Structural Change and Global Trade

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Abstract

Services, which are less traded than goods, rose from 50 percent of world expenditure in 1970 to 80 percent in 2015. Such structural change restrained "openness"—the ratio of world trade to world GDP—over this period. We quantify this with a general equilibrium trade model featuring non-homothetic preferences and input-output linkages. Openness would have been 70 percent in 2015, 23 percentage points higher than the data, if expenditure patterns were unchanged from 1970. Structural change is critical for estimating the dynamics of trade barriers and welfare gains from trade. Ongoing structural change implies declining openness, even absent rising protectionism.

JEL classifications: F41, L16, O41

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1 Introduction

The ratio of world trade to world GDP increased from 19 percent to 48 percent from 1970 to 2015. This remarkable growth in "openness" occurred over the same period that the world (and individual countries) experienced a seismic shift in the composition of total spending; global spending on services rose from about half of world expenditures in 1970 to 80 percent in 2015. This phenomenon of "structural change" is thoroughly studied and is well known to be a foundational component of economic growth and development. Less appreciated, however, are the implications of structural change on global trade, given that services are much less traded internationally than goods. Indeed, years when services grew faster tended to be exactly those in which openness grew more slowly.

Since an ever-greater share of the world economy has been devoted to services—less-tradable consumption categories—it must be that structural change held back trade flows during this time, and could potentially lead to declines going forward. Using a multi-country, multi-sector trade model with non-homothetic preferences and input-output linkages, this paper quantifies the effects of structural change on global trade flows over the years 1970–2015. Moreover, we identify the channels through which those effects are realized and demonstrate the importance of the ongoing process of structural change in the measurement of trade barriers and the gains from trade.

We start with a reduced-form counterfactual computation of openness without structural change; we assume that the share of expenditure on each sector is fixed at the initial year of data, while each sectoral trade-to-expenditure ratio (i.e., "sectoral openness") rises exactly as in the data. We find that openness in 2015 would have been 91 percent, or 43 percentage points higher than in the data. This simple calculation suggests that shifting toward less-tradable consumption substantially suppressed trade growth in the last five decades. At the same time, assuming that sectoral openness in the absence of structural change evolved exactly as it did in the real world is unpalatable; the underlying forces driving structural change, such as growth in sectoral productivity and reductions in trade costs, must also have affected sectoral openness. The linked interactions between these factors therefore call for a general equilibrium model to capture the full effect of structural change on trade.

For this reason, 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 (2016). On the production side, a continuum of varieties in each sector are produced with labor and intermediates. Countries differ in their sectoral productivity and trade barriers, forming the basis for comparative advantage. The dynamic behavior 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 non-homothetic 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

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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 goods and services. 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 from the structural equations of the model.

After solving the model, we conduct a counterfactual similar to the reduced-form one. We deliver constant expenditure shares for all sectors in each country across time by setting both the elasticity of substitution and the income elasticity to 1. The model differs from the reduced-form calculation in that it allows for an impact of the counterfactual expenditure shares on the prices for goods and services and on endogenous factor prices, all of which will affect sectoral openness. We show that the model-based counterfactual still implies a substantial increase in the global trade-to-expenditure ratio, reaching 70 percent by 2015 as opposed to 48 percent in the data. The magnitude that structural change has restrained trade flows is on par with the magnitude that declining trade costs boosted trade flows over the same time period.

Importantly, the model-based effect of structural change on world openness (23 percentage points) is smaller than the reduced-form one (43 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 baseline; however, as a result of input-output linkages weakening the overall effect, goods trade does not rise by the same degree.

Omitting structural change has implications for the measurement of two of the most important unobservables in international trade theory: trade costs and the gains from trade. Trade costs inferred from a one-sector model using aggregate trade flows barely decline during periods when structural change was prominent. Specifically, when trade growth diminished as a result of increased services expenditures, as in the years 1980–2000, such a model would attribute this trend to rising protectionism or slower declines in trade costs. In contrast, using the same underlying trade flow data, our model with structural change delivers larger declines in trade costs, which is consistent with the increased trade integration measures during this period.

Our estimates of the gains from trade are lower than than those estimated using otherwise similar models that ignore structural change. The logic underpinning this finding stems from the feature that changes in trade costs endogenously affect sectoral expenditure shares. In the typical multi-sector framework, the welfare gains from trade—the percent change in consumption when moving from autarky to open trade—are a weighted average of consumption gains coming from each sector, where the weights are determined by sectoral expenditure shares. And, since goods are traded more intensively than services, consumption generally increases by more in goods than in services. In our model of structural change, however, opening up to trade will change those sectoral expendi-

ture shares, through the following two channels: (i) a decline in the relative price of goods and (ii) an increase in aggregate income. Both of these features imply a decline in the goods expenditure share, dampening the gains accrued through higher levels of goods consumption. In other words, the aggregate gains are suppressed by the endogenous response of expenditure shares, a clear difference between our work and prior literature, such as Costinot and Rodríguez-Clare (2014), where expenditure shares are treated as exogenous. An important corollary is that 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 indicates that openness has essentially peaked, and will decline to around 40 percent by 2030. Importantly, this occurs without any changes in trade costs, meaning that the 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 a result of structural change; that is, structural change has been a drag on trade growth for decades, and the drag has not been stronger in recent years.

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 South Korea. We show in this paper that structural change may in fact be more consequential for international trade than international trade is for explaining the pattern of 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 (2016) 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, among other things, including non-homothetic preferences into a Hecksher-Ohlin model can help explain why we observe less trade than predicted by models without non-homotheticities.

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

Non-homothetic preferences are important in understanding other aspects of international trade as well. Fieler (2011) finds that non-homothetic preferences can explain why trade grows with income per capita but not population. Simonovska (2015) shows that non-homothetic 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 non-homothetic 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.

Finally, this paper also contributes to an earlier literature on how global trade grows relative to GDP. In an early theoretical contribution, Markusen (1986) includes non-homothetic 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) analyzes 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.

The remainder of the paper proceeds as follows. Section 2 describes the reduced-form counterfactual, while Section 3 sets up the general equilibrium model with endogenous trade and consumption shares. Section 4 describes the calibration and solution of the model, while 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 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 include "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 (available 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 a sector (i.e. sectoral expenditure) plus all usage of that sector as an intermediate input.

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

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

This section describes the patterns of openness and structural change in the world economy found in equation (1). Figure 2, panel (a) shows the trend in openness, which was 19 percent in 1970 and reached 55 percent by 2008. Openness grew strongly for much of the period, accelerating in the late 1990s and 2000s. Since 2011, the ratio has been nearly flat at about 50 percent.

Even while this trend was taking place, world consumption shifted to services. Figure 2 panel (b) demonstrates the substantial shift in expenditures from goods to services from 1970 to 2015. The service share increased steadily over the period by a total of 27 percentage points, from 53 percent in 1970 to 80 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. Figure 2 Panel (c) 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 6 percent for services but was 33 percent for goods in 1970. Over time, trade openness

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[2]More detail on this step can be found in Sposi (2016).

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

Figure 2: Openness and structural change

(a) Openness   (b) Sectoral Expenditure Shares   (c) Sectoral Openness
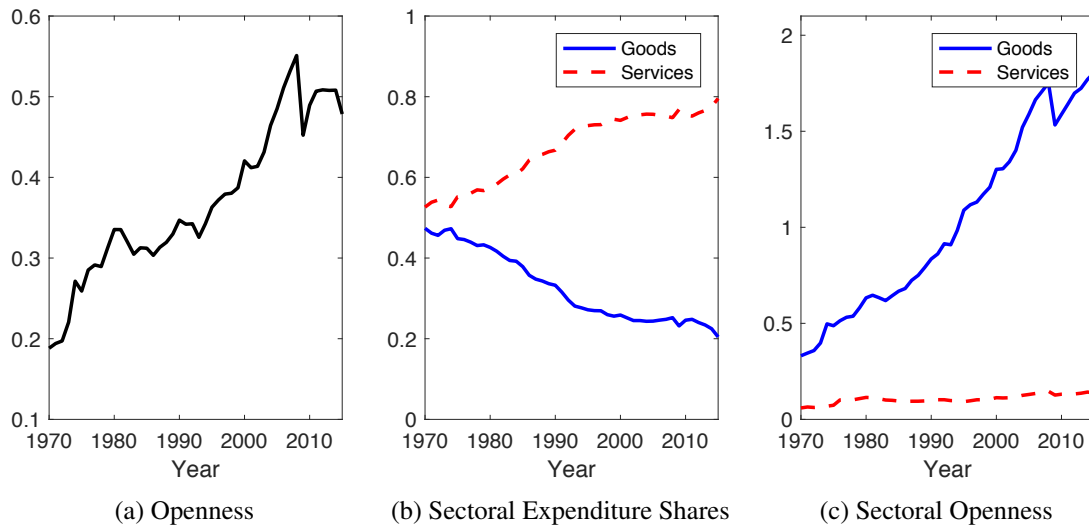
increased for both sectors but was much more pronounced for goods. By the end of the period, the trade-expenditure ratio was about 14 percent for services and 180 percent for goods.[4]

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? The answer is that trade grew spectacularly *in spite of* the ongoing transition to services in the world economy, meaning structural change held back 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 -0.72, meaning that periods of faster openness growth feature a slower-growing service share. The same result holds when calculating 10-year rolling correlations between the growth rates of the two series, as shown in figure 3.

