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BEYOND THE HUMP: STRUCTURAL CHANGE IN AN OPEN ECONOMY

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Abstract

In this paper I ask: how does openness to trade shape sectoral makeup of economies beyond the operation of the price- and income effects? I address this question by studying the changes in manufacturing value added shares in twenty developed and developing economies between years 1965 and 2011. I find that a third of the observed changes over the period had nothing to do with price- or income effects. Instead, it was driven by changes in sectoral productivities, trade costs, and aggregate trade imbalances, which affected the sectoral makeup of economies through two distinct channels: (i) specialization subject to comparative advantage, and (ii) compositional effects as the relative expenditures of economies changed over time. Furthermore, I show that these processes are key for understanding the heterogeneous experiences of (de)-industrialization among economies at similar levels of development, and for thinking about the dynamics of the composition of manufacturing sector broadly defined.

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1 Introduction

Structural transformation – the process of shifts in the relative sizes of major sectors of the economy – is typically characterized by a hump shaped pattern in the manufacturing share over time. A considerable literature has linked this pattern to changing expenditure shares as economies mature: first, due to non-homotheticities in consumer preferences, referred to as the *income channel*; and second, due to a non-unitary elasticity of substitution across sectoral goods in presence of shifting relative prices, referred to as the *price channel* (see Herrendorf, Rogerson, and Valentinyi (2014) for an overview). Importantly, previous studies have found little role for trade, unless operating through either the price- or income channels. At the same time, rapid increases in global economic integration, with global trade to GDP ratio almost tripling since 1965, as well as the gradual shifting of the locus of global trade towards Asian economies, raise a question: how does openness to trade shape sectoral makeup of economies beyond the operation of the price- and income effects?

I address this question by studying the changes in manufacturing value added shares in twenty developed and developing economies between years 1965 and 2011. I find that a third of the observed changes over the period had nothing to do with price- or income effects. Instead, it was driven by changes in sectoral productivities, trade costs, and aggregate trade imbalances, which affected the sectoral makeup of economies through two distinct channels: (i) specialization subject to comparative advantage, and (ii) compositional effects as the relative expenditures of economies changed over time. Moreover, I show that these processes are key for understanding structural change beyond the hump-shaped pattern in manufacturing shares: first, in terms of the heterogeneous experiences of structural change in different economies, and second, in terms of the heterogeneous behaviour of individual sub-sectors within manufacturing broadly defined.

In order to characterize the mechanisms of structural change in an open economy, I make use of a multi-sector model of international trade. I build on the Eaton and Kortum (2002) setup as it lends itself naturally to studying trade specialization. In the model, the sectoral varieties are produced using labor and intermediate inputs, and are subject to Pareto productivity draws. Varieties can be shipped abroad after paying iceberg trade costs. Sectoral good producers source sectoral varieties from the origin with the lowest cost, and combine them into sectoral bundles. These are consumed by the households, and used as intermediate inputs in the production of varieties. Final goods are produced with a constant elasticity of substitution production function, whereas the household preferences take a non-homothetic constant elasticity of substitution form studied by Comin, Lashkari, and Mestieri (2021). Finally, as in Dekle, Eaton, and Kortum (2007), international borrowing is exogenous and constitutes transfers between the economies in the form of aggregate trade imbalances.

Once the model is set up, I use the equilibrium conditions of the model to break down the changes in sectoral value added shares into the operation of three distinct channels. Trade specialization channel (TS) captures the effects of changes in sourcing decisions. In the model, economies are in direct competition with each other in supplying sectoral varieties. As costs of production evolve, these competitive pressures lead economies to specialize in production of goods that they can produce at a relatively low cost. Expenditure shares channel (ES) combines the effects of changes in final- and intermediate expenditure shares of both foreign and domestic agents on manufacturing shares in the home economy. This term combines the effects of changing relative prices and incomes, as well as of shocks to preferences and production technologies. Finally, relative expenditure channel (RE) captures the compositional effects of changes in the total expenditures of economies. This channel operates when demand for sectoral goods produced in a given origin differs across economies. An economy whose expenditure grows in relative terms stimulates the production of the goods that it consumes relatively more intensively. Most prominently, non-tradable services are consumed exclusively by domestic agents. Thus, when an economy becomes richer, its services sector experiences a surge in demand that is stronger than that in the tradable sectors, which have part of their consumer base abroad. This asymmetry in demand tilts the production towards the non-tradable services sectors. The three channels are brought into motion by six types of exogenous processes: sectoral productivities, sectoral trade costs, aggregate trade deficits, preference and production technology shocks, as well as countries' populations. The three mechanisms can be further broken down into the contributions of different exogenous drivers. This two-fold decomposition forms the basis of my analysis.

I show that the decomposition can be implemented empirically by simulating the model subject to appropriate restrictions. In particular, I use the empirical counterpart of the decomposition to ask: what was the role of the changes in sectoral productivities, trade costs, and aggregate trade deficits, in driving the evolution of sectoral shares, *outside* of the operation of price- and income effects? These can be obtained by simulating the model with each shock series operating one at a time, and with expenditure shares channel, capturing the operation of price- and income effects, shut off through forcing the final- and intermediate expenditure shares to remain fixed. Importantly, since a fully calibrated Eaton and Kortum (2002) model maps to data one to one, the difference between the simulated series and the observed changes in sectoral shares can be attributed exactly to the extant components of the decomposition: the endogenous response of expenditure shares to changes in relative prices, incomes, preference shocks and shocks to production function, as well as the way these responses feed into the trade competitiveness and relative income channels. The relative contribution of these different components can then be measured and compared.

In order to estimate the model, I need data on sector level bilateral trade flows, sectoral consumption, and intermediate inputs use. I obtain these from Groningen Growth and Development Centre Long-run World Input Output Database. I focus on twenty developed and developing economies, covering around 80% of the global GDP. The series runs from 1965 and 2011, and features thirteen tradable sectors, eleven of which are sub-sectors of manufacturing. I retain this level of disaggregation throughout my analysis. Much of the calibration is standard, except for the estimation of the sectoral productivity and trade cost shocks, where I rely on the fixed effect Poisson pseudo-maximum likelihood method proposed by Silva and Tenreyro (2006). Once the model is calibrated, I use the simulation-based decomposition to study the drivers of structural change in my sample.

My first set of results concerns the importance of changes in sectoral productivities, trade costs, and aggregate trade deficits, as operating through trade specialization and relative expenditure channels, in driving changes in manufacturing value added shares over years 1965 to 2011. I find that these three forces are responsible for 7%, 12% and 16% of the observed changes over the period. In turn, 63% was due to the changes in final- and intermediate expenditure shares. In other words, roughly a third of the observed patterns is driven by forces other than the operation of price- and income effects. However, the big picture masks the rich heterogeneity in experiences of structural change across countries and sub-sectors within manufacturing. I turn to discussing these aspects next.

First, I show that the three shock series are important in explaining the heterogeneity in structural change experiences of countries at similar levels of development. To do so, I split the sample into lower and higher income groups, and apply the decomposition to the change in manufacturing share compared to the group average. I find that for the lower income half of the sample, the relative importance of trade cost shocks increases to 23%. In particular, this channel has given a sizeable boost to the manufacturing shares in South Korea and Taiwan, respectively, making for some of the highest rates of industrialization in my sample. For the higher income group, in turn, the relative importance of changes in sectoral productivities and aggregate trade deficits increases to 12% and 28%. Here, lagging productivity has contributed to record deindustrialization rates in United Kingdom and Australia, whereas widening aggregate trade imbalances have led to further deindustrialization in the deficit economies (United Kingdom and United States), and to the maintenance of the relatively high manufacturing shares in surplus economies (Sweden, Finland and Germany).

However, the dynamics of the aggregate manufacturing share conceals the churn within it. How do the open economy forces shape the makeup of manufacturing sectors in terms of their constituent sub-sectors? First, I show that if the composition of manufacturing is taken into account, the changes in trade costs and sectoral productivities, as operating through trade specialization and relative expenditure channels, become relatively more important, explaining 19% and 16% of the observed changes in sub-sectoral shares respectively. Aggregate trade deficits contribute further 11%, whereas changes in expenditure shares explain the remaining 51%. Looking at individual sub-sectors, I find that half of the observed dynamics in the electrical- and transport equipment sub-sectors of manufacturing was driven by changes in productivities and trade costs, which contributed to divergence of the high-skilled manufacturing shares across the economies.

I conclude my analysis by breaking down the contribution of each of the simulated shock series into the operation of two active channels – trade specialization and relative expenditures. I find that the changes in sectoral productivities had two countervailing effects. On one hand, economies that experienced productivity-driven improvement in their competitiveness in manufacturing increased their manufacturing shares by poaching sales from their competitors. On the other hand, economies that grew the fastest overall ended up fuelling growth in their non-tradable sectors through the relative expenditure channel, pushing the production structure towards the non-tradable services. In contrast, changes in trade costs operated predominantly through the trade specialization channel. Even thought trade liberalization made many economies richer, this process did not lead to a substantial divergence in relative incomes across the economies.

Finally, the intensification of international capital flows, reflected in increased aggregate trade imbalances, had a double-whammy effect on the borrower economies. First, increases in domestic demand pushed up the wages, rendering the economies less competitive, and ultimately hurting domestic manufacturing through the trade specialization channel. Second, borrowing meant a disproportional increase in demand for non-tradable goods, further depressing manufacturing as a share of GDP. Thanks to this compounding of effects, surplus economies, on the contrary, saw a considerable boost to their manufacturing shares.

1.1 Related Literature

Much of the literature has studied structural transformation in a closed economy. Two mechanisms in particular have been recognized as key drivers of the hump shaped pattern in the manufacturing share: the price- and income effects.[2] The former has been studied in Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008), who show that if the relative price of manufacturing declines over time and if sectoral goods are complements, the final expenditure share of manufacturing, likewise, contracts. The latter, investigated in Kongsamut, Rebelo, and Xie (2001), Boppart (2014), and Comin, Lashkari, and Mestieri (2021), operates if preferences over sectoral goods are non-homothetic: as income grows, the household demand switches away from agricultural goods and towards services. Two recent contributions, Herrendorf, Rogerson, and Valentinyi (2021) and Garcia-Santana, Pijoan-Mas, and Villacorta (2021), point out that price- and income effects are also affecting the demand for investment goods and their composition. This paper can be viewed as a complementary exercise. I shut down the operation of price- and income effects, in order to study what other (open economy) mechanisms affect the process of structural change.

Structural transformation in an open economy received relatively less attention. A number of papers have focused on the operation of individual shocks and on the experiences of individual economies, such as Uy, Yi, and Zhang (2013), who study the contribution of falling trade costs and changing sectoral productivity to the industrialization of South Korea, or Kehoe, Ruhl, and Steinberg (2018), who study how international borrowing affected manufacturing employment share in the United States. Świecki (2017), Cravino and Sotelo (2019), and Sposi, Yi, and Zhang (2021), instead, study how openness shapes the process of structural transformation in a large sample of economies and consider the operation of multiple shocks simultaneously. Since the question and the setup are similar to my paper, I will discuss the differences between these papers and mine in more detail.

