Globalization, Structural Change and International Comovement*

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Abstract

We study the roles of globalization and structural change in the evolution of international GDP comovement among OECD countries over the period 1978-2007. In recent decades, trade integration between advanced economies has increased rapidly while business cycle comovement has remained stable. We show that structural change – trend reallocation of economic activity towards services – plays an important part in solving this apparent puzzle. Business cycle shocks in the service sector are less internationally correlated than in manufacturing, and thus structural change lowers GDP correlations by increasing the share of less correlated sectors in GDP. Globalization – trend reductions in trade costs – exerts two opposing effects on cross-border GDP comovement. On the one hand, greater trade linkages increase international transmission of shocks and therefore comovement. On the other, because services and goods are complements in both consumption and production, globalization induces structural change towards services because it reduces the relative price of goods to services. Thus the overall impact of globalization on international comovement is ambiguous. We use a multi-country, multi-sector model of international production and trade to quantify these effects. Quantitatively, the two opposing effects of globalization on comovement partly cancel each other out, limiting the net contribution of globalization to increasing international comovement over this period.

Keywords: globalization, structural change, international comovement
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1 Introduction

The decades between the end of World War II and the 2008 Great Trade Collapse are the golden age of trade globalization. The top panel of Figure 1 plots the evolution of the trade to GDP ratio from the late 1970s to 2007 for both the G7 and a wider group of wealthy OECD countries. As documented in countless studies, international trade in goods grew much faster than GDP over this period.

Both theory and empirical evidence argue that trade linkages transmit business cycle shocks across countries. It is thus a natural conjecture that these decades of ever closer trade integration should have seen an increase in business cycle comovement across countries. The bottom panel of Figure 1 plots the average 10-year rolling GDP growth correlations in the same two samples of countries. Surprisingly, there is little to no upward trend in GDP comovement over these 3 decades. Indeed, short-run variability in these rolling correlations is often larger than long-run changes. The stable GDP comovement is a puzzle: transmission through increasingly important trade and production networks does not appear to have translated into greater synchronization of GDP.

This paper resolves this apparent puzzle, along the way providing a broad narrative of the evolution of GDP comovement over this period. We isolate two forces that acted on international comovement over this period: structural change and globalization. Structural change is the secular rise in the share of services in value added and employment, and the corresponding fall in the share of manufacturing. It matters for comovement because, as documented below, business cycle shocks to services are less correlated internationally than business cycle shocks to manufacturing. Thus a secular reallocation of economic activity towards services increases the GDP share of the sector that is less correlated internationally. Structural change thus acts to push down cross-country GDP correlations, all else equal.

Globalization – changes in trade costs and tastes that lead to greater import shares – has two opposing effects. The first is the obvious one prominent in much of the literature: greater share of international trade in gross output produces stronger cross-border transmission of shocks and *ceteris paribus* increases comovement. The second one is underappreciated in the literature: globalization itself contributes to structural change. A relative fall in manufacturing trade costs lowers the relative price of manufacturing to services, and raises expenditure shares on services when manufacturing and services are complements (Cravino and Sotelo, 2019). This force shifts economic activity towards the service sector, whose shocks are less correlated internationally, lowering international comovement all else equal. Thus, globalization actually has an ambiguous effect on international comovement.

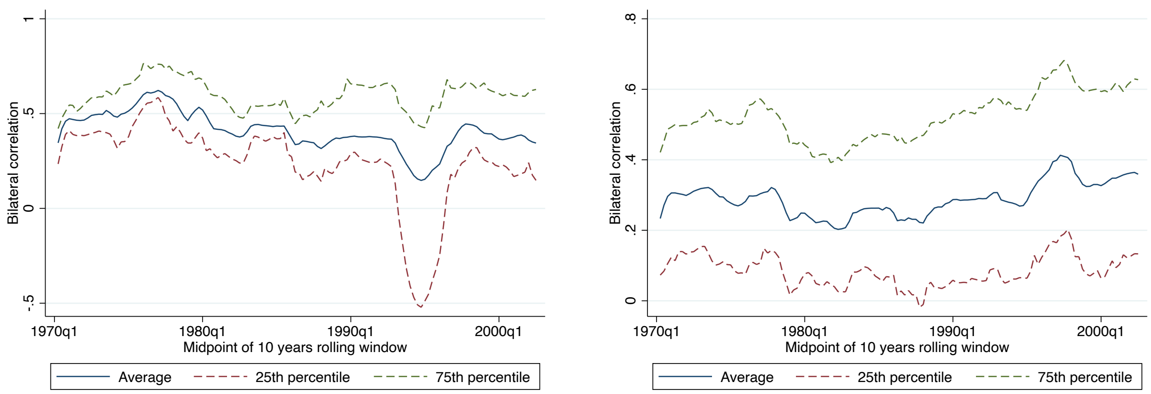
We build on the conceptual framework and modeling tools from Huo, Levchenko, and Pandalai-Nayar (2020), and combine it with data on the long-run evolution of the world input-output matrix from

Figure 1: Trends in Trade/GDP and GDP Comovement

Panel A: Trade integration

G7 OECD

Panel B: Average Bilateral GDP Correlation



G7 OECD

Notes: The top panel of this figure displays the total trade between pairs of countries as a fraction of total GDP. The right panel displays the average bilateral rolling quarterly (yoy) GDP growth correlation. The year denotes the midpoint of the 10 year rolling window. The OECD sample refers to countries members of the OECD since the beginning of the sample in the 1970s.

Johnson and Noguera (2017) and real output data from EU KLEMS (O'Mahony and Timmer, 2009). We work with a tractable multi-country, multi-sector model of production and international trade adapted to studying business cycle questions. The model admits a first-order analytical solution, permitting simple additive decompositions of international comovement that illuminate the forces at work. In particular, GDP correlation between any two countries can be decomposed additively into components that capture correlated shocks and cross-border shock transmission. Another important benefit of the linear analytical solution is that the model can be inverted to obtain the vector of country-sector-specific shocks that rationalizes observed real value added growth in every country and every sector given the observed structure of production and trade. By construction, when these shocks are fed back into the model, it reproduces actual real GDP growth of all countries, and thus can be used as a starting point for decompositions of GDP correlations in the data.

We apply the model to the production and trade data from 1978 to 2007, and provide an account of the evolution of international GDP comovement over this period. Not surprisingly, the component of GDP correlations due to the international transmission of shocks rose in relative importance over this period. This confirms much of the conventional wisdom about the role of international trade in the transmission of shocks. However, the component capturing the correlation of shocks trended downward at the same time. This is because shocks to the service sector are less correlated than shocks to the manufacturing sector, and thus the rise in the service share of GDP lowers international GDP correlations.

As argued by Cravino and Sotelo (2019), globalization can itself be a driver of the rise in the service share. To isolate globalization from other drivers of structural change (such as demand non-homotheticities and trend sectoral productivity growth differentials), we then present several counterfactuals designed to separate the impact of these forces. To implement these counterfactuals, we need to infer the long-run changes in trade costs, tastes, and productivities that drove long-run changes in sectoral shares and international trade openness. We therefore long-difference the model and invert it to obtain the changes in trade costs and preferences in all sectors that rationalize the evolution in sectoral expenditure shares and international trade shares between the 1978 and 2007 world economies. We then start with the 1978 world economy, and feed in one driver of structural change at a time to examine its impact on comovement.

Our first counterfactual focuses on the role of globalization. We compare comovement in the 1978 world economy to a counterfactual economy that started out with the 1978 structure and experienced only the 1978-2007 reductions in international trade costs. While globalization by itself leads to higher international GDP comovement, the effect of globalization on structural change highlighted above limits the increase in GDP correlations. The components of the overall correlation also change: globalization increases both the absolute and relative importance of shock transmission in the overall correlation. On the flip side, the component due to correlated shocks falls, counteracting the impact of greater international transmission. To further illustrate this point, we also present an alternative "globalization-only" counterfactual in which trade costs fall by the same amount but sectoral expenditure shares are held fixed at their 1978 levels. This scenario leads to a larger increase in comovement, as greater cross-border shock transmission is not offset by globalization-driven structural change. Comparing the two globalization counterfactuals, it turns out that 60% of the positive effect of increased transmission of shocks on comovement is un-done by globalization-induced structural change.

The next two counterfactuals evaluate the role of other drivers of structural change: productivity and preferences. Comovement falls substantially when only the long-run preference shifters are applied to the 1978 economy. This is expected, since demand shifts lead the economy to reallocate towards the less correlated services.[1] The effect of permitting only productivity shocks in the 1978 economy is weaker, with overall comovement remaining largely unchanged. This is because the relative long-run productivity shocks between the two sectors are small over this period, and they do not result in substantial reallocation across sectors.

Related Literature We contribute to the research program studying international comovement using both theory (see, among many others, Backus, Kehoe, and Kydland, 1992; Heathcote and Perri, 2002) and empirics (e.g. Imbs, 1999; Kose, Otrok, and Whiteman, 2003; Ambler, Cardia, and Zimmermann, 2004). There is relatively little work documenting how international comovement has changed in recent decades (the few recent contributions include Kose, Otrok, and Whiteman, 2008; Imbs and Pauwels, 2019; Ko, 2020; Miyamoto and Nguyen, 2020). This paper quantifies how the forces of globalization and structural change interacted to generate the observed evolution of comovement. In our quantification, the main international shock transmission mechanism is through trade in final goods and inputs, following, among others, Burstein, Kurz, and Tesar (2008), Johnson (2014), and our previous work.[2] This paper highlights how the heterogeneity across goods vs. service sectors in cross-border trade intensity and shock correlations conditions the evolution of comovement over time.

A large body of work attempts to understand and quantify the structural transformation process (see Herrendorf, Rogerson, and Valentinyi, 2014, for a recent survey). While the literature has proposed a variety of drivers of structural change, the most relevant for this paper is the idea that large sectors – such as goods and services – are complements (Baumol, 1967; Ngai and Pissarides, 2007). We draw on the literature on structural change in open economies (see, among many others, Matsuyama, 2009; Uy, Yi, and Zhang, 2013; Swiecki, 2017; Sposi, 2019; Alviarez et al., 2021). Most closely related are Lewis et al. (2020) and Cravino and Sotelo (2019). The former points out that the rise in the relatively non-tradeable services through the process of structural transformation lowers trade openness. The latter shows that the reduction in trade costs itself can shift economic activity towards the non-tradeable sectors. We explore and quantify the role of these mechanisms in international business cycle comovement.

The rest of this paper is organized as follows. Section 2 outlines our theoretical and quantitative

[1] Our preference shifters are a reduced-form way of capturing the role of demand hon-homotheticities in structural change (e.g. Kongsamut, Rebelo, and Xie, 2001; Boppart, 2014; Comin, Lashkari, and Mestieri, 2020), among other forces.

[2] Several recent papers provide micro empirical evidence on the role of input trade for transmitting shocks within and across countries (Barrot and Sauvagnat, 2016; Atalay, 2017; Boehm, Flaaen, and Pandalai-Nayar, 2019; Carvalho et al., 2016). Also related is the large empirical and quantitative literature on the positive association between international trade and comovement (e.g. Frankel and Rose, 1998; Imbs, 2004; Kose and Yi, 2006; di Giovanni and Levchenko, 2010; Ng, 2010; Liao and Santacreu, 2015; di Giovanni, Levchenko, and Mejean, 2018; Drozd, Kolbin, and Nosal, 2020).

framework. Section 3 illustrates basic patterns in the data. Section 4 presents the baseline results of the decomposition of GDP comovement, and discusses comovement in our counterfactual economies. Section 5 concludes.

2 Theoretical Framework

2.1 Setup

Preliminaries Let there be N countries indexed by n, m, and ℓ, and J sectors indexed by j, i, and k. In the quantitative implementation, $J = 4$: services, manufacturing, agriculture, and non-manufacturing industries. Each country n is populated by a representative household. The household consumes the final good available in country n and supplies labor to firms. Trade is subject to iceberg costs τ_{mnj} to ship good j from country m to country n (throughout, we adopt the convention that the first subscript denotes source, and the second destination). We describe the within-period equilibrium of the model, and omit time subscripts to streamline notation.

Households There is a continuum of workers in a representative household who share the same consumption. The problem of the household is

$$\max_{\mathcal{F}_n, \{H_{nj}\}} U\left(\mathcal{F}_n - \sum_j H_{nj}^{1+\frac{1}{\psi}}\right) \tag{2.1}$$

subject to

$$P_n \mathcal{F}_n = \sum_j W_{nj} H_{nj}$$

where $\mathcal{F}_n$ is consumption of final goods, and H_{nj} is the total labor hours supplied to sector j. Labor collects a sector-specific wage W_{nj}. Because it is the only primary factor of production, H_{nj} should be interpreted as "equipped labor" that encompasses all primary factor services (Alvarez and Lucas, 2007).

We highlight two features of the household problem. First, our formulation of the disutility of the within-period labor supply is based on the Greenwood, Hercowitz, and Huffman (1988) preferences. The GHH preferences mute the interest rate effects and income effects on the labor supply, which helps to study the properties of the static equilibrium.

Second, equipped labor is differentiated by sector, as the household supplies factors to each sector separately. In this formulation, labor is neither fixed to each sector nor fully flexible, and its responsiveness is determined by the Frisch elasticity ψ. As $\psi \to \infty$, labor supply across sectors becomes more sensitive to wage differentials, in the limit households supplying labor only to the sector offering the highest wage. At the opposite extreme, as $\psi \to 0$, the supply of labor is fixed in each sector by the preference parameters. We treat labor supply as elastic for the purposes of studying comovement at business-cycle frequencies. When constructing the long-run counterfactual scenarios that isolate sources of structural change over 1978-2007, we assume inelastic aggregate labor supply and perfect labor mobility across sectors, as is common in the growth and structural change literatures.

Final consumption $\mathcal{F}_n$ is a CES aggregate of sectoral consumption bundles:

$$\mathcal{F}_n = \left[\sum_j \zeta_{nj}^{\frac{1}{\rho}} \mathcal{F}_{nj}^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \qquad P_n = \left[\sum_j \zeta_{nj} P_{nj}^{1-\rho} \right]^{\frac{1}{1-\rho}},$$

where P_n is the final goods price index and $\mathcal{F}_{nj}$ is the quantity consumed of sector j.

Sector j is an Armington aggregate of goods coming from different countries:

$$\mathcal{F}_{nj} = \left[\sum_m \mu_{mnj}^{\frac{1}{\gamma}} \mathcal{F}_{mnj}^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}, \qquad P_{nj}^f = \left[\sum_m \mu_{mnj} (\tau_{mnj} P_{mj})^{1-\gamma} \right]^{\frac{1}{1-\gamma}},$$

$\mathcal{F}_{mnj}$ is the final consumption by country n of sector j goods imported from country m, and γ controls the substitution elasticity between different origin-sector goods within a category. The corresponding price index is P_{nj}^f, where P_{mj} is the price of sector j country m's product "at the factory gate" in the origin country. No arbitrage in shipping implies that the price faced by the consumer in n is P_{mj} times the iceberg cost τ_{mnj}.

The share of sector j composite in total final expenditure π_{nj}^f, and the share of the good from country m in total sector j final expenditure π_{mnj}^f are given by

$$\pi_{nj}^f = \frac{\zeta_{nj} \left(P_{nj}^f\right)^{1-\rho}}{\sum_k \zeta_{nk} \left(P_{nk}^f\right)^{1-\rho}} \qquad \pi_{mnj}^f = \frac{\mu_{mnj} \left(\tau_{mnj} P_{mj}\right)^{1-\gamma}}{\sum_\ell \mu_{\ell nj} \left(\tau_{\ell nj} P_{\ell j}\right)^{1-\gamma}}.$$

The labor supply curves are isoelastic in the wages relative to the consumption price index, and given by (up to a normalization constant):

$$H_{nj}^{\frac{1}{\psi}} = \frac{W_{nj}}{P_n}.$$

Firms A representative firm in sector j in country n operates a CRS production function

$$Y_{nj} = Z_{nj} H_{nj}^{\eta_j} X_{nj}^{1-\eta_j}, \tag{2.2}$$

where the total factor productivity is denoted by Z_{nj}, and the intermediate input usage X_{nj} is an aggregate of sectoral inputs:

$$X_{nj} \equiv \left(\sum_i \vartheta_{i,nj}^{\frac{1}{\varepsilon}} X_{i,nj}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

The total use of sector i inputs in sector j in country n is an Armington aggregate across different source countries:

$$X_{i,nj} \equiv \left(\sum_m \mu_{mi,nj}^{\frac{1}{\nu}} X_{mi,nj}^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}} \qquad P_{i,nj}^X = \left(\sum_m \mu_{mi,nj} \left(\tau_{mni} P_{mi} \right)^{1-\nu} \right)^{\frac{1}{1-\nu}},$$

where $X_{mi,nj}$ is the usage of inputs coming from sector i in country m in production of sector j in country n, $\mu_{mi,nj}$ is the taste shifter, and $P_{i,nj}^X$ is the price index of sector i inputs in production of sector j in country n.