The finding that a faster shift to services reduces growth in openness is also present 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 the 27 countries (including "Rest of World") in 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 a simplified view of how much structural change held back global trade growth.

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

Figure 3: 10-Year rolling correlations, growth rate of openness and service share
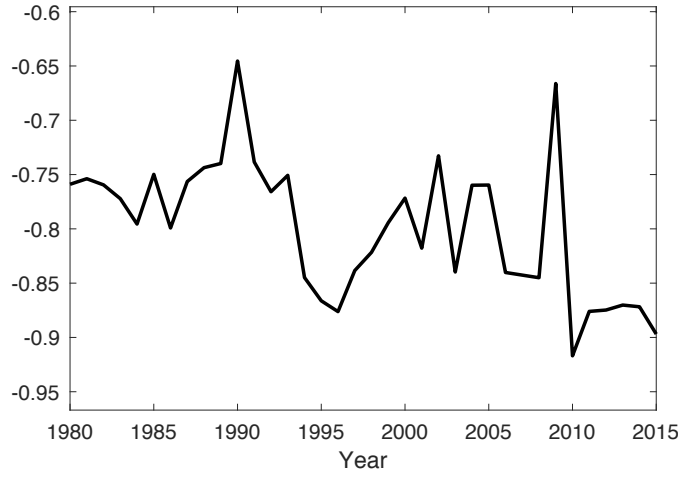

Table 1: Country-level openness and service share

	Dependent Variable: Openness Growth			
Services Share Growth	-0.464***	-0.459***	-0.220***	-0.235***
	(0.157)	(0.156)	(0.062)	(0.061)
Log Per-Capita GDP		-0.039***		-0.070***
		(0.011)		(0.010)
Year FE	NO	NO	YES	YES
Country FE	YES	YES	YES	YES
N	1215	1215	1215	1215
R^2	0.07	0.08	0.33	0.36

Note: Robust standard errors are in parentheses, with *** significance at the 99 percent level, ** at the 95 percent level, and * at the 90 percent level.

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 first period of data. We can now compute a counterfactual measure of openness as:

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

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

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change, but it is consistent with the observed sectoral openness. We calculate counterfactual trade openness for each country and the world economy. If openness in the counterfactual is significantly different from the data, it suggests that structural change has an important impact on openness.

Figure 4 contrasts the aggregate trade openness measure in the data with the reduced-form counterfactual. The gap between the counterfactual openness measure and the actual 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. According to this exercise, as of 2015, persistent structural change since 1970 has lopped about 45 percentage points off the ratio of trade to expenditure.

Figure 4: Openness
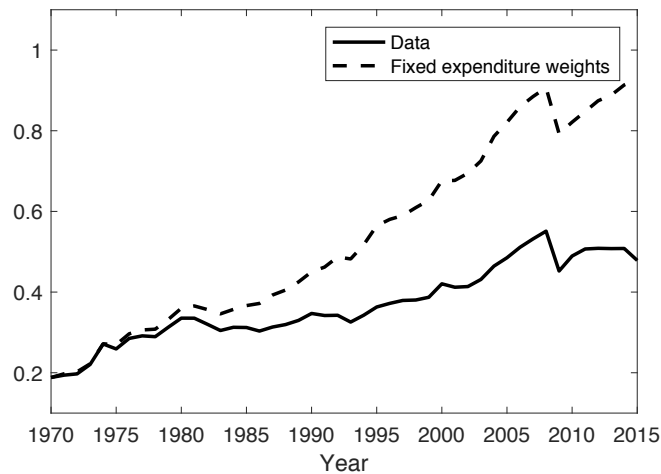
Note: The data line is the aggregate trade to expenditure ratio for 26 countries listed in the data appendix, plus a rest-of-world aggregate. The counterfactual line holds the expenditure shares constant at the start of the sample.

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 also 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 quantify the impact of structural change on international trade.

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3 Model

We consider a multi-country, two-sector Eaton Kortum trade model of the global economy with non-homothetic preferences. There are I countries and the two sectors are goods (g) and services (s). Household preferences have non-unitary income and substitution elasticities of demand. 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. Unless needed for clarification, we omit the time subscript below.

3.1 Endowments and Preferences

Labor is perfectly 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. The elasticity of substitution across sectoral composite goods is $\sigma > 0$. If $\sigma > 1$, the sectoral composite goods are substitutes, and if $\sigma \leq 1$, the sectoral composite goods are complements. ε_k denotes the income elasticity of demand for sector k.

This set of preferences (known as "normalized Constant Elasticity of Substitution") was first studied by Gorman (1965) and Hanoch (1975) and was found to be especially apt for studying long-run structural change by Comin et al. (2015). Comin et al. (2015) show that this specification of nonhomothetic preferences has two attractive properties. 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.[5] 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:

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

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 "ideal" 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, $\rho_i w_i L_i - R L_i$ 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 ideal aggregate price is given by:

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

The sectoral expenditure shares are given by:

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

Thus, how relative price and real income per capita shape the sectoral expenditure shares are governed by the elasticity of substitution between sectors σ and the sectoral elasticity of income ε_k. 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 the income per capita.

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[5]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.

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, fundamental 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, which is 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 is θ_k, the lower the heterogeneity or variance of $A_{ik}(z)$.[6] 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.[7]

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}:

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

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[6] $A_k(z)$ 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.

[7] 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.

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

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

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 across sectors.

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 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 $p_{ik}(z) = \min \left\{ p_{ijk}(z) \right\}_{j=1}^{I}$.

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.[8]

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:

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

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.

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[8]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.

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 all these conditions. Equations (D1)-(D4) are from the household demand side. (D1) and (D2) are optimal conditions for sectoral consumption and sectoral expenditure shares. (D3) specifies the ideal 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	$\pi_{ijk} = \dfrac{\left(T_{jk}^{-\lambda_{jk}} v_{jk} \tau_{ijk}\right)^{-\theta_k}}{\sum_{s=1}^{I} \left(T_{sk}^{-\lambda_{sk}} v_{sk} \tau_{isk}\right)^{-\theta_k}}$	$\forall i,j,k$
S2	$v_{ik} = B_{ik} w_i^{\lambda_{ik}} \prod_{n\in\{g,s\}} P_{in}^{(1-\lambda_{ik})\gamma_{ikn}}$	$\forall i,k$
S3	$P_{ik} = \Gamma_k \left(\sum_{j=1}^{I} \left(T_{jk}^{-\lambda_{jk}} v_{jk} \tau_{ijk}\right)^{-\theta}\right)^{-\frac{1}{\theta}}$	$\forall i,k$
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	$\sum_{k\in\{g,s\}} P_{ik} Y_{ik} - \sum_{k\in\{g,s\}} P_{ik} Q_{ik} = R L_i - \rho_i w_i L_i$	$\forall i$

Equations (S1)-(S7) are from the supply side. (S1) gives bilateral import shares in total absorption at the sectoral level. (S2) specifies the cost of an 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 all demand from all countries.

Equations (G1)-(G2) are from the global market clearing. Equation (G1) specifies net transfers across countries are zero globally. Equation (G2) is the resource constraint at the country level. These two conditions together imply that the good 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 parameters in the model match data from 26 countries plus one rest-of-the-world aggregate over period 1970-2015. Preference parameters, $(\sigma, \varepsilon_g, \varepsilon_s, \omega_g, \omega_s)$, are estimated using data on sectoral prices and expenditures. Processes for sectoral trade costs, τ_{ijkt}, productivity, T_{ikt}, and trade imbalances, ρ_{it}, are constructed to match data on sectoral value added, bilateral trade flows, and trade deficits. The production coefficients λ_{ikt} and γ_{iknt} are constructed using the input-output data, and the trade elasticity, θ_k, is taken from the literature.