Świecki (2017) and Sposi, Yi, and Zhang (2021) both study the importance of unbalanced productivity growth and changes in trade costs in an open economy setting. Both find that the former is key in explaining the process of structural change in an average economy. Cravino and Sotelo (2019) and Sposi, Yi, and Zhang (2021) find that trade liberalization, likewise, mattered for the experience of an average economy, through its effects on incomes and prices. Additionally, Świecki (2017) and Sposi, Yi, and Zhang (2021) find that trade cost declines were important for

2. Both value added share and employment share have been used as a measure of the relative size of the sectors. The two are highly correlated, but ultimately distinct and subject to different processes.

thinking about the deviation of individual country experiences from the average trend. The key differences between these three contributions and the present paper are as follows.

First, I study the way in which unbalanced productivity growth and trade liberalization drive the sectoral makeup of economies *through* their effect on the patterns of specialization. The existence of this channel is not new – the intuition behind its operation dates back at least to Ricardo. Recently, Matsuyama (2009) has revisited this idea, arguing that when manufacturing productivity increases in an open economy, forces of trade specialization will push against the relative price effect, potentially overturning it. However, in previous studies the two have often been conflated. By studying mechanisms as distinct from their fundamental drivers, I am able to disentangle the two, and find that trade specialization alone is a powerful driver of structural change. Second, this is the first study to assess the role of aggregate trade imbalances as a driver of structural change for a broad set of economies. Indeed, I find that international borrowing has been a systematic yet underappreciated driver of heterogeneous patterns of industrialization across economies, and is responsible for a number of puzzles in the data. Finally, previous studies have typically restricted their attention to the movements in the sectoral shares of two or three broad sectors of economy. However, focusing on the behaviour of aggregate manufacturing alone conceals the rich heterogeneity in the dynamics of its constituent sub-sectors. By conducting analysis at a more disaggregate level, I am able to think about the changes in composition of manufacturing over time and across economies.

In terms of the methodology, this paper relies on the machinery pioneered by Eaton and Kortum (2002), and the large number of papers that build upon it. In particular, I follow Dekle, Eaton, and Kortum (2007) in modelling international borrowing as exogenous wedges between the aggregate household income and expenditure, and Eaton et al. (2016) in recasting the model in changes, which aids calibration substantially. Finally, when estimating the productivity and trade cost series, I follow Silva and Tenreyro (2006), who recommend the use of Poisson pseudo-maximum likelihood method in the context of structural gravity.

The organization of this paper is as follows. In Section 2, I present a quantitative model of trade. In section 3, I use its equilibrium conditions to develop a decomposition of changes in sectoral value added shares into operation of different mechanisms and shocks. In Section 4, I present the dataset and discuss the calibration of the model. In Section 5, I use simulations to obtain the empirical counterparts to the components of the decomposition developed in Section 2, and use it to study the drivers of structural transformation in my sample. Finally, Section 6 concludes.

2 Model

In this section, I present the model that I will use to interpret structural transformation as observed in the data, and define its equilibrium. The model comprises of a series of static equilibria, time subscripts will be suppressed where possible for ease of exposition. There are I countries and K sectors in the model.

Producers. Each sector k in each country i can produce any of the continuum of varieties $z \in [0,1]$. Firms produce varieties using a nested constant elasticity of substitution production function and are exogenously assigned a productivity level $a_{ik}(z)$. Firms produce using labor l_{ik} and intermediate input bundles m_{ik}, which are comprised of sectoral input aggregates m_{ikn}. Output of a firm producing z in country i and sector k is as follows:

$$y_{ik}(z) = a_{ik}(z)\left(\omega_{ikl}^{\frac{1}{\sigma_l}} l_{ik}^{\frac{\sigma_l-1}{\sigma_l}}(z) + (1-\omega_{ikl})^{\frac{1}{\sigma_l}} m_{ik}^{\frac{\sigma_l-1}{\sigma_l}}(z)\right)^{\frac{\sigma_l}{\sigma_l-1}},$$

where

$$m_{ik}(z) = \left(\sum_n \omega_{ikn}^{\frac{1}{\sigma_m}} m_{ikn}^{\frac{\sigma_m-1}{\sigma_m}}(z)\right)^{\frac{\sigma_m}{\sigma_m-1}},$$

and

$$\omega_{ikl} \in [0,1], \quad \sum_n \omega_{ikn} = 1, \text{ and } \quad \omega_{ikl}, \omega_{ikn} \geq 0 \quad \forall k, n \in K.$$

Input share parameters are country and sector specific, and can vary over time: $\omega_{ikl,t}$, $\omega_{ikn,t}$. Firms optimally spend a fraction β_{ikl} of their revenue on labor:

$$w_i l_{ik}(z) = \beta_{ikl} p_{ik}(z) y_{ik}(z) = \frac{\omega_{ikl} w_{ik}^{1-\sigma_l}}{\omega_{ikl} w_{ik}^{1-\sigma_l} + (1-\omega_{ikl})\left(\sum_n \omega_{ikn} P_{in}^{1-\sigma_m}\right)^{\frac{1-\sigma_l}{1-\sigma_m}}} p_{ik}(z) y_{ik}(z), \tag{1}$$

and a fraction β_{ikn} on intermediate inputs from sector n:

$$P_{in} m_{ikn}(z) = \beta_{ikn} p_{ik}(z) y_{ik}(z) = \frac{\omega_{ikn} P_{in}^{1-\sigma_m}}{\sum_n \omega_{ikn} P_{in}^{1-\sigma_m}} (1-\beta_{ikl}) p_{ik}(z) y_{ik}(z), \tag{2}$$

where w_i is the cost of labor and P_{ik} is the price index of the sector k aggregate in country i.

The productivity level $a_{ik}(z)$ is drawn, independently for each country, from a Frechet distribution[3] with the cumulative distribution function as follows:

$$F_{ik}(a) = \exp\left[-\left(\frac{a}{\gamma A_{ik}}\right)^{-\theta}\right], \quad \gamma = \left[\Gamma\left(\frac{\theta - \xi + 1}{\theta}\right)\right]^{1/(1-\xi)}.$$

$A_{ik} > 0$ reflects the absolute advantage of country i in producing sector k goods: higher A_{ik}

3. Kortum (1997) shows that if the sectoral productivities are an outcome of search for the new production techniques and the ideas are Pareto distributed, the distribution of the technological frontier (best ideas found so far) is Frechet.

means that high productivity draws for varieties in i, k are more likely. $\theta > 1$ is inversely related to the productivity dispersion. If θ is high, productivity draws for any one country are more homogeneous.[4] γ is introduced to simplify the notation in the rest of the model.[5]

Varieties can be shipped abroad with an iceberg cost τ_{ijk} (τ_{ijk} goods need to be shipped for one unit of good to arrive from i to j). These costs capture transportation, tariff and non-tariff barriers to trade. Trade within an economy is costless: $\tau_{iik} = 1$ for all i, k.

The final goods producer aggregates individual varieties into the sectoral good bundles in each economy using CES technology. Specifically,

$$Q_{ik} = \Big(\int_0^1 q_{ik}(z)^{(\xi-1)/\xi} dz \Big)^{\xi/(\xi-1)}.$$

The sectoral good bundles are non-tradable.

Households. Country i houses a population of a mass L_i. Households are identical and are maximizing the aggregate consumption C_i, defined, following Comin, Lashkari, and Mestieri (2021), as an implicit function of consumption of sectoral bundles C_{ik}, $k \in K$:

$$\sum_k \Omega_{ik}^{\frac{1}{\sigma_c}} \left(\frac{C_{ik}}{C_i^{\epsilon_k}} \right)^{\frac{\sigma_c - 1}{\sigma_c}} = 1. \tag{3}$$

Expenditure weight parameters are country-specific and also vary over time: $\Omega_{ik,t}$. Comin, Lashkari, and Mestieri (2021) show that for a given set of sectoral price indices and aggregate expenditure level $E_i = \sum_k P_{ik} C_{ik}$, demand can be defined implicitly:[6]

$$C_{ik} = \Omega_{ik} \left(\frac{P_{ik}}{E_i} \right)^{-\sigma_c} C_i^{(1-\sigma_c)\epsilon_k}. \tag{4}$$

The sectoral expenditure share, then, is as follows:

$$\alpha_{ik} = \Omega_{ik} \Big(\frac{P_{ik}}{E_i} \Big)^{1-\sigma_c} C_i^{(1-\sigma_c)\epsilon_k}. \tag{5}$$

It can be shown that this preference specification features a constant elasticity of relative demand with respect to aggregate consumption:

$$\frac{\partial \log(C_{ik}/C_{in})}{\partial \log C_i} = (1 - \sigma_c)(\epsilon_k - \epsilon_n),$$

4. As will be shown, the choice of the origin of a variety to be purchased will then be closely tied to the average productivity, costs of trade or costs of production in the exporter country. This means that changes in each of these will induce larger shifts in trade. In this sense, θ operates like trade elasticity in this model.

5. Γ stands for the gamma function. Absent normalization, γ appears in the price equations as a shifter common across economies. The simplification is thus without loss of generality. I assume that $\theta > \xi - 1$. As long as this inequality is satisfied, the value of the parameter ξ does not matter for the analysis and need not be estimated.

6. Note that this demand specification collapses to the constant elasticity of substitution case when $\epsilon_k = 0$ for all k. If $\epsilon_k \neq 0$, on the other hand, sectoral demand depends additionally on total consumption C_i. In other words, this utility function can be viewed as a non-homothetic generalization of CES.

as well as a constant elasticity of substitution between sectoral goods:

$$\frac{\partial \log(C_{ik}/C_{in})}{\partial \log(P_{ik}/P_{in})} = \sigma_c.$$

The former gives rise to an income effect: as real consumption grows, demand for a sectoral good with higher income elasticity ϵ_k rises relatively more. The latter, σ_c, governs the operation of the price effect. If $\sigma_c < 1$, an empirically relevant case, the sectoral goods are complements and the expenditure on the good whose relative price is falling will be decreasing.

Finally, each household is endowed with one unit of labor which it supplies inelastically, such that labor income in each economy is $w_i L_i$. Households have no other source of income. Households can, however, borrow and lend internationally. I follow Dekle, Eaton, and Kortum (2007) in treating these borrowing decisions as exogenous.[7] I parameterize international borrowing by aggregate trade deficit terms D_i, such that:

$$E_i = D_i w_i L_i. \tag{6}$$

$D > 1$ means that the country is borrowing and $D < 1$ means that it is lending internationally. Trade balances at a global level, so $\sum_i w_i L_i (D_i - 1) = 0$.

Market clearing. Markets for variety z in any sector are perfectly competitive. Thus, the price of a variety z shipped from j to i is its marginal cost corrected for the cost of shipping:

$$p_{ijk}(z) = \frac{\tau_{ijk} c_{jk}}{a_{jk}(z)},$$

where

$$c_{ik} = \left(\omega_{ikl} w_{ik}^{1-\sigma_l} + (1-\omega_{ikl}) \left(\sum_n \omega_{ikn} P_{in}^{1-\sigma_m} \right)^{\frac{1-\sigma_l}{1-\sigma_m}} \right)^{\frac{1}{1-\sigma_l}} \tag{7}$$

is the unit cost of production of a firm with a unit productivity.

