure of openness as:

$$\frac{\widetilde{Trade_t}}{Exp_t} = \frac{Trade_{gt}}{Exp_{gt}} \frac{Exp_{g0}}{Exp_0} + \frac{Trade_{st}}{Exp_{st}} \frac{Exp_{s0}}{Exp_0}. \tag{2}$$

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[4] The ratio of trade to expenditure can be over 100 percent for two reasons. First, trade refers to import plus exports. Second, trade is a gross measure (as a result of trade in inputs) and expenditure is a final consumption measure.

Table 1: Country-level openness and service share

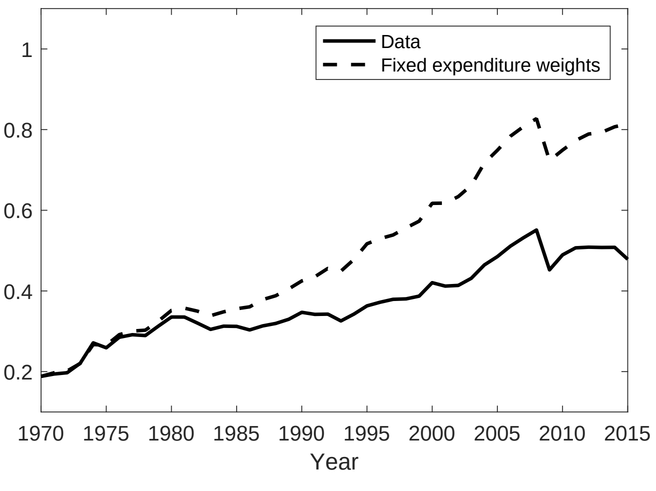
	Dependent variable: openness growth	
Services share growth	-0.379^{***}	-0.404^{***}
	(0.070)	(0.069)
Log GDP per-capita		-0.036^{***}
		(0.008)
Country FE	YES	YES
N	1215	1215
R^2	0.05	0.07

Note: Robust standard errors are in parentheses, with *** denoting a 99% significance level.

By holding the expenditure shares of sector k fixed at the first period, we shut down the process of structural change in the data. The counterfactual openness measure, $\widetilde{\frac{Trade_t}{Exp_t}}$, is free of structural change but retains the observed sectoral openness.

Figure 3 contrasts the aggregate trade openness measure in the data (the solid line) with the reduced-form counterfactual (the dashed line). The gap between the counterfactual measure and the data widens substantially over the 1990s and early 2000s, indicating that without underlying movements toward less-tradable services, global trade growth would have been far greater. As of 2015, persistent structural change since 1970 had lopped about 34 percentage points off the ratio of trade to expenditure.

Figure 3: Openness: data and empirical counterfactual



Of course, this reduced-form exercise has a major deficiency: Sectoral trade openness was *jointly* affected by the same forces that instigated structural change. The dynamics of sectoral productivity and trade barriers not only affect expenditure shares through relative prices and income levels but also affect sectoral openness through comparative advantage and trade flows. Additionally, input-output linkages are critical for identifying how changing expenditure shares feed through into production and trade. Thus, a structural model incorporating these endogenous relationships and featuring intermediate input-output linkages is needed to properly quantify the impact of structural change on international trade.

3 Model

We consider a multi-country, two-sector Eaton Kortum trade model of the global economy with nonhomothetic preferences. There are I countries and the two sectors are goods (g) and services (s). Household preferences have non-unitary income and substitution demand elasticities. In each sector, there is a continuum of goods, and production uses both labor and intermediate inputs. All goods are tradable, but trade costs vary across sectors, country-pairs, and over time. Productivities also differ in initial levels and subsequent growth rates across sectors and countries. These time-varying forces drive structural change. We omit the time subscript in this section for brevity.

3.1 Endowments and Preferences

Labor is mobile across sectors within a country, but immobile across countries. Let L_i denote total labor endowment in country i, which varies over time, and L_{ik} denote labor employed in sector k. The factor market clearing condition is given by:

$$L_i = L_{ig} + L_{is}. \tag{3}$$

The household in country i has a standard period utility function $U(C_i)$ over the level of aggregate consumption, C_i. Aggregate consumption combines sectoral composite goods according to the implicitly defined function:

$$\sum_{k=g,s} \omega_k \left(\frac{C_i}{L_i}\right)^{\frac{\varepsilon_k-\sigma}{\sigma}} \left(\frac{C_{ik}}{L_i}\right)^{\frac{\sigma-1}{\sigma}} = 1, \tag{4}$$

where for each sector $k \in \{g,s\}$, C_{ik} is consumption of the sector-k composite good, and the preference share parameters, ω_k, are positive and sum to one across sectors. These preferences, known as "Non-Homothetic Constant Elasticity of Substitution", were discussed by Hanoch (1975) and were also used by Comin et al. (2015). The elasticity of substitution across sectoral composite goods is σ. If $\sigma > 1$, the goods are substitutes, and if $\sigma < 1$, they are complements. The income elasticity of demand for sector k is ε_k. Hanoch (1975) showed that in order for these preferences to be well-behaved, i.e., monotone and quasi-concave, either (i) $0 < \sigma < 1$ and $\varepsilon_k > \sigma$ for all k or (ii)

$\sigma > 1$ and $\varepsilon_k < \sigma$ for all k must hold. As we will show later in the calibration, (i) is the one that is empirically relevant in our context.[5]

Comin et al. (2015) show that this specification of nonhomothetic preferences has two attractive properties for studying long-run structural change. First, the elasticity of the relative demand for the two sectoral composites with respect to consumption is constant. This contrasts with Stone-Geary preferences, where the elasticity of relative demand goes to zero as income or aggregate consumption rises—a prediction at odds with the data both at the macro and micro levels. Second, the elasticity of substitution between sectoral composites, given by σ, is constant over income, meaning that there is no functional relationship between income and substitution elasticities.[6] They demonstrate that this specification has the potential to be flexible enough to capture the structural change patterns in the data.

The representative household maximizes aggregate consumption in each period, C_i, by choosing sectoral consumption levels, C_{ik}, subject to the following budget constraint:

$$\underbrace{P_{ig}C_{ig} + P_{is}C_{is}}_{P_iC_i} + \rho_i w_i L_i = w_i L_i + RL_i, \tag{5}$$

where w_i and P_{ik} denote the wage rate and the price of the sector-k composite good, respectively, and P_i denotes the aggregate consumption price. The household supplies its labor endowment inelastically and spends its labor income on consumption. A fraction ρ_i of income is sent into a global portfolio, and the portfolio disperses R in lump sum equally across countries on a per-worker basis. ρ_i varies over time and R is determined by global portfolio balance in each period. Therefore, each country lends, on net, $\rho_i w_i L_i - RL_i$ to the rest of the world. This aspect enables the model to tractably match aggregate trade imbalances in the data, as in Caliendo, Parro, Rossi-Hansberg and Sarte (2016).

The first-order conditions imply that the consumption demand of sectoral goods satisfies:

$$C_{ik} = L_i \omega_k^{\sigma} \left(\frac{P_{ik}}{P_i}\right)^{-\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k}, \tag{6}$$

where the aggregate price is given by:

$$P_i = \frac{L_i}{C_i} \left[\sum_{k=g,s} \omega_k^{\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k - \sigma} P_{ik}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{7}$$

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[5] Our notation differs from Hanoch (1975). These conditions are a rewriting of his Expression (i) on page 403, with $d = \frac{\sigma-1}{\sigma}$ and $e_i = \frac{\varepsilon_i - \sigma}{1-\sigma}$.

[6] This is a key difference from the preferences used in Fajgelbaum and Khandelwal (2016) and Hottman and Monarch (2018), whose frameworks could be used to ask a similar question to ours.

The sectoral expenditure shares are given by:

$$e_{ik} = \frac{P_{ik}C_{ik}}{P_i C_i} = \omega_k^{\sigma} \left(\frac{P_{ik}}{P_i}\right)^{1-\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k - 1}. \tag{8}$$

Thus, the elasticity of substitution between sectors, σ, and the sectoral elasticity of income, ε_k, govern how relative price and real income per worker shape the sectoral expenditure shares. Specifically, when $\sigma < 1$, a rising sectoral relative price pushes up the expenditure share in that sector, and vice versa. When a sectoral income elasticity is larger than one, i.e., $\varepsilon_k > 1$, that sector's expenditure share also rises with income per worker.

3.2 Technology and Market Structure

There is a continuum of varieties, $z \in [0,1]$, in both the goods (g) and services (s) sectors. The sectoral composite good, Q_{ik}, is an aggregate of the individual varieties $Q_{ik}(z)$:

$$Q_{ik} = \left(\int_0^1 Q_{ik}(z)^{\frac{\eta-1}{\eta}} dz\right)^{\frac{\eta}{\eta-1}},$$

where the elasticity of substitution across varieties within a sector is $\eta > 0$. Each variety z is either produced locally or imported from abroad. The composite sectoral goods are used in domestic final consumption and domestic production as intermediate inputs:

$$Q_{ik} = C_{ik} + \sum_{n=g,s} M_{ink},$$

where M_{ink} is the intermediate input usage of composite good k in the production of sector n.

Each country possesses technologies for producing all the varieties in all sectors. Production requires labor and intermediate inputs as in Levchenko and Zhang (2016). The production function for variety $z \in [0,1]$ in sector $k \in \{g,s\}$ of country i is:

$$Y_{ik}(z) = A_{ik}(z)(T_{ik}L_{ik}(z))^{\lambda_{ik}} \left[\Pi_{n=g,s} M_{ikn}^{\gamma_{ikn}}(z)\right]^{1-\lambda_{ik}}, \tag{9}$$

where λ_{ik} denotes the country-specific value-added share in production, and γ_{ikn} denotes the country-specific share of intermediate inputs sourced from sector n; these parameters vary over time to track changes in input-output relationships. $Y_{ik}(z)$ denotes output, $L_{ik}(z)$ denotes labor input, and $M_{ikn}(z)$ denotes sector-n composite goods used as intermediates in the production of the sector k variety z. T_{ik} is the time-varying, exogenous productivity of varieties in sector k and scales value added equally across all varieties. $A_{ik}(z)$is a variety-specific productivity level that scales gross output, given by the realization of a random variable drawn from the cumulative distribution function $F(A) = Pr[Z \leq A]$. Following Eaton and Kortum (2002), we assume that $F(A)$ is a Fréchet distribution: $F(A) = e^{-A^{-\theta_k}}$, where $\theta_k > 1$. The larger θ_k is, the lower the heterogeneity or variance of $A_{ik}(z)$.[7] The parameters governing the distribution of idiosyncratic productivity draws are invariant across countries but different across sectors. We assume that the productivity is drawn each period.[8]

Total sectoral labor, input usage, and production in sector k in country i are the aggregates of the variety-level components taken over the set of varieties produced in country i, V_{ik}:

$$L_{ik} = \int_{V_{ik}} L_{ik}(z)\,dz; \quad M_{ikn} = \int_{V_{ik}} M_{ikn}(z)\,dz; \quad Y_{ik} = \int_{V_{ik}} Y_{ik}(z)\,dz.$$

Markets are perfectly competitive; prices are determined by marginal costs of production. The cost of an input bundle in sector k is:

$$v_{ik} = B_{ik} w_i^{\lambda_{ik}} \left(\Pi_{n=g,s} (P_{in})^{\gamma_{ikn}}\right)^{1-\lambda_{ik}},$$

where $B_{ik} = \lambda_{ik}^{-\lambda_{ik}}((1-\lambda_{ik})\Pi_{n=g,s}\gamma_{ikn}^{-\gamma_{ikn}})^{\lambda_{ik}-1}$. The cost of an input bundle is the same within a sector, but varies across sectors given different input shares.

3.3 Trade

When varieties are shipped abroad, they incur trade costs, which include tariffs, transportation costs, and other barriers to trade. We model these costs as exogenous iceberg costs, which vary over time to track the pattern of bilateral trade. Specifically, if one unit of variety z is shipped from country j, then $\frac{1}{\tau_{ijm}}$ units arrive in country i. We assume that trade costs within a country are zero, i.e., $\tau_{iig} = \tau_{iis} = 1$. This means that the price at which country j can supply variety z in sector k to country i equals $p_{ijk}(z) = \frac{\tau_{ijk} v_{jk}}{T_{ik}^{\lambda_k}}$. Since buyers will purchase from the cheapest source, the actual price for this variety in country i is $p_{ik}(z) = \min\{p_{ijk}(z)\}_{j=1}^{I}$.