We will discuss the calibration procedures in detail in the next three subsections. With these in hand, we can solve the baseline model completely in levels for each year $t = 1970, \ldots, 2015$.

4.1 Data Inputs and Imputed Data

This subsection briefly summarizes all of the observed data and imputed data that serves as inputs to the model. More detail can be found in Appendix A

Labor endowment   The country-specific, time-varying labor endowment, L_{it}, comes from version 9.0 of the Penn World Table and the World Bank's World Development Indicator Database. These data correspond to the number of workers engaged in market activity.

Value added   As in Section 2, we use the time series of sectoral value added—$w_i L_{ik}$ in our model—from the United Nations Main Aggregates Database. Dividing aggregate value added by the labor endowment gives the imputed wage w_i.

Trade   Again following Section 2, we use sectoral exports and imports by country from the WIOD for the years 1995-2011, splicing with other trade data to create a longer time series. The bilateral trade data that forms the π_{ijkt} terms are generated similarly. More detail on splice factors and other datasets is in Appendix A.

Production shares   The country-specific, time-varying production parameters, γ_{iknt} and λ_{ikt}, are constructed using the World Input-Output Database (WIOD), condensed down 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. We apply the 1995 values to all years prior to 1995, similarly, we apply the 2011 values to all years after 2011.

While these production shares vary quite a bit 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. Table 3 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 68 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 66 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.

Table 3: Parameter values

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	0.68
γ_{sg}	Good's share in intermediates used by service sector	0.34
Common parameters		
σ	Elasticity of substitution b/w sectors	0.4
ε_g	Elasticity of income in goods	1
ε_s	Elasticity of income in services	1.59
ω_g	Preferences share of goods	0.49
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

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

$$P_{ik}C_{ik} = P_{ik}Q_{ik} - \sum_{n=\{g,s\}} \left(1 - \lambda_{in}\right) \gamma_{ikn} \left(P_{in}Q_{in} + NX_{in}\right), \tag{12}$$

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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:

$$P_{ik}Q_{ik} + NX_{ik} = \frac{w_i L_{ik}}{\lambda_{ik}}. \tag{13}$$

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 (12) and (13).[9] From 1995-2011, we directly observed the sectoral final expenditures in the input-output tables so this procedure simply returns the observations. 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.

Trade imbalances 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 $\frac{R_t L_{it} - \rho_{it} w_{it} L_{it}}{w_{it} L_{it}}$. In the calibration we can 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) then the global portfolio is balanced. In the counterfactual analysis, the endogenous term R_t will adjust to ensure that the global portfolio balances period-by-period: $R_t \sum_{i=1}^{I} L_{it} = \sum_{i=1}^{I} \rho_{it} w_{it} L_{it}$.

4.2 Common Parameters

Preference parameters Our estimation of preference parameters uses data on sectoral prices, sectoral expenditure shares, and employment levels.[10] Taking the ratio of equation (8) as it applies to each sector we can show:

$$\left(\frac{e_{ig}}{e_{is}} \right) = \left(\frac{\omega_g}{\omega_s} \right)^{\sigma} \left(\frac{P_{ig}}{P_{is}} \right)^{1-\sigma} \left(\frac{C_i}{L_i} \right)^{\varepsilon_g - \varepsilon_s},$$

which illustrates the intuition. Holding fixed variation in total consumption (income effects), the extent that expenditure shares move with relative prices helps us identify the elasticity of substitution, σ. Holding fixed relative prices, the extent that expenditures shares move with the aggregate level of consumption helps us identify income elasticities, ε_k. By setting the sector weights, ω_k, to be constant across countries and over time allows us to exploit both the cross-sectional and time-series variation to identify the price and income elasticities.

We estimate the preference parameters $\omega_g, \omega_s, \sigma, \varepsilon_s$ to minimize the sum of the squared deviation

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[9]Equations (12) and (13) 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.

[10]Our data on gross-output sectoral prices comes from the United Nations Main Aggregates Database and the GGDC Productivity Level Deflator, as detailed in Appendix A. These prices are only used for estimating the preference parameters; we will solve for model-consistent prices in Section 4.3.

of relative sectoral expenditure shares between the model and the data. Specifically, we solve the constrained minimization problem:

$$\min_{\omega_g,\omega_s,\sigma,\varepsilon_s} \sum_{t=1970}^{2015} \sum_{i=1}^{I} \left[\left(\frac{\omega_g}{\omega_s} \right)^\sigma \left(\frac{\widehat{P_{igt}}}{\widehat{P_{ist}}} \right)^{1-\sigma} \left(\frac{C_{it}}{\widehat{L_{it}}} \right)^{\varepsilon_g - \varepsilon_s} - \left(\frac{\widehat{e_{igt}}}{\widehat{e_{ist}}} \right) \right]^2 \tag{14}$$

$$\text{s.t.} \quad \frac{\widehat{P_{it}C_{it}}}{\widehat{L_{it}}} = \left(\sum_{k \in \{g,s\}} \omega_k^\sigma \left(\frac{C_{it}}{\widehat{L_{it}}} \right)^{\varepsilon_k - \sigma} \widehat{P_{ikt}}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}, \forall (i,t) \tag{15}$$

$$\sum_{k \in \{g,s\}} \omega_k = 1, \tag{16}$$

where hats on variables indicate that the objects come from data. That is, we use data on sectoral prices, $\widehat{P_{ik}}$, sectoral expenditure shares, $\widehat{e_{ik}}$, aggregate expenditures, $\widehat{P_iC_i}$, and employment levels, $\widehat{L_i}$. We have no direct empirical counterpart to the aggregate consumption index, C_i, as it is defined in the model, so the constraint in the optimization problem allows us to pin this object down in a model-consistent way by internally deflating the aggregate expenditures by an appropriate price deflator.

Our procedure to solve the minimization problem is as follows. First we normalize the income elasticity for goods $\varepsilon_g \equiv 1$ as in Comin et al. (2015). Second, we make a guess for the remaining preference parameters: $(\omega_g, \omega_s, \sigma, \varepsilon_s)$. Third, given these parameter guesses, we solve for the internally consistent aggregate consumption index, C_{it}, for each country in every year using constraint (15), which is a simple nonlinear equation with one unknown. Fourth, given the imputed consumption indexes and the data discussed above, we use nonlinear least squares on the objective function (14) to obtain updated estimates of $(\omega_g, \omega_s, \sigma, \varepsilon_s)$. With the updated estimates of the preference parameters, we impute updated consumption indexes and, in turn, new estimates of the preference parameters. We continue the procedure until converging to a fixed point in the preference parameters.

The result of the estimation delivers $\sigma = 0.4$ and $\varepsilon_s = 1.59$. The ω_k parameters emerge during the estimation; we normalize prices such that $\omega_g = 0.49$ —the world expenditure share on goods in 1970. Implicitly we also obtain estimates of the aggregate consumption index, C_{it}, which has no direct empirical counterpart. This object will be used later on in order to calibrate productivity levels in an internally consistent manner.

Other common parameters The lower panel of table 3 provides the values for common parameters. We set $\theta_g = 4$ following Simonovska and Waugh (2014). There is no reliable estimate of the trade elasticity for services, so we set $\theta_s = 4$ as well. 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.

4.3 Technology and Trade Costs

We recover the productivity terms, T_{ik}, and trade costs, τ_{ijk}, by exploiting structural relationships from our model in order to match data on sectoral final 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 Sposi (2016). 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:

$$T_{ik}^{\lambda_{ik}} = \frac{B_{ikt} v_{ikt}}{\Gamma_k^{-1} P_{ik} (\pi_{iik})^{-\frac{1}{\theta_k}}},$$ (17)

$$\tau_{ijk} = \left(\frac{\pi_{ijk}}{\pi_{jjk}} \right)^{-\frac{1}{\theta_k}} \left(\frac{P_{ik}}{P_{jk}} \right).$$ (18)

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 common to Ricardian trade models.

Measurement of the trade costs takes into account relative 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 treated as wedges that reconcile the observed pattern of bilateral trade.

Inferring internally consistent prices Equations (17) and (18) require data on units costs, sectoral prices, and trade shares; unit costs themselves require wages and sectoral prices. While we have observed data on prices, we do not use them for this part of the calibration. Instead, we impute sectoral prices through the lens of the model so that they are internally consistent with sector expenditures. Our model does not have enough degrees of freedom to match both sectoral prices and sectoral expenditures simultaneously, so we choose to match expenditures since they are of first order interest to our question. In other words, given the sectoral expenditures and data on consumption levels, we recover the sectoral prices that support the expenditures using the representative household's first-order conditions.