Suppose that a variety z purchased from country i is a perfect substitute for the same variety purchased from any other country. In this case buyers choose to purchase variety z from a country with the lowest price, so that the price paid in i for variety z of sector k is $p_{ik}(z) = \min_j \{p_{ijk}(z)\}$. Eaton and Kortum (2002) show that if the firm level productivities follow a Frechet distribution,

7. In quantitative trade models, exogenous aggregate trade deficits are frequently used to match the imbalances in the data (Dekle, Eaton, and Kortum 2007; Cravino and Sotelo 2019; Świecki 2017). Alternatively, Eaton et al. (2016) have developed an algorithm for solving a dynamic version of the model with forward looking households, where agents lend and borrow to smooth consumption. However, in order to match the imbalances in the data, Eaton et al. (2016) fit the intertemporal preferences with impatience shocks which are time-variant. These impatience shocks are key for matching negative co-movement in GDP and imbalances observed in the data: the endogenous smoothing alone generates counterfactual flows. In other words, adding dynamic decisions entails replacing one exogenous shock fitting exercise with another, but at a considerable cost in terms of exposition. I thus choose the static setup with exogenous deficits.

and the sectoral aggregator is CES, then the price index for a sector k bundle in i equals

$$P_{ik} = \left[\sum_{l} \left(\frac{c_{lk}\tau_{ilk}}{A_{lk}} \right)^{-\theta} \right]^{-\frac{1}{\theta}}. \tag{8}$$

Crucially, the assumptions of the model give rise to trade shares – the expenditures on imports from any given destination as a share of the total spending on the sectoral bundle – that can be solved for in closed form:

$$\Pi_{jik} = \frac{X_{jik}}{X_{jk}} = \frac{(c_{ik}\tau_{jik}/A_{ik})^{-\theta}}{\sum_l (c_{lk}\tau_{jlk}/A_{lk})^{-\theta}} = \left(\frac{c_{ik}\tau_{jik}}{A_{ik}P_{jk}} \right)^{-\theta}. \tag{9}$$

Intuitively, j's share in the i's expenditure on sector k goods increases in j's productivity distribution location parameter A_{jk} and suffers from higher productivity in competitor economies A_{lk}. On the other hand, j's trade share declines in own bilateral trade costs τ_{jik} and increase if the costs of shipping from the competitors, τ_{ilk}, increase.

Labor market clearing condition (combined with variety cost minimization) is as follows:

$$w_i L_i = \sum_{k \in K} \int_0^1 w_i l_{ik}(z) dz = \sum_{k \in K} \beta_{ikl} Y_{ik}. \tag{10}$$

Goods markets clear when the sectoral bundles output equals the sectoral bundles final and intermediate demand. The market clearing condition, making use of the variety cost minimization condition and household optimal expenditure, takes the following form:

$$X_{ik} = X_{ik}^{FC} + \sum_n X_{ink}^{II} = \alpha_{ik} E_i + \sum_{n \in K} \beta_{ink} Y_{in}. \tag{11}$$

Finally, the value of sector k output in country i is a sum of what is demanded by each trading partner:

$$Y_{ik} = \sum_j \Pi_{jik} X_{jk}. \tag{12}$$

I normalize by setting the global GDP to 1:

$$\sum_i w_i L_i = 1. \tag{13}$$

Together, equations (1) - (13) constitute the equilibrium of the model for a given time period.

3 Mechanisms and Drivers of Structural Change

In this section, I discuss the origins of structural transformation through the lens of the model. In subsection 3.1, I present a decomposition of changes in sectoral value added shares into operation of three distinct mechanisms driven by trade specialization, expenditure shares, and relative expenditures. In subsection 3.2, I discuss how these are brought into motion by the exogenous drivers in the model. In subsection 3.3, I offer a decomposition of changes in sectoral shares that reflects both the exogenous drivers and the mechanisms that they operate through.

For ease of exposition, I begin my discussion by assuming away the use of intermediate inputs and population growth. I then discuss how these factors alter analysis in subsection 3.2. The simulation-based decomposition in Section 5 features both.

3.1 Mechanisms of structural change

The first decomposition builds on the sectoral demand and market clearing conditions (11), (12):

$$Y_{ik} = \sum_j X_{jik} = \sum_j \Pi_{jik} \alpha_{jk} E_j.$$

Note that sectoral sales depend on three objects: trade shares Π_{jik}, which reflect the sourcing decisions of both i's domestic households and of their trading partners, final expenditure shares α_{jk}, capturing the importance of sector k in households' consumption baskets, and the total expenditure of households at home and abroad E_j.

Consider the total derivative of sectoral sales with respect to the full set of changes in Π, α, and E. It is convenient to work with changes with respect to level, so let $\tilde{x}$ denote an infinitesimal change in variable x divided by its level: $\tilde{x} = dx/x$. Then, change in sectoral sales satisfies

$$\tilde{Y}_{ik} = \sum_j \phi_{jik} \tilde{\Pi}_{jik} + \sum_j \phi_{jik} \tilde{\alpha}_{jk} + \sum_j \phi_{jik} \tilde{E}_j, \quad \text{where} \quad \phi_{jik} = \frac{X_{jik}}{Y_{ik}}. \tag{14}$$

In other words, changes in sectoral sales can be traced back to changes in trade shares, expenditure shares or total expenditures, weighted by the market exposure ϕ_{jik}. For ease of notation, I denote each of the summands by listing the variable whose effect it reflects in the brackets, such that $\tilde{Y}_{ik} = \tilde{Y}_{ik}(\tilde{\Pi}) + \tilde{Y}_{ik}(\tilde{\alpha}) + \tilde{Y}_{ik}(\tilde{E})$.

Changes in value added shares, in turn, reflect changes in the relative sizes of sectors:

$$\tilde{va}_{ik} = \tilde{Y}_{ik} - \sum_n va_{in} \tilde{Y}_{in}.$$

Plugging in the expression for changes in sectoral sales I obtain the following decomposition:

$$\tilde{va}_{ik} = \underbrace{\tilde{Y}_{ik}(\tilde{\Pi}) - \sum_n va_{in} \tilde{Y}_{in}(\tilde{\Pi})}_{\text{trade specialization}} + \underbrace{\tilde{Y}_{ik}(\tilde{\alpha}) - \sum_n va_{in} \tilde{Y}_{in}(\tilde{\alpha})}_{\text{expenditure shares}} + \underbrace{\tilde{Y}_{ik}(\tilde{E}) - \sum_n va_{in} \tilde{Y}_{in}(\tilde{E})}_{\text{relative expenditure}}, \tag{15}$$

or $\tilde{va}_{ik} = \tilde{va}_{ik}(\tilde{\Pi}) + \tilde{va}_{ik}(\tilde{\alpha}) + \tilde{va}_{ik}(\tilde{E})$ for short. I discuss each term in turn.

Trade specialization term (TS) captures the direct effects of changes in sourcing decisions, both of domestic households and of those abroad. In particular, sector k value added share increases if consumers switch towards i as a supplier of sector k goods and away from other producers, *and* if this effect is stronger than that in other sectors of the economy.

Expenditure shares term (ES) combines the direct effects of changes in final expenditure shares of both domestic and foreign agents. If households switch their expenditures towards sector k goods, it's value added share will increase.

Finally, relative expenditure term (RE) captures the direct effect of changes in total expenditures of economies. This term is positive if an economy whose expenditure grew was a relatively more important market for i's sector k produce than it was for its other sectoral goods. Note that if sector k is non-tradable, $\phi_{iik} \geq \sum_n va_{in}\phi_{iin}$. Thus, if domestic expenditure increases, this tends to boost the sectoral share of non-tradables.

However, each of trade shares, expenditure shares and total expenditures are endogenous. What fundamental drivers bring them into motion?

3.2 Fundamental drivers of structural change

First, trade shares respond to changes in costs of production vis-à-vis the competitors:

$$\tilde{\Pi}_{jik} = \theta \left(\tilde{A}_{ik} - \tilde{\tau}_{jik} - \tilde{w}_i - \sum_l \Pi_{jlk} \left(\tilde{A}_{lk} - \tilde{\tau}_{jlk} - \tilde{w}_l \right) \right). \tag{16}$$

i's trade share of sector k goods in j increases if i's productivity increases, or if its export costs or input costs decrease by more than that of its average competitor in j, weighted by trade shares. Second, expenditure shares respond to preference shocks, as well as to changes in relative prices and aggregate consumption, which capture the operation of price- and income effects:

$$\tilde{\alpha}_{ik} = \tilde{\Omega}_{ik} + (1 - \sigma_c) \left[\tilde{P}_{ik} - \sum_n \alpha_{in} \tilde{P}_{in} + \left(\epsilon_k - \sum_n \alpha_{in} \epsilon_n \right) \tilde{C}_i \right], \; \tilde{C}_i = \frac{\tilde{E}_i - \sum_n \alpha_{in} \tilde{P}_{in}}{\sum_n \alpha_{in} \epsilon_n}. \tag{17}$$

Note that if $\sigma_c < 1$, then price increase in k compared to other sectors leads to increased expenditure shares. Likewise, expenditure share on sector k goods increases if the aggregate consumption increases, and the income elasticity of sector k goods – ϵ_k – is higher than that in other sectors. Sectoral price deflators are a function of the changing costs of production at home and abroad:

$$\tilde{P}_{ik} = \sum_l \Pi_{ilk} \left(\tilde{A}_{lk} - \tilde{\tau}_{ilk} - \tilde{w}_l \right), \tag{18}$$

and, finally, total expenditure is a function of growth rates of aggregate trade deficits and wages:

$$\tilde{E}_i = \tilde{D}_i + \tilde{w}_i. \tag{19}$$

Note that now the objects from decomposition (15) are obtained as a function of exogenous shocks and wage growth. Plugging in, changes in sectoral shares can now be expressed as follows:

$$\tilde{va}_{ik} = \tilde{va}_{ik}(\tilde{\Pi}(\tilde{A}, \tilde{\tau}, \tilde{w})) + \tilde{va}_{ik}(\tilde{\alpha}(\tilde{\Omega}, \tilde{A}, \tilde{\tau}, \tilde{D}, \tilde{w})) + \tilde{va}_{ik}(\tilde{E}(\tilde{D}, \tilde{w})). \tag{20}$$

This exercise highlights the fact that changes in sectoral productivity, for example, affect sectoral shares through all three mechanisms. Directly, by changing costs of production and therefore patterns of specialization, as well as by shifting relative prices which causes households to adjust their spending. However, changes in productivity also have indirect effects, operating through relative wages:

$$\tilde{w}_i = \sum_k va_{ik} \left[\tilde{Y}_{ik}(\tilde{\Pi}(\tilde{A}, \tilde{\tau}, \tilde{w})) + \tilde{Y}_{ik}(\tilde{\alpha}(\tilde{\Omega}, \tilde{A}, \tilde{\tau}, \tilde{D}, \tilde{w})) + \tilde{Y}_{ik}(\tilde{E}(\tilde{D}, \tilde{w})) \right], \tag{21}$$

which in turn have further knock-on effects on specialization, expenditure shares, and relative expenditures. Similarly for other exogenous drivers: their overall impact is a combination of the operation of mechanisms that are conceptually distinct.