Let $\pi_{i,nj}^x$ be the share of sector i in total intermediate expenditure by n, j, and $\pi_{mi,nj}^x$ is the share of intermediates from country m sector i in total intermediate spending by n, j, on sector i: given by:

$$\pi_{i,nj}^x = \frac{\vartheta_{i,nj} \left(P_{i,nj}^X \right)^{1-\varepsilon}}{\sum_k \vartheta_{k,nj} \left(P_{k,nj}^X \right)^{1-\varepsilon}} \qquad \pi_{mi,nj}^x = \frac{\mu_{mi,nj} \left(\tau_{mni} P_{mi} \right)^{1-\varepsilon}}{\sum_\ell \mu_{\ell i,nj} \left(\tau_{\ell mi} P_{\ell i} \right)^{1-\varepsilon}}.$$

Thus, both final and intermediate input use bundles have two nests, governed by different elasticities. The upper nest combines broad sectors, such as manufacturing and services. Following the tradition in the structural change literature going back to Baumol (1967), the upper nest sectors are complements. The lower nest is an Armington aggregate of items coming from different source countries. Following the tradition in both the international macro and trade literatures, the varieties in the lower nest are substitutes.

Cost minimization implies that the payments to primary factors and intermediate inputs are:

$$W_{nj} H_{nj} = \eta_j P_{nj} Y_{nj} \tag{2.3}$$

$$P_{mi,nj} X_{mi,nj} = \pi_{i,nj}^x \pi_{mi,nj}^x \left(1 - \eta_j\right) P_{nj} Y_{nj}, \tag{2.4}$$

Equilibrium An equilibrium in this economy is a set of goods and factor prices $\{P_{nj}, W_{nj}\}$, factor allocations $\{H_{nj}\}$, and goods allocations $\{Y_{nj}\}$, $\{\mathcal{F}_{mnj}, X_{mi,nj}\}$ for all countries and sectors such that (i) households maximize utility; (ii) firms maximize profits; and (iii) all markets clear.

At the sectoral level, the following market clearing condition has to hold for each country n sector j:

$$P_{nj}Y_{nj} = \sum_m P_m\mathcal{F}_m\pi^f_{mj}\pi^f_{nmj} + \sum_m\sum_i(1-\eta_i)P_{mi}Y_{mi}\pi^x_{j,mi}\pi^x_{nj,mi}. \tag{2.5}$$

Meanwhile, trade balance implies that each country's final expenditure equals the sum of value added across domestic sectors:

$$P_m\mathcal{F}_m = \sum_i \eta_i P_{mi}Y_{mi}. \tag{2.6}$$

Note that once we know the share of value added in production η_j, the expenditure shares π^f_{mj}, π^f_{nmj}, $\pi^x_{j,mi}$, and $\pi^x_{nj,mi}$ for all n, m, i, j, we can compute the nominal output $P_{nj}Y_{nj}$ for all country-sectors (n, j) after choosing a numeraire good. There is no need to specify further details of the model, and we will utilize this property to derive the influence matrix.

Analytical solution At a formal level, the only business cycle shocks in this economy are productivity shocks Z_{nj} in every country and sector. However, as emphasized by Baqaee and Farhi (2019) and Huo, Levchenko, and Pandalai-Nayar (2020), their interpretation could be broadened to include other factor supply shocks, as well as shocks – such as sentiments (Angeletos and La'O, 2013; Huo and Takayama, 2015) or news (Beaudry and Portier, 2006; Barsky and Sims, 2012) – that manifest themselves as shifts in factor supply. Thus, we refer to Z_{nj} as a composite supply shock.

As shown in Huo, Levchenko, and Pandalai-Nayar (2020), this model can be solved analytically to first order. Denote by "ln" the log-deviation from steady state/pre-shock equilibrium. Let the vector $\ln\mathbf{Y}$ of length NJ collect the worldwide sectoral output changes. The response of $\ln\mathbf{Y}$ to the global vector of supply shocks $\ln\mathbf{Z}$ is to a first order approximation given by

$$\ln\mathbf{Y} = \mathbf{\Lambda}\ln\mathbf{Z}. \tag{2.7}$$

The matrix $\mathbf{\Lambda}$ is the influence matrix. It encodes the general equilibrium response of sectoral output in a country to shocks in any sector-country, taking into account the full model structure and all direct and indirect links between the countries and sectors. The expression for $\mathbf{\Lambda}$ is provided in Appendix B (eq. B.3). While in general analytical solutions for $\mathbf{\Lambda}$ are hard to obtain, in our framework the elements of $\mathbf{\Lambda}$ are (i) observable final and intermediate expenditure shares, domestic and international and (ii) model elasticities. Thus, the model is easily parameterized and yields itself to quantification.[3]

The closed-form solution for $\mathbf{\Lambda}$ in equation (B.3) shows that it resembles the typical solution of a

[3]While our model does not explicitly feature a delayed response to shocks, Huo, Levchenko, and Pandalai-Nayar (2020) show that the large majority of business-cycle comovement is accounted for by the contemporaneous impact of composite supply shocks, captured by $\mathbf{\Lambda}$, in this framework. Therefore, abstracting from capital accumulation and related dynamics simplifies the analysis and comes at little cost for the key questions in this paper.

network model, that writes the equilibrium change in output as a product of the Leontief inverse and the vector of shocks. Our expression also features a vector of shocks, and an inverse of a matrix that is, in general, more complicated due to the multi-country structure of our model combined with elastic factor supply and non-unitary elasticities of substitution.

Real GDP Equation (2.7) states the change in gross output, whereas real GDP is defined as value added evaluated at base prices b:

$$V_n = \sum_{j=1}^{J} \left(P_{nj,b} Y_{nj} - P_{nj,b}^{X} X_{nj} \right), \tag{2.8}$$

where $P_{nj,b}$ is the gross output base price, and $P_{nj,b}^{X}$ is the base price of inputs in that sector-country. The real GDP change in any country n is to first order given by

$$\ln V_n = \sum_{j=1}^{J} \frac{P_{nj} Y_{nj}}{V_n} \ln Z_{nj} \; + \; \sum_{j=1}^{J} \eta_j \frac{P_{nj} Y_{nj}}{V_n} \ln H_{nj}. \tag{2.9}$$

The global vector of changes in hours is given by:

$$\ln \mathbf{H} = \boldsymbol{\mathcal{H}} \ln \mathbf{Z}, \tag{2.10}$$

where the formula for the influence matrix for hours $\boldsymbol{\mathcal{H}}$ is given by equation (B.4) in Appendix B. The first term in equation (2.9) captures the impact of domestic shocks on GDP. Note that there is no direct dependence of country n's GDP on foreign shocks. The second term in (2.9) captures the changes in hours. Equation (2.10) underscores that the labor input in every country and sector depend on the entire vector of $\ln Z_{nj}$ worldwide.

These expressions also highlight the need for within-period elastic labor supply in our model. Frameworks of structural change commonly assume inelastic labor supply – a reasonable assumption in the long run. However, in business cycle models with an input-output structure, the fixed aggregate labor supply assumption would imply that foreign shocks have no effect on domestic GDP – there is no transmission. This is clearly contrary to abundant empirical evidence suggesting that transmission of shocks is an important phenomenon at business cycle frequencies.

Evolution of international comovement To illustrate how we will use the model above to understand the long-run evolution of international comovement, we next present some simple accounting decompositions of GDP comovement.

The linear representation of the GDP change in country n as a function of the global vector of shocks (2.9) lends itself to an additive decomposition of the GDP change into the components due to domestic and foreign shocks. To first order, the log deviation of real GDP of country n from steady state can be written as:

$$d \ln V_n \approx \sum_m \sum_i s_{mni} Z_{mi}, \tag{2.11}$$

where s_{mni} are the elements of the global influence matrix, that give the elasticity of the GDP of country n with respect to shocks in sector i, country m, characterized by (2.9)-(2.10). To highlight the sources of international GDP comovement, write real GDP growth as

$$d \ln V_n = \underbrace{\sum_j s_{nnj} Z_{nj}}_{\mathcal{D}_n} + \underbrace{\sum_{n' \neq n} \sum_j s_{n'nj} Z_{n'j}}_{\mathcal{T}_n}. \tag{2.12}$$

This equation simply breaks out the double sum in (2.11) into the component due to country n's own shocks ($\mathcal{D}_n$), the component due to its trading partners' shocks $\mathcal{T}_n$.

Then, the GDP covariance between country n and country m is:

$$\begin{aligned} \text{Cov}(d \ln V_n, d \ln V_m) &= \underbrace{\text{Cov}(\mathcal{D}_n, \mathcal{D}_m)}_{\text{Shock Correlation}} \\ &+ \underbrace{\text{Cov}(\mathcal{D}_n, \mathcal{T}_m) + \text{Cov}(\mathcal{T}_n, \mathcal{D}_m) + \text{Cov}(\mathcal{T}_n, \mathcal{T}_m)}_{\text{Transmission}}. \end{aligned} \tag{2.13}$$

This expression underscores the sources of international comovement. The first term, $\text{Cov}(\mathcal{D}_n, \mathcal{D}_m)$, captures the fact that economies might be correlated even in the absence of trade if the underlying shocks themselves are correlated, especially in sectors influential in the two economies. The shock correlation term can be written as:

$$\text{Cov}(\mathcal{D}_n, \mathcal{D}_m) = \sum_j \sum_i s_{nnj} s_{mmi} \text{Cov}(Z_{nj}, Z_{mi}).$$

The second term captures international transmission. It reflects the fact that country m is sensitive to country n's shocks and vice versa, and that both countries n and m are sensitive to third-country shocks. The transmission terms would be zero in the absence of international trade in the model environment above. Taking one of the terms of the Transmission component:

$$\begin{aligned} \text{Cov}(\mathcal{D}_n, \mathcal{T}_m) &= \sum_j \sum_{n' \neq m} \sum_i s_{nnj} s_{n'mi} \text{Cov}(Z_{nj}, Z_{n'i}) \\ &= \sum_{n' \neq m} \boldsymbol{s}'_{n'n} \boldsymbol{\Sigma}_{n'} \boldsymbol{s}_{n'm}, \end{aligned} \tag{2.14}$$

where $\boldsymbol{\Sigma_n}$ is the $J \times J$ covariance matrix of shocks in country n, and $\boldsymbol{s}_{nm}$ is the $J \times 1$ influence vector collecting the impact of shocks in n on GDP in m. Thus, one source of comovement is that under trade, both country n and country m will be affected by shocks in n'. For instance, when $n' = n$, the element of (2.14) captures the sensitivity of both countries n and m to shocks in country n: $s'_{nn}\mathbf{\Sigma}_n\boldsymbol{s}_{nm}$. This term is nonzero when shocks to country n, that affect n's GDP by construction, also propagate to country m through trade and production linkages.

This paper provides an account of how the evolution of the influence terms s_{mni} shaped the long-run changes in international comovement. Both structural change and globalization act on the s_{mni}. Structural change can be thought of as a trend increase in the domestic influence of the service sector s_{nni} for i =services. The impact of globalization is more subtle. On the one hand, by lowering trade costs and therefore increasing foreign expenditure shares, it increases the foreign influence terms s_{mni}, $n \neq i$. On the other, if the substitution elasticities between services and manufacturing ρ and ε are below unity, a reduction in trade costs lowers the relative price of manufacturing to services, and increases the influence of services.

These forces interact with the correlations of shocks. Suppose, as we document below, service sector shocks are less correlated than manufacturing sector shocks. Then, the reallocation towards services lowers the Shock Correlation component $\text{Cov}(\mathcal{D}_n, \mathcal{D}_m)$, pushing down GDP correlations.

At the same time, a globalization-induced rise in the foreign influence terms s_{mni}, $n \neq i$ raises the Transmission components of the total correlation. The net effect is ambiguous, but we can use the machinery developed in this paper to separate and quantify these effects.

3 Data and Basic Facts

3.1 Data

We use data from two main sources to calibrate the model and estimate the key elasticities.

Trade shares We use the annual world input-output data compiled by Johnson and Noguera (2017). The data cover 4 sectors ("Agriculture", "Non-Manufacturing Industries", "Manufactures" and "Services") and years 1970 to 2009, and we use it to construct the trade and expenditure shares.

Sectoral data Sectoral quantities and prices come from the 2009 EU-KLEMS release (O'Mahony and Timmer, 2009). The KLEMS data are available at a finer level of disaggregation than the Johnson and Noguera (2017) trade data. We aggregate it to the 4 sectors by using the so called cyclical expansion procedure detailed in Appendix A.1, where we also provide the exact mapping of sectors to ISIC classification and detail the variables we use and how they map to the model.

To ensure sufficient country coverage, we use years 1978 to 2007. The resulting dataset is composed of 19 countries listed in Appendix Table A3 and a composite Rest of the World. The countries in our sample cover 96% of the OECD's GDP and 76% of world's GDP in 1978.

Elasticities We estimate the elasticities of substitution in the production and consumption aggregators. The details are discussed in Appendix A.2.

Extracting shocks We now describe how to recover the supply shocks Z_{nj} in such a way as to match actual value added growth in every country-sector (and therefore actual GDP growth in every country), as in Huo, Levchenko, and Pandalai-Nayar (2020).

Let the vector $\ln \mathbf{V}$ of length NJ denote sectoral value added in log deviations from steady state. Similar to GDP, sectoral value added can also be expressed as changes in primary inputs

$$\ln \mathbf{V} = \boldsymbol{\eta}^{-1} \ln \mathbf{Z} + \ln \mathbf{H}.$$

We have data on the $NJ \times 1$ vector of log changes in real value added $\ln \mathbf{V}$ in each year, which allows us to recover the shocks:

$$\ln \mathbf{Z} = \left(\boldsymbol{\mathcal{H}} + \boldsymbol{\eta}^{-1} \right)^{-1} \ln \mathbf{V}. \tag{3.1}$$

In other words, the structure of the model world economy and the observed/measured objects can be used to infer a global vector of supply shocks $\ln \mathbf{Z}$ that rationalizes observed growth rates in real value added in each country-sector. Note that the interdependence between country-sectors through input linkages implies that the entire global vector $\ln \mathbf{Z}$ must be solved for jointly. As stressed above, the recovered $\ln \mathbf{Z}$ should be viewed more broadly as a general sector-level supply shock. In the quantitative implementation below, as an alternative supply shock we will also consider the standard Solow residual.

3.2 Basic Facts

We now present two basic facts that motivate the focus on the rise in the service share as a driver of international comovement.

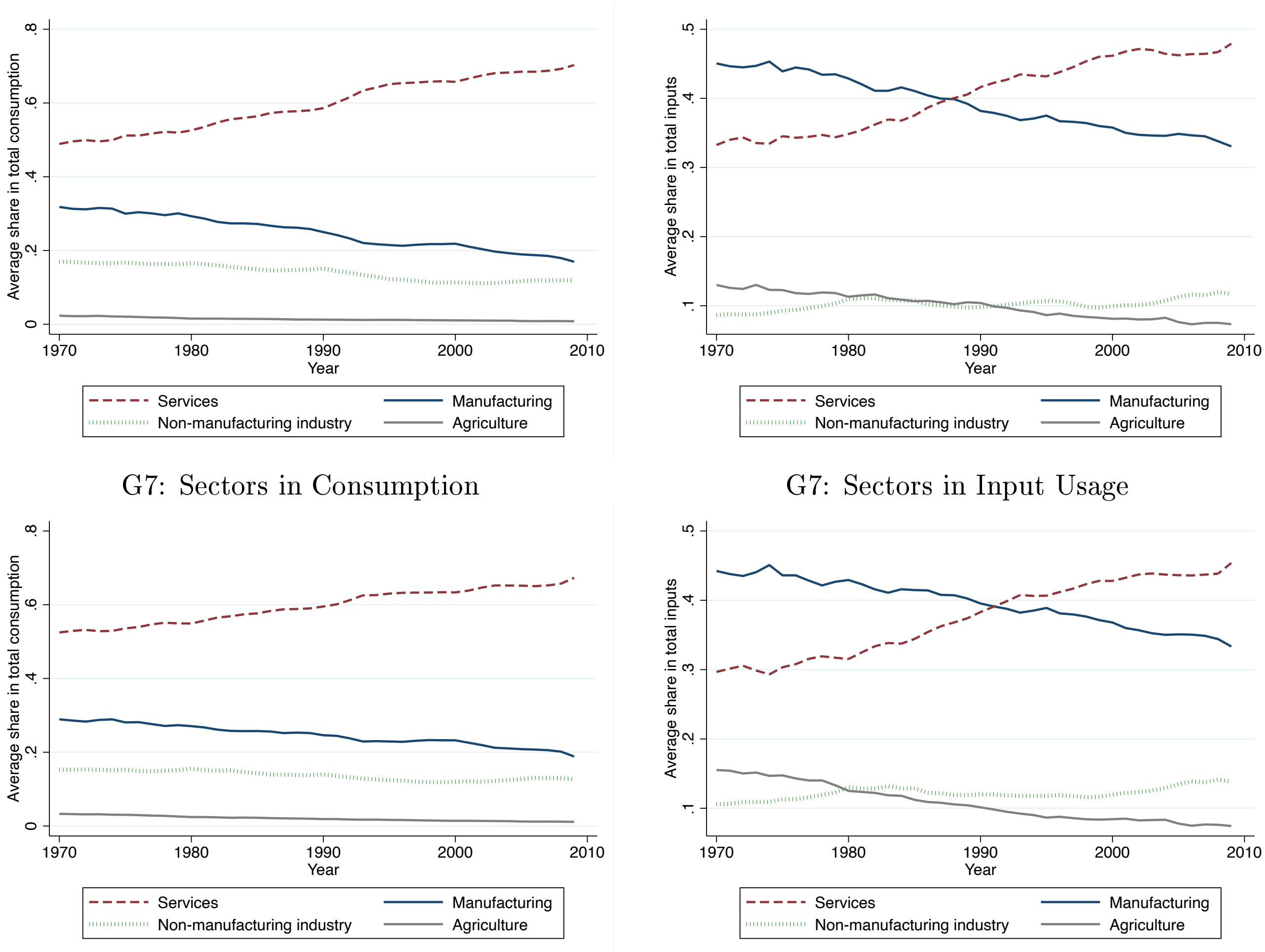
The rise in the service share Figure 2 displays the expenditure shares on the 4 sectors in our data, separating final consumption and intermediate usage. As has been documented in many studies, over this period the share of services rose, at the expense of manufacturing and agriculture. The figure also conveys the relative importance of different sectors. Agriculture and non-manufacturing industries are considerably smaller than services and manufacturing.