Under the Fréchet distribution of productivities, Eaton and Kortum (2002) show that the price of composite good $k \in \{g, s\}$ in country i is:

$$P_{ik} = \Gamma_k \left[\sum_{j=1}^{I} \left(T_{jk}^{-\lambda_{jk}} v_{jk} \tau_{ijk}\right)^{-\theta_k}\right]^{-\frac{1}{\theta_k}}, \tag{10}$$

where the constant $\Gamma_k = \Gamma(1 - \frac{\eta-1}{\theta_k})^{\frac{1}{1-\eta}}$ denotes the Gamma function, and the summation term on the right-hand side summarizes country i's access to global production technologies in sector k scaled by the relevant unit costs of inputs and trade costs.[9]

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[7] $A_k(z)$ has geometric mean $e^{\frac{\gamma}{\theta_k}}$ and its log has a standard deviation $\frac{\pi}{\theta_k\sqrt{6}}$, where γ is Euler's constant.

[8] Alternatively, we could assume that the productivity is drawn once in the initial period, and as the T's change over time, the productivity relative to T remains constant.

[9] We assume $\eta - 1 < \theta_k$ to have a well-defined price index. Under this assumption, the parameter η, which governs the elasticity of substitution across goods within a sector, can be ignored because it appears only in the constant term Γ.

The share of country i's expenditure on sector-k goods from country j, π_{ijk}, equals the probability of country i importing sector-k goods from country j, and is given by:

$$\pi_{ijk} = \frac{\left(T_{jk}^{-\lambda_{jk}} \nu_{jk} \tau_{ijk}\right)^{-\theta_k}}{\sum_{s=1}^{I} \left(T_{sk}^{-\lambda_{sk}} \nu_{sk} \tau_{isk}\right)^{-\theta_k}}. \tag{11}$$

Equation (11) shows how a higher average productivity, a lower unit cost of input bundles, and a lower trade cost in country j translates into a greater import share by country i.

3.4 Equilibrium

Combining the goods and factor market clearing conditions and demand equations with the equations for the consumption of the composite good, trade shares, prices, and the global portfolio balance yields a set of conditions that fully characterize the equilibrium of the model. Table 2 collects these conditions. Equations (D1)-(D4) describe the household demand side. (D1) and (D2) provide optimal conditions for sectoral consumption and sectoral expenditure shares. (D3) specifies the aggregate price index given the preferences. (D4) is the budget constraint.

Table 2: Equilibrium conditions

D1	$C_{ik} = L_i \omega_k^{\sigma} \left(\frac{P_{ik}}{P_i}\right)^{-\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k}$	$\forall i,k$
D2	$e_{ik} = \omega_k^{\sigma} \left(\frac{P_{ik}}{P_i}\right)^{1-\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k - 1}$	$\forall i,k$
D3	$P_i = \left(\sum_{k\in\{g,s\}} \omega_k^{\sigma} \left(\frac{C_i}{L_i}\right)^{\varepsilon_k - 1} P_{ik}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$	$\forall i$
D4	$P_i C_i + \rho_i w_i L_i = w_i L_i + R L_i$	$\forall i$
S1	$\pi_{ijk} = \frac{\left(T_{jk}^{-\lambda_{jk}} \nu_{jk} \tau_{ijk}\right)^{-\theta_k}}{\sum_{\ell=1}^{I} \left(T_{\ell k}^{-\lambda_{\ell k}} \nu_{\ell k} \tau_{i\ell k}\right)^{-\theta_k}}$	$\forall i,j,k$
S2	$\nu_{ik} = B_{ik} w_i^{\lambda_{ik}} \prod_{n\in\{g,s\}} P_{in}^{(1-\lambda_{ik})\gamma_{ikn}}$	$\forall i,k$
S3	$P_{ik} = \Gamma_k \left(\sum_{j=1}^{I} \left(T_{jk}^{-\lambda_{jk}} \nu_{jk} \tau_{ijk}\right)^{-\theta}\right)^{-\frac{1}{\theta}}$	$\forall i,k$
S4	$w_i L_{ik} = \lambda_{ik} P_{ik} Y_{ik}$	$\forall i,k$
S5	$P_{in} M_{ikn} = (1-\lambda_{ik}) \gamma_{ikn} P_{ik} Y_{ik}$	$\forall i,k,n$
S6	$C_{ik} + \sum_{n\in\{g,s\}} M_{ink} = Q_{ik}$	$\forall i,k$
S7	$\sum_{j=1}^{I} P_{jk} Q_{jk} \pi_{jik} = P_{ik} Y_{ik}$	$\forall i,k$
G1	$\sum_{i=1}^{I} \rho_i w_i L_i = R \sum_{i=1}^{I} L_i$	
G2	$\sum_{k\in\{g,s\}} P_{ik} Y_{ik} - \sum_{k\in\{g,s\}} P_{ik} Q_{ik} = \rho_i w_i L_i - R L_i$	$\forall i$

Equations (S1)-(S7) are from the supply side. (S1) gives bilateral import shares in total absorption at the sector level. (S2) specifies the cost of a unit of the input bundle. (S3) gives sectoral prices. (S4) and (S5) state the optimal value added and intermediate input usages implied by the Cobb-Douglas production function. (S6) links sectoral aggregate absorption with final demand and intermediate input demand. (S7) links a country's total output in a sector with the sum of demand from all countries.

Equations (G1)-(G2) are from the global market clearing conditions. Equation (G1) specifies net transfers across countries are zero globally. Equation (G2) is the resource constraint at the country level. Together, these two conditions imply that the goods and services market clears.

We define a competitive equilibrium of our model economy with the exogenous time-varying processes for every country: labor endowment $\{L_i\}$, trade costs $\{\tau_{ijg}, \tau_{ijs}\}_{i,j=1}^{I}$, productivity $\{T_{ig}, T_{is}\}$, and contribution shares to the global portfolio $\{\rho_i\}$; time-varying structural parameters for every country $\{\lambda_{ik}, \gamma_{ikn}\}$; and time-invariant structural parameters $\{\sigma, \varepsilon_k, \omega_k, \theta_k\}_{k=g,s}$ as follows.

Definition 1. *A competitive equilibrium* is a sequence of output and factor prices $\{w_i, P_{ig}, P_{is}, P_i\}_{i=1}^{I}$, allocations $\{L_{ig}, L_{is}, M_{igg}, M_{igs}, M_{isg}, M_{iss}, Q_{ig}, Q_{is}, Y_{ig}, Y_{is}, e_{ig}, e_{is}, C_{ig}, C_{is}, C_i\}_{i=1}^{I}$, transfers from the global portfolio, R, and trade shares $\{\pi_{ijg}, \pi_{ijs}\}_{i,j=1}^{I}$, such that each condition in table 2 holds.

4 Calibration and Solution

To quantify the role of structural change in global trade flows, we calibrate the exogenous processes and the parameters in the model to match data from the 26 countries plus one rest-of-the-world aggregate over 1970–2015. Preference parameters, $(\sigma, \varepsilon_g, \varepsilon_s, \omega_g, \omega_s)$, are estimated using panel data on sectoral prices, expenditure shares, and total expenditure per worker. The trade elasticity, θ_k, is taken from the literature. Trade imbalances, ρ_{it}, and labor endowment, L_{it}, are set to match data on trade deficits and total number of employees. The production coefficients λ_{ikt} and γ_{iknt} are constructed using the input-output data. Processes for sectoral trade costs, τ_{ijkt}, and productivity, T_{ikt}, are constructed to match data on bilateral trade shares and expenditure shares.

We discuss the calibration procedures together with the corresponding data sources in the next three subsections. With the calibrated parameters, we can solve the baseline model fully in levels for each year $t = 1970, \ldots, 2015$. In the following section, we check the model fit by comparing untargeted moments in the model with those in the data.

4.1 Preference parameters

We recover preference parameters using the household optimality condition in equation (8) together with data on sectoral expenditure shares, prices and total expenditure per worker. As this equation applies to each sector, we take the log of the ratio of expenditure shares and obtain:

$$\log\left(\frac{e_{is}}{e_{ig}}\right) = \sigma \log\left(\frac{1-\omega_g}{\omega_g}\right) + (1-\sigma)\log\left(\frac{P_{is}}{P_{ig}}\right) + (\varepsilon_s - \varepsilon_g)\log\left(\frac{C_i}{L_i}\right). \tag{12}$$

Equation (12) explains the identification of parameters. Holding fixed variation in total expenditure per worker (income effects), the extent that relative expenditure shares move with relative prices helps us identify the elasticity of substitution, σ. Holding fixed relative prices, the extent that relative expenditures shares move with aggregate expenditure helps us identify income elasticities, $\varepsilon_g - \varepsilon_s$. Setting the sector weights, ω_k, to be constant across countries and over time allows us to exploit both the cross-section and time-series variation to identify the price and income elasticities.

To estimate the preferences parameters, we need data on sectoral expenditure shares, e_{ik}, sectoral prices, P_{ik}, aggregate expenditure, C_i, and employment levels, L_i. The construction of sectoral expenditure data are discussed in section 2. For sectoral prices, we use the World KLEMS and EU KLEMS Growth and Productivity Accounts databases, which contain gross output price deflators for about 20 countries in our sample.[10]

Aggregate expenditure corresponds to real domestic absorption (real private and public consumption and investment at current PPPs in 2011 US$) from the Penn World Table 9.0 (Feenstra, Inklaar and Timmer 2015). Aggregate employment also comes from the Penn World Table and corresponds to "number of persons engaged". Details of data construction and data sources are discussed in Appendix A.

We conduct the OLS regression given by equation (12) to uncover the preference parameters. The estimated results are reported in the second column of Table 3, with $\sigma = 0.36$ and $\varepsilon_s - \varepsilon_g = 0.47$. Both estimates are statistically significant at the 99% level. Encouragingly, these preference parameter estimates are in line with Comin et al. (2015), even though the underlying datasets are quite different, as they use data on sectoral employment and value added shares, instead of data on sectoral expenditure.[11] The estimates imply that goods and services are complements, and services have a higher income elasticity than goods.

We also report the results when either the logged relative prices or the logged real income per worker are used alone in the regression. As shown in the third and fourth columns of Table 3, both the relative price effect and the income effect are important in accounting for variation in expenditure shares, though the marginal importance of the income effect is greater. Moreover, the explanatory power is much higher when including both relative prices and income, compared to including only one at a time. The R^2 is 72% with both variables, while it is only 41% with relative

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[10] The price deflators in these databases are at the industry level, so we weigh by the value of gross output in each industry to generate goods and services prices. To make the prices comparable across countries, we splice the price indexes to the 2005 cross-country price level data from the Groningen Growth and Development Centre's Productivity Level Database (Inklaar and Timmer 2014). More detail on this data is provided in Appendix A.

[11] Comin et al. (2015) estimate a substitution elasticity of 0.50 and $\varepsilon_s - \varepsilon_g$ of 0.21 with data on agriculture, manufacturing, and services value added and employment. Their data goes back to 1947, and includes 37 countries.

prices alone and 66% with relative income per worker alone. Thus, nonhomothetic preferences are crucial in accounting for the patterns of expenditure shares observed in the data.

Table 3: Regression results

Variable	Prices & income	Income only	Prices only
σ	0.36^{***}		-0.44^{***}
	(0.05)		(0.07)
$\varepsilon_s - \varepsilon_g$	0.47^{***}	0.58^{***}	
	(0.02)	(0.01)	
constant	-4.13^{***}	-5.32^{***}	0.89^{***}
	(0.18)	(0.15)	(0.01)
N	846	846	846
Adjusted R^2	0.72	0.66	0.41

Note: Robust standard errors are in parentheses, with *** denoting a 99% significance level.

Notice that including only the relative price on the right-hand side results in a negative price elasticity, which is outside of the range of theoretically plausible estimates. This omitted variable bias stems from the underlying pattern in the data that in all countries, expenditure shifted towards services—the sector which became relatively more expensive. On the other hand, including only aggregate expenditure implies a larger income elasticity compared to including both aggregate expenditures and relative prices, since the relative price of services and consumption per worker both rise with development.