The total impact a given exogenous series has on sectoral shares, both directly and indirectly, can be measured using the total derivative:

$$\tilde{va}_{ik} = \sum_{i,k} \frac{\partial va_{ik}/va_{ik}}{\partial \Omega_{ik}/\Omega_{ik}} \tilde{\Omega}_{ik} + \sum_{i,k} \frac{\partial va_{ik}/va_{ik}}{\partial A_{ik}/A_{ik}} \tilde{A}_{ik} + \sum_{i,j,k} \frac{\partial va_{ik}/va_{ik}}{\partial \tau_{ijk}/\tau_{ijk}} \tilde{\tau}_{ijk} + \sum_i \frac{\partial va_{ik}/va_{ik}}{\partial D_i/D_i} \tilde{D}_i,$$

such that

$$\tilde{va}_{ik} = \tilde{va}_{ik}(\tilde{\Omega}) + \tilde{va}_{ik}(\tilde{A}) + \tilde{va}_{ik}(\tilde{\tau}) + \tilde{va}_{ik}(\tilde{D}).$$

The role of intermediate inputs and population. Up until now, I have abstracted from the input-output structure of production and assumed away population growth. However, both can be accommodated with minimal alterations.

First, since firms produce with CES technology, the demand for sectoral intermediate inputs varies over time. This constitutes yet another moving part driving sectoral sales. In the decomposition by mechanisms, I treat changes in intermediate input shares as a component of expenditure shares channel. Population growth has no effect on the mechanisms decomposition. While the presence of intermediate inputs makes for more involved algebra, the decomposition by mechanism still obtains and can be summarized as follows:

$$\tilde{va}_{ik} = \underbrace{\tilde{va}_{ik}(\tilde{\Pi})}_{\text{trade specialization}} + \underbrace{\tilde{va}_{ik}(\tilde{\alpha}, \tilde{\beta})}_{\text{expenditure shares}} + \underbrace{\tilde{va}_{ik}(\tilde{E})}_{\text{relative expenditure}}. \tag{22}$$

The decomposition by fundamental drivers now has further exogenous shocks: to intermediate input and labour weights in the production function $\hat{\omega}_{ikl}$ and $\hat{\omega}_{ikl}$, as well as to population sizes $\hat{L}_i$. These have a multitude of direct and indirect effects. However, the contribution of these different shocks can be measured as before – as a total derivative:

$$\tilde{va}_{ik} = \tilde{va}_{ik}(\tilde{\Omega}) + \tilde{va}_{ik}(\tilde{A}) + \tilde{va}_{ik}(\tilde{\tau}) + \tilde{va}_{ik}(\tilde{D}) + \tilde{va}_{ik}(\tilde{L}) + \tilde{va}_{ik}(\tilde{\omega}).$$

3.3 Joint treatment of shocks and mechanisms

The decompositions by mechanisms and by fundamental shocks give different, but complementary perspectives on the same process. However, it is the combination of the two approaches that offers most flexibility in addressing a richer set of questions about structural change in an open economy. Consider a few examples.

In 2001, China has joined the World Trade Organization. Through the lens of the model, this episode can be thought of as a decline in bilateral trade costs with China. A burgeoning literature has been assessing the impact of this event on local employment, investment, migration and inequality (Autor et al. 2014; Autor, Dorn, and Hanson 2016; Bloom, Draca, and Van Reenen 2016; Bloom et al. 2019). Importantly, in all cases, the underlying mechanism is understood to be the competitive pressure that cheaper Chinese produce may have had on domestic economies. However, notable as it is, entry of China into WTO is only one data-point in the greater picture of trade liberalization over the last half century. What was the overall effect of trade liberalization on the production structure of different economies as mediated *through* trade specialization?

In 1999, Finland's Nokia became the world's largest mobile phone producer – the status it kept for the following decade. This rise was led by a doubling of Finland's electrical equipment value added share between 1995 and 2004. While salient, this pattern, again, is not unique. One might ask: how did the asymmetric evolution of sectoral productivities affect the geography of production of different kinds of manufacturing goods? Once again, addressing this question requires focusing on trade specialization as the channel through which changes in sectoral productivity drive structural transformation.

These questions cannot be addressed with decompositions based on mechanisms or driving shocks. However, a combination of the two can help shed light on how different exogenous processes feed through individual channels. The method boils down to taking the total derivative with respect to a given shock series, but shutting down the operation of individual mechanisms. For example, solving the system of equations (14) - (21) with $\tilde{\tau} = \tilde{D} = \tilde{L} = 0$, as well as imposing $\tilde{\alpha} = \tilde{E} = 0$, identifies the effect of changes in sectoral productivities as they feed through the trade specialization channel directly and indirectly through their effect on wages. Denote this object $\tilde{va}_{ik}(\tilde{A} \mid \tilde{\alpha} = \tilde{E} = 0)$. Note however, that sectoral productivity can also have indirect effects on trade shares by affecting wages through relative expenditures channel. This type of indirect feedback is not captured by the exercise.

A related exercise can be viewed as its reverse. Consider the difference of the total change in sectoral value added share and the component obtained by letting all shocks operate but shutting down one mechanism: $\tilde{va}_{ik} - \tilde{va}_{ik}(\tilde{A}, \tilde{\tau}, \tilde{D} \mid \tilde{\alpha} = 0)$. This difference captures the total effect of all the links missing in the sectoral share change with expenditure shares channel shut down: the direct effect of all shocks on expenditure shares, as well as the indirect effects that the resultant changes in expenditure shares have on wages, and through wages, on trade specialization, expenditure shares and the relative expenditure channels of structural change.

In Section 5 I use these exercises to size up the contribution of different shocks as these feed through channels other than the expenditure shares. However, first I calibrate the model.

4 Calibration

In this section, I first describe the dataset that I use. I then present the model in changes – an equivalent representation that requires the estimation of fewer parameters. Finally, I discuss the calibration, and in particular the estimation of trade cost- and sectoral productivity shocks.

4.1 Data Description

I use Groningen Growth and Development Centre Long-run World Input Output Database as a source of data on annual sector level bilateral trade flows, final consumption, intermediate inputs use, and sectoral output and value added. There are two key features of this dataset. First, it covers global consumption and production by including a Rest of World region which aggregates the trade flows to and from all countries not included in the dataset. Second, it is internally consistent, in the sense that at a sectoral level, total value of resources used in production equals the total value of its sales. Thus, it maps readily to the equilibrium conditions of the model.

The dataset covers twenty five economies and an aggregate rest of the world region over years 1965 to 2011. I restrict my analysis to twenty economies, and group the remaining five together with the rest of the world.[8] The sectoral coverage is at a two digit level and is subject to ISIC rev. 3.1 industrial classification. There are twenty three sectors in the data, thirteen of which are tradable: agriculture, mining, and eleven sectors that produce different manufacturing goods. I group the remaining ten sectors into one aggregate services sector, so that $K = 14$. The list of countries and sectors can be found in Appendix B.

To calibrate the model, I use the full contents of the world input-output tables. I use the data on sector level intermediate inputs use which varies by country and sector of both origin and destination, i.e. X^{II}_{jinkt}, as well as consumption series which vary by destination, sector and country of origin: X^{FC}_{jikt}. I construct all the variables of interest using these two time series, and supplement with the population series from the Socio Economic Accounts segment of LR-WIOD.

I do minimal cleaning of the dataset. First, as I am focusing on the long run processes, I smooth the data using a moving average of the series with a window length of 10 years. This removes the jumps in the data while keeping the long run trends intact. Second, I force no trade in the services sectors. While some services are tradable in practice, in WIOD services export values are not compiled from raw trade data and instead are imputed as a residual. Since these values are unlikely to match the true trade in services, I attribute all sales of service sectors to domestic absorption. Finally, the consumption reported in WIOD includes inventories and thus can take negative values. I subtract inventories from sectoral sales such that my measure of output is now akin to 'goods delivered'. This alteration leaves all other intermediate and final use categories intact and the dataset remains internally consistent.

8. I exclude Austria, Belgium, Hong Kong, Ireland and Netherlands from the analysis as the time series for these countries feature abnormalities. Austria and Netherlands series feature structural breaks in years 1995 and 1969 respectively. Hong Kong series show zero final or intermediate consumption of textiles, but positive production throughout the period. Belgium and Ireland do not show a clear structural break, but feature self-shares that dip down to zero for consecutive years absent a corresponding drop in sectoral sales. Since domestic sales in the dataset are obtained as a residual between output and exports, I interpret these observations as reflective of a measurement error in either the sales or the exports series.

4.2 Model in Changes

Dekle, Eaton, and Kortum (2007) and Eaton et al. (2016) show that the model can be rewritten in changes, such that all objects in the model are solved for using the base year values of endogenous variables and the changes in the values of exogenous variables: $\hat{A}, \hat{\tau}, \hat{D}, \hat{\Omega}, \hat{\omega}, \hat{L}$, where change is from the level of the previous period: $\hat{x} = x_{t+1}/x_t$. Note that under this notation, $\hat{x} = 1$ means no change, and, conversely, $\hat{x} \neq 1$ means that x has changed its value between $t+1$ and t. Thus, I will be referring to changes in exogenous variables as 'shocks'. The benefit of this approach is a much smaller set of data required to parameterize the model. The model in changes is presented in Appendix A.1.

The calibration of the model in changes requires the values of Y_{ik}, Π_{jik}, α_{ik}, β_{ikl}, β_{ikn} and E_i for the base year. I derive these using the final and intermediate consumption series from WIOD, X^{FC}_{jik} and X^{II}_{jikn}, as follows:

$$\Pi_{ijk} = \frac{X_{ijk}}{\sum_l X_{ilk}}, \quad Y_{ik} = \sum_j X_{jik}, \quad X_{ijk} = X^{FC}_{ijk} + \sum_n X^{II}_{ijnk},$$
$$\beta_{ikn} = \frac{\sum_j X^{II}_{ijkn}}{Y_{ik}}, \quad \beta_{ikl} = 1 - \sum_n \beta_{ikn}, \quad VA_{ik} = \beta_{ikl} Y_{ik},$$
$$\alpha_{ik} = \frac{\sum_j X^{FC}_{ijk}}{E_i}, \quad E_i = \sum_{j,k} X^{FC}_{ijk}, \quad D_i = \frac{E_i}{\sum_k VA_{ik}}.$$

The only parameter set externally is the productivity draw dispersion/trade elasticity parameter θ. I follow the literature by setting it to 4, as estimated in Simonovska and Waugh (2014) and Donaldson (2018).

4.3 Calibration of the Shocks Series

I calibrate the model at a yearly frequency. I obtain $\hat{D}$ and $\hat{L}$ by computing the ratios of variables in consecutive years. $\hat{A}$ and $\hat{\tau}$, in turn, are calibrated as follows.

The trade shares in the changes formulation of the model take the following form:

$$\hat{\Pi}_{jik} = \left(\frac{\hat{c}_{ik} \hat{\tau}_{jik}}{\hat{A}_{ik} \hat{P}_{jk}} \right)^{-\theta}, \tag{23}$$

where, as before, $\hat{x} = x_{t+1}/x_t$. The multiplicative form of the structural gravity equations makes them straightforward to estimate. Specifically, observe that equation (23) can be rewritten as a product of exporter fixed effect $e_{ik} = (\hat{c}_{ik}/\hat{A}_{ik})^{-\theta}$, importer fixed effect $m_{jk} = \hat{P}^{\theta}_{jk}$, and an error term $\varepsilon_{jik} = \hat{\tau}^{-\theta}_{jik}$:

$$\hat{\Pi}_{jik} = m_{jk} e_{ik} \varepsilon_{jik}. \tag{24}$$

Following Silva and Tenreyro (2006), I estimate the model using the Poisson pseudo-maximum likelihood method (PPLM). Once the model is estimated, the exporter fixed effect coefficients can be used to back out price shock series as $\hat{P}_{ik} = (exp(e_{ik})/\hat{\Pi}_{iik})^{-1/\theta}$, which, together with wage and trade share changes from the data, are sufficient to solve for sectoral productivity and trade cost shocks.