Differences in shock correlations Less well-known is how the correlation of business cycle shocks differs across broad sectors. We will work with two types of shocks in the paper: (i) Solow residuals and (ii) composite supply shocks (3.1) extracted to match value added perfectly. The advantage

FIGURE 2: Structural change

Consumption

Intermediate Inputs



G7: Sectors in Consumption

G7: Sectors in Input Usage

OECD: Sectors in Consumption

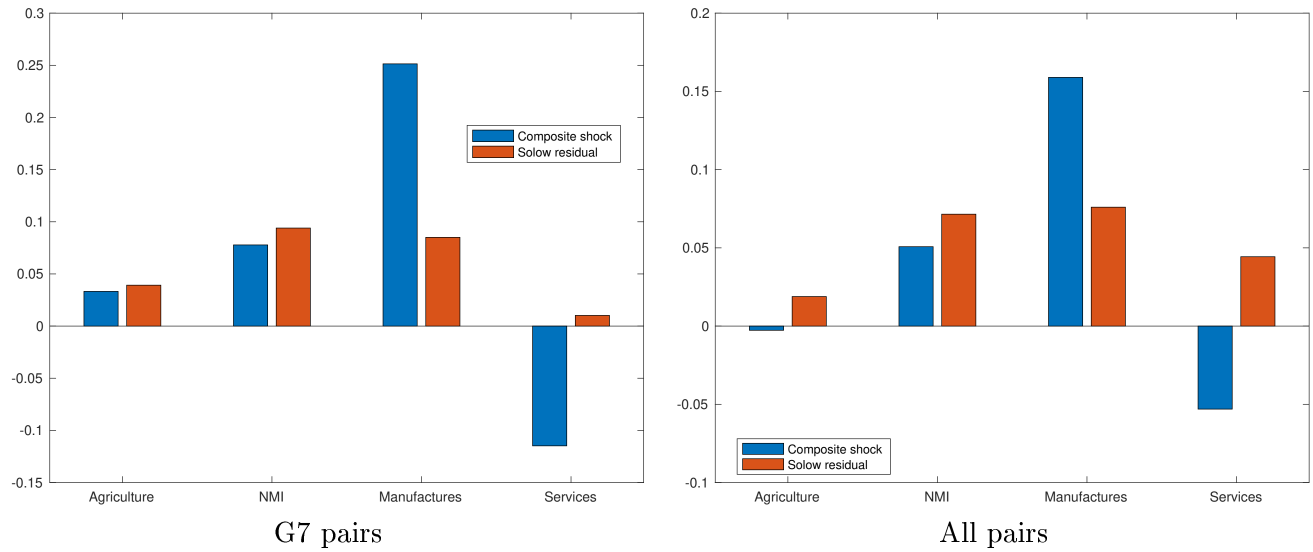
OECD: Sectors in Input Usage

Notes: The left panels of this figure display the average share of each sector in consumption expenditure. The right panel shows the average share of each sector in intermediate input spending. The OECD sample refers to countries members of the OECD since the beginning of the sample in the 1970s.

of the former is that it is relatively model-free and easy to interpret, and has been the main shock considered by the international business cycle literature. The disadvantage is that when fed into the model, it does not reproduce actual value added growth, and by extension actual GDP correlations in the data. The latter shock does that by construction, but is a composite shock that is more difficult to interpret structurally. Extracting the composite supply shock requires the full model solution and calibration.

Figure 3 reports the sectoral shock correlations, averaged across country pairs, for the composite

FIGURE 3: Overall sectoral shock correlations



Notes: This figure plots the correlation of the sectoral Solow residual and composite shock, extracted using equation (3.1), with foreign aggregate shocks over the 1979-2007 sample. The correlations are averaged across country pairs.

shock (blue bars) and the Solow residual (red bars). By both measures, manufacturing shocks are the most correlated, while the service sector shocks are the least correlated. Appendix Figure C1 illustrates that the same pattern holds for nearly all 10-year rolling correlations on the samples.

4 Quantification

4.1 Calibration and parameter estimation

Table 1 summarizes the parameters we use. We provide our own estimates for the substitution elasticities between goods and service bundles in final consumption (ρ) and intermediate use (ε), as well as Armington elasticities of substitution between domestic and foreign goods in final (γ) and intermediate (ν) use. The details are in Appendix A.2. The only remaining structural parameter is the Frisch labor supply elasticity, which we set to 2 following the business cycle literature. Production function parameters and final/input shares are taken directly from the data.

4.2 Decomposition

The top panel of Figure 4 plots the evolution of GDP correlation and its decomposition into transmission and shock correlation. We first use every year's corresponding influence vector to compute the growth in GDP attributable to different countries' shocks as in equation (2.12). Then, we compute

Table 1: Parameter Values

Param.	Value	Source	Related to
ρ	0.2	Herrendorf, Rogerson, and Valentinyi (2013a), own estimates	final cross-sector substitution elasticity
γ	1.5	own estimates	trade elasticity in final consumption
ε	0.2	own estimates	intermediate cross-sector subst. elasticity
ν	1.5	own estimates	trade elasticity in intermediate inputs
ψ	2		Frisch elasticity of labor supply
η_j	[.49,.44,.31,.60]	EU-KLEMS	value added share in gross output
π^f_{nj}		Johnson and Noguera (2017)	sectoral consumption shares
π^f_{mnj}		Johnson and Noguera (2017)	trade shares in final trade
$\pi^x_{i,nj}$		Johnson and Noguera (2017)	sectoral intermediate use
$\pi^x_{mi,nj}$		Johnson and Noguera (2017)	trade shares in sectoral intermediate use

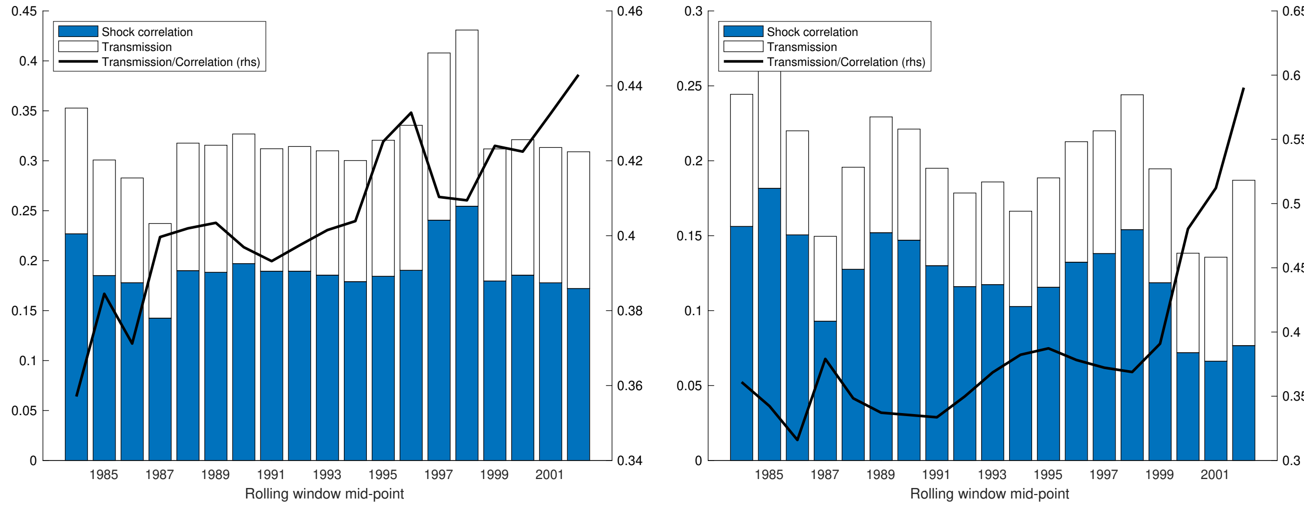
Notes: This table summarizes the parameters and data targets used in the baseline quantitative model and their sources. For η_j, the table reports the values for Agriculture, NMI, Manufactures and Services respectively. Alternative parameters are considered in Appendix C.

the rolling correlations of those terms following equation (2.13), in 10-year windows. Each bar is the average bilateral correlation of GDP growth across countries as in Figure 1. The blue part of the bar displays the shock correlation term, and the white part displays the transmission terms. The superimposed black line (right axis) shows the fraction of transmission in total correlation.

The left panel shows the decomposition for the composite supply shock for all country pairs, while the right panel illustrates the decomposition with the Solow residual as the supply shock. As in Figure 1, there is no clear increase in GDP correlations over this period. The decomposition helps understand why. Structural change leads to an erosion of the shock correlation term, as economic activity is reallocated to the less correlated service sector. Correspondingly, the relative importance of transmission in total correlation rises over this period, from about 35% at the beginning to 45% (composite shock) and 60% (Solow residual). A similar picture emerges for just the set of G7 countries: transmission increases while shock correlation remains stable or even decreases (Appendix Table C1).

Figure 4 displays correlations in 10-year windows. Thus, 2 things change over time in this figure: the structure of the economy, and the realizations of shocks. The advantage of doing it this way is that the GDP correlations match the GDP correlations in the data. The disadvantage is that it cannot separate changing sample shock correlations over time from the changing production structure. This issue is exacerbated by the fact that 10 yearly growth rates is quite a small sample, so changes in 10-year shock correlations between one period and the next could be dominated by small sample

FIGURE 4: Correlation decomposition through time: OECD country pairs



Composite shock | Solow residual

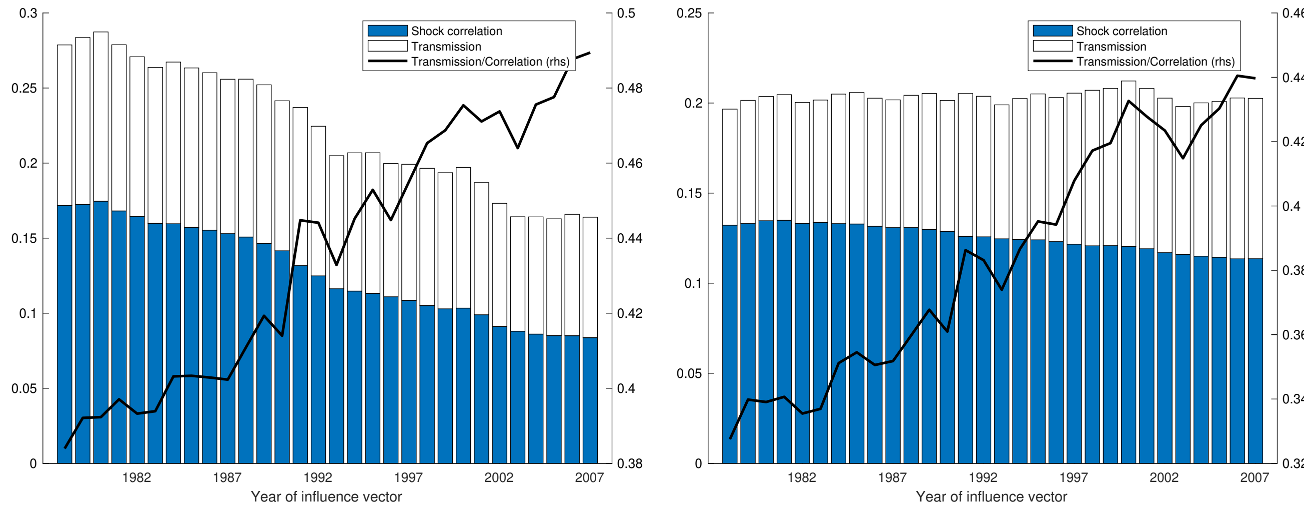
Notes: The figure displays the rolling decomposition of the total correlation (the height of the bar) into shock correlation (blue bars) and transmission (stacked white bars). We use the yearly influence vector in equation (2.7) to compute the decomposition in (2.2). The shocks used are the composite supply shocks on the left and the Solow residual on the right. The solid line shows the ratio between the transmission and total correlation.

variability rather than true changes in the shock process. To isolate the importance of the changing influence matrix from changes in shock realizations, we follow the approach of Carvalho and Gabaix (2013) and di Giovanni, Levchenko, and Méjean (2014) and feed the entire 30-year time series of shocks into the influence matrix for each year. This exercise answers the question: what would be the GDP correlations in, say, 1978 if the world as it was in 1978 experienced 30 years of business cycle shocks that occurred over 1978-2007? It may be a less noisy estimate of the true GDP comovement in the 1970s world economy, as it uses a longer time series as the estimation sample. Figure 5 shows the results of this exercise. The trends are more evident. For the composite shock, the total correlation falls substantially. For both shocks, the trend is driven by a fall in the shock correlation component. The share of transmission rises over time by a similar amount as in the rolling 10-year exercise. Appendix Table C2 displays additional statistics of the decomposition for the G7 country pairs.

4.3 Counterfactuals

Figures 4-5 summarize the evolution of GDP correlations over the 1978-2007 period taking the changes in the structure of the economy directly from the data. In this section, we separate the different proximate sources of structural change, to assess how each of these affected international comovement. Specifically, we isolate reductions in trade costs (Cravino and Sotelo, 2019), differentials in productivity growth cross sectors (Baumol, 1967), and a residual "taste" component that would

FIGURE 5: Correlation decomposition from changing influence: OECD country pairs



Composite shock | Solow residual

Notes: The figure displays the decomposition of the total correlation (total bar height) into shock correlation (blue bars) and transmission (white bars) for all OECD country pairs. We use the yearly influence vector in equation (2.7) to compute the decomposition in (2.2) using the full time-series of shocks. Hence, the x-axis corresponds to the year of the influence vector used for the decomposition. The shocks used are the composite supply shocks on the left panel and the Solow residual on the right panel. The solid line shows the ratio between transmission and total correlation.

be a reduced-form way of capturing non-homotheticicities in the demand for services (e.g. Kongsamut, Rebelo, and Xie, 2001; Boppart, 2014; Comin, Lashkari, and Mestieri, 2020), among other things.

Shock extraction for the long run We invert the model to jointly recover taste shifters ζ_{nj} and $\vartheta_{i,nj}$ and trade costs-cum-tastes $(\mu_{mnj})^{\frac{1}{1-\gamma}}\tau_{mnj}$ and $(\mu_{mi,nj})^{\frac{1}{1-\varepsilon}}\tau_{mni}$ to rationalize long-run changes in (i) sectoral final and intermediate expenditure shares π^f_{nj} and $\pi^x_{i,nj}$; and (ii) international trade shares π^f_{mnj} and $\pi^x_{mi,nj}$. Since this exercise is applied to long-run changes, for the purposes of extracting these shifters we switch to the specification of factor supply typical in models of structural change, as well as textbook international trade. Namely, we set the Frisch elasticity of *aggregate* labor supply to 0, and assume instead that labor is perfectly mobile across sectors.[4]

In this exercise, we must take a stand on how to treat long-run productivity changes $\ln Z_{nj}$. Our business cycle frequency shock extraction procedure described in Section 3.1 delivers yearly time series of productivity changes that rationalize year-to-year changes in sectoral value added. Our first approach is to cumulate those yearly productivity changes to build a long-run productivity change over the period 1978-2007. We then extract taste and trade cost shocks that match the sectoral expenditure and trade shares conditional on these long-run $\ln Z_{nj}$'s. In another approach,

[4]This amounts to setting $\psi = \infty$ and imposing the additional constraint that $\sum_j H_{nj} = \overline{H}_n$, $\forall n$. Note that this specification accommodates trend shifts in aggregate factor supplies driven by population changes and physical and human capital accumulation through sector-neutral changes in the composite shock Z_{nj}.

we compute long-run (1978-2007) differences in sectoral value added, and extract long-run TFP differences jointly with taste and trade cost shifters in one step. In both cases, when all three types of shocks are fed into the model, they reproduce the changes in sectoral expenditure shares and international trade shares over the period 1978-2007. The advantage of the former approach is that the productivity shocks used for short-run (correlations) and long-run (structural change) purposes coincide. The advantage of the second approach is that when all three sets of shocks are fed back into the model, it replicates the 1978-2007 changes in real value added by sector as well, which the first approach does not. The implications of the two approaches for international comovement and our counterfactuals are similar, so we relegate the second to the appendix.