We normalize the income elasticity for goods $\varepsilon_g \equiv 1$ as in Comin et al. (2015). As a result of the estimation, the income elasticity for services ε_s is 1.47 . We have flexibility in setting ω_g by changing the units of relative prices. Specifically, we normalize relative prices such that $\omega_g = 0.21$—the U.S. expenditure share on goods in 2011.[12] We also normalize all prices so that the model-implied estimate of C/L matches U.S. data in 2011—\$113,725 (real domestic absorption per worker, in 2011 U.S. prices).[13] This alignment of prices is critical for the upcoming estimation of productivity levels in a model with nonhomothetic preferences where the scale matters. Table 4 summarizes the parameter values for the preferences. Note that these parameters are consistent with the regularity conditions (i) from Section 3.1 required by the preferences specification, namely $0 < \sigma < 1$ and $\varepsilon_k > \sigma$ for all k.

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[12] Using equation (12), we define $\log(s_{rp}) = \frac{\text{constant}}{1-\sigma} - \frac{\sigma}{1-\sigma}\log(\frac{1-\omega_g}{\omega_g})$, where constant is -4.13 from the baseline regression in the first column of Table 3. s_{rp} is the scale parameter applied to the relative prices series. Clearly, s_{rp} is a constant that does not affect the estimation of σ and $\varepsilon_s - \varepsilon_g$.

[13] We scale both P_g and P_s so that the model-implied consumption levels, C in the U.S. in 2011 is the same as in the data. These scaling adjustments are applied proportionately in all countries and years meaning all the estimates are invariant. This adjustment essentially scales the units of productivity in the model. The scale adjustment for relative prices scales the relative productivity in goods versus services.

Table 4: Preferences parameter values

σ	Elasticity of substitution b/w sectors	0.36
ε_g	Elasticity of income in goods	1
ε_s	Elasticity of income in services	1.47
ω_g	Preference weight on goods	0.21

4.2 Parameters directly from the literature and the data

We set the dispersion parameter of productivity draws in the goods sector, θ_g, at 4, following Simonovska and Waugh (2014). There is no reliable estimate of the trade elasticity for services, so we set $\theta_s = 4$ as well. We conduct sensitivity analysis for a smaller θ_s of 2.5 in Appendix C; the main results are robust. The elasticity of substitution between varieties in the composite good, η, plays no quantitative role in the model other than satisfying $1 + (1-\eta)/\theta > 0$; we set this value at 2. The upper panel of Table 5 summarizes these parameter values that are common across countries and constant over time.

The country-specific, time-varying production parameters, γ_{iknt} and λ_{ikt}, are constructed using the World Input-Output Database (WIOD), condensed to a two-sector input-output construct for each country from 1995-2011. Specifically, λ_{ikt} is the ratio of value added to total production in sector k, while the γ_{iknt} terms are the share of sector k inputs that are sourced from sector n. For years prior to 1995 and after 2011, we impute the shares by (i) estimating a relationship between each share and GDP per worker during 1995 and 2011 and (ii) using the estimates and observed GDP per worker before 1995 and after 2011.

While these production shares vary significantly across countries, they change only mildly over time. Moreover, there are notable patterns that hold across countries. First, production of services is more value-added intensive than production of goods. The lower panel of Table 5 indicates that, on average, 61 percent of total service production compensates value-added factors, compared to 39 percent in goods. Second, inputs from goods sectors account for 70 of intermediate expenditures by the goods sector. That is, goods production is goods-intensive. Similarly, services production is service intensive: inputs from the service sector account for 64 percent of intermediate expenditures by the service sector. Still, cross-sector linkages are relatively strong: roughly one-third of intermediate inputs in each sector is sourced from the other sector.

The parameters, ρ_{it}, are calibrated to match each country's ratio of net exports to GDP. In the model, the ratio of net exports to GDP in country i at time t is $\frac{\rho_{it} w_{it} L_{it} - R_t L_{it}}{w_{it} L_{it}}$. In the calibration we let $R_t = 0$ and simply set $\rho_{it} = \frac{NX_{it}}{GDP_{it}}$. So long as net exports sum to zero across countries (which it does in our data), the global portfolio is balanced. In the counterfactual analysis, the endogenous term R_t adjusts to ensure that the global portfolio balances period-by-period: $R_t \sum_{i=1}^{I} L_{it} = \sum_{i=1}^{I} \rho_{it} w_{it} L_{it}$.

Table 5: Production parameter values

Common parameters		
θ_g	Trade elasticity in goods sector	4
θ_s	Trade elasticity in service sector	4
η	Elasticity of substitution b/w varieties in composite good	2
Cross-country, cross-time averages		
λ_g	Ratio of value added to gross output in goods	0.39
λ_s	Ratio of value added to gross output in goods	0.61
γ_{gg}	Good's share in intermediates used by goods sector	0.70
γ_{sg}	Good's share in intermediates used by service sector	0.36

4.3 Technology and Trade Costs

We recover the exogenous productivity terms, T_{ik}, and trade costs, τ_{ijk}, by exploiting structural relationships from our model in order to match data on sectoral expenditures and bilateral trade flows in each country and every year. Our procedure is similar to that of Święcki (2017), but incorporates input-output linkages as in Levchenko and Zhang (2016) and Sposi (2018). By explicitly making use of the observed input-output linkages, our procedure also implies that we simultaneously match sectoral value added.

Two key structural relationships provide identification for productivity and trade costs:

$$T_{ik}^{\lambda_{ik}} = \frac{v_{ik}}{\Gamma_k^{-1} P_{ik} \left(\pi_{iik}\right)^{-\frac{1}{\theta_k}}}, \tag{13}$$

$$\tau_{ijk} = \left(\frac{\pi_{ijk}}{\pi_{jjk}}\right)^{-\frac{1}{\theta_k}} \left(\frac{P_{ik}}{P_{jk}}\right). \tag{14}$$

Both structural relationships are derived by manipulating equations (10) and (11). Measurement of sectoral productivity takes into account differences between imputed input costs and imputed output prices. Holding fixed the unit costs of inputs, the model assigns a high productivity to a country with a low price, meaning that inputs are converted to output at an efficient rate. It also takes into account the home trade share, which reflects the selection effect in Ricardian trade models.

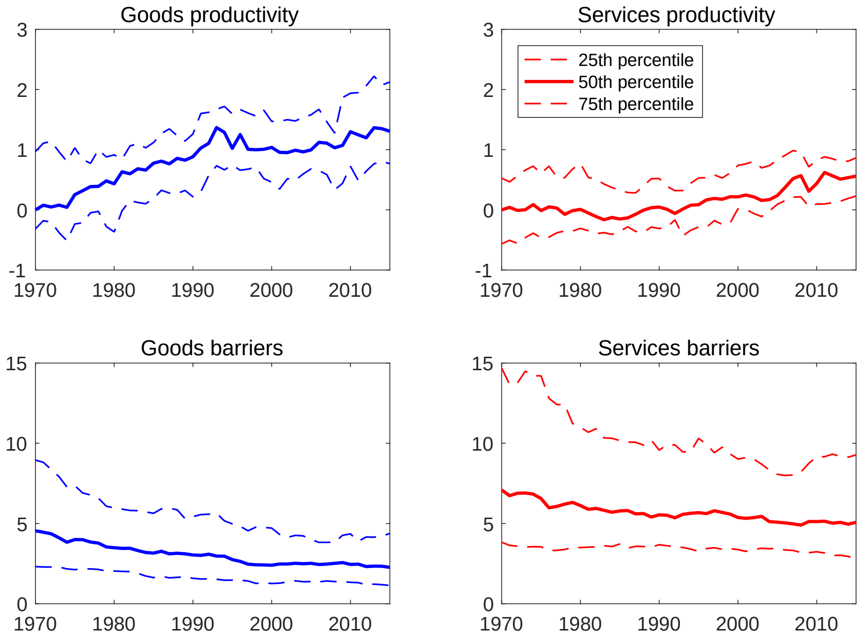
Measurement of the trade costs takes into account imputed price differences and the bilateral trade shares. Holding fixed the imputed price difference between countries i and j, if country i imports a large share from country j relative to what j sources from itself, the inferred trade barrier is low. In this sense, the trade costs are simply wedges that reconcile the observed pattern of trade.

To match sectoral expenditure shares, we need to target prices that would deliver observed expenditure shares given the estimated preferences parameters and observed aggregate expenditure per worker. Specifically, given preference parameters, $(\omega_g, \omega_s, \sigma, \varepsilon_g, \varepsilon_s)$, sectoral expenditure shares,

e_{ik}, labor endowment, L_i, and aggregate real expenditure, C_i, we invert the household's first-order condition (8) to recover model-implied price levels that support the expenditure shares for each country in each period. Our model does not have enough degrees of freedom to match data on both sectoral prices and sectoral expenditures simultaneously. We choose to match expenditures since they are of first order interest to our question and expenditures shares have higher quality data.

In addition to sectoral prices, we also need data on trade shares π_{ijk} and wages w_i, where wages are used to construct unit costs. With these data series, we use equations (13) and (14) to compute the sectoral productivity and trade costs, which are illustrated in figure 4. The upper panel plots the log of the fundamental productivity levels, T_{ik}, of the median country (solid lines), the 25th percentile country and the 75th percentile country (dashed lines) at the sector level in each year. As shown in the figure, productivity grows faster in goods than in services. Specifically, over the sample period, on average the median fundamental productivity series grows by 3.5% per year in the goods sector and by 1.5% in the services sector. The cross-country productivity dispersion barely changes over time in the goods sector, but shrinks in the services sector.

Figure 4: Calibrated global productivity and trade costs



Note: Productivity plots in each sector are normalized by the 1970 value of the median series of that sector. Trade barrier plots report the net trade cost, $\tau - 1$.

To gauge how reasonable these fundamental productivity series are, we compare the model implied labor productivity with that in the data. Note that in a model with trade selection, the model-implied labor productivity is in general higher than the fundamental productivity. By targeting aggregate value added and total employment in the calibration, the model matches the observed aggregate labor productivity (GDP per worker, deflated by the consumer price index) for each country and each year perfectly. We then examine the model-implied sectoral labor productivity, and find it consistent with the data. On average, median labor productivity for goods grows by 4.7% per year in the model, compared to 4% in the data. For services, the median labor productivity grows by 1.7% per year in the model, compared to 1.5% in the data. While perfectly fitting aggregate productivity growth, the calibrated model slightly overshoots in sectoral productivity growth, because the calibration does not target sectoral employment or sectoral prices in the data.

The lower panel of figure 4 plots the net trade barriers, $\tau_{ijk}-1$, for goods and services over time. Again, the solid line is for the median level, and the dashed lines are for the 25th percentile and the 75th percentile. As illustrated in the figure, trade costs for both goods and services decline over time, and trade costs in services are generally higher than those in goods. Also, the cross-country dispersion of the trade barriers declines substantially in both sectors over time. Furthermore, the trade barriers decline faster in the goods sector than in the services sector. Over the sample period, the median trade barriers decline by about 50% (from 4.5 to 2.3) for goods, but only by about 30% (from 7.1 to 5.1) for services. The magnitudes of our estimated trade barriers for the goods sector are similar to those in Levchenko and Zhang (2016), and many other papers in the literature.

4.4 Model Fit

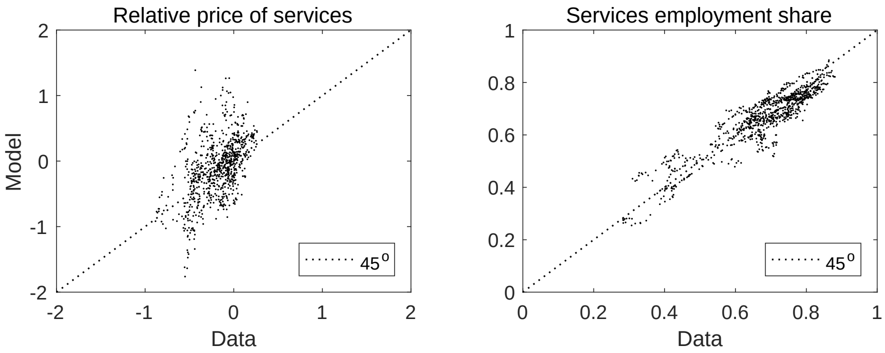
Our calibration procedure ensures that the model fits data on sectoral value added, sectoral gross output, sectoral absorption, sectoral bilateral trade flows, sectoral expenditures, aggregate real expenditures, and total employment. We now check the fit of the model on two observed moments that are not targeted directly by the calibration.