Specifically, given preference parameters, $(\omega_g, \omega_s, \sigma, \varepsilon_g, \varepsilon_g)$, sectoral expenditures, $P_{ik} C_{ik}$, labor endowment, L_i, and the estimated levels of aggregate consumption, C_i (obtained from estimating preference parameters), we invert the household's first-order condition (8) and use the definition of aggregate expenditures (7) to recover model-implied price levels that support the expenditures.

With these constructed sectoral prices in hand, we compute the sectoral productivity and trade costs in equations (17) and (18). Figure 5 illustrates the calibrated processes at the world level. The left panel plots the global sectoral productivity growth index. The global sectoral productivity is computed as the average across countries weighted by each country's share in sectoral value added. The index is taken relative to 1970 and is reported in logs. As shown in the figure, the global sectoral productivity grows faster in goods than in services.

Figure 5: Calibrated global productivity and trade costs
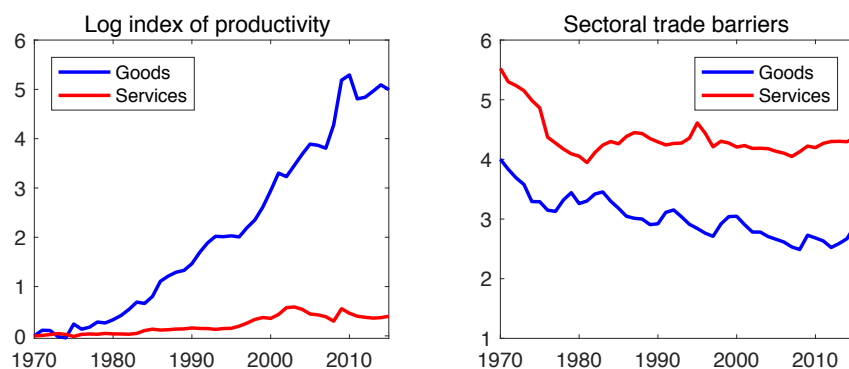
The right panel of Figure 5 plots the global trade costs for goods and services. The global trade cost is computed as an average of all bilateral trade costs weighted by the bilateral trade flows. As illustrated in the figure, trade costs for both goods and services decline over time, and trade costs in services are higher than those in goods, in general. This completes the description of the baseline model equilibrium.

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, and sectoral expenditures. In order to rationalize the sectoral expenditures under our preference specification, the set of equilibrium prices differ from those in the data. Alternatively, one could force the model to match the observed price data, but then the model would not match the sectoral expenditures due to the limited degrees of freedom in the preference specification. We opt to match expenditures since the sectoral ratios of trade to expenditure are of first-order interest in our counterfactuals.

Nonetheless, we can compare the prices generated by the model to those in the data as a test of fit. This is illustrated in figure 6; all prices are taken relative to the U.S. in 2015. Each point corresponds to the price in one country in one year. The prices of services fit the data very well; the correlation between model and data is 0.96. The price variation for goods in the model is overstated

relative to that in the data, but the correlation seems quite reasonable: 0.69.

Figure 6: Sectoral prices: model versus data, in logs, relative to the U.S. in 2015
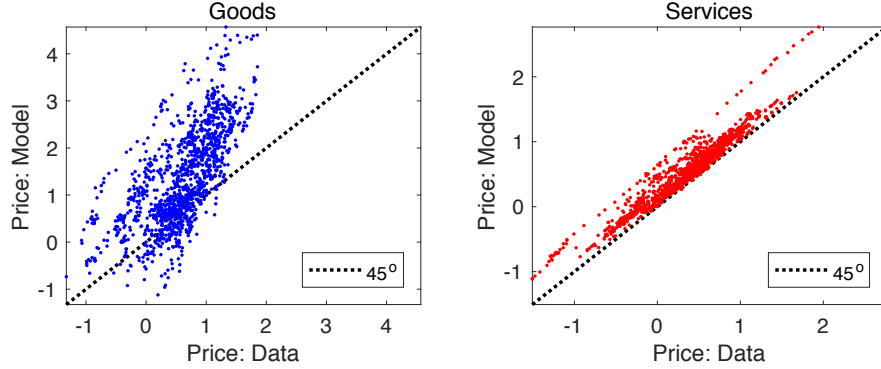
5 Model-based Counterfactuals

This section quantitatively assesses the role of structural change on global trade volumes by conducting counterfactuals using the calibrated model. We also highlight the importance of structural change on model-based measures of trade costs and welfare 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 analog to our reduced-form counterfactual in Section 2. To do so, we assume that the preferences in the counterfactual are given by:

$$C_i = \prod_{k \in \{g,s\}} C_{ik}^{\omega'_{ik}}. \tag{19}$$

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, the expenditure shares across sectors are constant over time. That is:

$$e_{ikt} = e_{ik0} = \omega'_{ik}. \tag{20}$$

All underlying processes in the counterfactual are identical to those in the baseline. To be more specific, 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. We choose values for $\omega'_{ik} = e_{ik0}$ so that in 1970 the sectoral expenditure shares are identical to those in the baseline model.

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 the 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 7. In the data and baseline model, the goods share of total expenditure falls from about 50 in 1970 percent to 20 percent in 2015, as illustrated by the solid line. In the counterfactual, the goods expenditure share is held fixed at its initial value, 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 7: Goods expenditure shares, baseline and counterfactual
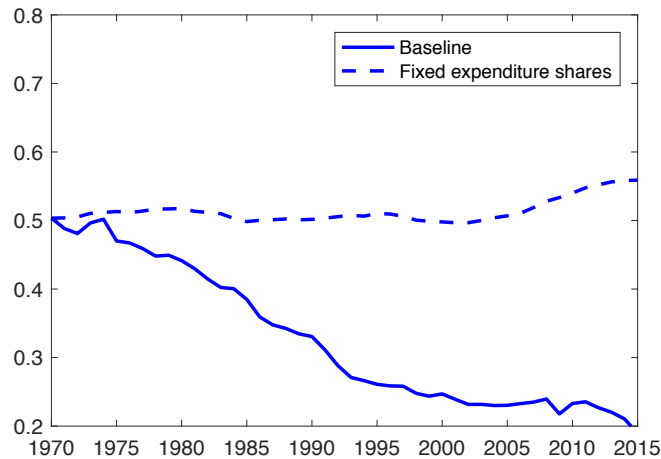
We next present the implications for global trade flows. Figure 8 compares openness between the model baseline (solid line), model counterfactual (dashed line), and reduced-form counterfactual (dotted line). In both counterfactuals, global trade would have been much higher had structural

change not occurred. By 2015, the reduced-form counterfactual puts openness at 91 percent while the model counterfactual puts it at 68 percent, compared with 45 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.[11]

Figure 8: Openness: baseline and counterfactuals
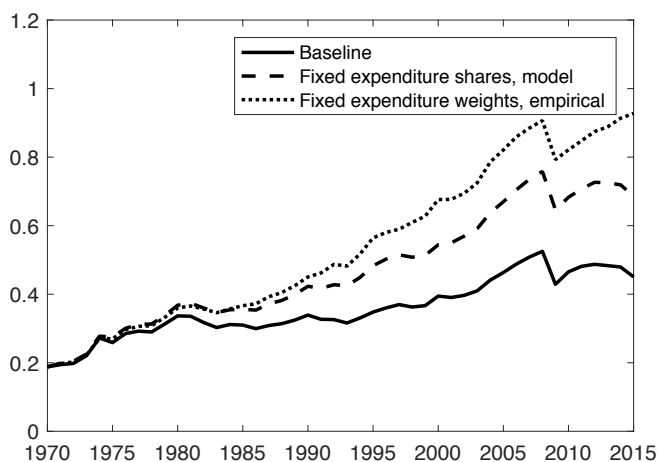
5.1.2 Quantitative mechanisms

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 9 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 70 percentage points lower relative to the baseline in 2015, while services openness is about 5 percentage points higher.