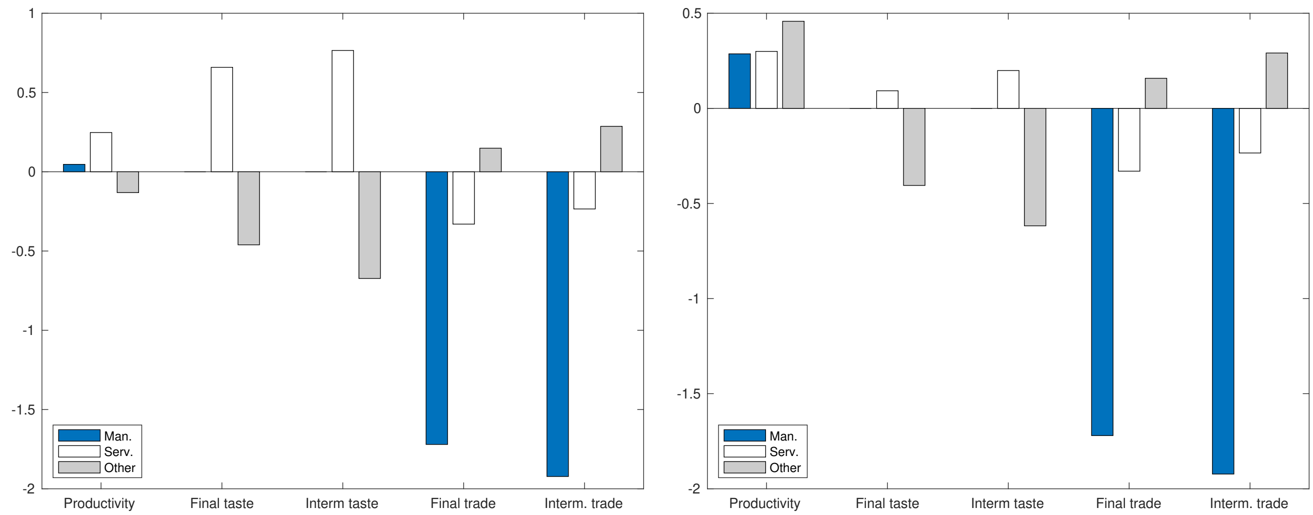
Figure 6 presents the productivity, taste shifter, and trade cost changes under the two approaches. As is clear from the figure, trade costs have fallen dramatically over this period in manufacturing, relative to services.[5] This pattern, which has been documented in numerous studies, holds for both intermediate goods trade and final goods trade. At the same time, tastes for services relative to manufacturing have increased in both intermediate goods trade and final goods trade. Our model also implies that relative productivity in services has increased over this period. The existing evidence on this shift is mixed, while some studies use a relative increase in manufacturing productivity as a driver of structural change, a large literature studying the introduction of cognitive-intensive technologies such as Information and Communications Technology (ICT) since 1980 find that they disproportionately benefited workers in many service sectors (see for instance Autor, Levy, and Murnane, 2003; Adão, Beraja, and Pandalai-Nayar, 2020)[6]

Counterfactual correlations Figure 7 presents the results of the counterfactuals. Throughout, to compute business cycle correlations, we take each model and feed in 30 years of shocks to either Z_{nj} or the Solow residual, as in Figure 5. The left-most bar summarizes the average GDP correlation in the world characterized by the 1978 production structure. The white and blue bars depict the transmission and shock correlation components, respectively. The second bar displays the "globalization-only" counterfactuals, that starts with the 1978 world economy, and feeds in only the

[5]Without data on import prices, we cannot separate changes in tastes for foreign goods μ_{mnj} and $\mu_{mi,nj}$ from true iceberg costs τ_{mnj}, as their effects on international expenditure shares are isomorphic. In what follows, for expositional purposes we attribute the entirety of the change in trade shares to τ_{mnj}, for instance when plotting it in Figure 6. This is purely to streamline discussion. None of the conclusions with respect to international GDP correlations are sensitive to whether trade globalization has been driven by trade cost or taste changes.

[6]Jovanovic and Rousseau (2005) discuss the introduction and adoption of two "General-Purpose Technologies" in the last century – electricity and ICT. The first resulted in the structural transformation towards manufacturing between 1900-1940, while the latter benefited sectors intensive in cognitive skills. Additionally, they find the productivity increase due to the ICT technology has been slower, consistent with the small relative productivity change in Figure 6. Adão, Beraja, and Pandalai-Nayar (2020) illustrate this pattern is consistent with this technology being adopted slower, as the skills required to adopt it are not prevalent in the existing workforce. This additionally leads to the implication that purely productivity-driven structural transformation towards services would be slower, as we find in our counterfactuals below.

FIGURE 6: Long-run productivity, taste, and trade cost changes



Cumulative Composite Shocks for Productivity — Long-run Shocks

Notes: The figure displays the long-run changes in productivity, taste shifters (relative to manufacturing), and trade costs. The left panel displays the changes under the assumption that the long-run productivity shock is the cumulative change in the composite shock. The right panel extracts the change in productivity to match the long-run sectoral value-added change.

1978-2007 change in trade costs. Intriguingly, in spite of a large reduction in trade costs, average correlations change relatively little compared to the 1978 world. The breakdown between transmission and shock correlation components helps understand why. Globalization increases international trade shares, and substantially raises international shock transmission (the white bar widens). However, as discussed above, when manufacturing and services are complements, a fall in trade costs lowers the manufacturing expenditure shares in favor of services.[7] Services have less correlated shocks, so a fall in trade costs moves value added into less correlated sectors, shrinking the shock correlation component of GDP comovement (the blue bar).

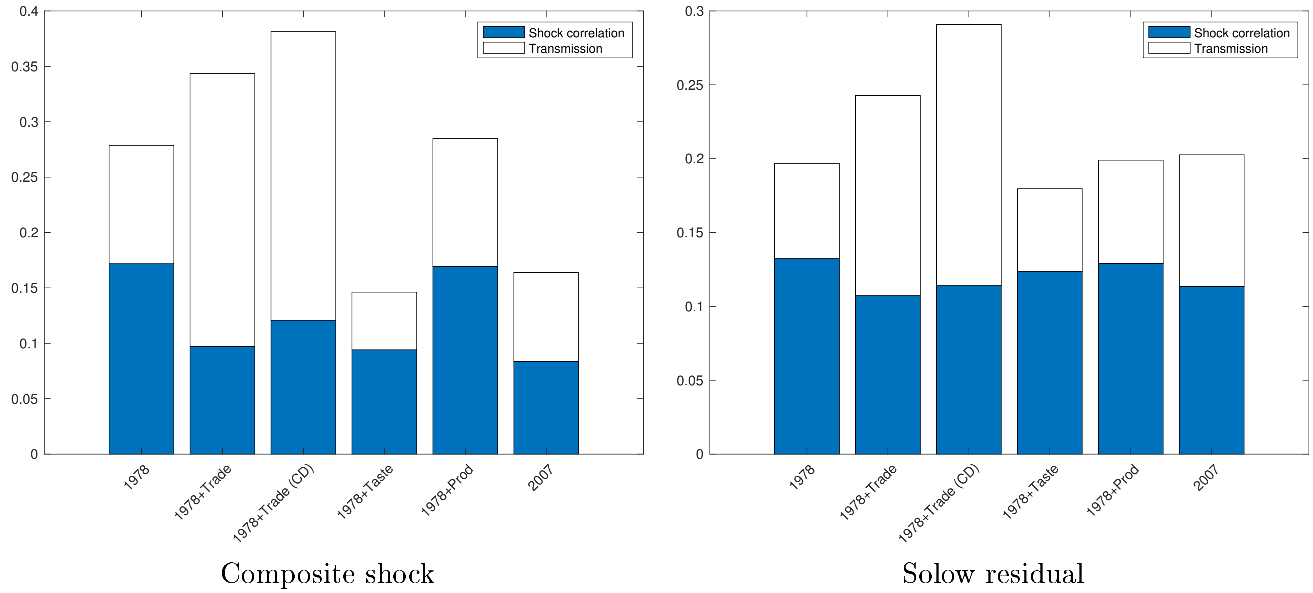
To separate these two forces of globalization, the third bar displays GDP correlations under an alternative "globalization-only" counterfactual, that reduces the trade costs by the same amount, but forces manufacturing/services expenditure shares to stay constant.[8] When trade costs fall but expenditure shares are not allowed to change, comovement increases noticeably, because the increase in international transmission is not accompanied by a large fall in the shock correlation components.

To complete the picture, the next two bars display international comovement in the alternative worlds in which only taste, and only productivity experienced long-run changes starting from 1978.

[7]Appendix Figure C2 displays the sectoral shares and foreign trade shares in the data and counterfactuals.

[8]This is accomplished by applying the trade cost changes to a model where sectors are Cobb-Dougles in both final consumption and production. When we simulate business cycle comovement, we still use the baseline (complementary) elasticities.

FIGURE 7: Counterfactual correlations



Notes: The bars display the average GDP growth correlations, decomposed into a shock correlation term (in blue) and transmission term (in white). Each bar represents a different scenario. "1978" is a counterfactual world in which the influence remained the same as the 1978 world, "1978+Trade" is a world in which only trade costs changed, "1978+Trade" is a world in which only trade costs changed but sectoral shares remained constant, "1978+Taste" is a world in which only taste shocks evolved since 1978, and "1978+Prod" is a world in which only the productivity shocks happened since 1978. "2007" performs the decomposition using the 2007 influence vector. In all cases, the correlation decomposition is computed on the same time series of shock from 1978 to 2007. Appendix Table C3 displays the numbers underlying the figure and additional statistics.

As expected, applying long-run taste shocks to the 1978 world economy lowers comovement relative to 1978, as taste shocks favor the service sector which is less correlated. On the other hand, feeding in only productivity changes makes very little difference for international comovement, compared to the initial structure of the economy. Finally, the last bar plots the comovement in the 2007 world economy, that experienced all three drivers of globalization and structural change. It is by and large an average of the three shock-by-shock counterfactuals.

Appendix figures C3 and C5 document similar patterns across counterfactuals for the alternative approach to constructing the long run productivity shock, as well as for each decade within the sample. The patterns differ slightly in the last decade, as during this period the correlation of services shocks was noticeably higher than in previous decades (see figure C1).

5 Conclusion

We provide a resolution to the puzzle that increasing globalization, coupled with increased transmission of shocks, has not resulted in an increase in international comovement in recent decades. We show that structural change towards services sectors in both final consumption and in input usage in advanced economies is important to understand this puzzle. The service sector, which has been growing over time, displays shocks with lower international correlation than the manufacturing sector. Additionally, when services and goods are complements in both consumption and production, globalization – in the form of decreasing trade costs– itself induces structural change towards services because it reduces the relative price of goods to services.

Thus the overall impact of globalization on international comovement is actually ambiguous – the shift it induces towards services can theoretically offset the increased transmission through increasing trade and input linkages. We quantify these opposing effects using a multi-country, multi-sector model of international production implemented on the countries of the OECD. We find that while transmission due to increased trade and input linkages would have increased comovement all else equal, the offsetting effects due to both structural change and the decreased relative price of manufacturing from globalization have both contributed to keeping overall comovement stable over time. Comovement on average would have declined if structural change had been the only force at work, while it would have increased if globalization occurred without inducing a shift towards service sectors through complementarity.

References

Adão, Rodrigo, Martin Beraja, and Nitya Pandalai-Nayar. 2020. "Technological Transitions with Skill Heterogeneity Across Generations." Working Paper 26625, National Bureau of Economic Research.

Alvarez, Fernando and Robert E., Jr. Lucas. 2007. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade." *Journal of Monetary Economics* 54 (6):1726–1768.

Alviarez, Vanessa, Cheng Chen, Nitya Pandalai-Nayar, Liliana Varela, Kei-Mu Yi, and Hongyong Zhang. 2021. "Multinationals and Structural Change." Mimeo.

Ambler, Steve, Emanuela Cardia, and Christian Zimmermann. 2004. "International business cycles: What are the facts?" *Journal of Monetary Economics* 51 (2):257–276.

Angeletos, George-Marios and Jennifer La'O. 2013. "Sentiments." *Econometrica* 81 (2):739–779.

Atalay, Enghin. 2017. "How Important Are Sectoral Shocks?" *American Economic Journal: Macroeconomics* 9 (4):254–280.

Autor, David H., Frank Levy, and Richard J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *The Quarterly Journal of Economics* 118 (4):1279–1333.

Backus, David K, Patrick J Kehoe, and Finn E Kydland. 1992. "International Real Business Cycles." *Journal of Political Economy* 100 (4):745–75.

Baqaee, David Rezza and Emmanuel Farhi. 2019. "The Macroeconomic Impact of Microeconomic Shocks: Beyond Hulten's Theorem." *Econometrica* 87 (4):1155–1203.

Barrot, Jean-Noël and Julien Sauvagnat. 2016. "Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks." *Quarterly Journal of Economics* 131 (3):1543–1592.

Barsky, Robert B. and Eric R. Sims. 2012. "Information, Animal Spirits, and the Meaning of Innovations in Consumer Confidence." *American Economic Review* 102 (4):1343–77.

Baumol, William J. 1967. "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis." *American Economic Review* 57 (3):415–426.

Beaudry, Paul and Franck Portier. 2006. "Stock Prices, News, and Economic Fluctuations." *American Economic Review* 96 (4):1293–1307.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar. 2019. "Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tohoku Earthquake." *The Review of Economics and Statistics* 101 (1):60–75.

Boppart, Timo. 2014. "Structural Change and the Kaldor Facts in a Growth Model With Relative Price Effects and Non-Gorman Preferences." *Econometrica* 82:2167–2196.

Burstein, Ariel, Christopher Kurz, and Linda L. Tesar. 2008. "Trade, Production Sharing, and the International Transmission of Business Cycles." *Journal of Monetary Economics* 55:775–795.

Carvalho, Vasco M. and Xavier Gabaix. 2013. "The Great Diversification and its Undoing." *American Economic Review* 103 (5):1697–1727.

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi. 2016. "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake." Mimeo, University of Cambridge, Policy Research Institute, Ministry of Finance of Japan, RIETI, and Columbia GSB.

Comin, Diego A., Danial Lashkari, and Martí Mestieri. 2020. "Structural Change with Long-run Income and Price Effects." Forthcoming, *Econometrica*.

Cravino, Javier and Sebastian Sotelo. 2019. "Trade-Induced Structural Change and the Skill Premium." *American Economic Journal: Macroeconomics* 11 (3):289–326.

di Giovanni, Julian and Andrei A. Levchenko. 2010. "Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement." *American Economic Journal: Macroeconomics* 2 (2):95–124.

di Giovanni, Julian, Andrei A. Levchenko, and Isabelle Méjean. 2014. "Firms, Destinations, and Aggregate Fluctuations." *Econometrica* 82 (4):1303–1340.

di Giovanni, Julian, Andrei A. Levchenko, and Isabelle Mejean. 2018. "The Micro Origins of International Business Cycle Comovement." *American Economic Review* 108 (1):82–108.

Drozd, Lukasz A., Sergey Kolbin, and Jaromir B. Nosal. 2020. "The Trade-Comovement Puzzle." Forthcoming, *American Economic Journal: Macroeconomics*.

Frankel, Jeffrey A. and Andrew K. Rose. 1998. "The Endogeneity of the Optimum Currency Area Criteria." *Economic Journal* 108 (449):1009–25.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *American Economic Review* 78 (3):402–17.

Heathcote, Jonathan and Fabrizio Perri. 2002. "Financial autarky and international business cycles." *Journal of Monetary Economics* 49 (3):601–627.

Herrendorf, Berthold, Richard Rogerson, and Ákos Valentinyi. 2013a. "Two perspectives on preferences and structural transformation." *American Economic Review* 103 (7):2752–2789.

Herrendorf, Berthold, Richard Rogerson, and Ákos Valentinyi. 2013b. "Two Perspectives on Preferences and Structural Transformation." *American Economic Review* 103 (7):2752–89.

———. 2014. "Growth and Structural Transformation." In *Handbook of Economic Growth*, *Handbook of Economic Growth*, vol. 2, chap. 6. Elsevier, 855–941.

Huo, Zhen, Andrei A. Levchenko, and Nitya Pandalai-Nayar. 2020. "International Comovement in the Global Production Network." NBER Working Paper 25978.