The first one is the relative price, which is illustrated in the left panel of figure 5. Each point corresponds to the relative price for a country-year with the model value on the y-axis and the data value on the x-axis. Of course, the points are limited by the incomplete coverage of the price data. All relative prices are taken relative to the U.S. in 2011. The relative prices fit the data reasonably well; the correlation between the model and the data is 0.50. The correlation between the model and the data for goods prices is 0.49 and that for services is 0.47.

The second moment we check is the sectoral employment share. In the right panel of figure 5, we plot the services employment shares in the data against those implied by the baseline model. The baseline model succeeds in replicating the labor shares across sectors for all sample countries over time. The correlation between the data series and the model series is 0.92.

The calibration successfully matched the targeted moments in the data. Moreover, the calibrated model fits well on the above data moments that are not directly targeted by the calibration. Thus, the baseline model closely maps into the relevant data for our analysis, and serves as the base for the counterfactual analysis in the next section.

Figure 5: Relative prices and services labor shares: model versus data



Note: Relative prices are normalized relative to the U.S. in 2011. Employment share depicts the number of workers engaged in services as a share of the entire workforce.

5 Model-based Counterfactuals

This section quantitatively assesses the dampening effect of structural change on global trade volumes in the past five decades by conducting counterfactuals using the calibrated model. We find that the magnitude of this dampening effect from structural change is as large as the boosting effect of declining trade costs on openness in this period. We also highlight the importance of structural change on the measurement of the gains from trade.

5.1 Global Trade in the Absence of Structural Change

To examine the implications on global trade flows from structural change, we construct a counterfactual in which structural change is absent by restricting expenditure shares to be constant over time. This provides the closest model-based analogue to our reduced-form counterfactual in Section 2. To do so, we assume that the preferences in the counterfactual are given by:

$$C_i = \prod_{k \in \{g,s\}} C_{ik}^{\omega'_{ik}}. \tag{15}$$

With the Cobb-Douglas specification, the income elasticities are 1 for both sectors and the substitution elasticity is also 1 across the two sectors. Consequently, expenditure shares across sectors are constant over time. That is, we choose values for $\omega'_{ik} = e_{ik0}$ so that in 1970 the sectoral expenditure shares are identical to those in the baseline model.

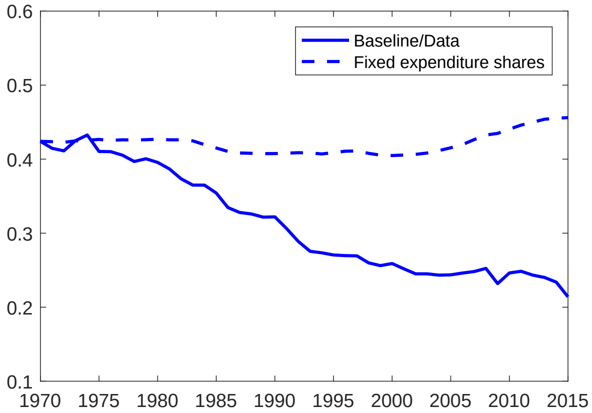
All underlying processes in the counterfactual are identical to those in the baseline. Specifically, in the counterfactual we assume all other parameters and time varying processes for T, τ, and L are unchanged from the baseline, except that the preference parameters $\{\sigma, \varepsilon_k, \omega_k\}$ in the baseline are set to $\{1, 1, \omega'_{ik}\}$ in the counterfactual experiment. That is, prices and trade flows still evolve endogenously over time, and are determined by the patterns of technological change and changes in trade costs.

We compute the equilibrium for the counterfactual experiment and analyze how the absence of structural change impacts global trade flows. Our solution procedure is based on Alvarez and Lucas (2007). Start with an initial guess for the vector of wages. Given wages, recover all remaining prices and quantities across countries using optimality conditions and market clearing conditions, excluding the trade balance condition. Then use departures from the trade balance condition to update the wages. Iterate on wages until the trade balance condition holds. The exact details are available in Appendix B.

5.1.1 Model counterfactual results

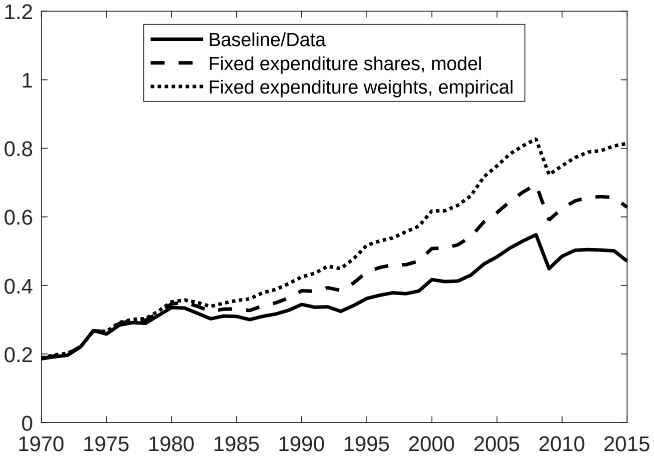
We start by highlighting the driving force of the counterfactual in figure 6. In the data and baseline model, the goods share of total expenditure falls from about 42 in 1970 percent to 20 percent in 2015, as shown by the solid line. In the counterfactual, the goods expenditure share is held fixed at the 1970 values, country-by-country. When aggregated to a global expenditure share, it remains close to 50 percent over time, increasing somewhat near the end of the sample, as shown by the dashed line. The slight rise since 2002 is driven by the increasing weight of China and India in the world economy, both of which have larger expenditure shares in goods compared to the developed countries.

Figure 6: Goods expenditure shares: baseline and counterfactual



We next present the implications for global trade flows. Figure 7 compares openness between the model baseline (solid line), model counterfactual (dashed line), and reduced-form counterfactual (dotted line). In both counterfactuals, global trade would have been much higher had structural change not occurred. By 2015, the reduced-form counterfactual puts openness at 81 percent while the model counterfactual puts it at 63 percent, compared with 48 percent in the data. The difference between the two counterfactuals peaks in 2015 and is driven by the endogenous changes to sectoral openness generated by the model.[14]

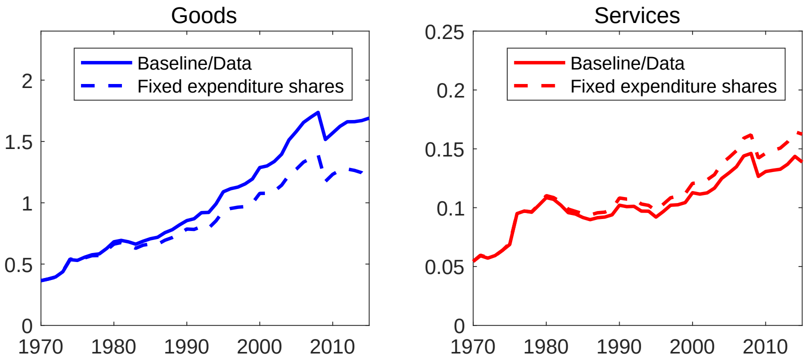
Figure 7: Openness: baseline and counterfactuals



5.1.2 Quantitative mechanisms

The motivation for our model of structural change is the ability of the model to deliver an alternate path for sectoral openness that responds to the same forces that drive structural change. Figure 8 shows sectoral openness in the model counterfactual compared with observed sectoral openness (which both the model baseline and the reduced-form counterfactual use). The left panel shows that goods openness (the ratio of goods trade to goods expenditure) is about 50 percentage points lower relative to the baseline in 2015, while services openness is about 2 percentage points higher.

Figure 8: Sectoral openness: baseline and counterfactual



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[14] Appendix D shows structural change and the model-based counterfactual for each country in figure 17 and 18 respectively, as well as a decomposition of each country's contribution to the aggregate counterfactual in table 6 for 2015.

To understand how sectoral openness endogenously responds to changes in expenditure shares in the model, we decompose sectoral trade openness into two terms: (i) the ratio of trade to absorption and (ii) the ratio of absorption to expenditure:

$$\frac{Trade_{kt}}{Exp_{kt}} = \left(\frac{Trade_{kt}}{Abs_{kt}}\right) \times \left(\frac{Abs_{kt}}{Exp_{kt}}\right). \tag{16}$$

These two terms correspond to two potential channels of bias inherent in the reduced-form counterfactual. Through endogenous general equilibrium effects, changing sectoral demand might change the relative wages across countries, and thus the ratio of trade to absorption, which is captured by the first term. In the model, at the country level, the first term resembles $1-\pi_{iik}$ for each country i and sector k.[15] Also, changing the sectoral demand shares might affect the ratio of absorption to expenditure through input-output linkages, as captured by the second term.

We now quantify the bias of each channel. The ratios of trade to absorption in each sector are almost identical in the baseline and in the counterfactual, as shown in the upper panel of figure 9. Recall the expression of π_{iik} in equation (S1) in table 2. Since the productivity and the trade cost processes are exogenous and thus unchanged, changing expenditure patterns affect the trade-over-absorption ratios only through their impact on relative wages across countries. It turns out that the general equilibrium effect on relative wages is quantitatively small in the model counterfactual. Thus, the share of each country's absorption that is sourced from abroad in each sector barely changes from the baseline to the counterfactual.

The primary reason why sectoral trade openness in the model counterfactual differs from the baseline is due to differences in the ratio of absorption to expenditure, as shown in the lower panel of figure 9. The ratios of absorption to expenditure in the counterfactual rise by less over time for the goods sector, but rise by more over time for the services sector, compared with the baseline. Using the expression of sectoral absorption in equation (S6) of table 2, we can write the sectoral ratio of absorption to expenditure as:

$$\frac{Q_{ig}}{C_{ig}} = \frac{C_{ig}+M_{igg}+M_{isg}}{C_{ig}}, \qquad \frac{Q_{is}}{C_{is}} = \frac{C_{is}+M_{igs}+M_{iss}}{C_{is}},$$

where sectoral absorption equals final plus intermediate demand for the sectoral composite good. In order to counterfactually increase consumption of goods, C_{ig}, intermediates must be sourced from both sectors, implying that M_{igg} and M_{igs} rise, since these are directly used to produce the greater demand for goods consumption. At the same time, derived demand for M_{isg} and M_{iss} decline in response to a decline in C_{is}. Consequently, absorption rises by less than expenditure in the goods sector, while absorption declines by less than expenditure in the services sector, implying lower $\frac{Q_{ig}}{C_{ig}}$

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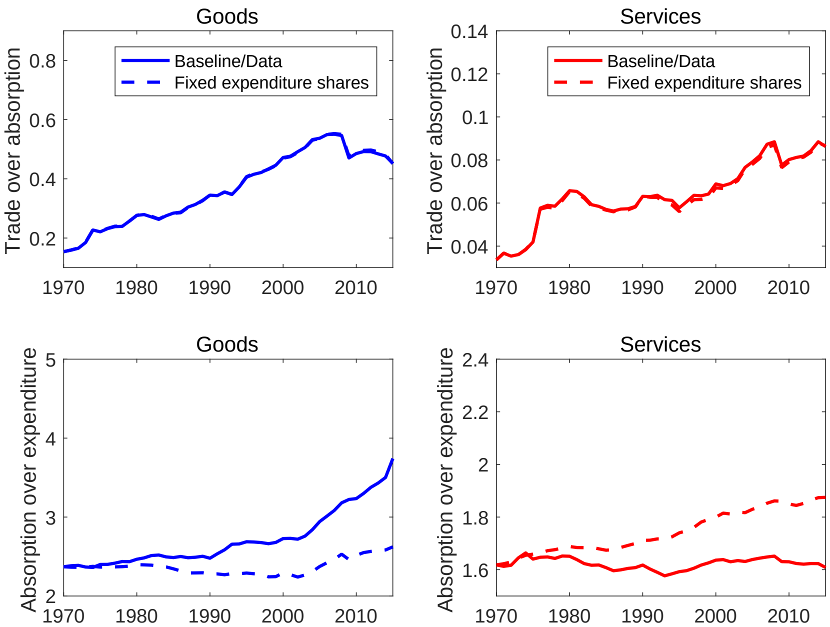
[15] Sectoral imports over expenditure is exactly equal to $1-\pi_{iik}$. Sectoral exports differ, but quantitatively they are highly correlated with sectoral imports across countries.