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:

$$\frac{Trade_{kt}}{Exp_{kt}} = \left(\frac{Trade_{kt}}{Abs_{kt}}\right) \times \left(\frac{Abs_{kt}}{Exp_{kt}}\right). \tag{21}$$

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

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[11]Appendix C shows structural change and the model-based counterfactual for each sample country in figure 18 and 19 respectively, as well as a decomposition of each country's contribution to the aggregate counterfactual in table 4 for 2015.

the first term. In the model, at the country level, the first term is similar to $1 - \pi_{iik}$ for each country i and sector k.[12] Also, changing the sectoral demand shares might affect the ratio of absorption to expenditure through input-output linkages, captured by the second term.

Figure 9: Sectoral openness: baseline and model counterfactual
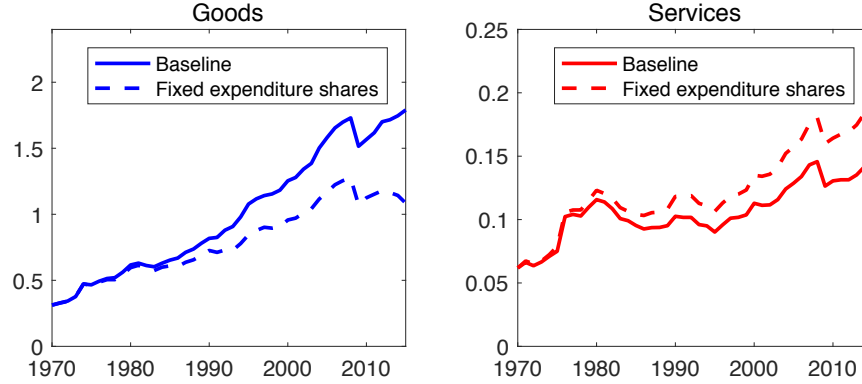
We now quantify the bias of each channel. The ratios of trade to absorption in each sector are almost identical in the baseline and in the counterfactual, as shown in the upper panel of figure 10. Recall the expression of π_{iik} in equation (S1) in table 2. Since the productivity and the trade cost processes are unchanged, the only way that changing expenditure patterns affect the trade-over-absorption ratios is through its 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 10. 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

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[12]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 10: Sectoral trade over absorption, sectoral absorption over expenditure
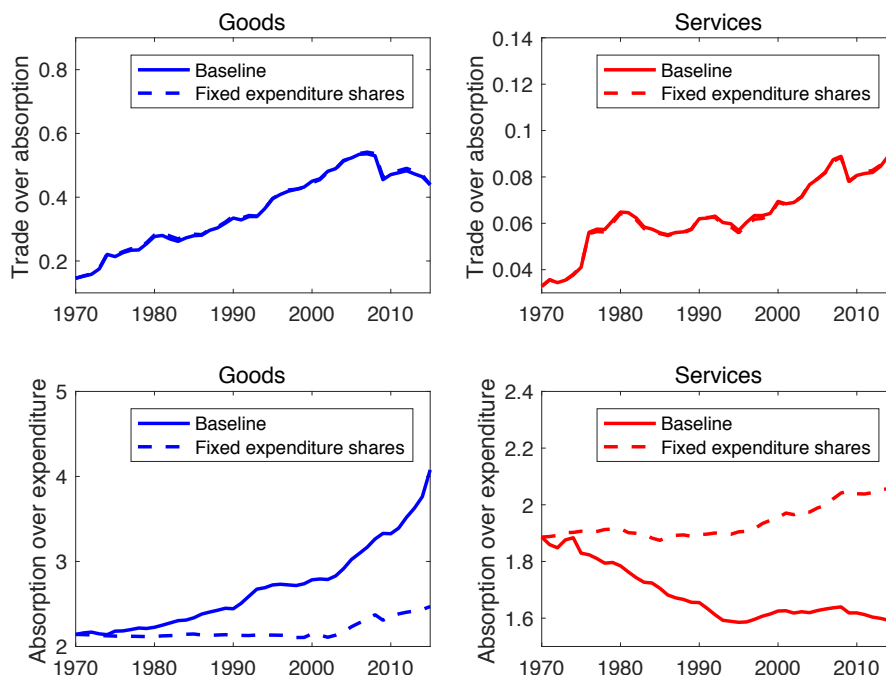
demand for goods consumption. At the same time, derived demand for M_{isg} and M_{iss} decline in response to a decline in C_{is}. Consequently, absorption rises by less than expenditure in the goods sector, while absorption declines by less than expenditure in the services sector, implying lower $\frac{Q_{ig}}{C_{ig}}$ and higher $\frac{Q_{is}}{C_{is}}$ in the model counterfactual compared with the baseline.

Going back to figure 9, 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 input-output linkages, we recalibrate the baseline model and the corresponding counterfactual in a world with no input-output linkages ($\gamma_{gg} = \gamma_{ss} = 1$).[13] In this world, the absence of structural change in the model counterfactual implies little deviation in sectoral trade openness from the baseline/data. As can be seen in figure 11, the sectoral ratios of trade to expenditure barely change from the baseline to the counterfactual. Also, the sectoral ratios of absorption to expenditure barely change either. In other words, in the model with no intersectoral linkages, the model counterfactual yields the same prediction as the reduced-form counterfactual.

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[13]This recalibration requires a manipulation of sectoral expenditures using equations (12) and (13) to ensure that the model matches the sectoral value added and sectoral net exports as in the data and the national accounting identity holds.

Figure 11: Sectoral trade over absorption, sectoral absorption over expenditure: $\gamma_{gg} = \gamma_{ss} = 1$
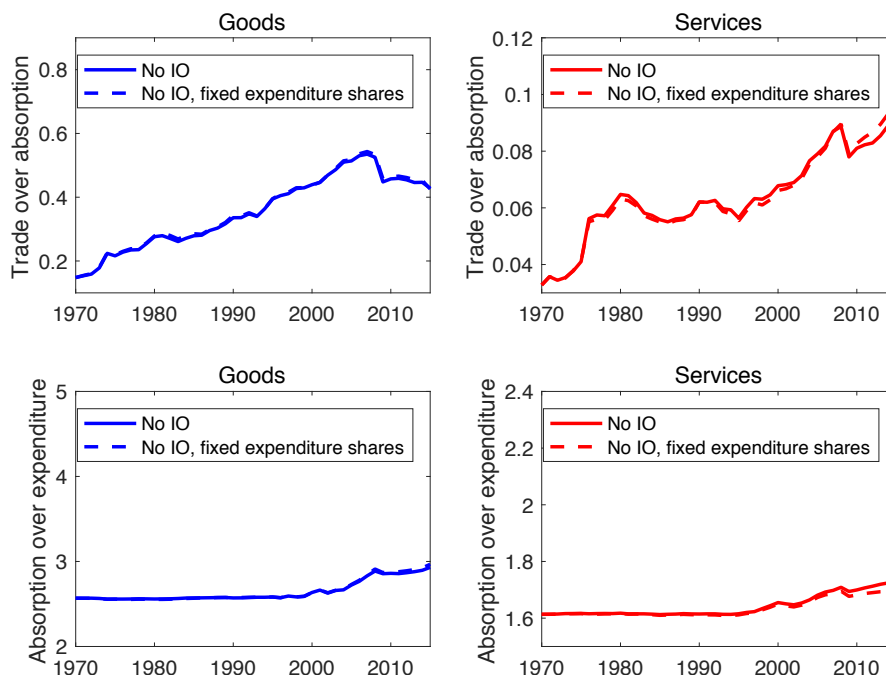
5.1.3 Decomposing income versus substitution effects

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.[14] 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 12 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

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

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 10 percentage points higher than the data, or about one-fourth 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 12: Openness: baseline, model counterfactual, and no-income-effect counterfactual ($\varepsilon = 1$)
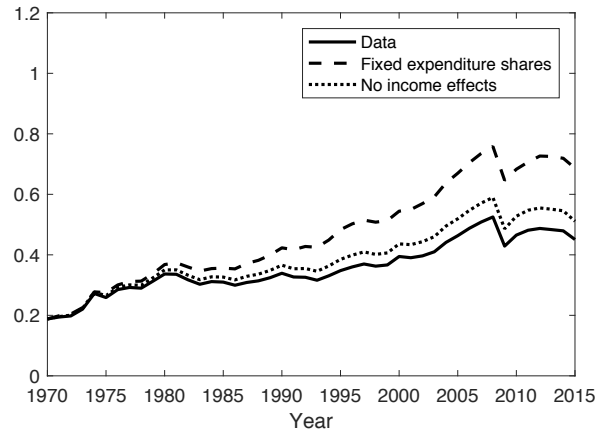
5.2 Global Trade in the Absence of Declining Trade Costs

Arguably, declining trade costs is the most common factor attributed to the rise in global openness. Indeed, the past few decades have witnessed drastic reductions in shipping costs and in 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 13. In this world, the global ratio of trade to expenditure barely grows at all. Of course, trade costs in the baseline model are calculated as the residuals required to account for changes in trade 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 13, structural change has held back trade by roughly the same magnitude that reductions in trade costs have boosted trade over the past four decades.