Huo, Zhen and Naoki Takayama. 2015. "Higher Order Beliefs, Confidence, and Business Cycles." Mimeo, University of Minnesota.

Imbs, Jean. 1999. "Technology, growth and the business cycle." *Journal of Monetary Economics* 44 (1):65 – 80.

———. 2004. "Trade, Finance, Specialization, and Synchronization." *Review of Economics and Statistics* 86 (3):723–34.

Imbs, Jean and Laurent Pauwels. 2019. "Fundamental Moments." CEPR Discussion Paper 13662.

Johnson, Robert C. 2014. "Trade in Intermediate Inputs and Business Cycle Comovement." *American Economic Journal: Macroeconomics* 6 (4):39–83.

Johnson, Robert C. and Guillermo Noguera. 2017. "A Portrait of Trade in Value-Added over Four Decades." *The Review of Economics and Statistics* 99 (5):896–911.

Jovanovic, Boyan and Peter L. Rousseau. 2005. "General Purpose Technologies." In *Handbook of Economic Growth*, *Handbook of Economic Growth*, vol. 1, edited by Philippe Aghion and Steven Durlauf, chap. 18. Elsevier, 1181–1224.

Ko, Paul I. 2020. "Dissecting Trade and Business Cycle Co-movement." Mimeo, Penn State.

Kongsamut, Piyabha, Sergio Rebelo, and Danyang Xie. 2001. "Beyond Balanced Growth." *The Review of Economic Studies* 68 (4):869–882.

Kose, M. Ayhan, Christopher Otrok, and Charles H. Whiteman. 2003. "International Business Cycles: World, Region, and Country-Specific Factors." *American Economic Review* 93 (4):1216–1239.

Kose, M. Ayhan, Christopher Otrok, and Charles H. Whiteman. 2008. "Understanding the evolution of world business cycles." *Journal of International Economics* 75 (1):110–130.

Kose, M. Ayhan and Kei-Mu Yi. 2006. "Can the Standard International Business Cycle Model Explain the

Relation Between Trade and Comovement." *Journal of International Economics* 68 (2):267–295.

Lewis, Logan T., Jing Zhang, Ryan Monarch, and Michael J. Sposi. 2020. "Structural Change and Global Trade." Forthcoming, *Journal of the European Economic Association*.

Liao, Wei and Ana Maria Santacreu. 2015. "The Trade Comovement Puzzle and the Margins of International Trade." *Journal of International Economics* 96 (2):266–288.

Matsuyama, Kiminori. 2009. "Structural Change in an Interdependent World: A Global View of Manufacturing Decline." *Journal of the European Economic Association* 7 (2-3):478–486.

Miyamoto, Wataru and Thuy Lan Nguyen. 2020. "International Linkages and the Changing Nature of International Business Cycles." Mimeo, University of Hong Kong, Federal Reserve Bank of San Francisco, and Santa Clara University.

Ng, Eric C.Y. 2010. "Production fragmentation and business-cycle comovement." *Journal of International Economics* 82 (1):1 – 14.

Ngai, L. Rachel and Christopher A. Pissarides. 2007. "Structural Change in a Multisector Model of Growth." *American Economic Review* 97 (1):429–443.

O'Mahony, Mary and Marcel P. Timmer. 2009. "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS Database." *The Economic Journal* 119 (538):F374–F403.

Sposi, Michael. 2019. "Evolving comparative advantage, sectoral linkages, and structural change." *Journal of Monetary Economics* 103:75–87.

Swiecki, Tomasz. 2017. "Determinants of Structural Change." *Review of Economic Dynamics* 24:95–131.

Uy, Timothy, Kei-Mu Yi, and Jing Zhang. 2013. "Structural change in an open economy." *Journal of Monetary Economics* 60 (6):667–682.

Table A1: Sectoral conversion list

Sector	KLEMS code
Agriculture	AtB
NMI	C, E, F
Manufactures	15t16, 17t19, 20t22, 23t24, 25, 26, 27t28, 29t37
Services	G, H, 60t63, 64, J, 70, 71t74, L, M, N, O, P, Q

Table A2: Link with KLEMS variable

Model object	Description	Link with KLEMS variable
Y_{nj}	output	$\ln Y_{nj} = \ln GO - \ln GO\_P$
X_{nj}	intermediate inputs	$\ln X_{nj} = \ln II - \ln II\_P$
η_j	Share of value added	$\eta_j = 1 - \frac{1}{N}\sum_n \frac{(LAB_{nj}+CAP_{nj}}{GO_{nj}}$

Appendix A Data and Estimation Appendix

A.1 Data description details

Sectoral classification and aggregation Our final analysis uses the four broad sectors (“Agriculture", “Non-Manufacturing Industries", “Manufactures" and “Services") as defined in Johnson and Noguera (2017). To aggregate the sectoral data from KLEMS to those four sectors, we use the mapping displayed in Table A1.

To aggregate to the fours sectors, we follow Herrendorf, Rogerson, and Valentinyi (2013b) and use the so called cyclical expansion procedure. Denote by Y_{it} the nominal value, Q_{it} the quantity index, and P_{it} the price index for a sub-sector i at time t. These are the values taken directly from KLEMS disaggregated data. The goal is to compute real values (Q_t) and deflators (P_t) for the aggregate $Y_t = \sum_i Y_{it}$. We define the growth rate of the real value of the aggregate as:

$$\frac{Q_t}{Q_{t-1}} = \sqrt{\frac{\sum_i P_{it-1}y_{it}}{\sum_i P_{it-1}y_{it-1}} \frac{\sum_i P_{it}y_{it}}{\sum_i P_{it}y_{it-1}}}$$

From there, we compute $\frac{P_t}{P_{t-1}} = \frac{Y_t}{Y_{t-1}} / \frac{Q_t}{Q_{t-1}}$.

Table A2 displays the variables we use from KLEMS and how they map to model objects.

Country coverage After merging the trade and sectoral data, the final dataset consists of 19 countries and a composite Rest of the World. The list of countries is presented in table A3, and covers 75% of the countries that were part of the OECD at the beginning of our sample (96% in terms of GDP).

Table A3: Country list

Country code	Country name	Country code	Country name
AUS	Australia	GRC	Greece
AUT	Austria	IRL	Ireland
BEL	Belgium	ITA	Italy
CAN	Canada	JPN	Japan
DEU	Germany	KOR	Korea
DNK	Denmark	NLD	Netherlands
ESP	Spain	PRT	Portugal
FIN	Finland	ROW	Rest of the World
FRA	France	SWE	Sweden
GBR	United Kingdom	USA	United States

A.2 Elasticity Estimation

To calibrate the model, we require a few key elasticities of substitution in the intermediate and final goods bundles. We estimate these key elasticities using optimality conditions from the model.

Elasticity of substitution between sectors in production The elasticity of substitution in production between sectors ε is estimated by regressing changes in the relative shares of spending on sectors (eg manufacturing relative to services), on changes in relative prices in the sectors:

$$\ln \frac{\Delta \pi^x_{i,nj,t}}{\Delta \pi^x_{k,nj,t}} = (1-\varepsilon) \ln \frac{\Delta P_{i,nj,t}}{\Delta P_{k,nj,t}} + \omega_{ikt} + u_{ik,nj,t}. \tag{A.1}$$

Here, the price of the sector composites used in the input bundle $P_{i,nj,t}$ are constructed by aggregating weighted domestic producer price indices from all source countries for that sector, where the weights are lagged shares of spending on a source country.[9] This implies that, if the true purchaser price $P_{mi,nj,t} = \tau_{mi,nj,t} P_{mi,t}$ where $\tau_{mi,nj,t}$ are unobserved "iceberg" trade costs, then the structural error $u_{ik,nj,t}$ includes the ratios of deviations of these costs in the numerator and denominator sectors from the average captured by the weights in the aggregator. Iceberg trade costs include both transport/tariff changes as well as changes in local distribution margins and idiosyncratic bilateral preferences for country m sector i's output as an input. Further, the destination country-sector's relative preference changes for between the two sectors will also be in the structural error term. We include sector-pair time fixed effects ω_{ijt} to soak up much of this variation. For instance, a worldwide shift in preferences between services and manufacturing in a particular period will be absorbed by this fixed effect, as would a worldwide reduction in the relative trade cost of services to manufacturing.

Residual threats to identification then are a correlation in the domestic PPI change in country m sector i with changes in bilateral trade costs or preference shifts, broadly defined, between country m sector i and country n sector j. Additionally, deviations of the destination country's relative preferences for i and j from the world average in period t might be correlated with the relative price changes between i and j. Such correlations are unlikely in an annual differenced specification, but might be more of a concern in a long differenced specification (for instance, a persistent preference shift towards manufacturing correlated with a decrease in the relative manufacturing price). We therefore present the results both of an OLS estimation of this relative differences specification, as well as the results of an IV specification. For instruments, we use oil

[9] Each domestic PPI is appropriately multiplied by an exchange rate to convert all prices to US dollars, as KLEMS reports the PPIs in domestic currency.

and defense spending shocks, as well as upstream and downstream versions of these shocks, constructed as detailed below in subsection A.3. Additionally, we estimate ε using an annual differenced specification and a long differenced specification. For the latter we do not use an IV, as the exclusion restriction is more likely to be violated (a persistent relative change in demand due to a persistent relative defense spending shock can spur technological changes in a sector and changes in sectoral prices).

Elasticity of substitution across countries, within sectors in production The estimating equation for the elasticity of substitution across countries, within a sector of production, is given by:

$$\ln \frac{\Delta \pi^x_{mi,nj,t}}{\Delta \pi^x_{m'i,nj,t}} = (1-\nu) \ln \frac{\Delta P_{mi,nj,t}}{\Delta P_{m'i,nj,t}} + \omega_{mm't} + u_{mm',inj,t}. \tag{A.2}$$

As above, we use the fact that $P_{mi,nj,t} = \tau_{mi,nj,t} P_{mi,t}$, and use data on relative PPIs of sector i in countries m and m' to measure the price ratio. Then the structural error $u_{mm',inj,t}$ includes changes in relative trade costs as well as relative taste shifters. We soak up most of this unobserved variation by including an importer country-exporter country pair-year fixed effect. Any relative trade or taste shifter common to all sectors within the triplet of countries will be absorbed by the fixed effect.

A residual threat to our identification strategy involves a correlation between the exporter countries price and the importer-exporter taste for a specific sector. This could arise, for example, from a positive taste shock for inputs of sector i from country m relative to country m', that results in an increased price if the importer is large enough. We alleviate this concern in two ways. First, we run the estimation on a subsample of G7 exporter and non-G7 importers. In this sample, it is unlikely that taste shocks in the small importer countries lead to price changes in the large exporter countries. Second, we use an IV estimation based on similar instruments as above.

Elasticities of substitution in consumption The estimation of the elasticities ρ and γ uses the optimality conditions on the household side that lead to very similar estimating equations as for the production side. These elasticities have been previously estimated by Herrendorf, Rogerson, and Valentinyi (2013b), and Huo, Levchenko, and Pandalai-Nayar (2020) among others. For consistency we re-estimate the parameters in our data using the following two estimating equations:

$$\ln \frac{\Delta \pi^f_{nj,t}}{\Delta \pi^f_{nk,t}} = (1-\rho) \ln \frac{\Delta P^f_{nj,t}}{\Delta P^f_{nk,t}} + \omega_{jkt} + u_{nj,nk,t} \tag{A.3}$$

$$\ln \frac{\Delta \pi^f_{mnj,t}}{\Delta \pi^f_{m'nj,t}} = (1-\gamma) \ln \frac{\Delta P_{mj,t}}{\Delta P_{m'j,t}} + \omega_{mm't} + u_{mm',nj,t} \tag{A.4}$$

A.3 Instruments

We use two sources of exogenous variation. The first is an oil price shock, defined as the difference between the (log) oil price and the maximum (log) price in the preceding year. The oil shock - denoted OIL_t - is either zero (when the difference is negative), or positive (when the difference is positive). The second source of exogenous variation is the lagged change in real government defense spending and denoted DEF_{nt}.

The instruments are constructed by exploiting the difference in input exposure to oil and demand exposure to government spending. Formally, define $OIL_{njt} = OIL_t \sum_{m,i=oil} \pi^x_{mi,nj}$ and $DEF_{njt} = DEF_{nt} G_{nj}/Y_{nj}$, where G_{nj} are the sales of sector j, country n, to the government in country n. [10] OIL_{njt} and DEF_{njt} are the *direct* shocks. We further construct upstream and downstream versions of these shocks by exploiting variation

[10]In practice, because our sectors are highly aggregated, we use the WIOD disaggregated IO matrix to construct

in up- and down-stream exposure to sectors with different direct exposure to the shock.[11]

A.4 Elasticities estimates

Table A4 displays the results of the estimation of the elasticity of substitution across input types. Our results suggest complementarity between between input sectors, with elasticities significantly lower than 1 even at the 10 year horizon. Table A5 displays the results of the estimation of the elasticity of substitution across origin countries within input type.

Table A6 displays the results of the estimation of the elasticity of substitution across consumption types. Again, our results suggest complementarity between between sectors, with elasticities significantly lower than 1 even at the 10 year horizon. Table A7 displays the results of the estimation of the elasticity of substitution across origin countries within consumption type.

TABLE A4: Estimation of the elasticity between input types, ε

	1 year difference				10 year difference	
	G7		All countries		G7	All countries
	OLS	IV	OLS	IV	OLS	OLS
ε	0.368 (0.058)	0.409 (0.349)	0.167 (0.200)	3.160 (1.193)	0.285 (0.209)	0.742 (0.187)
KP-F		19.42		18.15		
N	4,704	4,704	12,765	12,765	3,192	8,661
FE	✓	✓	✓	✓	✓	✓

Notes: This table presents the results of estimating equation A.1. FE refers to supplier sector pairs fixed effects. Standard errors are clustered at the user country-sector times supplier pair level and displayed in parenthesis. KP-F refers to the first stage Kleibergen-Paap F-statistic.

sub-sectors specific exposure to the oil sector or government spending, and aggregate the exposure using a weighted average, where the weight is equal to the sub-sector's output.

[11]For a *direct* instrument Z_{njt}, define the upstream instrument Z^{up} and downstream instrument Z^{down} as:

$$Z^{up}_{njt} = \sum_{mi} \pi^x_{mi,nj} Z_{mi,t}$$

and

$$Z^{down}_{mit} = \sum_{nj} \pi^x_{mi,nj} Z_{nj,t}$$

Table A5: Estimation of the elasticity across origins in inputs, ν

	1 year difference				10 year difference	
	G7, non-G7		All countries		G7, non-G7	All countries
	OLS	IV	OLS	IV	OLS	OLS
ν	1.196	0.876	1.080	0.968	1.480	1.574
	(0.144)	(0.858)	(0.104)	(1.012)	(0.153)	(0.115)
KP-F		4230.33		1664.54		
N	112,471	110,383	1,279,025	1,269,993	75,795	848,538
FE	✓	✓	✓	✓	✓	✓

Notes: This table presents the results of estimating equation A.2. "G7, non-G7" refers to the sample using G7 exporters and non-G7 importers only. FE refers to supplier sector pairs fixed effects. Standard errors are clustered at the user country-sector times supplier sector pair level and displayed in parenthesis. KP-F refers to the first stage Kleibergen-Paap F-statistic.

Table A6: Estimation of the elasticity between consumption types, ρ

	1 year difference				10 year difference	
	G7		All countries		G7	All countries
	OLS	IV	OLS	IV	OLS	OLS
ρ	0.397	0.305	0.457	0.300	0.433	0.525
	(0.051)	(0.142)	(0.033)	(0.097)	(0.092)	(0.070)
KP-F		11.66		30.92		
N	1,218	1,218	3,306	3,306	840	2280
FE	✓	✓	✓	✓	✓	✓

Notes: This table presents the results of estimating equation A.3. FE refers to supplier sector pairs fixed effects. Standard errors are clustered at the user country-sector times supplier pair level and displayed in parenthesis. KP-F refers to the first stage Kleibergen-Paap F-statistic.

TABLE A7: Estimation of the elasticity across origins in consumption, γ

	1 year difference				10 year difference	
	G7, non-G7		All countries		G7, non-G7	All countries
	OLS	IV	OLS	IV	OLS	OLS
γ	1.146	-0.434	0.887	1.214	1.943	1.501
	(0.297)	(1.604)	(0.248)	(3.490)	(0.381)	(0.346)
KP-F		682.03		233.23		
N	22,291	21,903	251,627	249,947	14,199	159,376
FE	✓	✓	✓	✓	✓	✓

Notes: This table presents the results of estimating equation A.4. "G7, non-G7" refers to the sample using G7 exporters and non-G7 importers only. FE refers to supplier country pairs fixed effects. Standard errors are clustered at the user country-sector times supplier sector pair level and displayed in parenthesis. KP-F refers to the first stage Kleibergen-Paap F-statistic.