With a large sample of countries at a relatively fine level of disaggregation, many trade flows are very close to zero. Even small volume changes from a near zero base give rise to extreme values of trade share changes $\hat{\Pi}$. For example, there are 513 observations with $\hat{\Pi} > 10^3$, 233 observations with $\hat{\Pi} > 10^6$, 109 observations with $\hat{\Pi} < 10^{-3}$, and 44 observations with $\hat{\Pi} < 10^{-6}$. In comparison, the 10th and the 90th percentiles of trade share changes are 0.89 and 1.19 respectively. Thus, a substantial number of observations are orders of magnitude away from the rest.

Extreme trade share change values pose a problem for the estimation. It is well known that models with no fixed costs of trade struggle to generate near zero trade flows. In such models, the lack of trade with a particular partner can be rationalized only by an extreme value of the bilateral trade cost parameter. Similarly for the hat algebra formulation: increases of trade flows from a near zero baseline require extreme values of trade cost shocks. In the Poisson estimation, these observations will carry error terms that are orders of magnitude away from the rest, and will thus dominate the estimation.

I investigate this problem by simulating trade flow data based on the structural model and using the PPLM to recover the (known) values of the underlying shocks. In particular, I pick the shock series such that some trade flows are near zero in the initial period, whereafter they increase, giving rise to trade share changes above 10^3. In Appendix D, I show that the productivity shocks estimated using the full sample are completely off the mark. However, restricting the sample to exclude the extreme trade share change observations and re-estimating the model gives rise to productivity shock estimates which fit the true underlying series with a high degree of precision.

I experiment with different trade share change cutoffs when estimating equation (24). For my baseline specification, I use the 10th and the 90th percentiles of the full sample of trade share changes as the cutoffs.

The summary statistics of trade cost and sectoral productivity shocks can be found in Appendix C. This completes the calibration of the model. I turn to the model simulation next.

5 Structural Transformation Beyond the Hump

In this section, I use the calibrated version of the model to study structural change in an open economy beyond the operation of price- and income effects. In order to do so, I first discuss how to implement the theoretical decompositions from Section 3.3 using the data and simulations. I then use it to interpret the changes in manufacturing shares and their composition in the data.

5.1 Simulation-Based Decomposition

In Section 3.3, I argued that taking a total derivative of sectoral shares with respect to individual shock series, with some of the mechanisms shut off, can be used to measure the contribution of different processes to structural change through unrestricted channels. The calibrated version of the model can be used to derive a simulation-based counterpart of this theoretical exercise.

First, observe that the shocks estimated in Section 4 constitute the empirical counterparts to the changes in exogenous variables used in decompositions in Section 3.3:

$$\tilde{A} = \frac{dA_{ik}}{A_{ik}} \quad \rightarrow \quad \hat{A}_{ik} - 1 = \frac{A_{ik,t+1} - A_{ik,t}}{A_{ik,t}},$$

and likewise for other shocks.

Second, simulating the model using a given subset of shocks $\hat{X}$ and computing change from the value added share in the previous period constitutes the empirical counterpart to the total derivative with respect to that subset of shocks in the model:

$$dva_{ik}(\tilde{X}) \quad \rightarrow \quad \Delta va_{ik}(\hat{X}) = va_{ik,t+1}(\hat{X}) - va_{ik,t}.$$

Shutting off the operation of an individual mechanism amounts to replacing the endogenous response in the model with an appropriate no-change condition.

Finally, the fully calibrated version of the model maps to data one to one. Thus, the sectoral share changes observed in the data can be used in place of the model simulated with all shocks and channels in operation: $\Delta va_{ik} = \Delta va_{ik}(\hat{\Omega}, \hat{A}, \hat{\tau}, \hat{D}, \hat{L}, \hat{\omega})$.

With this mapping in mind, I carry out the following simulation-based decomposition. First, I simulate the model with shocks to sectoral productivity, trade costs, aggregate trade deficits and population size operating one at a time, and with changes in final- and intermediate expenditure shares shut off. I denote the resultant changes in sectoral shares as $\Delta va_{ik}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)$, for each $X \in \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\}$. Next, I simulate the model with all four shock series operating together, and with expenditure shares channel still switched off. I label the difference between sectoral share changes in the data and this object Δva_{ik}^{ES}:

$$\Delta va_{ik}^{ES} = \Delta va_{ik} - \Delta va_{ik}(\hat{A}, \hat{\tau}, \hat{D}, \hat{L} \mid \hat{\alpha}, \hat{\beta} = 1).$$

These five terms make up my main decomposition exercise:

$$\Delta va_{ik} = \sum_X \Delta va_{ik}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1) + \Delta va_{ik}^{ES}, \quad \text{where} \quad X = \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\}. \tag{25}$$

The interpretation of the exercise is as follows. The first four terms measure the contribution of each of sectoral productivities, trade costs, aggregate trade deficits and population sizes to driving sectoral shares, as these operate through the trade specialization and relative expenditures channels. In other words, through channels *other* than price- and income effects. The final term can be thought of as everything that the first four exclude: namely, direct effects of all shocks on sectoral shares as they operate through expenditure shares channel, as well as the second-order effects of these as wages adjust and bring other mechanisms into motion.

Now the decomposition is set up I use it to ask: what forces, other than the operation of price- and income effects drove the patterns of industrialization in my sample?

5.2 Drivers of Structural Transformation: 1965-2011

Figure 1 below presents the decomposition (25), applied to the manufacturing shares between years 1965 and 2011. I simulate the model with fourteen sectors at a yearly frequency. The changes in aggregate manufacturing share represent the sum of share changes in eleven manufacturing sub-sectors in my sample. I add up differences over time to obtain the change over the whole period.

First, note that expenditure share channel, which captures the operation of price- and income effects, as well as the operation of preference and production function shocks, is the key driver behind the changes in manufacturing shares in this period. To quantify this statement, I divide the yellow bars by the sum of the area of all coloured bars, such that

$$RC^{ES} = \frac{\sum_i |\Delta va_{im}^{ES}|}{\sum_i |\Delta va_{im}^{ES}| + \sum_X |\Delta va_{im}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|}, \quad \text{where} \quad X = \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\}.$$

I find that expenditure shares channel is responsible for 63% of manufacturing share changes observed in the data. Note, however, that this implies that 37% of the observed changes has nothing to do with price- and income effects, and is instead due to trade specialization and changes in relative expenditures. In turn, these were shaped by developments in sectoral productivities, trade costs and aggregate trade deficits. Computing relative contributions as before,

$$RC(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1) = \frac{\sum_i |\Delta va_{im}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|}{\sum_i |\Delta va_{im}^{ES}| + \sum_X |\Delta va_{im}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|}, \quad \text{where} \quad X = \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\},$$

I find that the three are responsible for 7%, 12% and 16% of the observed changes respectively. In other words, each of the series is important for understanding the evolution of manufacturing shares in the period.

Second, observe that visually, the three series seem important in explaining the heterogeneous patterns of structural change across economies. I formalize this observation as follows.

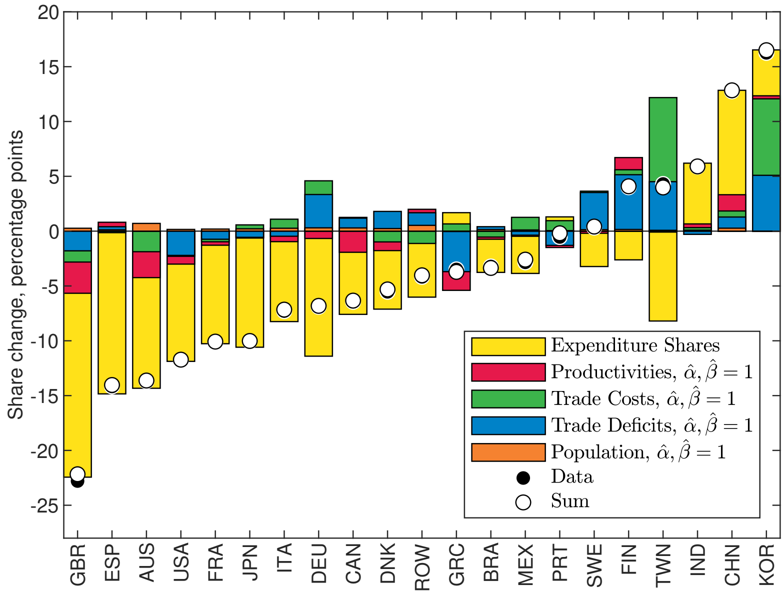

Figure 1: Drivers of Manufacturing Value Added Shares

Note: The yellow bar marks the difference between manufacturing share change in the data and in the simulation with expenditure shares channel shut off. The other bars mark the contributions of indicated shock series with expenditure shares channel shut off. The black circles mark the change in the manufacturing value added shares in the data, and the white circles mark the sum of the five terms of the decomposition.

The classical models of structural change predict that economies at similar levels of development follow similar patterns in their sectoral makeup. To model this notion, I split my sample into two equally sized groups on the basis of their GDP per capita in the first year of the sample. Next, for each of the groups, I break down the the change in manufacturing share compared to the group average into a sum of de-meaned components of decomposition (25):

$$\Delta va_{im} - \overline{\Delta va_m} = \sum_X \left(\Delta va_{im}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1) - \overline{\Delta va_m(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)} \right) + \Delta va_{ik}^{ES} - \overline{\Delta va_m^{ES}}, \quad (26)$$

where $X = \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\}$. Once again, I compute the relative contributions of each of the terms in (26). The results can be seen in Table 1.

Note that expenditure shares, while still the main contributor, play a smaller role in thinking about deviations from a common trend than for overall changes in manufacturing shares. Instead, around half of the dynamics can now be attributed to forces of trade specialization and changes in relative expenditures. However, the exogenous drivers behind those differ by group. In the lower income group, changes in trade costs have played an important role in driving the divergence in manufacturing shares. This is immediately apparent in Figure 1: Taiwan and South Korea, two of the economies with highest rates of industrialization over the period, saw an eight and seven percentage point increases in their manufacturing shares attributable to this force. These are remarkable transformations in the period where most economies underwent deindustrialization,

	Lower Income	Higher Income
Expenditure Shares	55	47
Productivities, $\hat{\alpha}, \hat{\beta} = 1$	5	12
Trade costs, $\hat{\alpha}, \hat{\beta} = 1$	23	12
Aggregate deficits, $\hat{\alpha}, \hat{\beta} = 1$	17	28
Population, $\hat{\alpha}, \hat{\beta} = 1$	1	1

Table 1: Relative Contributions to De-meaned Changes in Manufacturing Shares
Note: Values in percentage points. Lower income group: China, India, South Korea, Brazil, Taiwan, Portugal, Mexico, Japan, Greece and Spain. Higher income group: Italy, Finland, United Kingdom, Germany, Denmark, Australia, France, Canada, Sweden and United States.

and point to the power of open economy forces in reshaping economies through reallocation of global production. For the higher income group, it is changes in sectoral productivities and aggregate trade deficits instead that explain a chunk of the heterogeneity. Once again, results in Figure 1 are illustrative. Note that among the higher income group, losses associated with changes in productivity have contributed to two of the fastest experiences of deindustrialization in my sample – that of the United Kingdom and Australia, costing three and two percentage points of their manufacturing shares over the period, respectively. The contribution of aggregate trade deficits is, likewise, instructive. Note that this factor is the only reason that high income, surplus economies of Sweden and Finland record increases in manufacturing shares in this period – against the predictions of the standard models. Indeed, had only price- and income effects been at play, both would have seen their manufacturing shrink. Similarly, the ability of Germany to maintain a relatively high manufacturing share despite its high income can be explained entirely through its aggregate trade surpluses. In fact, the contribution of expenditure shares channel is indeed strongly negative, second only to that of United Kingdom and Spain. United States and United Kingdom, both running aggregate trade deficits over the period, instead saw their manufacturing shrink due to the operation of this force – by two percentage points respectively.