Figure 13: Openness: baseline, model counterfactual, and constant-trade-cost counterfactual
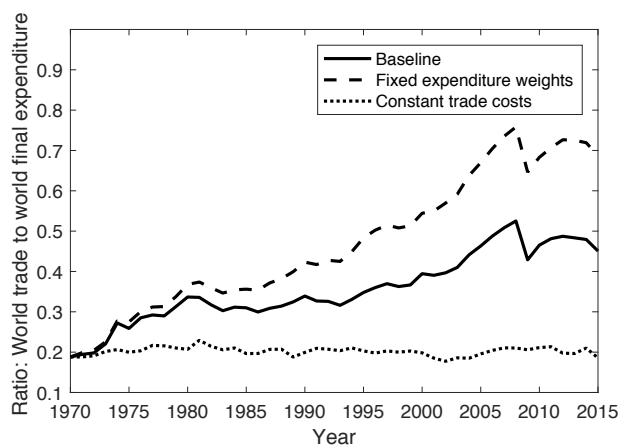

5.3 Importance of Structural Change for the Gains From Trade

Following the convention in the literature, we define gains from trade as the percentage change in real income associated with moving from autarky to the observed level of trade. 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 and we do not want our estimate of the gains from trade to be influenced by the addition or removal of transfers.

The solid line in Figure 14 illustrates the global gains from trade over time using our baseline model with endogenous structural change. The global gain is computed as the percent change in the sum of real income across countries with trade relative to that under autarky. We compare these gains to those estimated using a model where structural change is absent by imposing Cobb-Douglas preferences with expenditure shares held fixed as of 1970 (Cobb-Douglas model with fixed shares). The gains from trade are substantially greater in the Cobb-Douglas model with fixed shares than in the baseline model. Moreover, the gains increase by far more over time in the Cobb-Douglas model with fixed shares than in the baseline model.

Figure 14: Global gains from trade
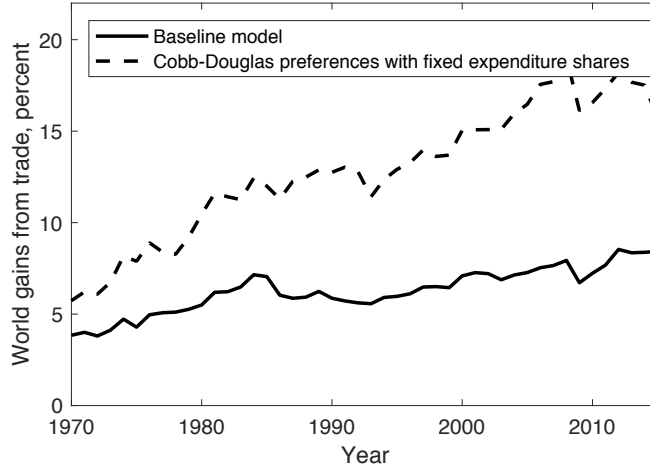
Why are the gains from trade lower in our baseline model compared to those in a model with Cobb-Douglass preferences? The answer lies in the in the fact that changes in the consumer price index capture changes in expenditures from goods to services, a feature not captured by Cobb-Douglas, or even homothetic CES, preferences. To expose this intuition we derive the gains from trade for a simplified case of our baseline model where there is balanced trade period by period and no input-output linkages. Let $\widehat{x} = x^{AUT}/x$ denotes the ratio of the variable x in the autarky relative to that in the baseline. 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 the expenditure shares in equation (D2), we can manipulate the above equation to obtain

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

Thus, since $P_i C_i = w_i L_i$, the gains from trade are given by

$$G_i = 1 - \widehat{C}_i = 1 - \frac{\widehat{w}_i}{\widehat{P}_i} = 1 - \left[\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \left(\frac{\widehat{w}_i}{\widehat{P}_{ik}} \right)^{\sigma - 1} \right]^{\frac{1}{\sigma - 1}}. \tag{22}$$

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

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

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

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

Substituting the above equation into equation (22) gives

$$G_i = 1 - \widehat{C}_i = 1 - \left[\sum_k e_{ik} \widehat{C}_i^{\varepsilon_k - 1} \left(\pi_{iik}^{\frac{1}{\theta_k}}\right)^{\sigma-1}\right]^{\frac{1}{\sigma-1}}. \tag{23}$$

The above equation can be used to solve (implicitly) for $\widehat{C}_i$ and thus G_i, given observables (π_{iik}, e_{ik}) and parameters (θ_k, σ, ε_k).

The gains from trade under the standard homothetic CES and Cobb-Douglas preferences are special cases of our generalized preferences. For the homothetic CES case, we set $\varepsilon_k = 1$ in equation (23) and obtain

$$G_i^{\text{CES}} = 1 - \left[\sum_k e_{ik} \left(\pi_{iik}^{\frac{1}{\theta_k}}\right)^{\sigma-1}\right]^{\frac{1}{\sigma-1}}. \tag{24}$$

The gains from trade under the Cobb-Douglas preferences can be derived by further taking σ to 1:

$$G_i^{\text{CD}} = 1 - \prod_k \pi_{iik}^{\frac{e_{ik}}{\theta_k}}. \tag{25}$$

Cobb-Douglas preferences are commonly used in the existing literature on welfare gains from trade. As shown in equation (25), the gains from trade consider only the changes in sectoral prices impacted by the changes in trade regimes, weighted by the observed sectoral expenditure shares. That is, the gains from trade calculation does not factor in how expenditure shares change. The gains from trade when assuming homothetic CES preferences, as shown in equation (24), are also subject to the same criticism. As discussed in Costinot and Rodríguez-Clare (2014), the gains from trade under the homothetic CES with an elasticity of substitution across sectors less than one are higher than under the Cobb-Douglas case with the identical sectoral trade shares π_{iik}, which highlights the importance of the "right" specification of the preferences. Indeed, both Cobb-Douglas and CES preferences ignore the impact of the trade regime on expenditure shares.

Our non-homothetic CES preferences, however, generate endogenous expenditure share shifts,

i.e., structural change, in response to the changes in relative prices and real income as a result of changing trade regimes. Importantly, these shifts are accounted for in the aggregate price index. As shown in equation (23), in addition to the impact of changes in relative sectoral prices captured by $\pi_{iik}^{\theta_k}$, the changes in real income, captured by $\widehat{C}_i^{\varepsilon_k-1}$, modify the sectoral expenditure shares used to weigh the changes in sectoral prices. Since sectors differ in their income elasticity ε_k, the effect of changes in sectoral prices from trade to autarky on welfare will be weighed together with a consideration of the response of expenditure shares when moving from trade to autarky.

What happens to the expenditure shares when a country goes from autarky to open trade? In our model, opening up to trade reduces the relative price of goods and raises income, both generating a decline in the goods expenditure share. Figure 15 demonstrates this result by comparing the goods expenditure shares in our model between autarky and free trade. The figure, using 2010 as an example, demonstrates that the model-implied expenditure share on goods tends to fall by about 3 percentage points on average when a country moves from autarky to trade.

Figure 15: Goods expenditure shares in 2010: Trade versus autarky
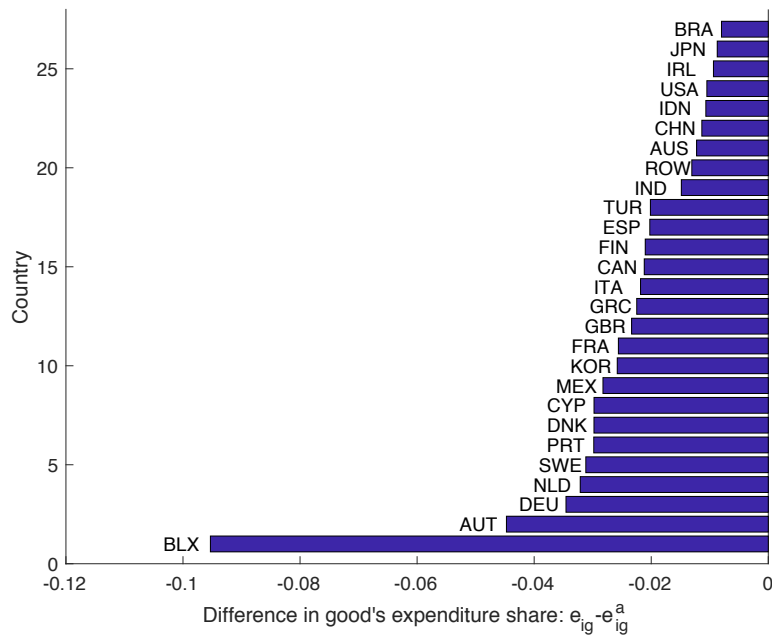
Thus, the contribution to gains from trade coming from goods consumption is lower in the baseline model than in the counterfactual because of the lower weight attached to goods consumption in the trading equilibrium. Empirically, the goods sector is most important for the gains from trade (since it is more open), hence, our model implies smaller aggregate gains from trade compared to a model with fixed expenditure shares.