Figure 9: Decomposition of sectoral openness



and higher $\frac{Q_{is}}{C_{is}}$ in the model counterfactual compared with the baseline.

Going back to figure 8, we conclude that although services trade openness goes up, goods openness decreases sufficiently to imply a lower overall trade openness in the model counterfactual than in the empirical counterfactual. This major bias of the reduced-form counterfactual in predicting global trade openness in the absence of structural change comes from ignoring input-output linkages across sectors. To confirm the importance of cross-sector input-output linkages, we recalibrate the baseline model with no cross-sector input-output linkages ($\gamma_{gg} = \gamma_{ss} = 1$). We then conduct a similar fixed expenditure counterfactual, and find that the absence of structural change now barely impacts sectoral trade openness.

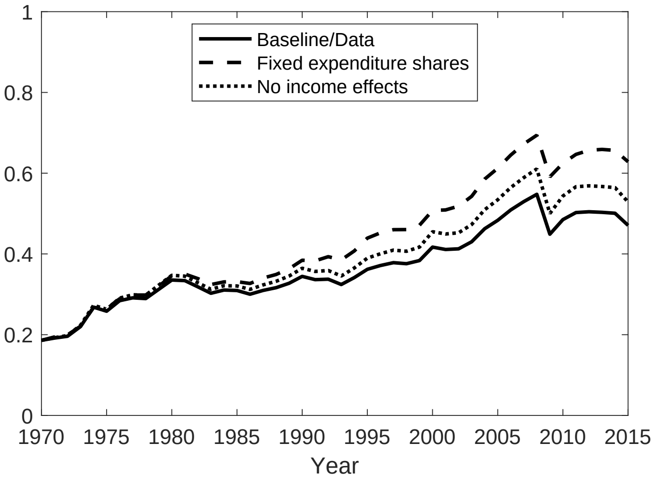
5.1.3 Decomposing income versus substitution effects

The literature on structural change has established two key mechanisms: income effects and substitution effects. Boppart (2014) provides the first model that incorporates both income and substitution effects to generate structural transformation along a balanced growth path. Herrendorf, Rogerson and Valentinyi (2013) demonstrate that when structural change is defined over final expenditures instead of value added, as it is in our paper, then income effects play a nontrivial role relative to substitution effects.

We use our model to evaluate the relative importance of each effect in shaping global trade flows. In our model counterfactual, we set $\varepsilon_s = 1$ so that preferences are homothetic, i.e., income elasticity of demand in each sector equals 1.[16] By comparing global trade openness implied by this experiment with that of the counterfactual with both effects shut off, we can see to what extent the income effect drives our results. Alternatively, the comparison will illustrate the power of the substitution effect alone.

Figure 10 plots the world ratio of trade to expenditure implied by our model counterfactual without the income effect, depicted with the dotted line. For comparison, we also plot trade openness in the data with the solid line and the one implied by our model counterfactual without the income and substitution effect with the dashed line. As can be seen in the figure, the model that shuts down the income effect leads to a ratio of trade to expenditure about 5 percentage points higher than the data, or about one-third of the difference between the data and the fixed-expenditure-shares counterfactual. Thus, the income effect's contribution to structural change affects international trade over this time period, but the substitution effect's contribution is greater.

Figure 10: Openness: no-income-effect counterfactual



5.2 Global Trade in the Absence of Declining Trade Costs

Arguably, declining trade costs are the most common factor attributed to the rise in global openness. Indeed, the past few decades have witnessed drastic reductions in both shipping costs and tariffs. To examine the role of declining trade barriers, consider a counterfactual in the model where trade barriers are held at their 1970 levels. The resulting trade openness is illustrated by the dotted line in figure 11. In this world, the global ratio of trade to expenditure grows only by about 15 percentage points instead of about 30 over the sample period. That is, declining trade costs since 1970 have added about 15 percentage points to the ratio of trade to expenditures by 2015. Of course, trade costs in the baseline model are calculated as the residuals required to account for changes in trade

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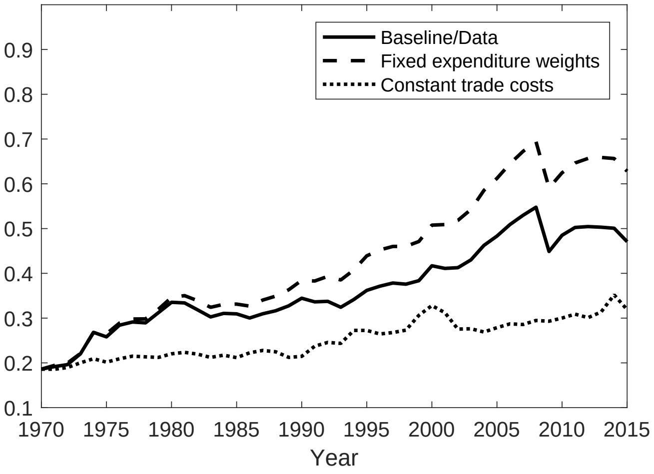
[16] We adjust the preferences weights, ω_{ik}, so that in 1970 the sectoral expenditures are identical to those in the baseline model.

not driven by technology or demand. As such, they incorporate a wide variety of economic forces, including tariff reductions, improvements in shipping technology, or even compositional changes in demand at a finer level of disaggregation than our goods and services distinction.

That said, the constant-trade-cost counterfactual also demonstrates the quantitative significance of structural change on global trade openness. As shown in figure 11, structural change has held back trade by roughly the same magnitude as reductions in trade costs have boosted trade over the past four decades. However, structural change has not received enough attention in the trade literature when accounting for the dynamics of openness. The following section shows that incorporating structural change also impacts one of the central themes in international trade: the measurement of the gains from trade.

Figure 11: Openness: constant-trade-cost counterfactual



5.3 Importance of Structural Change for the Gains from Trade

This section illustrates the importance of incorporating structural change in estimating the gains from trade. Following the convention in the literature, we define gains from trade as the absolute percent change in real value added, $y_i = \frac{w_i L_i}{P_i}$, associated with moving from the observed level of trade to autarky.[17] Our baseline model with *endogenous structural change* permits differences in the expenditure shares across the two different trade regimes used when calculating the gains from trade. To highlight this implication, we consider two alternative specifications: (i) *no structural change*, in which expenditure shares are fixed over time; (ii) *exogenous structural change*, in which expenditure shares vary over time in line with the data, but do not change when moving from the

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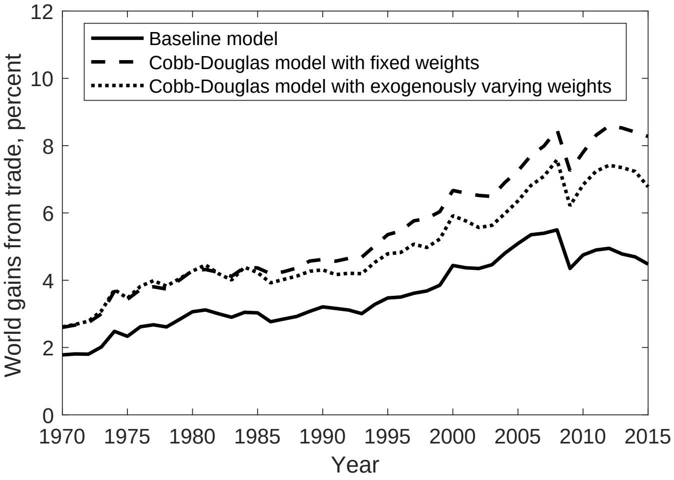
[17] We choose real income rather than consumption because our baseline model includes trade imbalances via transfers using a global portfolio. Under autarky, trade must balance. We do not want our estimate of the gains from trade to be influenced by the addition or removal of transfers. Results are robust when we assume balanced trade in the baseline.

level of observed trade to autarky.[18] When compared to either specification, endogenous structural change delivers systematically lower gains from trade.[19]

Figure 12 compares the global gains from trade, in terms of global real value added, over time for these three scenarios. The solid line is for the endogenous structural change case; the dashed line is for the no structural change case; and the dotted line is for the exogenous structural change case. In all three cases, the gains from trade increase over time alongside rising global openness. The gains from trade rise from 2.6% in 1970 to 8.3% and 6.8% in 2015 for the no structural change case and for the exogenous structural change case, respectively. In contrast, the baseline model with endogenous structural change implies that the gains from trade rise only from 1.8% in 1970 to 4.5% in 2015. Thus, exogenous structural change dampens the growth in the gains from trade relative to the no structural change case. Endogenous structural change further dampens the growth in the gains from trade; by 2015, the gains from trade in the endogenous structural change case are about two-thirds of those in the exogenous structural change case and about one-half of those in the no structural change case.

Figure 12: Global gains from trade



Why are the gains from trade lower with structural change? The intuition is that structural change pushes a greater share of expenditures to the sector with lower gains from trade. When the world integrates, greater consumption of both goods and services yield increasing gains from trade over time. However, the gains are greater in the highly-traded goods sector compared to the

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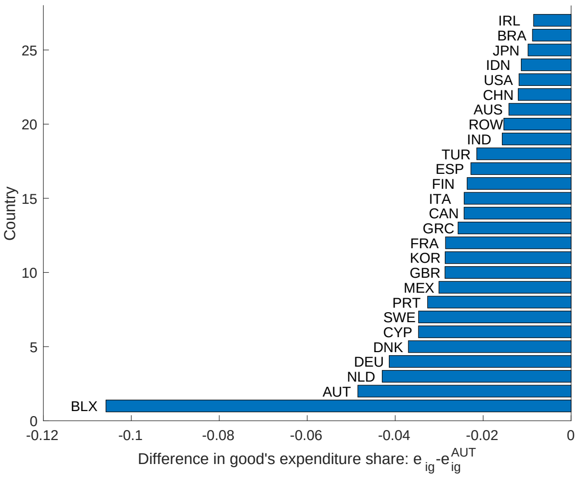
[18] Specifically, the endogenous structural change model incorporates our baseline model's nonhomothetic, CES preferences. The model with no structural change features Cobb-Douglas preferences with expenditure shares fixed at the 1970 levels. The exogenous structural change model features Cobb-Douglas preferences with time-varying expenditure shares.

[19] Importantly, this result depends on the relationship the fact that $\pi_{iis} > \pi_{iig}$ and $\varepsilon_s > \varepsilon_g$. That is, including nonhomothetic CES preferences in any arbitrary multi-sector model will not necessarily reduce the gains from trade—it does so here because of the presence of structural change.

less-traded services sector. Relative to the constant expenditure case, exogenous structural change dampens the growth of the gains from trade by allocating less expenditures on goods over time.

Endogenous structural change introduces an additional dampening mechanism: within each year, expenditures tilt even further away from goods to services as income rises and the relative goods price declines in response to increasing trade integration. That is, declining trade costs associated with moving from autarky to open trade themselves induce structural change. This mechanism is absent in the other two cases. Using 2010 as an example, Figure 13 shows that the model-implied expenditure share on goods falls by an average of about 3 percentage points when a country moves from autarky to trade. Thus, the contribution to gains from trade coming from higher goods consumption is lower with endogenous structural change. Empirically, the goods sector is most important for the gains from trade (since it is more open), hence, endogenous structural change implies smaller aggregate gains from trade compared to the other cases.[20]

Figure 13: Difference in goods expenditure shares in 2010: Trade versus autarky



Although the argument laid out above is intuitive, the quantitative result remains somewhat puzzling, as Costinot and Rodríguez-Clare (2014) and others have demonstrated that trade models featuring CES-style preferences with an elasticity parameter $\sigma < 1$ (as we have) tend to deliver *larger* gains from trade than those with Cobb-Douglas preferences, the opposite of our result. Thus, it is useful to connect to this literature by illustrating how our nonhomothetic CES preferences alters the gains from trade. To do so, we use a simplified version of our baseline model in which trade is balanced in each period and there are no input-output linkages. We derive a sufficient-statistic formula for the gains from trade for this simplified version of our model.