5.3 Structural Transformation within Manufacturing

It is common to think about structural change across two or three sectors: goods and services, or agriculture, manufacturing and services respectively. However, manufacturing contains a diverse range of industries – from textile production to electrical equipment to mineral processing to automotive industry. Should these be treated as homogeneous? In this subsection, I break down changes in sectoral shares of sub-sectors of manufacturing between years 1965 and 2011 using decomposition (25) and discuss their individual dynamics. Figure 2 presents the results.

First, observe that individual sub-sectors vary a lot in terms of their underlying dynamics. Sectors such as food production and textiles, for example, or minerals and metals, all saw a squeeze driven by falling expenditure shares. Notably, these forces have had a similar effect across the economies. Thus, decline in demand for these sectoral goods has contributed to a global trend. In turn, forces of trade specialization and changes in relative expenditures have

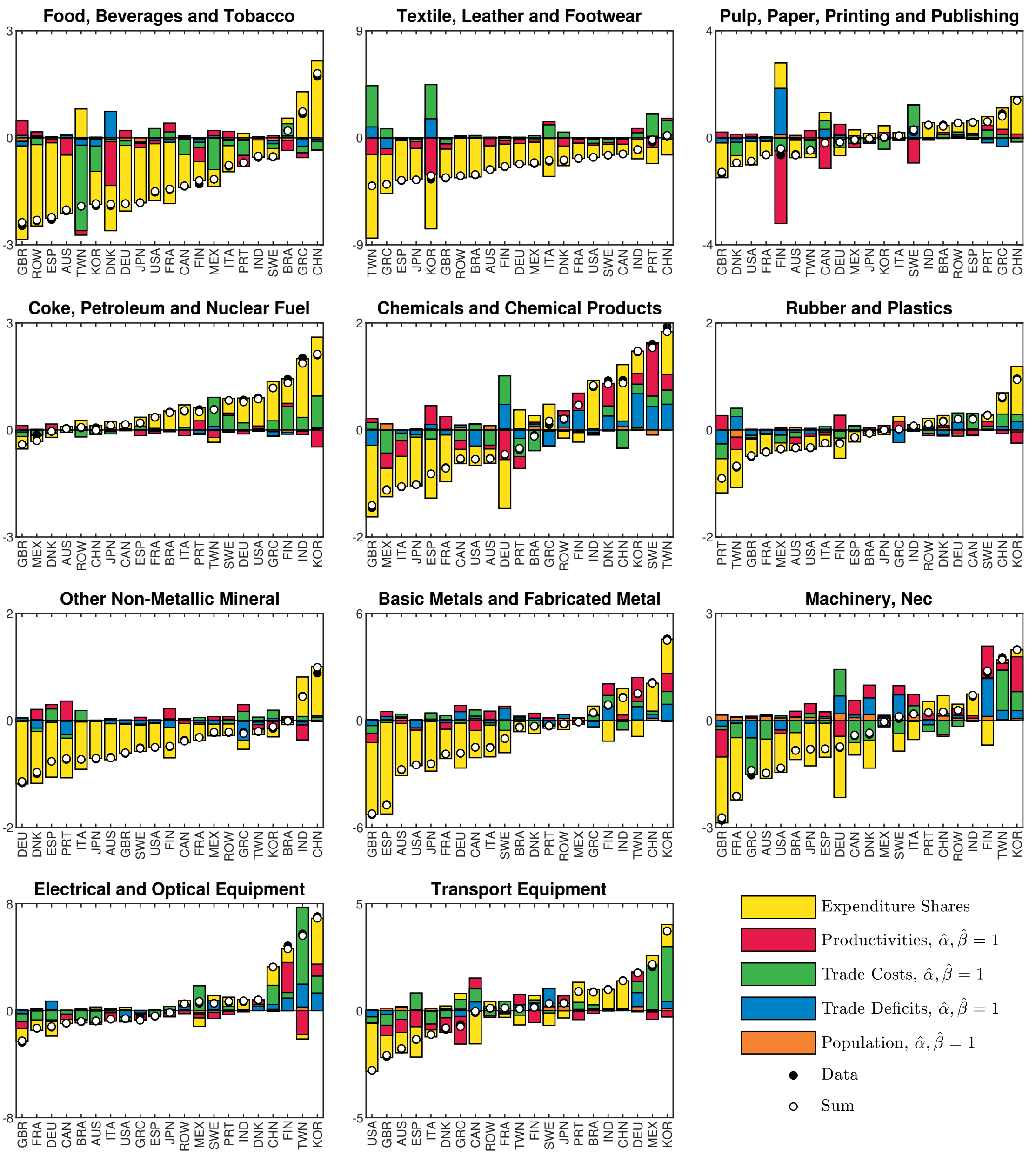

Figure 2: Drivers of Structural Transformation within Manufacturing

Note: The yellow bar marks the difference between manufacturing share change in the data and in the simulation with expenditure shares channel shut off. The other bars mark the contributions of indicated shock series with expenditure shares channel shut off. The black circles mark the change in the manufacturing value added shares in the data, and the white circles mark the sum of the five terms of the decomposition.

contributed to divergence of sectoral shares in my sample, most notably in the high-skilled manufacturing sub-sectors of electrical and transport equipment. Here, there was no global trend of declining expenditure shares. Instead, the location of production has shifted.

To quantify this statement, I compute the relative contribution of each of the components of the decomposition, but now take into account the changes in the composition of manufacturing:

$$RC^{ES} = \frac{\sum_{i,n} |\Delta va_{in}^{ES}|}{\sum_{i,n} |\Delta va_{in}^{ES}| + \sum_X |\Delta va_{in}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|},$$

$$RC(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1) = \frac{\sum_{i,n} |\Delta va_{in}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|}{\sum_{i,n} |\Delta va_{in}^{ES}| + \sum_X |\Delta va_{in}(\hat{X} \mid \hat{\alpha}, \hat{\beta} = 1)|},$$

where $X = \{\hat{A}, \hat{\tau}, \hat{D}, \hat{L}\}$ and subscript n indexes the sub-sectors of manufacturing. I find that changes in expenditure shares are now responsible for 51% of observed dynamics in the sub-sectoral shares. The other half is driven by trade specialization and changes in relative expenditures. Among those, changes in trade costs and sectoral productivities played the key role, responsible for 19% and 16% respectively. Aggregate trade deficits, in turn, contributed further 11%. Note that the increase in the relative importance of productivities and trade costs is unsurprising. Inasmuch as these operate through trade specialization channel, their effects will be more prominent at higher levels of disaggregation: it is easier to specialize in a sub-sector of manufacturing than in manufacturing as a whole.

5.4 Trade Specialization and Relative Expenditure Channels

Finally, I study the relative importance of trade specialization and relative expenditure channels in propagating shocks to sectoral productivities, trade costs and aggregate trade deficits. To do so, I take the changes in sectoral shares in counterfactuals with expenditure shares channel shut off, and apply the decomposition (22). I present the results in Figure 3.

Sectoral productivity shocks have opposing effects through trade specialization and relative expenditure channels. First, economies that see their productivities grow become relatively more attractive as suppliers of sectoral goods both at home and abroad. This means that trade shares, including self-shares Π_{iik}, increase, pushing up sectoral shares of tradable goods through the trade specialization channel. At the same time, productivity growth pushes up home's income, which in turn means that the expenditure of domestic agents increases vis-à-vis that in other economies. This disproportionally fuels the growth in non-tradable sectors. The operation of relative expenditure shares channel, then, boost the relative size of the non-tradable sectors, and squeezes that of the tradable sectors.

Trade cost shocks operate almost invariably through the trade specialization channel. Here, trade cost declines make some economies more attractive as a supplier, boosting their manufacturing shares. However, trade liberalization in the period has applied broadly symmetrically, so that relative incomes were not affected. Thus, unlike in the case of sectoral productivities, the operation of trade specialization channel was not undone by the relative expenditure effects.

Finally, aggregate trade deficits push the operation of the two channels in the same direction. Economies that run trade surpluses do not spend all of their income. This leads to faltering demand for domestic producers, but more so in the non-tradable sectors. Thus, the relative size of

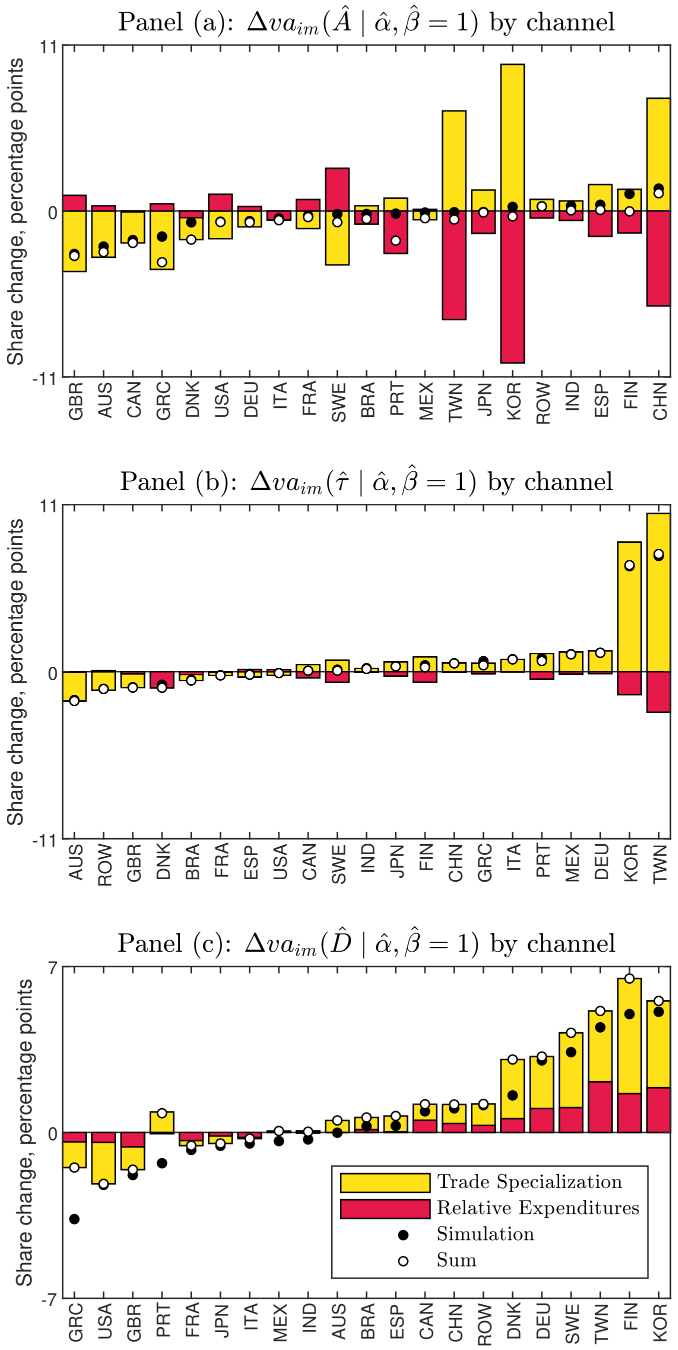

Figure 3: Trade Specialization and Relative Size Channels

Note: The figure presents the decomposition of simulated manufacturing share changes into the operation of trade specialization and relative size channels as per equation (22). The black circles mark the value added share change in the simulation. The white circles mark the sum of the contributions of two mechanisms.

the tradable sectors increases through the relative expenditure channel. Moreover, this suppresses home's wages, which in turn make domestic goods more competitive on international markets. Home's trade shares increase, and thus tradable sector's share increases further through the operation of trade specialization channel. The reverse applies to the deficit economies. Through this compounding of effects, aggregate trade imbalances can lead to considerable reconstitution of the sectoral makeup of economies.