Appendix B Model Appendix

B.1 Short-run model

Combining the goods market clearing condition (2.5) with the balanced trade equation (2.6) and log-linearizing yields:

$$\begin{aligned}\ln P_{nj} + \ln Y_{nj} &= \sum_m \sum_i \frac{\eta_i P_{mi} Y_{mi}}{P_m \mathcal{F}_m} \frac{\pi^f_{mj}\pi^f_{nmj} P_m \mathcal{F}_m}{P_{nj} Y_{nj}} \left(\ln \pi^f_{mj} + \ln \pi^f_{nmj} + \ln P_{mi} + \ln Y_{mi}\right) \\ &+ \sum_m \sum_i (1-\eta_i) \frac{P_{mi,t} Y_{mi,t}}{P_{nj,t} Y_{nj,t}} \pi^x_{j,mi,t} \pi^x_{nj,mi,t} \left(\ln \pi^x_{j,mi} + \ln \pi^x_{nj,mi} + \ln P_{mi} + \ln Y_{mi}\right) \qquad \text{(B.1)}\end{aligned}$$

where the changes in shares are given by:

$$\begin{aligned}\ln \pi^f_{nj} &= \ln \zeta_{nj} + (1-\rho) \sum_m \pi^f_{mnj} \left(\ln \tilde{\tau}^f_{mnj} + \ln P_{mj}\right) \\ &- \sum_k \pi^f_{nk} \ln \zeta_{nk} - (1-\rho) \sum_k \pi^f_{nk} \left[\sum_m \pi^f_{mnk} \left(\ln \tilde{\tau}^f_{mnk} + \ln \hat{P}_{mk}\right)\right],\end{aligned}$$

$$\ln \pi^f_{mnj} = (1-\gamma) \left(\ln \tilde{\tau}^f_{mnj} + \ln P_{mj} - \sum_o \pi^f_{onj} \left(\ln \tilde{\tau}^f_{onj} + \ln P_{oj}\right)\right),$$

$$\begin{aligned}\ln \pi^x_{i,nj} &= \ln \varpi_{i,nj} + (1-\varepsilon) \left(\sum_m \pi^x_{mi,nj,t} \left(\ln \tilde{\tau}^x_{mi,nj} + \ln \hat{P}_{mi}\right)\right) \\ &- \sum_k \pi^x_{k,nj,t} \ln \varpi_{k,nj} - (1-\varepsilon) \sum_k \pi^x_{k,nj,t} \sum_m \pi^x_{mk,nj,t} \left(\ln \tilde{\tau}^x_{mk,nj} + \ln \hat{P}_{mk}\right),\end{aligned}$$

and

$$\ln \pi^x_{mi,nj} = (1-\nu) \left(\ln \tilde{\tau}^x_{mi,nj} + \ln P_{mi} - \sum_k \pi^x_{ki,nj} \left(\ln \tilde{\tau}^x_{ki,nj} + \ln P_{ki}\right)\right),$$

Define the following matrices:

- $\mathbf{\Psi^f}$ is a $NJ \times N$ matrix whose (nj, m)th element is $\frac{\pi^f_{mj}\pi^f_{nmj} P_m \mathcal{F}_m}{P_{nj} Y_{nj}}$, the share of nj's total revenue that comes from final sales to country m.
- $\mathbf{\Upsilon}$ is a $N \times NJ$ matrix whose (m, mi)th element is $\frac{\eta_i P_{mi} Y_{mi}}{P_m \mathcal{F}_m}$, the share of value added of sector i in country m's GDP. Elements (n, mi) are 0 whenever $n \neq m$.
- $\mathbf{\Psi^x}$ is a $NJ \times NJ$ matrix whose $(nj, mi)th$ element is $\frac{\pi^x_{nj,mi}\pi^x_{j,mi}(1-\eta_i) P_{mi} Y_{mi}}{P_{nj,t} Y_{nj,t}}$, the share of country m,sector i's purchases from country n, sector j, in country n, sector j's total output.
- $\mathbf{\Pi^{1f}}$ is a $N \times NJ$ matrix whose $(m, nj)th$ element is $\pi^f_{mj}\pi^f_{nmj}$, the share of country n, sector j in country m's total consumption.

- $\mathbf{\Pi^{2f}}$ is a $N \times NJ$ matrix whose $(m, nj)\,th$ element is π^f_{nmj}, the share of country n in country m, sector j's spending.
- $\mathbf{\Pi^{1x}}$ is a $NJ \times NJ$ matrix whose $(nj, mi)th$ element is $\pi^x_{i,nj}\pi^x_{mi,nj}$, the share of country m, sector i in country n, sector j's total inputs.
- $\mathbf{\Pi^{2x}}$ is a $NJ \times NJ$ matrix whose $(mi, nj)th$ element is $\pi^x_{mi,nj}$.

Ignoring taste shocks and trade costs changes, the market clearing can be written in matrix form as:

$$\begin{aligned}\ln \mathbf{P} + \ln \mathbf{Y} = & \left(\mathbf{\Psi^f \Upsilon} + \mathbf{\Psi^x}\right)(\ln \mathbf{P} + \ln \mathbf{Y}) \\ & + \left[(1-\gamma)\, diag\left(\mathbf{\Psi^f 1}\right) + [(1-\rho) - (1-\gamma)]\, \mathbf{\Psi^c \Pi^{2f}} - (1-\rho)\, \mathbf{\Psi^f \Pi^{1f}}\right] \ln \mathbf{P} \\ & + \left[(1-\nu)\, diag\left(\mathbf{\Psi^x 1}\right) + [(1-\varepsilon) - (1-\nu)]\, \mathbf{\Psi^x \Pi^{2x}} - (1-\varepsilon)\, \mathbf{\Psi^x \Pi^{1x}}\right] \ln \mathbf{P},\end{aligned}$$

which allows us to solve for prices as a function of quantities:

$$\ln \mathbf{P} = \mathcal{P}\mathbf{Y},$$

where

$$\mathcal{P} = -\left(I - \mathcal{M}\right)^{+}\left(\mathbf{I} - \mathbf{\Psi^f \Upsilon} - \mathbf{\Psi^x}\right),$$

and

$$\begin{aligned}\mathcal{M} = & \mathbf{\Psi^f \Upsilon} + \mathbf{\Psi^x} + \left[(1-\gamma)\, diag\left(\mathbf{\Psi^f 1}\right) + [(1-\rho) - (1-\gamma)]\, \mathbf{\Psi^c \Pi^{2f}} - (1-\rho)\, \mathbf{\Psi^f \Pi^{1f}}\right] \\ & + \left[(1-\nu)\, diag\left(\mathbf{\Psi^x 1}\right) + [(1-\varepsilon) - (1-\nu)]\, \mathbf{\Psi^x \Pi^{2x}} - (1-\varepsilon)\, \mathbf{\Psi^x \Pi^{1x}}\right].\end{aligned}$$

From the labor supply and firm optimality condition:

$$\frac{1}{\psi} \ln H_{nj} = \ln W_{nj} - \ln P_n = \ln P_{nj} + \ln Y_{nj} - \ln H_{nj} - \ln P_n,$$

so that:

$$\ln H_{nj} = \frac{\psi}{1+\psi}\left[\ln P_{nj} + \ln Y_{nj} - \ln P_n\right]. \tag{B.2}$$

The consumption price index (in a NJ vector, where element (nj) has value $\ln P_n$,$\forall j$) can be written as:

$$\ln \mathbf{P^f} = \left(\mathbf{\Pi^{1f}} \otimes \mathbf{1}\right) \ln \mathbf{P},$$

so the vector of sectoral hours is given by:

$$\ln \mathbf{H} = \frac{\psi}{1+\psi}\left[\ln \mathbf{Y} + \left(\mathbf{I} - \left(\mathbf{\Pi^{1f}} \otimes \mathbf{1}\right)\right) \ln \mathbf{P}\right].$$

Turning to the intermediates, the firm's optimality conditions imply that:

$$\ln \mathbf{P} + \ln \mathbf{Y} = \ln \mathbf{P^x} + \ln \mathbf{X},$$

where

$$\ln \mathbf{P^x} = \mathbf{\Pi^{1x}} \ln \mathbf{P},$$

so that

$$\ln \mathbf{X} = \ln \mathbf{Y} + \left(\mathbf{I} - \mathbf{\Pi^{1x}}\right) \ln \mathbf{P}.$$

Plugging in the production function gives:

$$\begin{aligned}
\ln \mathbf{Y} &= \ln \mathbf{Z} + \frac{\psi}{1+\psi}\boldsymbol{\eta}\left[\ln \mathbf{Y} + \left(\mathbf{I} - \left(\mathbf{\Pi^{1f}} \otimes \mathbf{1}\right)\right)\ln \mathbf{P}\right] + \left(\mathbf{I} - \boldsymbol{\eta}\right)\left[\ln \mathbf{Y} + \left(\mathbf{I} - \mathbf{\Pi^{1x}}\right)\ln \mathbf{P}\right] \\
&= \ln \mathbf{Z} + \frac{\psi}{1+\psi}\boldsymbol{\eta}\left[\ln \mathbf{Y} + \left(\mathbf{I} - \left(\mathbf{\Pi^{1f}} \otimes \mathbf{1}\right)\right)\mathcal{P}\ln \mathbf{Y}\right] + \left(\mathbf{I} - \boldsymbol{\eta}\right)\left[\ln \mathbf{Y} + \left(\mathbf{I} - \mathbf{\Pi^{1x}}\right)\boldsymbol{\mathcal{P}}\ln \mathbf{Y}\right] \\
&= \ln \mathbf{Z} + \left[\frac{\psi}{1+\psi}\boldsymbol{\eta}\left[\mathbf{I} + \left(\mathbf{I} - \left(\mathbf{\Pi^{1f}} \otimes \mathbf{1}\right)\right)\boldsymbol{\mathcal{P}}\right] + \left(\mathbf{I} - \boldsymbol{\eta}\right)\left[\mathbf{I} + \left(\mathbf{I} - \mathbf{\Pi^{1x}}\right)\boldsymbol{\mathcal{P}}\right]\right]\ln \mathbf{Y},
\end{aligned}$$

where $\boldsymbol{Eta}$ is a diagonal matrix where element (nj, nj) is equal to η_j. This leads to equation (2.7):

$$\ln \boldsymbol{Y} = \mathbf{\Lambda} \ln \mathbf{Z},$$

where

$$\mathbf{\Lambda} = \left[\mathbf{I} - \frac{\psi}{1+\psi}\boldsymbol{\eta}\left[\boldsymbol{I} + \left(\boldsymbol{I} - \left(\mathbf{\Pi}^{\boldsymbol{1f}} \otimes 1\right)\right)\boldsymbol{\mathcal{P}}\right] - \left(\boldsymbol{I} - \boldsymbol{\eta}\right)\left[\boldsymbol{I} + \left(\boldsymbol{I} - \mathbf{\Pi}^{\boldsymbol{1x}}\right)\boldsymbol{\mathcal{P}}\right]\right]^{-1}. \tag{B.3}$$

To get equation (2.10), plug in (2.7) in (B.2) to get:

$$\ln \boldsymbol{H} = \boldsymbol{\mathcal{H}} \ln \mathbf{Z},$$

where

$$\boldsymbol{\mathcal{H}} = \frac{\psi}{1+\psi}\left[\mathbf{I} + \left(\boldsymbol{I} - \left(\mathbf{\Pi}^{\boldsymbol{1f}} \otimes \mathbf{1}\right)\right)\boldsymbol{\mathcal{P}}\right]\mathbf{\Lambda}. \tag{B.4}$$

B.2 Taste shifters and trade costs and long-run influence

To characterize the influence vector of the taste shifters and trade costs, define the additional following matrices:

- $\mathbf{\Psi}^{\boldsymbol{\zeta}}$ a $NJ \times NJ$ matrix such that $\mathbf{\Psi}^{\boldsymbol{\zeta}} = \mathbf{\Psi}^{\mathbf{1}\boldsymbol{\zeta}} + \mathbf{\Psi}^{\mathbf{2}\boldsymbol{\zeta}}$, where:
  - $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\zeta}}_{nj,mj} = \mathbf{\Psi}^{\boldsymbol{f}}_{nj,m}$, and $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\zeta}}_{nj,mi} = 0, \forall i \neq j$
  - $\mathbf{\Psi}^{\mathbf{2}\boldsymbol{\zeta}}_{nj,mj} = -\mathbf{\Psi}^{\boldsymbol{f}}_{nj,m}\pi^{f}_{mk}$
- $\mathbf{\Psi}^{\boldsymbol{\tau^f}}$ a $NJ \times NNJ$ matrix such that $\mathbf{\Psi}^{\boldsymbol{\tau^f}} = \mathbf{\Psi}^{\mathbf{1}\boldsymbol{\tau^f}} + \mathbf{\Psi}^{\mathbf{2}\boldsymbol{\tau^f}} + \mathbf{\Psi}^{\mathbf{3}\boldsymbol{\tau^f}}$, where:
  - $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\tau^f}}_{nj,nmj} = (1-\gamma)\,\mathbf{\Psi}^{\boldsymbol{f}}_{nj,m}$, and $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\tau^f}}_{nj,omi} = 0, \forall i \neq j$ or $n \neq o$
  - $\mathbf{\Psi}^{\mathbf{2}\boldsymbol{\tau^f}}_{nj,omj} = [(1-\rho) - (1-\gamma)]\,\mathbf{\Psi}^{\boldsymbol{f}}_{nj,m}\pi^{f}_{omj}$, and $\mathbf{\Psi}^{\mathbf{2}\boldsymbol{\tau^f}}_{nj,omi} = 0, \forall j \neq i$
  - $\mathbf{\Psi}^{\mathbf{3}\boldsymbol{\tau^f}}_{nj,omi} = -(1-\rho)\,\mathbf{\Psi}^{\boldsymbol{f}}_{nj,m}\pi^{f}_{mi}\pi^{f}_{omi}$
- $\mathbf{\Psi}^{\boldsymbol{\vartheta}}$ a $NJ \times NJJ$ matrix such that $\mathbf{\Psi}^{\boldsymbol{\vartheta}} = \mathbf{\Psi}^{\mathbf{1}\boldsymbol{\vartheta}} + \mathbf{\Psi}^{\mathbf{2}\boldsymbol{\vartheta}}$, where:
  - $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\vartheta}}_{nj,mij} = \mathbf{\Psi}^{\boldsymbol{x}}_{nj,mi}$, and $\mathbf{\Psi}^{\mathbf{1}\boldsymbol{\vartheta}}_{nj,mik} = 0, \forall j \neq k$
  - $\mathbf{\Psi}^{\mathbf{2}\boldsymbol{\vartheta}}_{nj,mik} = -\mathbf{\Psi}^{\boldsymbol{x}}_{nj,mi}\pi^{x}_{k,mi}$

- $\boldsymbol{\Psi^{\tau^x}}$ a $NJ \times NJNJ$ matrix such that $\boldsymbol{\Psi^{\tau^x}} = \boldsymbol{\Psi^{1\tau^x}} + \boldsymbol{\Psi^{2\tau^x}} + \boldsymbol{\Psi^{3\tau^x}}$, where:
  - $\boldsymbol{\Psi^{1\tau x}_{nj,njmi}} = (1-\nu)\,\Psi^x_{nj,mi}$, and $\boldsymbol{\Psi^{1\tau^x}_{nj,okmi}} = 0, \forall n \neq o$ or $k \neq j$
  - $\boldsymbol{\Psi^{2\tau x}_{nj,ojmi}} = [(1-\varepsilon) - (1-\nu)]\,\Psi^x_{nj,mi}\pi^x_{oj,mi}$, and $\boldsymbol{\Psi^{2\tau x}_{nj,okmi}} = 0, \forall j \neq k$
  - $\boldsymbol{\Psi^{3\tau x}_{nj,okmi}} = -(1-\varepsilon)\,\Psi^x_{nj,mi}\pi^x_{k,mi,t}\pi^x_{ok,mi}$

Then equation (B.1) can be written as:

$$\begin{aligned}
\ln \boldsymbol{P} + \ln \boldsymbol{Y} = &\left(\boldsymbol{\Psi^f \Upsilon} + \boldsymbol{\Psi^x}\right)(\ln \boldsymbol{P} + \ln \boldsymbol{Y}) \\
&+ \left[(1-\gamma)\, diag\left(\boldsymbol{\Psi^f 1}\right) + [(1-\rho)-(1-\gamma)]\,\boldsymbol{\Psi^c \Pi^{2f}} - (1-\rho)\,\boldsymbol{\Psi^f \Pi^{1f}}\right] \ln \boldsymbol{P} \\
&+ \left[(1-\nu)\, diag\left(\boldsymbol{\Psi^x 1}\right) + [(1-\varepsilon)-(1-\nu)]\,\boldsymbol{\Psi^x \Pi^{2x}} - (1-\varepsilon)\,\boldsymbol{\Psi^x \Pi^{1x}}\right] \ln \boldsymbol{P} \\
&+ \boldsymbol{\Psi^\zeta} \ln \boldsymbol{\zeta} + \boldsymbol{\Psi^{\tau f}} \ln \boldsymbol{\tau^f} + \boldsymbol{\Psi^\vartheta} \ln \boldsymbol{\vartheta} + \boldsymbol{\Psi^{\tau x}} \ln \boldsymbol{\tau^x}
\end{aligned}$$

where:

- $\boldsymbol{\zeta}$ is a NJ vector where the $(nj)th$ element is ζ_{nj},
- $\boldsymbol{\tau^f}$ is a NNJ vector where the $(nmj)th$ element is τ^f_{mnj},
- $\boldsymbol{\vartheta}$ is a NJJ vector where the $(nji)th$ element is $\vartheta i, nj$,
- $\boldsymbol{\tau^x}$ is a $NJNJ$ vector where the $(nmj)th$ element is τ^x_{minj}.