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[20] Arkolakis, Costinot, Donaldson and Rodríguez-Clare (2017) use additively separable nonhomothetic preferences to study the implications of variable markups on the gains from trade and find that the welfare gains are lower than the CES case with constant markups. In contrast, our model features perfect competition (zero markups), and nonhomothetic preferences lower the gains from trade relative to the CES case due to a different mechanism that we highlight here.

Proposition 1: The gains from trade in the simplified version is given by

$$G_i = 1 - \widehat{C}_i = 1 - \left(\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \pi_{iik}^{\frac{\sigma-1}{\theta_k}} \right)^{\frac{1}{\sigma-1}}, \tag{17}$$

where $\widehat{x} = x^{AUT}/x$ denotes the ratio of the variable x in autarky relative to trade.

Proof: See Appendix E.

To obtain the intuition for the expression for the gains from trade, let's start with the term that captures the inverse of the sectoral gains from trade, $\pi_{iik}^{\frac{1}{\theta_k}}$, which are governed by the home absorption share π_{iik} and the trade elasticity θ_k at the sector level. The lower the home absorption share is, the greater are the sectoral gains. Moreover, the sectoral gains from trade are invariant to the preferences specification. Aggregate gains from trade G_i, on the other hand, depend on the specification of preferences, and the preference weights across sectors $e_{ik}\widehat{C}_i^{\varepsilon_k - 1}$, in addition to the sectoral gains from trade, as shown in equation (17). Notice that we can solve (implicitly) for $\widehat{C}_i$ and thus G_i from equation (17), given observables (π_{iik}, e_{ik}) and parameters (θ_k, σ, ε_k).

The gains from trade under standard homothetic CES and Cobb-Douglas preferences are special cases of our generalized preferences. For the homothetic CES case, set $\varepsilon_k = 1$ in equation (17):

$$G_i^{\text{CES}} = 1 - \left[\sum_k e_{ik} \left(\pi_{iik}^{\frac{1}{\theta_k}} \right)^{\sigma-1} \right]^{\frac{1}{\sigma-1}}, \tag{18}$$

which is derived in Costinot and Rodríguez-Clare (2014) with a different approach. The gains from trade under the Cobb-Douglas preferences can be derived by further taking σ asymptotically to 1:

$$G_i^{\text{CD}} = 1 - \prod_k \pi_{iik}^{\frac{e_{ik}}{\theta_k}}. \tag{19}$$

Cobb-Douglas preferences are widely used in the existing trade literature. As shown in equation (19), the gains from trade geometrically average the sectoral gains with the observed sectoral expenditure shares e_{ik}. Homothetic CES preferences aggregate the sectoral gains differently with the observed expenditure shares e_{ik} and σ as in equation (18), which already changes the implied gains from trade. However, both Cobb-Douglas and homothetic CES preferences fail to account for the fact that expenditure shares respond to changes in the trade regime. Our nonhomothetic CES preferences factor in endogenous shifts of the expenditure shares to changing trade regimes through changes in total consumption. As shown in equation (17), the changes in real income, $\widehat{C}_i^{\varepsilon_k - 1}$, modify the sectoral expenditure shares used to weigh the changes in the sectoral gains. Since sectors differ in their income elasticity ε_k, the sectoral gains from trade will be weighed differently with a consideration of the response of expenditure shares when moving from trade to autarky.

We next illustrate that the gains from trade in our nonhomothetic CES preferences are positive under the regularity conditions in Proposition 2. Moreover, Proposition 3 shows that the gains from trade under the nonhomothetic case are lower than those under the homothetic CES case.

Proposition 2: The gains from trade in equation (17) are positive with $0 < \sigma < 1$ and $\varepsilon_s > \varepsilon_g = 1$.

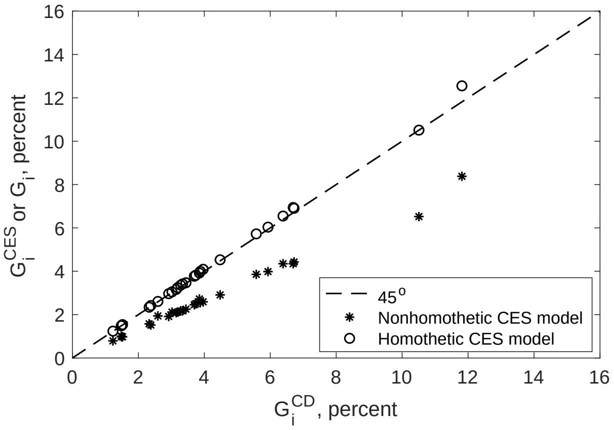
Proof: See Appendix E.

Proposition 3: The gains from trade in equation (17) are lower than those for the homothetic CES preferences, given by equation (18) with $0 < \sigma < 1$ and $\varepsilon_s > \varepsilon_g = 1$.

Proof: See Appendix E.

Figure 14 compares the gains from trade computed for (i) nonhomothetic CES preferences G_i in equation (17), (ii) homothetic CES preferences G_i^{CES} in equation (18), and (iii) Cobb-Douglas preferences G_i^{CD} in equation (19), using the identical sectoral trade openness observed in 2010. Each observation corresponds to a country. Circles contrast G_i^{CD} on the horizontal axis with G_i^{CES} on the vertical axis, while stars contrast G_i^{CD} on the horizontal axis with G_i on the vertical axis. As can be seen from the circles, the CES preferences with $\sigma = 0.36$ result in slightly higher welfare gains for all countries than the Cobb-Douglas preferences. This is consistent with the finding in Costinot and Rodríguez-Clare (2014): when $\sigma < 1$, it becomes more costly to substitute consumption acrss sectors. Thus, the reallocation of production following lower trade barriers has marginally higher effects on overall welfare. However, as shown by the stars in figure 14, the gains from trade for all countries are substantially lower under nonhomothetic preferences than under both the CES and Cobb-Douglas cases. This finding is consistent with the results in figure 12.

Figure 14: Country gains from trade



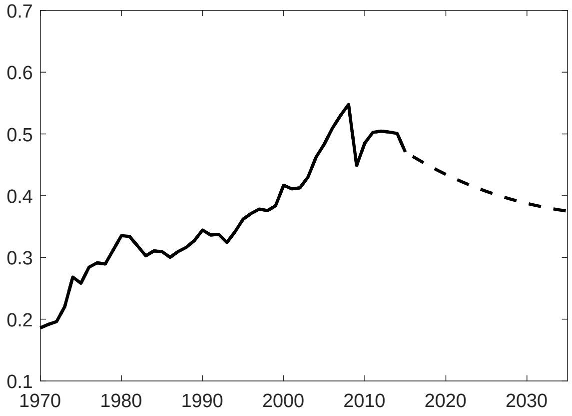
Connecting income differences to gains from trade through structural change This analysis also implies that a country's level of economic development is indicative of its gains from trade. That is, emerging economies tend to have higher goods expenditure shares than advanced economies. This means that, even with the same home trade shares, emerging economies will tend to have greater gains from trade than advanced economies.

5.4 Projecting the Future Impact of Structural Change on Trade

The recent slowdown in the growth of international trade has prompted careful consideration of the forces that might be restraining trade or no longer boosting it (IMF 2016b, Lewis and Monarch 2016). While structural change has not been a stronger drag on trade growth recently than it was in preceding decades, world trade as a share of total expenditure is likely to fall in the future absent additional trade cost reductions.

We show this possibility quantitatively through the lens of our model. Specifically, we extrapolate our sample of countries holding trade costs fixed at their 2015 value and letting goods and services productivity grow at their respective world average rates observed between 1970-2015.[21] Without additional factors boosting trade, our model implies that the ratio of trade to expenditure would fall from 45 percent in 2015 to 37 percent in 2035, shown in figure 15.

Figure 15: Openness: projection



This quantitative example highlights the importance of paying attention to the role of the prevalent process of structural change when considering trade flows. Without incorporating structural change into the model, the downward pattern in the ratio of trade to GDP from figure 15 would be attributed to rising trade costs. However, we find such a result even without any change in trade costs, as the effects of increased services consumption in a world without rapid trade growth materially affects the trajectory of global trade openness. In other words, it is perfectly within reason

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[21] Goods productivity grows 14.1 percent and services grows 1.1 percent annually.

to imagine a decline in the ratio of trade to GDP, or even a decline in total trade flows, without any increased trade barriers. All that would be necessary is the combination of ongoing changes in services consumption along the lines of that seen in the past four decades with the continuation of current levels of trade barriers.

6 Conclusion

We show that structural change, in which the world consumes an ever greater share of total income on services relative to goods, has exerted a significant drag on global trade growth over the past four decades. In the absence of structural change, defined as fixing expenditure shares in goods and services at their 1970 level, the global ratio of trade to GDP would be 16 percentage points higher, or 33 percent higher, than in the data. This is about the same magnitude that declining trade costs have contributed to the increase in global openness over the same period.

We quantify the effect of structural change on global trade with a general-equilibrium model incorporating comparative advantage, nonhomothetic preferences, and an input-output structure. The model highlights that sectoral openness is endogenous, and that holding expenditures fixed at their 1970s levels would have resulted in lower goods openness through the presence of input-output linkages. On the other hand, had structural change not occurred, aggregate openness would have been higher, as goods openness is much greater than services openness. The model also implies that income effects alone account for about one-third of the effect structural change has had on trade volumes.

We show that our model with structural change and endogenous expenditure shares implies lower gains from trade than a model with exogenous time-varying expenditure shares or a model with unchanging expenditure shares. Relative to autarky, trade improves welfare, which is a weighted average of consumption of goods and services. This positive income through higher welfare effect induces structural change through an endogenous shift in expenditures towards services. Since the goods sector is more open than the service sector, consumption gains are greater in goods than in services and, thus, the structural shift in expenditures toward services reduces the gains from trade relative to a model with exogenous expenditure shares.

Though structural change has been a significant drag on global trade growth over recent decades, it has not been a particularly strong drag since the global financial crisis. Instead, the recent slowdown in trade can be attributed to a lack of factors that have historically caused trade to rise relative to expenditure. Indeed, our paper demonstrates how unusual the 1990s and 2000s were: Even as the share of services in expenditure rose, international trade flows expanded, as input-output linkages proliferated across country borders. For the same reasons, however, our results indicate that world trade as a fraction of GDP may have peaked, and similar patterns of structural change projected into the future foreshadow declines in this measure of openness.

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A Data Appendix

This section describes the data used to construct the empirical counterfactual in Section 2 and to estimate the model in Section 4. These data cover 1970–2015 for 27 countries/regions: Australia, Austria, Belgium-Luxembourg, Brazil, Canada, China, Cyprus, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, Netherlands, Portugal, Spain, Sweden, Turkey, United Kingdom, and United States, plus a "Rest of World". The empirical counterfactual requires time series of 1) total exports and imports of goods and services and 2) value added in goods and services. The model estimation requires these series as well as 3) bilateral goods and services trade data; 4) input-output coefficients; 5) value added to gross output ratios; 6) sectoral price indices; and 7) aggregate real expenditure, 8) the aggregate wage bill, and 9) total employment.

Our strategy is to work with the World Input-Output Database (WIOD) from 1995-2011, which is described in Timmer, Dietzenbacher, Los, Stehrer and de Vries (2015), then build the rest of the time sample out from those numbers using splicing techniques with other longer-running datasets. This ensures that the WIOD-based input-output coefficients generate sensible expenditure shares during WIOD years- otherwise, the input-output coefficients would be applied to trade data that may not match the underlying WIOD data used to generate those coefficients.

Aggregate expenditure by country The empirical counterpart to aggregate expenditure, C_{it}, is real final domestic absorption. We gather this data from version 9.0 of the Penn World Table (Feenstra et al. 2015) which corresponds to private and household consumption and investment in PPPs at current US$.

Labor endowment by country We take total employment data in the Penn World Table as our measure of L_i that goes into the model. These data correspond to the number of workers engaged in market activity. Since these data only go through 2014, we create a splicing factor with WDI total employment data in 2015 in order to estimate the model through 2015.

Wage by country Dividing aggregate value added in current US$ by the labor endowment gives the imputed wage w_i.

Total exports and imports by country For each of the 27 groupings above, we take total goods and services exports and imports from the WIOD from 1995-2011. Then, for all other years (i.e. 1970-1994 and 2012-2015), we splice with other data. The splicing procedure divides the average of three years of the WIOD data by the average of three years of a longer dataset to generate a splicing factor, then applying that splicing factor to the longer dataset in non-WIOD years. The averages are calculated from 1995-1997 for all years before 1995, and from 2009-2011 for all years after 2011.