Figure 16 compares the gains from trade using (i) our non-homothetic CES preferences, G_{it} from equation (23) (ii) homothetic CES preferences, G_{it}^{CES} from equation (24) and (iii) Cobb-Douglass preferences, G_{it}^{CD} from equation (25). As a benchmark, G_{it}^{CD} is plotted on the horizontal axis. Each dot corresponds to a one country in 2010. As can be seen from the yellow dots, welfare gains are slightly higher for all countries when moving from Cobb-Douglas to homothetic CES— G_{it}^{CES}. However, the opposite holds when moving from Cobb-Douglas to our non-homothetic CES preferences—G_{it}, consistent with Figure 14.

Figure 16: Country gains from trade
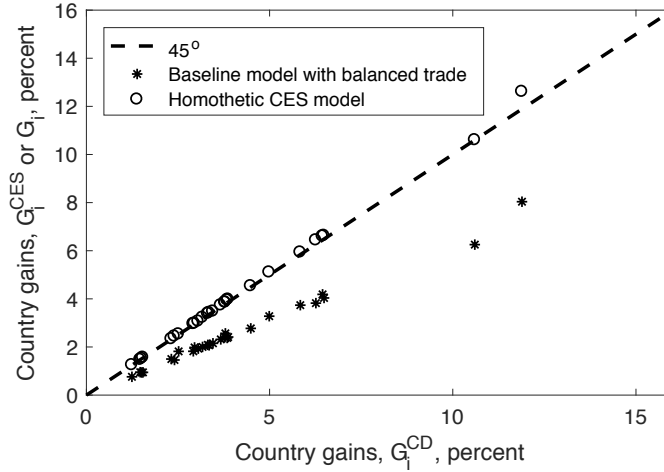
Importantly, the well-known result that the welfare gains from trade are falling in the elasticity of substitution σ still holds. Costinot and Rodríguez-Clare (2014) demonstrate that the gains from trade are always higher for models with CES preferences with $\sigma < 1$ than in models using Cobb-Douglas preferences. In our case as well, for a fixed set of $\{\varepsilon_g, \varepsilon_s\}$, welfare gains are declining in σ. However, the additional non-homotheticity is key to understanding our result: the higher ε_s becomes relative to ε_g, for a given σ, the lower the welfare gains from trade become.

Returning to figure 14, it is clear that our model also delivers lower growth in the gains from trade over time compared to a one-sector model. Similar logic as above carries through to consider the time series path of welfare gains: as structural change occurs, captured by declining goods expenditure share, global openness is suppressed since less-traded services, become more prominent. Mechanically, since the weight on the services home trade share rises over time, the gains are lower compared to a world without structural change, i.e., constant expenditure shares.

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.[15] 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 17.

Figure 17: Openness: projection
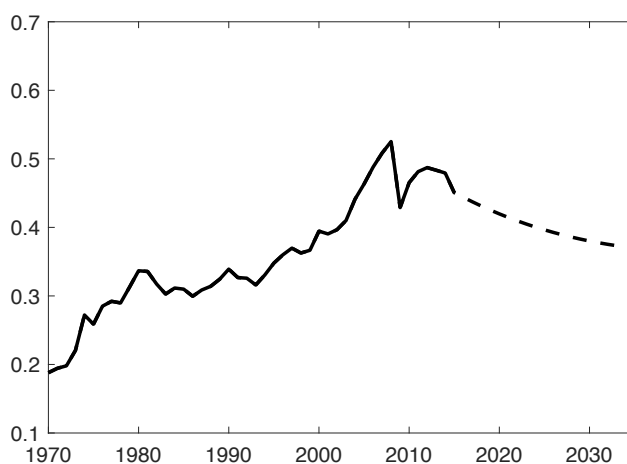
This quantitative example highlights the importance of paying attention to the role of the prevalent process of structural change when considering trade flows. Without incorporating structural change into the model, the downward pattern in the ratio of trade to GDP from figure 17 would be attributed 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 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

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

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 is consuming 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 23 percentage points higher, or 71 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 implication of structural change on global trade with a general-equilibrium model incorporating comparative advantage, non-homothetic 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-quarter of the effect structural change has had on trade volumes.

We also show that with structural change and endogenous expenditure shares, a two-sector model can imply lower gains from trade than a one-sector model, in contrast to similar models without structural change. Common to most models of international trade, as trade barriers decline, consumption of both goods and services rise, while the trade-induced increase in consumption of goods exceeds that of services. In addition, declining trade barriers also reduce the relative price of goods and increase income levels, both triggering a shift in expenditures away from goods and into services. As a result of this trade-induced structural change in expenditures, the contribution from higher goods consumption declines, implying lower estimated gains from trade compared to a world with fixed expenditure shares. The ongoing process of structural change causes declining goods expenditure shares and implies that gains from trade become more suppressed over time.

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) the real wage.

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.

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 world trade from the IMF Direction of Trade Statistics (IMF 2016a) database. For services, we use aggregate services trade data from the World Development Indicators (WDI) as the comparison. If WDI data on services is not available, we supplement in growth rates where necessary with OECD services data.

Value added   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".[16]

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[16]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.

Bilateral goods and services trade 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 is 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.

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. In both cases, we use 1995 coefficients for years prior to 1995, and 2011 coefficients for years after 2011.

Sectoral prices In order to estimate the preference parameters ε_k, ω_k and σ, we need gross-output sectoral prices. First, we take nominal and real value added (indexed to 2005) data in goods and services from the UN Main Aggregates Database. We generate sectoral prices for each sector as the ratio of nominal to real value added. We then multiply the sectoral value added indices in PPP terms from the GGDC Productivity Level Database "2005 Benchmark" (Inklaar and Timmer 2014) by our value added price terms to make the country-level price indices comparable to each other in each year. Finally, we "gross up" the value added prices using the equation for the value added deflator in Appendix C4 of Sposi (2016). Note that these prices are only used in our estimating equation for the preference parameters; the price indices in the calibration of the model are separate model-specific objects. The iterative procedure for deriving elements of the model, including prices, relies on our estimates of the preference parameters.

Labor We take total employment data in the Penn World Tables as our measure of L_i that goes into the model. Since this data only goes through 2014, we create a splicing factor with WDI total employment data in 2015 in order to estimate the model through 2015.

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 v_{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-capita 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:

$$Z_i^w = \frac{P_i Y_i - P_i Q_i - (RL_i - \rho_i w_i L_i)}{w_i}.$$

  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 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 18 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 19 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 18.

Table 4 shows the contribution to the aggregate fixed expenditure counterfactual depicted in figure 8 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 0.236 or about 23 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.