We can again solve for the prices as:

$$\ln \boldsymbol{P} = \boldsymbol{\mathcal{P}} \ln \boldsymbol{Y} + \boldsymbol{\mathcal{P}^\zeta} \ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}^{\tau f}} \boldsymbol{\tau^f} + \boldsymbol{\mathcal{P}^\vartheta} \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}^{\tau x}} \boldsymbol{\tau^x},$$

where $\boldsymbol{\mathcal{P}}$ is the same as above and for the other shocks $s \in \{\zeta, \tau^f, \vartheta, \tau^x\}$:

$$\boldsymbol{\mathcal{P}^s} = -\left(\boldsymbol{I} - \boldsymbol{\mathcal{M}}\right)^+ \boldsymbol{\Psi^s}.$$

In the long-run, the aggregate labor supply becomes inelastic and labor is perfectly mobile across sectors. Hence the equilibrium on the labor market is given by the following condition:

$$W_n \overline{H}_n = \sum_j (1-\alpha_j)\,\eta_j P_{nj} Y_{nj}$$

In log-changes:

$$\ln W_n = \sum_j \frac{\eta_j P_{nj} Y_{nj}}{P_n F_n} \ln P_{nj} + \ln Y_{nj},$$

so that the change in sectoral hours is given by:

$$\ln H_{nj} = \ln P_{nj} + \ln Y_{nj} - \ln W_n = \ln P_{nj} + \ln Y_{nj} - \sum_i \Upsilon_{n,ni}\left(\ln P_{ni} + \ln Y_{ni}\right).$$

In vector notation:

$$\ln \boldsymbol{H} = \ln \boldsymbol{P} + \ln \boldsymbol{Y} - \left(\boldsymbol{1}_J \otimes \boldsymbol{\Upsilon}\right)(\ln \boldsymbol{P} + \ln \boldsymbol{Y}).$$

Plugging in the production function, with the same expression for $\ln X$ as above:

$$\begin{aligned}
\ln \boldsymbol{Y} &= \ln \boldsymbol{Z} + \boldsymbol{\eta}\left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\ln \boldsymbol{Y} + \ln \boldsymbol{P}) + (\boldsymbol{I} - \boldsymbol{\eta})\left[\ln \boldsymbol{Y} + \left(\boldsymbol{I} - \boldsymbol{\Pi}^{\mathbf{1x}}\right)\ln \boldsymbol{P}\right] \\
&= \ln \boldsymbol{Z} + \boldsymbol{\eta}\left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\boldsymbol{I} + \boldsymbol{\mathcal{P}})\ln \boldsymbol{Y} + (\boldsymbol{I} - \boldsymbol{\eta})\left[\boldsymbol{I} + \left(\boldsymbol{I} - \boldsymbol{\Pi}^{\mathbf{1x}}\right)\boldsymbol{\mathcal{P}}\right]\ln \boldsymbol{Y} \\
&+ \boldsymbol{\eta}\left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right]\left(\boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}}\right) \\
&+ (\boldsymbol{I} - \boldsymbol{\eta})\left(\boldsymbol{I} - \boldsymbol{\Pi}^{\mathbf{1x}}\right)\left(\boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}}\right) \\
&= \ln \boldsymbol{Z} + \left[\boldsymbol{\eta}\left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\boldsymbol{I} + \boldsymbol{\mathcal{P}}) + (\boldsymbol{I} - \boldsymbol{\eta})\left[\boldsymbol{I} + \left(\boldsymbol{I} - \boldsymbol{\Pi}^{\mathbf{1x}}\right)\boldsymbol{\mathcal{P}}\right]\right]\ln \boldsymbol{Y} \\
&- \boldsymbol{\eta}(\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\left(\boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}}\right) \\
&- (\boldsymbol{I} - \boldsymbol{\eta})\boldsymbol{\Pi}^{\mathbf{1x}}\left(\boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}}\right),
\end{aligned}$$

which leads to the following expression:

$$\ln \boldsymbol{Y} = \boldsymbol{\Lambda}^{\boldsymbol{Z}}\ln \boldsymbol{Z} + \boldsymbol{\Lambda}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\Lambda}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\Lambda}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\Lambda}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}},$$

where:

$$\boldsymbol{\Lambda}^{\boldsymbol{Z}} = \left(\boldsymbol{I} - \left[\boldsymbol{\eta}\left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\boldsymbol{I} + \boldsymbol{\mathcal{P}}) + (\boldsymbol{I} - \boldsymbol{\eta})\left[\boldsymbol{I} + \left(\boldsymbol{I} - \boldsymbol{\Pi}^{\mathbf{1x}}\right)\boldsymbol{\mathcal{P}}\right]\right]\right)^{-1}$$

and for the other shocks $s \in \{\zeta, \tau^f, \vartheta, \tau^x\}$:

$$\boldsymbol{\Lambda}^{\boldsymbol{s}} = -\boldsymbol{\Lambda}^{\boldsymbol{Z}}\left[\boldsymbol{\eta}(\mathbf{1}_J \otimes \boldsymbol{\Upsilon}) + (\boldsymbol{I} - \boldsymbol{\eta})\boldsymbol{\Pi}^{\mathbf{1x}}\right]\boldsymbol{\mathcal{P}}^{\boldsymbol{s}}.$$

For the remainder of the section, it will be useful to define a stacked vector of shock $\boldsymbol{\theta} = [\boldsymbol{Z}, \boldsymbol{\zeta}, \boldsymbol{\tau}^{\boldsymbol{f}}, \boldsymbol{\vartheta}, \boldsymbol{\tau}^{\boldsymbol{x}}]'$ and a similar influence $\boldsymbol{\Lambda}^{\boldsymbol{\theta}} = [\boldsymbol{\Lambda}^{\boldsymbol{Z}}, \boldsymbol{\Lambda}^{\boldsymbol{\zeta}}, \boldsymbol{\Lambda}^{\boldsymbol{\tau f}}, \boldsymbol{\Lambda}^{\boldsymbol{\vartheta}}, \boldsymbol{\Lambda}^{\boldsymbol{\tau x}}]$.

The change in hours is then given by:

$$\begin{aligned}
\ln \boldsymbol{H} &= \left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\boldsymbol{\mathcal{P}} + \boldsymbol{I})\boldsymbol{\Lambda}\boldsymbol{\theta} \\
&+ \left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right]\left[\boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}\ln \boldsymbol{\zeta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}\ln \boldsymbol{\tau}^{\boldsymbol{f}} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}\ln \boldsymbol{\vartheta} + \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\ln \boldsymbol{\tau}^{\boldsymbol{x}}\right] \\
&= \boldsymbol{\mathcal{H}}^{\boldsymbol{\theta}}\boldsymbol{\theta},
\end{aligned}$$

where:

$$\begin{aligned}
\boldsymbol{\mathcal{H}}^{\boldsymbol{\theta}} &= \left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right](\boldsymbol{\mathcal{P}} + \boldsymbol{I})\boldsymbol{\Lambda} \\
&+ \left[\boldsymbol{I} - (\mathbf{1}_J \otimes \boldsymbol{\Upsilon})\right]\left[\mathbf{0}_{NJ \times NJ}, \boldsymbol{\mathcal{P}}^{\boldsymbol{\zeta}}, \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau f}}, \boldsymbol{\mathcal{P}}^{\boldsymbol{\vartheta}}, \boldsymbol{\mathcal{P}}^{\boldsymbol{\tau x}}\right].
\end{aligned}$$

B.3 Long-run shocks extraction

To extract the set of long-run shocks $\{\boldsymbol{Z}, \boldsymbol{\zeta}, \boldsymbol{\tau}^{\boldsymbol{f}}, \boldsymbol{\vartheta}, \boldsymbol{\tau}^{\boldsymbol{x}}\}$, we match the long-run changes in value added, final consumption sectoral shares (π^f_{nj}), final trade shares (π^f_{mnj}), intermediates sectoral shares ($\pi^x_{,nj}$) and intermediate trade shares ($\pi^x_{mi,nj}$). In practice, because the taste shifters and trade costs are only defined up to a normalization, we match the change in sectoral shares relative to the first sector, and the change in trade shares relative to domestic share, and we impose $\ln \zeta_{n1} = 0$, $\ln \tau^f_{nnj} = 0$, $\ln \vartheta_{1,nj} = 0$, and $\ln \tau^x_{ni,nj} = 0$.

Change in sectoral value added The change in sectoral value added is given by:

$$\begin{aligned}\ln \boldsymbol{V} &= \boldsymbol{\eta}^{-1} \ln \boldsymbol{Z} + \ln \boldsymbol{H} \\ &= \boldsymbol{\mathcal{V}}^{\boldsymbol{\theta}} \ln \boldsymbol{\theta},\end{aligned} \tag{B.5}$$

where

$$\boldsymbol{\mathcal{V}}^{\boldsymbol{\theta}} = \left[\boldsymbol{\eta}^{-1}, \mathbf{0}\right] + \boldsymbol{\mathcal{H}}^{\boldsymbol{\theta}}.$$

Change in final sectoral shares The change in relative final sectoral shares is given by:

$$\ln \pi^f_{nj} - \ln \pi^f_{n1} = \ln \zeta_{nj} + (1-\rho) \sum_m \pi^f_{mnj} \left(\ln \tilde{\tau}^f_{mnj} + d \ln P_{mj}\right) - (1-\rho) \sum_m \pi^f_{mn1} \left(\ln \tilde{\tau}^f_{mn1} + \ln P_{m1}\right), \tag{B.6}$$

where $\tilde{\tau}^f_{mnj} = \mu_{mnj}^{\frac{1}{1-\gamma}} \tau^f_{mnj}$ is the trade cost-cum-tastes shock.

Change in final trade shares The change in relative final trade shares is given by:

$$\ln \pi^f_{mnj} - \ln \pi^f_{nnj} = (1-\gamma) \left(d \ln \tilde{\tau}^f_{mnj} + d \ln P_{mj} - d \ln P_{nj}\right). \tag{B.7}$$

Change in intermediate sectoral shares The change in relative final sectoral share is given by:

$$\begin{aligned}\ln \pi^x_{i,nj} - \ln \pi^x_{1,nj} =& \ln \vartheta_{i,nj} + (1-\varepsilon) \left(\sum_m \pi^x_{mi,nj,t} \left(\ln \tilde{\tau}^x_{mi,nj} + \ln P_{mi}\right)\right) \\ &- (1-\varepsilon) \left(\sum_m \pi^x_{m1,nj,t} \left(\ln \tilde{\tau}^x_{m1,nj} + \ln P_{m1}\right)\right),\end{aligned} \tag{B.8}$$

where $\tilde{\tau}^x_{minj} = \mu_{minj}^{\frac{1}{1-\nu}} \tau^x_{minj}$ is the trade cost-cum-tastes shock.

Change in intermediate trade shares The change in relative final trade shares is given by:

$$\ln \pi^x_{mi,nj} - \ln \pi^x_{ni,nj} = (1-\nu) \left(d \ln \tilde{\tau}^x_{mi,nj} + \ln P_{mi} - \ln P_{ni}\right). \tag{B.9}$$

Inversion procedure Writing equations (B.5) to (B.9) in matrix notation, stacking them, and inverting for $\boldsymbol{\theta}$ gives the long-run shocks matching the desired moments.

When we use the cumulative composite shock as long-run productivity shock, we drop the value-added equation from the moments to be matched and remove the effect of the cumulative composite shock on the sectoral and trade shares. We then use the residual changes to invert the shock and recover $\boldsymbol{\zeta}$, $\boldsymbol{\tau^f}$, $\boldsymbol{\vartheta}$ and $\boldsymbol{\tau^x}$.

Appendix C Quantitative Appendix

C.1 Basic facts appendix

Figure C1 displays the rolling correlations of the different shocks. It is apparent that throughout the sample, the ordering of the sectors remained constant except towards the end.

FIGURE C1: Rolling sectoral shock correlations

G7 pairs (composite)

All pairs (composite)

G7 pairs (Solow)

All pairs (Solow)

Notes: This figure plots the rolling correlation of the sectoral composite shock with foreign GDP growth.

Table C1: Changes in correlation decomposition

	All countries, composite shock				G7 pairs, composite shock			
Tot corr	Mean	Median	p25	p75	Mean	Median	p25	p75
1984	0.353	0.377	0.149	0.570	0.383	0.415	0.170	0.599
2002	0.309	0.342	-0.046	0.687	0.433	0.446	0.253	0.728
Shock corr								
1984	0.227	0.232	0.078	0.412	0.276	0.313	0.107	0.448
2002	0.172	0.220	-0.128	0.461	0.256	0.246	0.147	0.490
Trans.								
1984	0.126	0.116	0.074	0.165	0.107	0.086	0.059	0.149
2002	0.137	0.132	0.062	0.214	0.177	0.173	0.106	0.257
	All countries, Solow residuals				**G7 pairs, Solow residuals**			
Tot corr	Mean	Median	p25	p75	Mean	Median	p25	p75
1984	0.244	0.252	0.008	0.494	0.166	0.126	-0.074	0.449
2002	0.187	0.216	-0.044	0.451	0.306	0.297	0.158	0.451
Shock corr								
1984	0.156	0.177	-0.045	0.400	0.083	0.034	-0.170	0.302
2002	0.077	0.106	-0.134	0.312	0.150	0.080	0.031	0.298
Trans.								
1984	0.088	0.078	0.046	0.117	0.083	0.068	0.031	0.115
2002	0.110	0.108	0.025	0.173	0.155	0.166	0.113	0.206

Notes: This table presents the average, median, and percentiles of the correlation decomposition in the first and last available decades (1978-1988, mid-year 1984 and 1997-2007, midyear 2002). The top panel displays the decomposition using the composite shock and the bottom panel shows the decomposition using the Solow residual. G7 country pairs' results are displayed on the right.

Table C2: Changes in correlation decomposition

	All countries, composite shock				G7, composite shock			
Tot corr	Mean	Median	p25	p75	Mean	Median	p25	p75
1978	0.279	0.283	0.125	0.416	0.437	0.398	0.314	0.566
2007	0.164	0.135	0.024	0.337	0.260	0.383	0.065	0.421
Shock corr								
1978	0.172	0.199	0.002	0.300	0.329	0.292	0.228	0.484
2007	0.084	0.059	-0.061	0.243	0.166	0.182	0.015	0.351
Trans.								
1978	0.107	0.098	0.068	0.137	0.108	0.106	0.085	0.138
2007	0.080	0.069	0.043	0.106	0.094	0.098	0.068	0.115

	All countries, Solow residuals				G7, Solow residuals			
Tot corr	Mean	Median	p25	p75	Mean	Median	p25	p75
1978	0.197	0.216	0.064	0.324	0.186	0.199	0.018	0.344
2007	0.203	0.204	0.054	0.334	0.124	0.144	-0.048	0.293
Shock corr								
1978	0.132	0.153	0.003	0.265	0.113	0.123	-0.045	0.268
2007	0.114	0.131	-0.018	0.234	0.040	0.074	-0.104	0.208
Trans.								
1978	0.064	0.052	0.034	0.082	0.073	0.064	0.053	0.092
2007	0.089	0.076	0.049	0.114	0.084	0.073	0.053	0.106

Notes: This table presents the average, median, and percentiles of the correlation decomposition when using the start year influence vector (1978) and last year influence vector (2007). The top panel displays the decomposition using the composite shock and the bottom panel shows the decomposition using the Solow residual. G7 country pairs' results are displayed on the right.