For goods trade, we splice the WIOD trade data with total trade from the IMF Direction of Trade Statistics (IMF 2016a) database. For services, we use aggregate services exports and imports data from the World Development Indicators (WDI) as the comparison. If WDI data on services are not available, we supplement in growth rates where necessary with OECD services data.

Bilateral goods and services trade by sector and country As with total goods trade, when not taken directly from the WIOD, goods trade between two different regions in our sample is generated by splicing importer-reported bilateral goods trade data in the IMF DOTS database with WIOD data, using the same three-year combinations as above. Bilateral services data are sparse, so instead of splicing, we simply apply average bilateral shares over three year periods to the total services trade data calculated as above. Again, for all years prior to 1995, we use average bilateral shares from 1995-1997, and for all years after 2011, we use average bilateral shares from 2009-2011.

Value added by sector and country For value added data, we rely on the UN Main Aggregates Database (UN 2017). We take nominal goods value added in a country to be the combination of expenditure in "Agriculture, hunting, forestry, fishing" and "Mining, Manufacturing, Utilities", while services value added is expenditure in "Construction", "Wholesale, retail trade, restaurants and hotels", "Transport, storage, and communication", and "Other Activities".[22]

Input-output coefficients and value added to gross output ratios To construct γ_{ikn}, the country-specific share of intermediate inputs sourced from sector n, we use the numbers directly from WIOD. The value added to gross output ratio in sector k, λ_{ik} is also a straightforward manipulation of data in the WIOD. Since the WIOD covers only 1995-2014, we impute γ_{ikn} and λ_{ik} for the remaining years as follows. Using data from 1995-2011 we first estimate:

$$\log\left(\frac{\lambda_{ikt}}{1-\lambda_{ikt}}\right) = \alpha + \beta \log(y_{it}) + \varepsilon_{it}, \tag{20}$$

and then impute the ratio, $\log(\frac{\lambda_{ikt}}{1-\lambda_{ikt}})$, for non-WIOD years using the observed GDP per worker, y_{it} and the estimated of α and β. The imputed value for λ_{ikt} is ensured to be between 0 and 1. We follow a similar procedure to impute values for γ_{ikst}, for each (i,k), and then set $\gamma_{ikgt} = 1 - \gamma_{ikst}$.

Sectoral expenditure The WIOD provides data of sectoral expenditures for the years 1995-2011. In order to recover sectoral expenditures for the other years, some manipulation of the equilibrium

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[22] Results are qualitatively similar defining construction as a goods category, but given the lack of direct trade in construction, categorizing it as a service will make goods sectoral openness lower and services sectoral openness higher. Both the model-based counterfactual and especially the reduced-form counterfactual would be smaller in magnitude relative to the data.

conditions is required. First, combining (S5)-(S7) yields the following expression:

$$P_{ik}C_{ik} = P_{ik}Q_{ik} - \sum_{n=\{g,s\}} (1-\lambda_{in})\,\gamma_{ikn}\left(P_{in}Q_{in} + NX_{in}\right), \tag{21}$$

where NX_{ik} is net exports in country i sector k, and $P_{ik}Q_{ik}$ is total absorption. From equilibrium condition S4, we also know total absorption of the composite good can be written as:

$$P_{ik}Q_{ik} + NX_{ik} = \frac{w_i L_{ik}}{\lambda_{ik}}. \tag{22}$$

Using data on sectoral value added, $w_i L_{ik}$, along with sectoral net exports, NX_{ik}, and the production share, λ_{ik}, we can calculate total expenditure, $P_{ik}C_{ik}$, via equations (21) and (22).[23] From 1995-2011, we directly observe the sectoral final expenditures in the input-output tables, so this procedure simply replicates WIOD. For all of the other years these data are unavailable, however, this procedure allows us to construct the sectoral expenditures in a reliable way. Once the sectoral expenditures are generated, the expenditure shares e_{ik} are straightforward to compute.

Sectoral prices In order to estimate the preference parameters ε_k, ω_k and σ, we need gross-output sectoral prices. As described in the main text, we rely on the World KLEMS and EU KLEMS Growth and Productivity Accounts database, which includes gross output price deflators for a wide variety of sectors for most of the countries in our sample. More specifcally, for EU countries, we use the 2017 vintage of EU KLEMS, which has price indexes from 1990 through 2015 and the 2009 vintage of EU KLEMS, which has price indexes from 1970 through 2007 (Jäger 2017). The vintages are spliced to generate one index for each country and Belgium and Luxembourg are combined into one aggregate. Other country-level KLEMS databases available through World KLEMS are Korea, China, Australia, Canada, India, and the United States. We weight up individual industries into goods and services using the same definition of goods and services as above with the value of gross output in each industry. Finally, in order to compare these price indexes across countries, we multiply them by sectoral value added indices in PPP terms from the GGDC Productivity Level Database, maintained by the Groningen Growth and Development Centre, "2005 Benchmark" (Inklaar and Timmer 2014).

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[23] Equations (21) and (22) exactly summarize how we constructed sectoral expenditure for the empirical results in Section 2, and is detailed in words in Section 2.1 and figure 1.

B Solution Algorithm

This appendix details the solution algorithm for each period of the model economy. Equations that we refer to are listed in table 2. For each time period:

- Guess the vector of wages, w_i, across countries.
- Compute the sectoral unit costs ν_{ik} and the sectoral prices P_{ik} using conditions (S2) and (S3) jointly.
- Compute the sectoral bilateral trade shares π_{ijk} using condition (S1).
- Compute the per-worker transfers from the global portfolio R using condition (G1).
- Compute the aggregate price levels P_i and aggregate consumption indexes C_i using conditions (D3) and (D4) simultaneously.
- Compute sectoral consumption C_{ik} using condition (D1).
- Compute sectoral labor demand L_{ik} using condition (S4).
- Compute sectoral intermediate input demand M_{ikn} using condition (S5).
- Compute sectoral gross absorption Q_{ik} using condition (S6).
- Compute sectoral gross production Y_{ik} using condition (S7).
- Define excess demand as net exports minus net contributions to the global portfolio:

  $$Z_i^w = \frac{\sum\limits_{k\in\{g,s\}} (P_{ik}Y_{ik} - P_{ik}Q_{ik}) - (\rho_i w_i L_i - RL_i)}{w_i}.$$

  Condition (G2) requires that $Z_i^w = 0$, for all i, in equilibrium. If this is different from zero in at least some country, then update the wage vector as follows:

  $$w_i' = w_i \left(1 + \kappa \frac{Z_i^w}{L_i}\right),$$

  where w_i' is the updated guess of wages and κ is chosen to be sufficiently small so that $w_i' > 0$. Use the updated wage vector and repeat every step to get a new value for excess demand. Continue this procedure until the excess demand is sufficiently close to zero in every country simultaneously. Note that Walras' Law ensures that the labor market clears in each country.

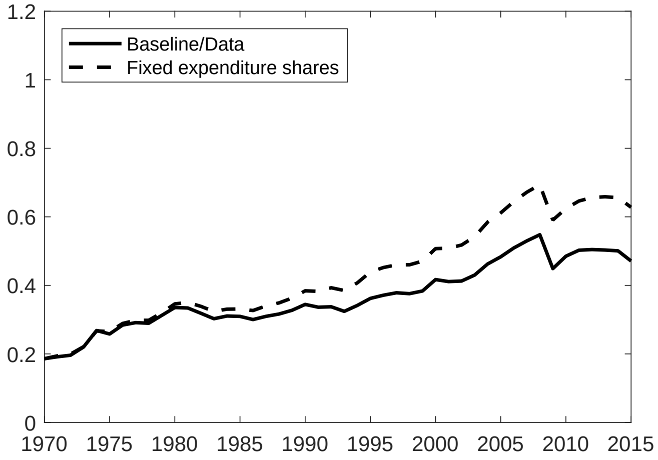
C Robustness

C.1 Sector-specific trade elasticity

Throughout the paper we assumed that $\theta = 4$ in both goods and services sectors. The trade elasticity for goods is widely accepted in the literature. However, there is no widely accepted value for the trade elasticity for services, largely because many studies ignore trade in services. We now consider a robustness exercise by setting $\theta_s = 2.5$, while keeping $\theta_g = 4$. For this experiment, we need to recalibrate T_{is} and τ_{ijs} as in our baseline calibration, to target observed sectoral trade and sectoral expenditure. The remaining parameters are unchanged relative to our baseline calibration.

We compute the equilibrium for two versions of the recalibrated model: (i) a baseline case with endogenous structural change, and (ii) a counterfactual with fixed expenditures (Cobb-Douglas preferences with expenditure shares fixed at 1970 levels). Figure 16 plots the results. Holding fixed expenditure shares in 1970 does result in greater increases in openness, just as in our baseline calibration. In other words, structural change dampens growth in openness. By 2015, global openness is 33 percent higher in the model with fixed expenditure shares compared to the model with endogenous structural change (0.63 compared to 0.47). This effect is almost identical to the effect obtained in our baseline calibration.

Figure 16: Openness: Baseline and counterfactual under $\theta_s = 2.5$



D Country Results

In this appendix, we break down structural change and the structural model-based counterfactual for each country in our sample and highlight their contribution to the aggregate counterfactual. Figure 17 shows the goods and services expenditure shares for each country and the rest of world aggregate. In all countries, the expenditure share of goods is falling, though for some countries, including Greece, Mexico, and Sweden, the shift is more gradual.

Figure 18 shows the baseline model solution and the model-based counterfactual result holding expenditure shares fixed for each country. The trade to expenditure ratio in the counterfactual is higher for every country, though by starkly different amounts. The counterfactual tends to be more consistent in percent, rather than percentage point, terms across countries. For example, Belgium-Luxembourg starts out with a high degree of openness, and the counterfactual is about 50 percent higher than the baseline. The same is roughly true for other countries, like India and Japan, with a far lower degree of openness.

For some countries, however, the counterfactual level of openness is not much greater. This tends to relate directly to the degree to which the countries are experiencing structural change: Greece, Mexico, and Sweden all have fairly modest increases in their openness in the model-based counterfactual, which echoes their modest structural change from figure 17.

Table 6 shows the contribution to the aggregate fixed expenditure counterfactual depicted in figure 7 for the year 2015, the last year of the sample. The first column provides the expenditure share of each country in the world aggregate, while the second is its trade share (exports plus imports in each country as a share of world trade). The third column represents the percentage point contribution of each country to the difference between the model-based counterfactual and the baseline, which sums to 0.157 or about 16 percentage points. The final column shows the equivalent percent contribution. The table makes clear that the contribution to the aggregate counterfactual largely follows the country's trade share, not its expenditure share. For example, with the United States being relatively closed, with an expenditure share about twice its trade share, the contribution of the U.S. to the aggregate counterfactual is close to the trade share. By contrast, China has a similar trade share and a smaller expenditure share and contributes the most of any single country to the aggregate counterfactual.