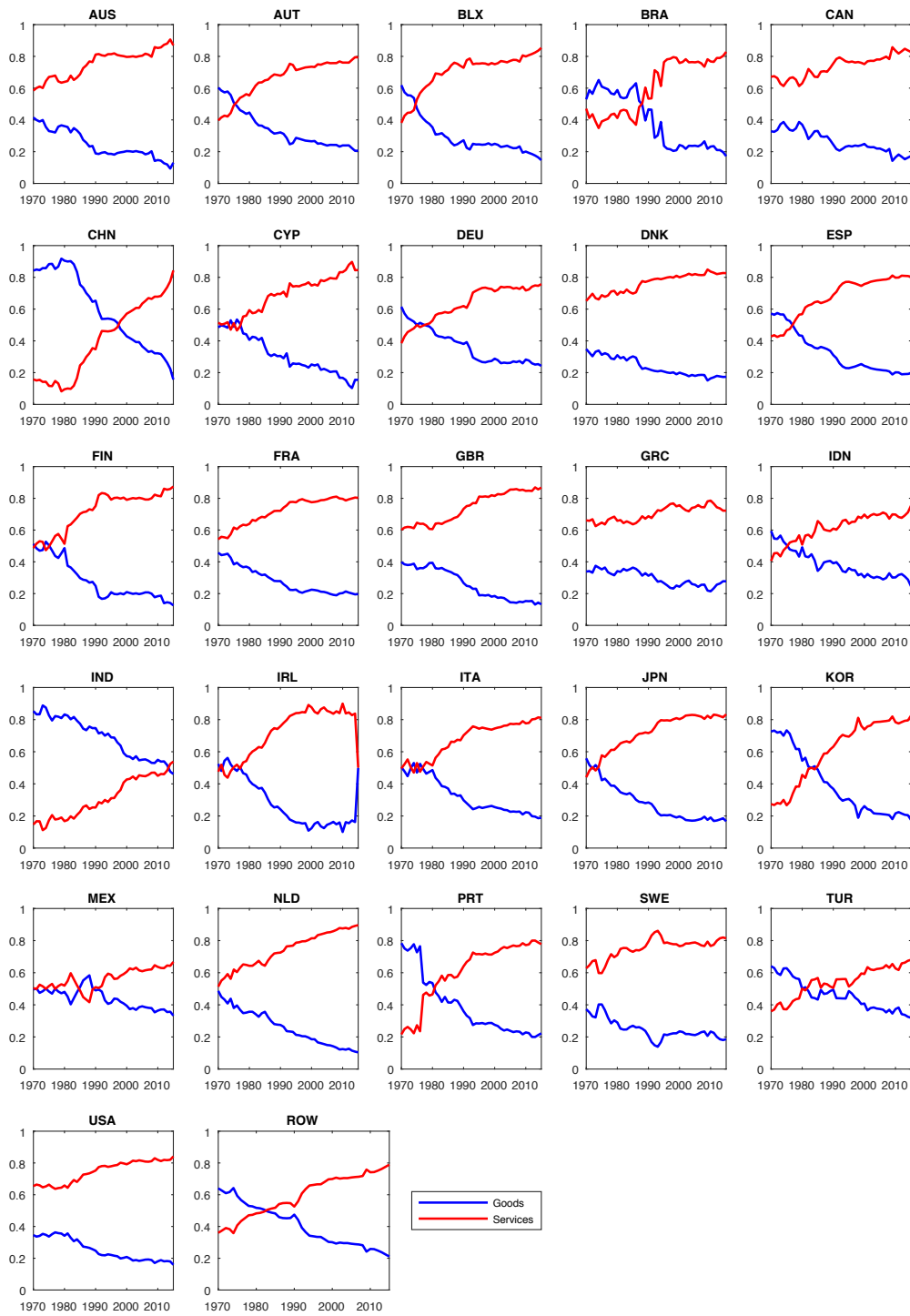Figure 18: Sectoral expenditure shares by country

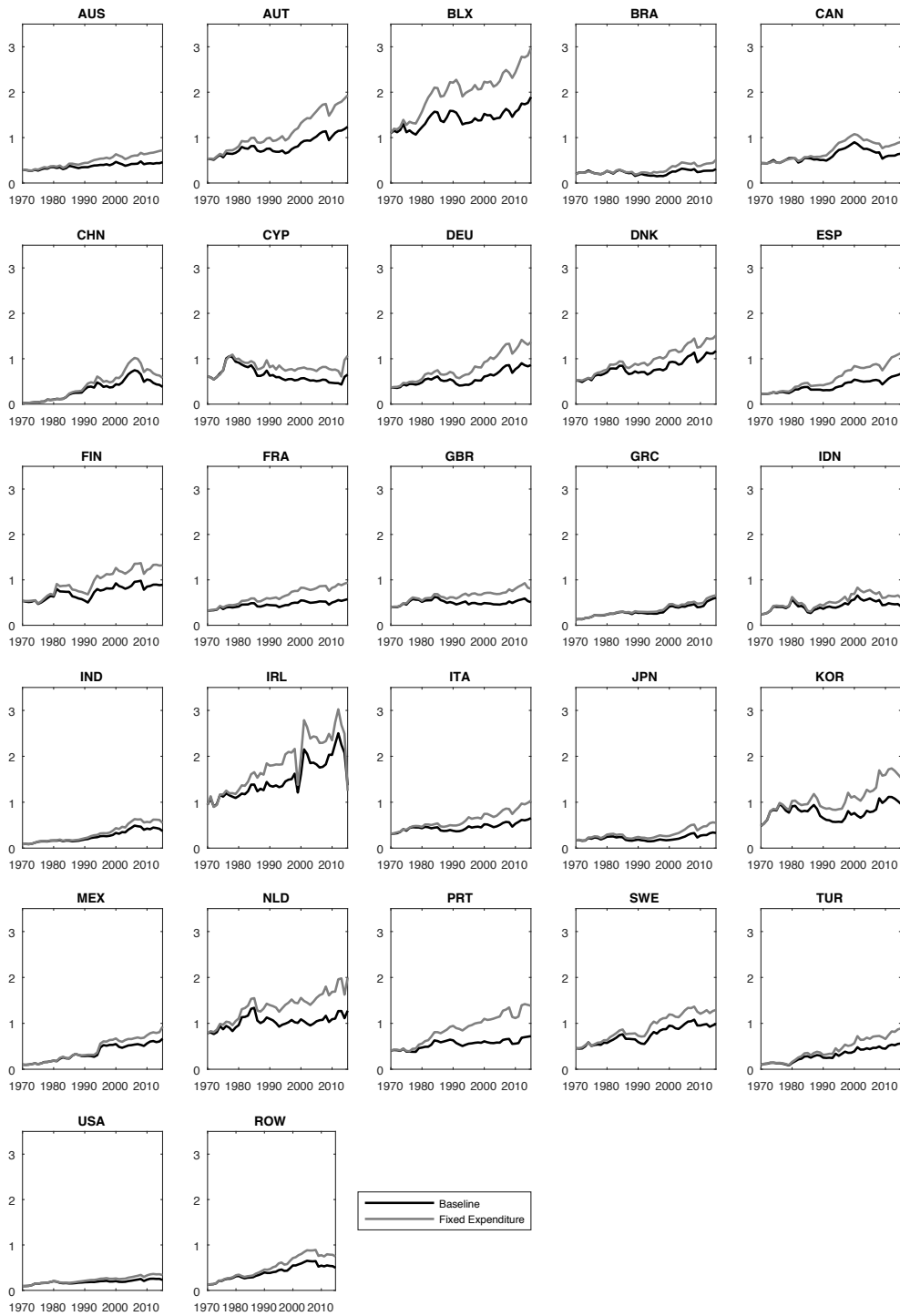Figure 19: Trade to expenditure ratio by country

Table 4: Contributions to fixed expenditure counterfactual in 2015

Country	Expenditure Share	Trade Share	Contribution	Pct. Contribution
Australia	1.6%	1.7%	0.004	1.8%
Austria	0.4%	1.2%	0.003	1.2%
Belgium-Luxembourg	0.6%	2.3%	0.005	2.1%
Brazil	2.2%	1.5%	0.005	2.0%
Canada	2.1%	3.0%	0.006	2.4%
China	15.2%	12.8%	0.032	13.8%
Cyprus	0.0%	0.0%	0.000	0.0%
Germany	3.5%	6.6%	0.018	7.6%
Denmark	0.3%	0.9%	0.001	0.5%
Spain	1.5%	2.3%	0.007	2.8%
Finland	0.3%	0.5%	0.001	0.5%
France	3.1%	3.9%	0.011	4.7%
United Kingdom	3.6%	4.0%	0.009	4.0%
Greece	0.3%	0.3%	0.000	0.0%
Indonesia	1.2%	1.1%	0.003	1.1%
India	2.7%	2.3%	0.005	2.1%
Ireland	0.3%	1.0%	-0.001	-0.3%
Italy	2.2%	3.2%	0.009	3.7%
Japan	6.1%	4.5%	0.013	5.4%
Korea	1.6%	3.4%	0.010	4.1%
Mexico	1.5%	2.3%	0.004	1.9%
Netherlands	0.7%	1.9%	0.004	1.7%
Portugal	0.3%	0.4%	0.001	0.6%
Sweden	0.6%	1.2%	0.002	0.8%
Turkey	1.0%	1.2%	0.003	1.4%
United States	26.4%	13.5%	0.026	11.0%
Rest of World	20.9%	23.1%	0.054	22.9%
Total	100.0%	100.0%	0.236	100.0%