C.2 Counterfactual results appendix

Table C3: Counterfactual correlation details

	All countries, composite shock					
Total correlation	1978	Trade	Trade (CD)	Taste	Prod.	2007
mean	0.279	0.344	0.381	0.146	0.285	0.164
median	0.283	0.334	0.378	0.117	0.282	0.1349
p25	0.125	0.212	0.234	-0.041	0.141	0.0239
p75	0.416	0.494	0.537	0.376	0.448	0.337
Shock correlation						
mean	0.172	0.097	0.121	0.094	0.170	0.0837
median	0.199	0.096	0.122	0.066	0.188	0.0585
p25	0.002	-0.013	-0.012	-0.069	0.021	-0.0607
p75	0.300	0.192	0.231	0.278	0.304	0.2427
Transmission						
mean	0.107	0.247	0.260	0.052	0.115	0.0802
median	0.098	0.234	0.245	0.040	0.107	0.0688
p25	0.068	0.149	0.153	0.019	0.070	0.0432
p75	0.137	0.333	0.351	0.073	0.147	0.1059

	All countries, Solow residual					
Total correlation	1978	Trade	Trade (CD)	Taste	Prod	2007
mean	0.197	0.243	0.291	0.180	0.199	0.2026
median	0.216	0.247	0.305	0.188	0.216	0.204
p25	0.064	0.093	0.153	0.040	0.057	0.0539
p75	0.324	0.398	0.423	0.337	0.335	0.3338
Shock correlation						
mean	0.132	0.107	0.114	0.124	0.129	0.1135
median	0.153	0.108	0.128	0.135	0.143	0.1306
p25	0.003	-0.015	-0.005	-0.010	-0.003	-0.0183
p75	0.265	0.228	0.224	0.258	0.261	0.2344
Transmission						
mean	0.064	0.136	0.177	0.056	0.070	0.0891
median	0.052	0.112	0.159	0.046	0.056	0.0762
p25	0.034	0.066	0.103	0.028	0.040	0.0489
p75	0.082	0.180	0.228	0.074	0.087	0.114

Notes: This table presents the average, median, and percentiles of the correlation decomposition in each counterfactuals. The "mean" row corresponds to the bars plotted in figure C3. "1978" performs the decomposition using the 1978 influence vector, "Trade" is a world in which only trade costs changed under the baseline elasticities, "Trade (CD)" is a world in which only trade costs changed, under Cobb-Douglass sectoral elasticities. "Taste" is a world in which only taste shocks evolved since 1978, "Prod" is a world in which only the productivity shocks happened since 1978, and "1978" is a counterfactual world in which the influence remained the same as the 1978 world In all cases, the correlation decomposition is computed on the same time series of shock from 1978 to 2007.

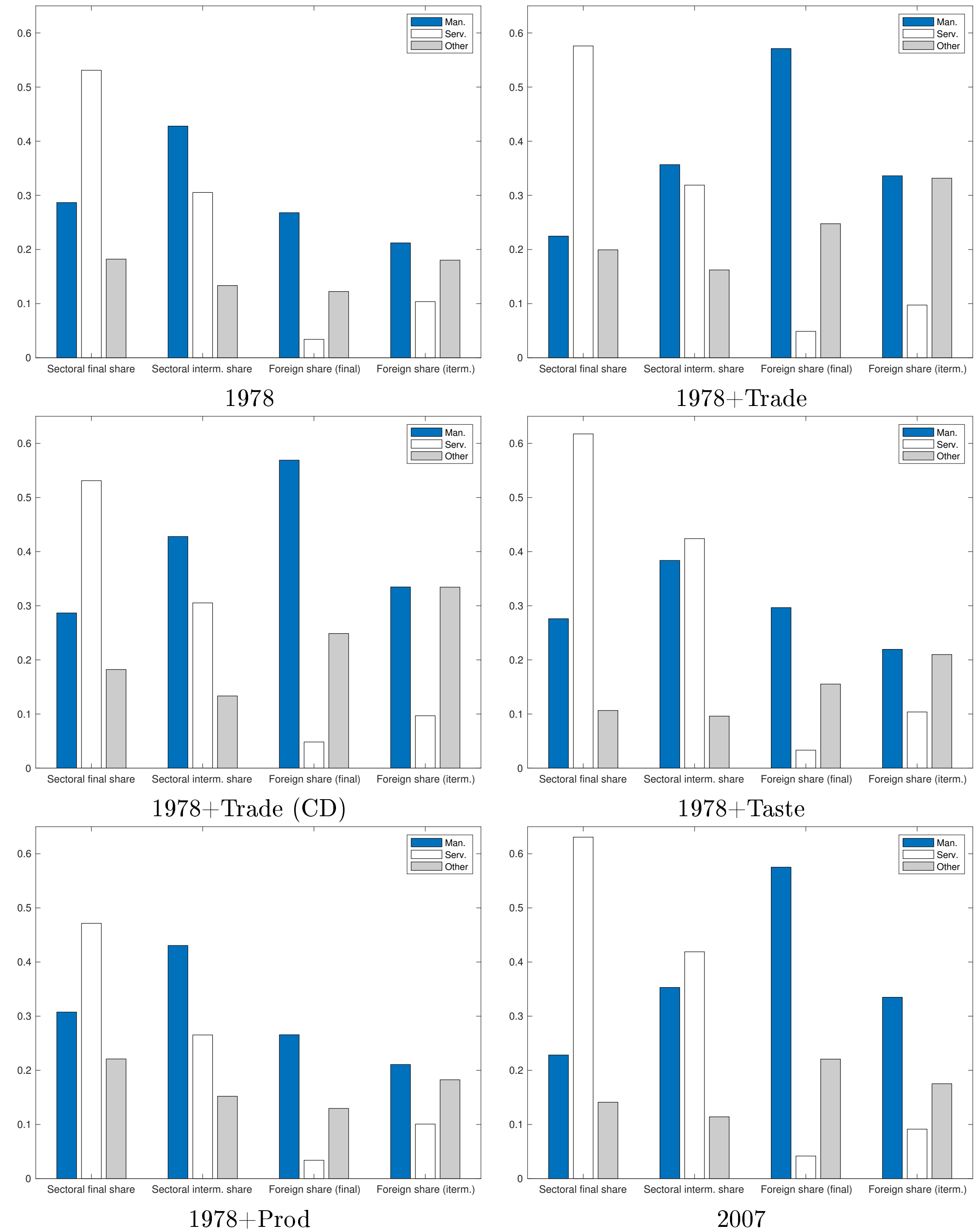
Table C4: Counterfactual correlation details: G7 country pairs

	G7 countries, composite shock					
Total correlation	1978	Trade	Trade (CD)	Taste	Prod.	2007
mean	0.437	0.505	0.515	0.250	0.470	
median	0.398	0.495	0.484	0.373	0.450	
p25	0.314	0.389	0.421	0.097	0.357	
p75	0.566	0.639	0.618	0.428	0.555	
Shock correlation						
mean	0.329	0.218	0.258	0.187	0.338	
median	0.292	0.191	0.218	0.307	0.298	
p25	0.228	0.132	0.189	0.034	0.248	
p75	0.484	0.334	0.374	0.356	0.442	
Transmission						
mean	0.108	0.288	0.257	0.063	0.132	
median	0.106	0.273	0.256	0.056	0.136	
p25	0.085	0.175	0.185	0.039	0.104	
p75	0.138	0.400	0.339	0.089	0.169	

	G7 countries, Solow residual					
Total correlation	1978	Trade	Trade (CD)	Taste	Prod	2007
mean	0.186	0.216	0.296	0.115	0.222	
median	0.199	0.238	0.290	0.114	0.226	
p25	0.018	0.020	0.178	-0.057	0.035	
p75	0.344	0.403	0.441	0.281	0.354	
Shock correlation						
mean	0.113	0.061	0.093	0.057	0.134	
median	0.123	0.092	0.098	0.067	0.156	
p25	-0.045	-0.064	-0.024	-0.113	-0.034	
p75	0.268	0.242	0.237	0.239	0.279	
Transmission						
mean	0.073	0.155	0.204	0.058	0.089	
median	0.064	0.146	0.220	0.056	0.075	
p25	0.053	0.108	0.156	0.033	0.069	
p75	0.092	0.217	0.242	0.069	0.111	

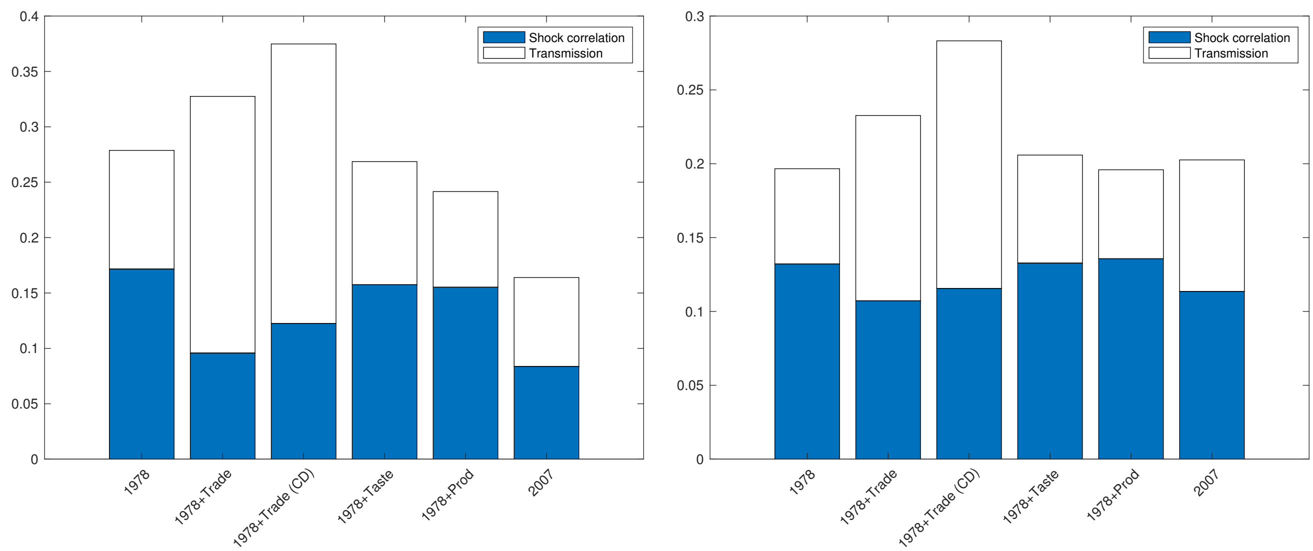
Notes: This table presents the average, median, and percentiles of the correlation decomposition in each counterfactuals for G7 country pairs. “1978” is a counterfactual world in which the influence remained the same as the 1978 world, “Trade” is a world in which only trade costs changed, “Trade (CD)” is a world in which only trade costs changed but sectoral shares remained constant, “Taste” is a world in which only taste shocks evolved since 1978, and “Prod” is a world in which only the productivity shocks happened since 1978. “2007" performs the decomposition using the 2007 influence vector. In all cases, the correlation decomposition is computed on the same time series of shock from 1978 to 2007.

Figure C2: Counterfactual shares



Notes: The first two sets of bars display the average sectoral shares in consumption and intermediates, and the last two sets of bars display the average foreign share in final and intermediates. Each panel represents a different scenario. "1978" is are 1978 shares, "1978+Trade" is a world in which only trade costs changed, "1978+Trade (CD)" is a world in which only trade costs changed but sectoral shares remained constant, "1978+Taste" is a world in which only taste shocks evolved since 1978, and "1978+Prod" is a world in which only the productivity shocks happened since 1978. "2007" are the 2007 shares.

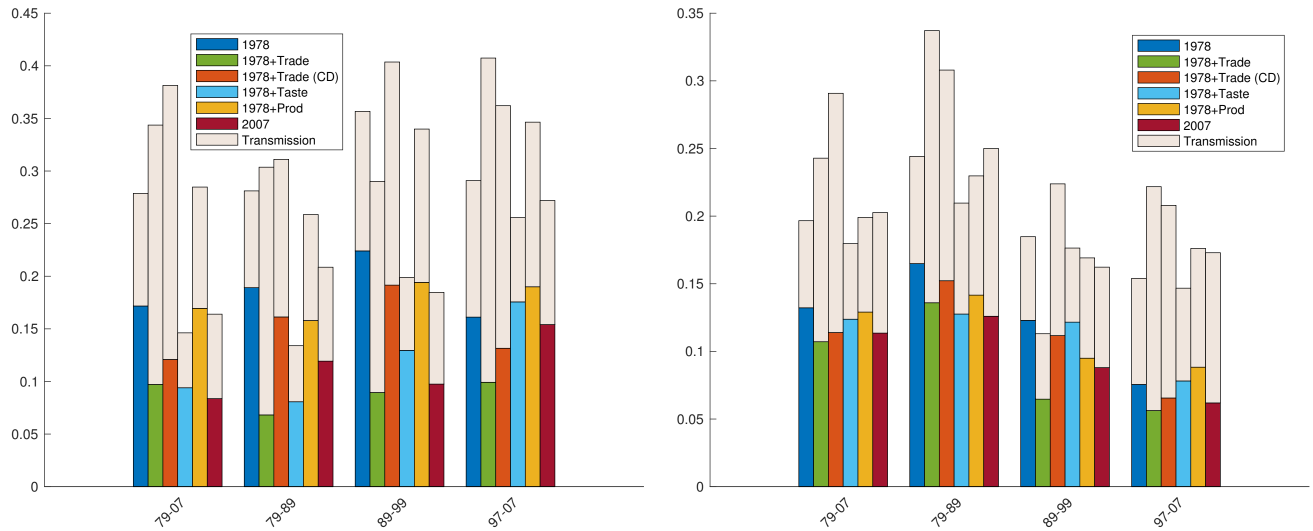
Figure C3: Counterfactual correlations (simultaneous Z extraction)



Composite shock — Solow residual

Notes: The bars display the average GDP growth correlations, decomposed into a shock correlation term (in blue) and transmission term (in white). Each bar represents a different scenario. "1978" is a counterfactual world in which the influence remained the same as the 1978 world, "1978+Trade" is a world in which only trade costs changed, "1978+Trade" is a world in which only trade costs changed but sectoral shares remained constant, "1978+Taste" is a world in which only taste shocks evolved since 1978, and "1978+Prod" is a world in which only the productivity shocks happened since 1978. "2007" performs the decomposition using the 2007 influence vector. In all cases, the correlation decomposition is computed on the same time series of shock from 1978 to 2007.

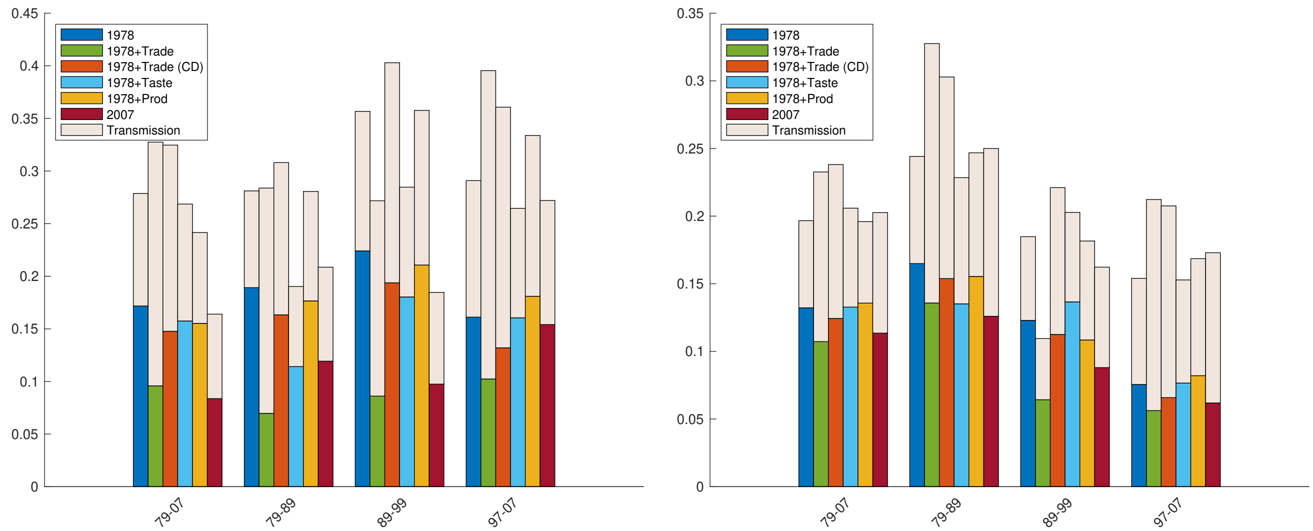
Figure C4: Counterfactual correlations by decade



Composite shock　　　　Solow residuals

Notes: The bars display the average GDP growth correlations, decomposed into a shock correlation term (in blue) and transmission term (in white). Each bar represents a different scenario. "1978" is a counterfactual world in which the influence remained the same as the 1978 world, "1978+Trade" is a world in which only trade costs changed, "1978+Trade" is a world in which only trade costs changed but sectoral shares remained constant, "1978+Taste" is a world in which only taste shocks evolved since 1978, and "1978+Prod" is a world in which only the productivity shocks happened since 1978. "2007" performs the decomposition using the 2007 influence vector. Each bar group represents the results of feeding different time periods of the shock.

Figure C5: Counterfactual correlations by decade (simultaneous Z)



Composite shock — Solow residuals

Notes: The bars display the average GDP growth correlations, decomposed into a shock correlation term (in blue) and transmission term (in white). Each bar represents a different scenario."1978" is a counterfactual world in which the influence remained the same as the 1978 world, "1978+Trade" is a world in which only trade costs changed, "1978+Trade" is a world in which only trade costs changed but sectoral shares remained constant, "1978+Taste" is a world in which only taste shocks evolved since 1978, and "1978+Prod" is a world in which only the productivity shocks happened since 1978. "2007" performs the decomposition using the 2007 influence vector. Each bar group represents the results of feeding different time periods of the shock.