Figure 17: Sectoral expenditure shares by country

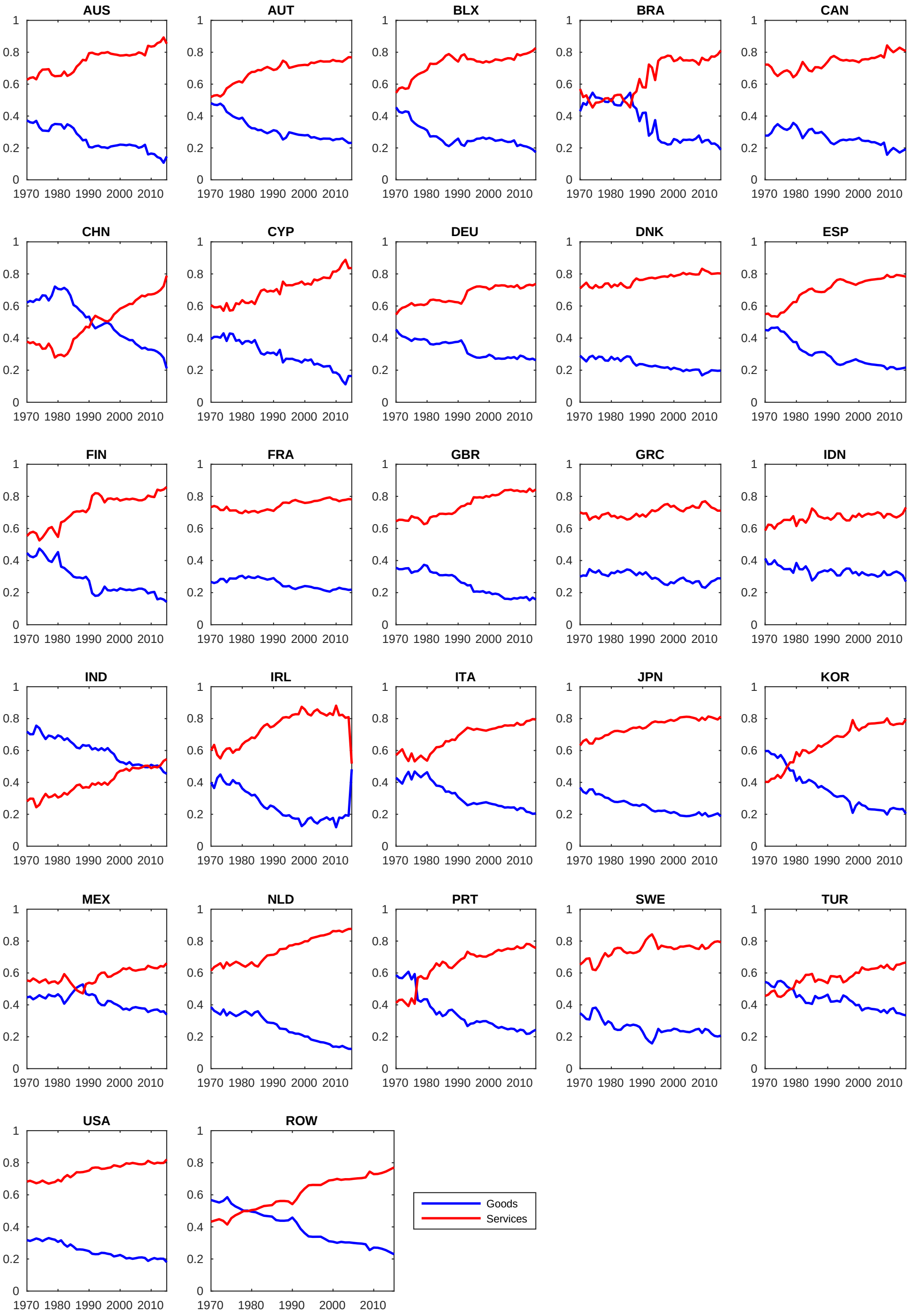


Figure 18: Trade to expenditure ratio by country

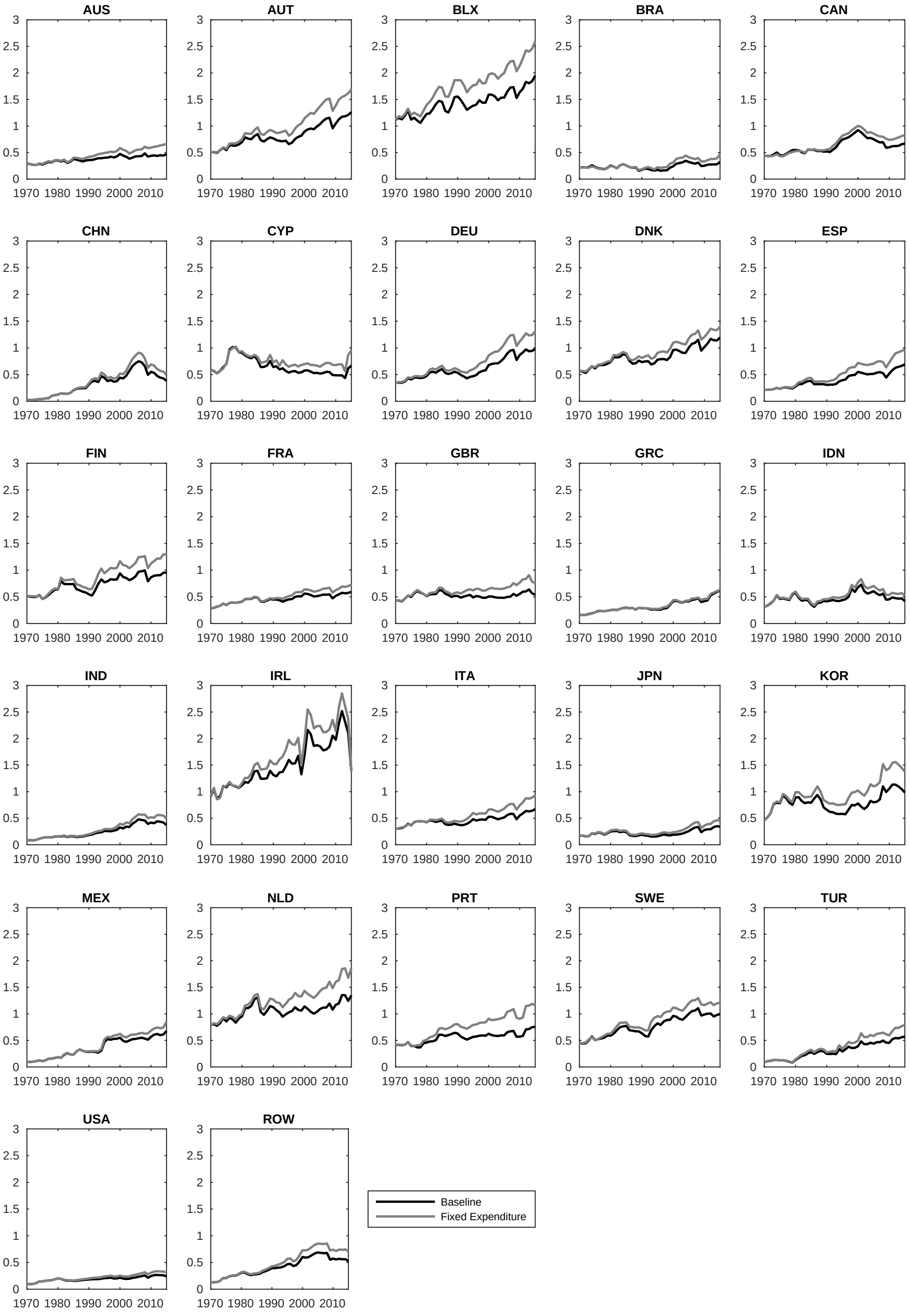


Table 6: Contributions to fixed expenditure counterfactual in 2015

Country	Expenditure Share	Trade Share	Ppt. Contribution	Pct. Contribution
Australia	1.6%	1.6%	0.003	1.9%
Austria	0.4%	1.2%	0.002	1.1%
Belgium+Luxembourg	0.6%	2.3%	0.003	1.9%
Brazil	2.2%	1.5%	0.003	2.1%
Canada	2.1%	2.9%	0.004	2.3%
China	15.2%	12.4%	0.021	13.2%
Cyprus	0.0%	0.0%	0.000	0.0%
Germany	3.7%	7.6%	0.013	8.2%
Denmark	0.3%	0.8%	0.001	0.4%
Spain	1.5%	2.2%	0.004	2.7%
Finland	0.3%	0.5%	0.001	0.6%
France	3.1%	3.8%	0.005	3.1%
United Kingdom	3.6%	4.1%	0.007	4.4%
Greece	0.3%	0.3%	0.000	0.0%
Indonesia	1.2%	1.1%	0.001	0.9%
India	2.8%	2.2%	0.003	2.2%
Ireland	0.3%	1.0%	-0.000	-0.1%
Italy	2.2%	3.1%	0.006	3.7%
Japan	6.0%	4.4%	0.007	4.5%
Korea	1.6%	3.4%	0.007	4.2%
Mexico	1.6%	2.2%	0.003	1.9%
Netherlands	0.7%	2.0%	0.003	1.9%
Portugal	0.3%	0.4%	0.001	0.6%
Sweden	0.6%	1.2%	0.001	0.8%
Turkey	1.0%	1.2%	0.002	1.4%
United States	26.3%	13.3%	0.018	11.4%
Rest of World	20.9%	23.3%	0.039	24.6%
Total	100.0%	100.0%	0.157	100.0%

E Proofs

Proof of Proposition 1: Equation (D3) implies that:

$$\widehat{P}_i = \frac{P_i^{AUT}}{P_i} = \left(\sum_k \omega_k^{\sigma} \left(\frac{C_i^{AUT}}{L_i}\right)^{\varepsilon_k - 1} \left(\frac{P_{ik}^{AUT}}{P_i}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}.$$

Using the expression of e_{ik} in equation (D2), we can manipulate the above equation to obtain:

$$\widehat{P}_i = \left(\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \widehat{P}_{ik}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}.$$

With balanced trade ($P_i C_i = w_i L_i$), the gains from trade are given by:

$$G_i = 1 - \widehat{C}_i = 1 - \frac{\widehat{w}_i}{\widehat{P}_i} = 1 - \left(\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \left(\frac{\widehat{w}_i}{\widehat{P}_{ik}} \right)^{\sigma - 1} \right)^{\frac{1}{\sigma - 1}}. \tag{23}$$

In the case without intermediates, the sectoral prices in (S1) and (S3) can be simplified to:

$$\pi_{iik} = \frac{\left(T_{ik}^{-1} w_i\right)^{-\theta_k}}{\sum_{s=1}^{I} \left(T_{sk}^{-1} w_s \tau_{isk}\right)^{-\theta_k}} = \left(\frac{T_{ik}}{\Gamma_k} \right)^{\theta_k} \left(\frac{w_i}{P_{ik}} \right)^{-\theta_k}.$$

A straightforward derivation using the above equation and the fact that $\pi_{iik}^{AUT} = 1$ gives rise to:

$$G_{ik}^{-1} = \frac{\widehat{w}_i}{\widehat{P}_{ik}} = \widehat{\pi}_{iik}^{-\frac{1}{\theta_k}} = \pi_{iik}^{\frac{1}{\theta_k}}. \tag{24}$$

Substituting the above equation into equation (23) gives equation (17). *Q.E.D.*

Proof of Proposition 2: Using equation (17), we define the function F by plugging in $\varepsilon_g = 1$:

$$F(\widehat{C}_i) = \widehat{C}_i^{\sigma - 1} - e_{ig} \pi_{iig}^{\frac{\sigma - 1}{\theta_g}} - (1 - e_{ig}) \widehat{C}_i^{\varepsilon_s - 1} \pi_{iis}^{\frac{\sigma - 1}{\theta_s}}.$$

$\widehat{C}_i$ is the solution to $F(\widehat{C}_i) = 0$. Since $\pi_{iik} < 1$ and $0 < \sigma < 1$, we have:

$$F(1) = 1 - e_{ig} \pi_{iig}^{\frac{\sigma - 1}{\theta_g}} - (1 - e_{ig}) \pi_{iis}^{\frac{\sigma - 1}{\theta_s}} < 0.$$

Under the empirically relevant regularity conditions, F is monotonically decreasing in $\widehat{C}_i$ since:

$$F'(\widehat{C}_i) = -(1 - \sigma) \widehat{C}_i^{\sigma - 2} - (1 - e_{ig})(\varepsilon_s - 1) \widehat{C}_i^{\varepsilon_s - 2} \pi_{iis}^{\frac{\sigma - 1}{\theta_s}} < 0.$$

Thus, $\widehat{C}_i < 1$, or equivalently, $G_i = 1 - \widehat{C}_i > 0$. *Q.E.D.*

Proof of Proposition 3: Since Proposition 2 establishes $\widehat{C}_i < 1$, we have:

$$\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \pi_{iik}^{\frac{\sigma - 1}{\theta_k}} < \sum_k e_{ik} \pi_{iik}^{\frac{\sigma - 1}{\theta_k}}.$$

This implies:

$$G_i = 1 - \left(\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \pi_{iik}^{\frac{\sigma - 1}{\theta_k}} \right)^{\frac{1}{\sigma - 1}} < 1 - \left(\sum_k e_{ik} \pi_{iik}^{\frac{\sigma - 1}{\theta_k}} \right)^{\frac{1}{\sigma - 1}} = G_i^{\text{CES}}. \quad \textit{Q.E.D.}$$