6 Conclusion

In this paper, I have argued in favour of thinking beyond price- and income effects as drivers of structural change. In an open economy, two further mechanisms are at play: countries specialize subject to comparative advantage, and, if expenditure patterns vary across borders, uneven growth of expenditures across economies has repercussions for their production structures. I have argued that the operation of these channels is quantitatively important for understanding structural change over the long run in a large sample of economies. However, it is the divergent experiences of economies where these two channels come to bite. For example, I showed that industrialization miracles in South Korea and Taiwan can be attributed to shifts in comparative advantage due to trade liberalization, that some of the most rapid episodes of deindustrialization can be linked to lagging productivity growth and associated loss of competitiveness, and, finally, that much of the heterogeneity in rates of deindustrialization among the richer economies is due to widening aggregate trade imbalances. The second contribution of the paper is to lift the veil of aggregate manufacturing and consider the changes in its composition over time. Unsurprisingly, I find a wide variety of dynamics across the sub-sectors of manufacturing. For high-skilled manufacturing in particular, reallocation of production due to trade specialization in particular played an important role.

References

Acemoglu, Daron, and Veronica Guerrieri. 2008. "Capital deepening and nonbalanced economic growth." *Journal of political Economy* 116 (3): 467–498.

Autor, David H, David Dorn, and Gordon H Hanson. 2016. "The China shock: Learning from labor-market adjustment to large changes in trade." *Annual review of economics* 8:205–240.

Autor, David H, David Dorn, Gordon H Hanson, and Jae Song. 2014. "Trade adjustment: Worker-level evidence." *The Quarterly Journal of Economics* 129 (4): 1799–1860.

Bloom, Nicholas, Mirko Draca, and John Van Reenen. 2016. "Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity." *The review of economic studies* 83 (1): 87–117.

Bloom, Nicholas, Kyle Handley, Andre Kurman, and Phillip Luck. 2019. "The impact of chinese trade on us employment: The good, the bad, and the debatable." *Unpublished draft.*

Boppart, Timo. 2014. "Structural Change and the Kaldor Facts in a Growth Model With Relative Price Effects and Non-Gorman Preferences." *Econometrica* 82 (6): 2167–2196.

Comin, Diego, Danial Lashkari, and Martí Mestieri. 2021. "Structural change with long-run income and price effects." *Econometrica* 89 (1): 311–374.

Cravino, Javier, and Sebastian Sotelo. 2019. "Trade-induced structural change and the skill premium." *American Economic Journal: Macroeconomics* 11 (3): 289–326.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum. 2007. "Unbalanced trade." *American Economic Review* 97 (2): 351–355.

Donaldson, Dave. 2018. "Railroads of the Raj: Estimating the impact of transportation infrastructure." *American Economic Review* 108 (4-5): 899–934.

Eaton, Jonathan, and Samuel Kortum. 2002. "Technology, geography, and trade." *Econometrica* 70 (5): 1741–1779.

Eaton, Jonathan, Samuel Kortum, Brent Neiman, and John Romalis. 2016. "Trade and the global recession." *The American Economic Review* 106 (11): 3401–3438.

Garcia-Santana, Manuel, Josep Pijoan-Mas, and Lucciano Villacorta. 2021. "Investment demand and structural change." *Econometrica* 89 (6): 2751–2785.

Herrendorf, Berthold, Richard Rogerson, and Akos Valentinyi. 2014. *Growth and Structural Transformation.* 2:855–941.

———. 2021. "Structural Change in Investment and Consumption—A Unified Analysis." *The Review of Economic Studies* 88 (3): 1311–1346.

Kehoe, Timothy J, Kim J Ruhl, and Joseph B Steinberg. 2018. "Global imbalances and structural change in the United States." *Journal of Political Economy* 126 (2): 761–796.

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

Kortum, Samuel S. 1997. "Research, patenting, and technological change." *Econometrica: Journal of the Econometric Society,* 1389–1419.

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.

Ngai, L Rachel, and Christopher A Pissarides. 2007. "Structural change in a multisector model of growth." *The American Economic Review* 97 (1): 429–443.

Silva, JMC Santos, and Silvana Tenreyro. 2006. "The log of gravity." *The Review of Economics and statistics* 88 (4): 641–658.

Simonovska, Ina, and Michael E Waugh. 2014. "The elasticity of trade: Estimates and evidence." *Journal of International Economics* 92 (1): 34–50.

Sposi, Michael, Kei-Mu Yi, and Jing Zhang. 2021. *Deindustrialization and Industry Polarization.* Technical report. National Bureau of Economic Research.

Święcki, 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.

A Mathematical Appendix

A.1 Model in Changes

Suppose that base year values of endogenous variables Y_{ik}, Π_{jik}, α_{ik}, β_{ikl}, β_{ikn} (and their combinations X^{FC}_{jik} and X^{II}_{jink}) are known, as are the shocks to the exogenous variables $\hat{A}_{ik}$, $\hat{\tau}_{ijk}$, $\hat{D}_i$, $\hat{L}_i$, $\hat{\Omega}_{ik}$, $\hat{\omega}_{ikl}$, $\hat{\omega}_{ikn}$ for all $i, j \in I$ and $k, n \in K$. Equations [i] to [ix] constitute the equilibrium of the changes formulation of the model and can be used to solve for all the endogenous objects in the next period:

[i] Changes in labour shares can be derived from (1):

$$\hat{\beta}_{ikl} = \frac{\beta_{ikl}\hat{\omega}_{ikl}\hat{w}_{ik}^{1-\sigma_l}}{\beta_{ikl}\hat{\omega}_{ikl}\hat{w}_{ik}^{1-\sigma_l} + (1-\beta_{ikl})\hat{\omega}_{ikN}\left(\sum_n \beta_{ikn}\hat{\omega}_{ikn}\hat{P}_{in}^{1-\sigma_m}\right)^{\frac{1-\sigma_l}{1-\sigma_m}}}.$$

[ii] Changes in intermediate input shares can be derived from (2):

$$\hat{\beta}_{ikn} = (1-\beta_{ikl})\omega_{\hat{ikN}}\frac{\hat{\omega}_{ikn}\hat{P}_{in}^{1-\sigma_m}}{\sum_n \beta_{ikn}\hat{\omega}_{ikn}\hat{P}_{in}^{1-\sigma_m}}.$$

[iii] Changes in the final expenditure shares can be derived from conditions (3)-(5):

$$\hat{\alpha}_{ik} = \hat{\Omega}_{ik}\Big(\frac{\hat{P}_{ik}}{\hat{E}_i}\Big)^{1-\sigma_c}\hat{C}_i^{(1-\sigma_c)\epsilon_k}, \quad \text{where } \hat{C}_i \text{ satisfies } \sum_k \alpha_{ik}\hat{\Omega}_{ik}\Big(\frac{\hat{P}_{ik}}{\hat{E}_i}\Big)^{1-\sigma_c}\hat{C}_i^{(1-\sigma_c)\epsilon_k} = 1.$$

[iv] Changes in total expenditure can be derived from (6):

$$\hat{E}_i = \hat{D}_i\hat{w}_i\hat{L}_i.$$

[v] Changes in production costs can be derived from (7):

$$\hat{c}_{ik} = \left(\beta_{ikl}\hat{\omega}_{ikl}\hat{w}_{ik}^{1-\sigma_l} + (1-\beta_{ikl})\hat{\omega}_{ikN}\left(\sum_n \beta_{ikn}\hat{\omega}_{ikn}\hat{P}_{in}^{1-\sigma_m}\right)^{\frac{1-\sigma_l}{1-\sigma_m}}\right)^{\frac{1}{1-\sigma_l}}.$$

[vi] Changes in trade shares and price indices can be derived from conditions (8) and (9):

$$\hat{\Pi}_{jik} = \left(\frac{\hat{c}_{ik}\hat{\tau}_{jik}}{\hat{A}_{ik}\hat{P}_{jk}}\right)^{-\theta} \qquad \hat{P}_{ik} = \left[\sum_l \Pi_{ilk}\Big(\frac{\hat{c}_{lk}\hat{\tau}_{ilk}}{\hat{A}_{lk}}\Big)^{-\theta}\right]^{-\frac{1}{\theta}}.$$

[vii] Using equation (10), wages change as to clear the labor market in the next period:

$$\hat{w}_i\hat{L}_i\sum_{k\in K}\beta_{ikl}Y_{ik} = \sum_{k\in K}\beta_{ikl}\hat{\beta}_{ikl}Y_{ik}\hat{Y}_{ik}.$$

[viii] $\hat{Y}_{ik}$ satisfies the sectoral market clearing condition in the next period, a combination of conditions (11) and (12):

$$Y_{ik}\hat{Y}_{ik} = \sum_{j} \Pi_{jik}\hat{\Pi}_{jik} \left(X_{jik}^{FC}\hat{\alpha}_{ik}\hat{E}_{i} + \sum_{n \in K} X_{jink}^{II}\hat{\beta}_{ink}\hat{Y}_{in} \right).$$

[ix] Finally, the next period global output is normalized as per (13):

$$\sum_{i} w_{i}\hat{w}_{i}L_{i}\hat{L}_{i} = 1$$

B Data Appendix

B.1 Dataset Description

List of countries: Australia, Brazil, Canada, China , Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, India, Italy, Japan, Republic of Korea, Mexico, Portugal, Sweden, Taiwan, United States.

List of sectors: see Table 2.

ISIC Rev. 3.1 Title	Type
Agriculture, Hunting, Forestry and Fishing	Primary
Mining and Quarrying	Primary
Food, Beverages and Tobacco	Manufacturing
Textile, Leather and Footwear	Manufacturing
Pulp, Paper, Printing and Publishing	Manufacturing
Coke, Petroleum and Nuclear Fuel	Manufacturing
Chemicals and Chemical Products	Manufacturing
Rubber and Plastics	Manufacturing
Other Non-Metallic Mineral	Manufacturing
Basic Metals and Fabricated Metal	Manufacturing
Machinery, Nec	Manufacturing
Electrical and Optical Equipment	Manufacturing
Transport Equipment	Manufacturing
Manufacturing, Nec; Recycling	Services
Electricity, Gas and Water Supply	Services
Construction	Services
Wholesale and Retail Trade	Services
Hotels and Restaurants	Services
Transport and Storage	Services
Post and Telecommunications	Services
Financial Intermediation	Services
Real Estate, Renting and Business Activities	Services
Community Social and Personal Services	Services

Table 2: Sectors in Long Run WIOD

Note: I include Manufacturing, Nes; Recycling into the services sector. This sector contains manufacturing of jewellery, musical instruments, games equipment, and toys; and recycling of metal- and non-metal scrap. Thus, this sector combines both manufacturing production, but also the provision of the service of recycling. I attribute it wholly to services.

C Shock Summary Statistics

	Agriculture	Mining & Quarrying	Food	Textiles	Pulp & Paper	Coke & Petroleum	Chemicals	Rubber & Plastics	Non-Metallic Mineral	Basic/Fabricated Metal	Machinery, Nec	Electrical & Optical	Transport Equipment
Australia	0.98	0.88	0.92	0.90	0.94	0.94	0.72	0.92	1.04	0.72	0.62	0.62	0.82
Brazil	1.21	0.77	1.09	0.51	0.75	0.87	0.72	0.55	0.78	0.82	0.58	0.59	0.86
Canada	0.86	0.94	0.71	0.69	0.99	0.82	0.63	0.83	0.83	0.97	0.64	0.58	0.87
China	0.98	0.69	0.87	0.52	0.67	1.16	0.64	0.72	0.31	0.70	0.44	0.35	0.61
Germany	0.66	0.68	0.59	0.37	0.51	0.97	0.54	0.67	0.76	0.55	0.63	0.60	0.67
Denmark	0.92	2.24	0.72	0.36	0.76	0.99	0.63	0.67	0.80	0.87	0.67	0.71	0.58
Spain	0.69	0.80	0.74	0.29	0.71	0.49	0.57	0.49	0.65	0.55	0.63	0.51	0.45
Finland	0.83	0.79	0.92	0.62	0.91	1.09	0.73	0.67	0.74	0.83	0.93	0.66	1.03
France	0.98	0.76	0.72	0.50	0.79	0.53	0.55	0.73	0.85	0.92	0.65	0.56	0.66
United Kingdom	1.10	0.87	0.84	0.57	0.91	0.57	0.55	0.61	0.79	0.84	0.75	0.52	0.54
Greece	0.88	0.74	1.01	0.63	1.02	1.10	0.78	0.92	1.03	1.12	0.61	1.03	1.27
India	1.22	0.53	1.05	0.62	1.12	1.11	0.78	0.74	1.10	0.68	0.96	0.60	0.76
Italy	0.82	0.87	0.72	0.63	0.74	0.64	0.67	0.65	0.74	0.72	0.68	0.80	0.65
Japan	1.18	0.75	1.07	0.73	0.78	0.84	0.86	0.55	0.62	0.85	0.70	0.68	0.66
Republic	0.81	0.47	0.62	0.75	0.70	1.05	0.70	0.51	0.82	0.89	0.94	0.77	1.01
Mexico	0.66	1.15	1.13	1.34	0.85	0.86	0.97	0.36	1.02	1.09	0.84	0.53	1.07
Portugal	0.88	2.65	0.92	0.65	0.83	1.33	0.85	0.65	0.66	0.81	0.67	0.72	0.73
Sweden	0.92	0.76	0.83	0.45	0.97	0.88	0.74	0.77	0.79	0.97	0.75	0.68	1.02
Taiwan	0.66	0.44	0.84	0.43	0.54	1.02	0.73	0.39	0.69	0.63	1.05	0.48	0.90
United States	1.06	0.74	1.13	0.58	0.81	0.89	0.66	0.84	0.80	0.88	0.73	0.63	0.65

Table 3: Inward Trade Cost Shocks, 1965-2011

Note: Trade costs are obtained in two steps. First, inward trade cost changes are averaged, weighting by the import share. Next, the resultant averages are multiplied across time periods to obtain change over the whole period.

	Agriculture	Mining & Quarrying	Food	Textiles	Pulp & Paper	Coke & Petroleum	Chemicals	Rubber & Plastics	Non-Metallic Mineral	Basic/Fabricated Metal	Machinery, Nec	Electrical & Optical	Transport Equipment	Services
Australia	1.35	1.72	1.28	1.37	1.54	0.77	1.24	1.12	1.27	1.16	1.30	1.23	1.18	0.89
Brazil	3.14	1.52	1.39	2.62	1.93	0.98	1.59	1.64	1.78	1.43	1.72	1.23	1.09	1.71
Canada	1.40	1.85	1.28	1.32	0.99	0.88	1.06	1.20	1.19	0.91	1.29	1.02	1.08	1.04
China	3.08	1.64	1.73	1.43	1.29	1.99	1.23	1.27	1.67	1.47	1.26	1.12	1.23	0.76
Germany	1.97	1.05	1.61	1.52	1.71	1.14	1.41	1.74	1.66	1.48	1.35	1.67	1.65	1.38
Denmark	1.48	2.28	1.19	1.32	1.44	1.03	1.47	1.64	1.76	1.52	1.49	1.53	1.19	1.22
Spain	3.83	1.66	1.33	1.80	1.48	1.13	1.91	1.74	2.28	1.52	1.59	1.43	1.30	1.19
Finland	2.17	1.62	1.20	1.92	0.99	1.60	1.65	2.21	1.99	1.26	1.81	2.23	1.25	1.19
France	1.51	0.81	1.34	1.23	1.19	1.00	1.01	1.48	1.15	1.11	1.26	1.09	1.05	1.09
United Kingdom	1.30	2.59	1.48	1.30	1.25	0.99	1.02	1.32	1.22	1.00	0.96	1.04	1.15	0.95
Greece	2.51	2.05	1.09	1.68	1.07	1.03	1.08	1.36	1.42	0.94	1.27	0.53	1.24	1.35
India	2.44	2.10	1.03	1.40	0.86	0.85	0.87	0.92	0.79	0.97	0.89	0.84	1.04	0.88
Italy	2.50	2.84	1.48	1.79	1.35	0.90	1.15	1.49	1.84	1.55	1.32	1.34	1.39	1.20
Japan	2.54	1.85	2.18	1.43	1.19	2.00	1.34	1.79	1.49	1.19	1.60	1.35	1.38	1.73
Republic	9.66	2.45	1.36	1.58	1.79	1.06	1.89	1.79	2.05	1.34	2.70	1.54	2.10	2.24
Mexico	1.74	1.83	1.39	1.28	0.93	0.92	0.84	1.30	1.45	0.97	1.08	0.94	1.07	1.06
Portugal	3.35	1.88	1.08	1.28	1.50	1.69	1.17	2.73	2.22	1.61	1.28	0.90	0.77	1.41
Sweden	1.68	0.85	1.35	1.22	0.87	1.05	1.73	1.38	1.13	1.04	1.00	0.93	1.17	0.87
Taiwan	2.68	2.97	1.46	1.41	1.83	1.93	1.22	1.35	1.49	1.32	1.09	1.13	1.99	1.96
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4: Sectoral Productivity Shocks, 1965-2011

Note: Sectoral productivities in the table are obtained by multiplying yearly changes over time to obtain change over the whole period.

D PPML with Near Zero Trade Flows

In order to gauge the importance of outliers for the estimation of fixed effects in gravity equations, I generate simulated time series with known data generating process and asses the ability of the method to recover the underlying shock series. I generate series for 20 economies and 14 sectors to replicate the sample size for my estimations.

I begin by generating the initial period sectoral sales and trade flows. To do this, I need to specify a set of exogenous variables in levels for all countries and sectors: A, τ, L, Ω. I assume there is no input-output structure and no capital flows. The baseline simulation is symmetric: I set $A_{ik} = L_i = 1$ for all countries and sectors, $\Omega_{ik} = 1/K$. I set $\tau_{jik} = 2.8$ for $i \neq j$ and $\tau_{iik} = 1$, which yield $\Pi_{iik} = 0.76$, the average value in my sample. To generate the next period observations, I shock all productivities and trade costs by a 'true' multiplicative shock, which I assume is normally distributed with unit mean and standard deviation of 0.01, or 1% for both variables. I then estimate the fixed effect terms in the following model:

$$\hat{\Pi}_{jik} = m_{jk} e_{ik} \varepsilon_{jik},$$

where $e_{ik} = (\hat{c}_{ik}/\hat{A}_{ik})^{-\theta}$, $m_{jk} = \hat{P}^{\theta}_{jk}$, and $\varepsilon_{jik} = \hat{\tau}^{-\theta}_{jik}$, using Poisson pseudo-maximum likelihood method. In order to solve for sectoral productivity and trade cost shocks, I use the exporter fixed effect and the equilibrium condition linking self-trade shares and the sectoral price deflator:

$$\hat{\Pi}_{iik} = \left(\frac{\hat{c}_{ik}}{\hat{A}_{ik}} \frac{1}{\hat{P}_{ik}}\right)^{-\theta} = e_{ik} \left(\frac{1}{\hat{P}_{ik}}\right)^{-\theta} \quad \rightarrow \quad \hat{P}_{ik} = \left(e_{ik}/\hat{\Pi}_{iik}\right)^{-1/\theta}.$$

Once the sectoral deflators are obtained, I use wage changes $\hat{w} = \hat{Y}/\hat{L}$ to solve for the input bundle cost changes, which in turn are sufficient to back out sectoral productivity shocks from the exporter fixed effects:

$$\hat{A}_{ik} = \hat{c}_{ik} e^{1/\theta}_{ik}.$$

The trade cost changes, then, are as follows:

$$\hat{\tau}_{jik} = \frac{\hat{A}_{ik}\hat{P}_{jk}}{\hat{c}_{ik}\hat{\Pi}^{1/\theta}_{jik}}.$$

I redo the estimation for a thousand draws of shock series. The average correlation between the underlying productivity shocks and the productivity shock estimates over the thousand estimations is 0.97. The average coefficient in a regression with no constant of the estimates on true values of the shocks is 1.

Next, I simulate the scenario of increases in trade volumes from near zero baseline. To do this, pick a set of initial trade cost parameters, such that a randomly selected 12 τ_{jik} parameters are at 10.8. In the second period, I set the trade cost parameters of these observations to 2.8. I shock all other parameters with a multiplicative shock, which, as before, is normally distributed with unit mean and standard deviation of 0.01, or 1%. This gives rise to a sample where 12 out of 5600 $\hat{\Pi}$ observations, or 0.18%, fall just above the 10^3 mark – the same proportion as in the data. I redo the estimation for a thousand draws of productivity shocks and locations of the near zero trade shares. The average correlation between the estimated productivity shocks and the underlying shock values is 0, with the average value of the coefficient in the regression with no constant at 0.

Finally, I redo the estimation using the trade share series generated with twelve extreme trade cost shocks; but this time I leave out the observations with the extreme values of $\hat{\Pi}$. The productivity shocks estimated in this way are once again recovered with high precision. Notably, exclusion of trade share changes above the 90th and below the 10th percentile leads to no deterioration of the fit.