Structural Change with Endogenous Input-Output Linkages

Hang Hu*

University of Melbourne

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Abstract

Do sectoral reallocations of value-added (GDP) depend on input-output linkages? This paper proposes a new mechanism for structural change through outsourcing of intermediate-inputs (I-I). I build a multi-sector general equilibrium model, featuring endogenous input-output linkages, nonhomothetic CES preferences and technology, and heterogeneous firms. As relative outsourcing cost changes, sectors which demand external outsourcing (I-I demand) shed labor, while sectors which supply external outsourcing (I-I supply) absorb labor. The model is structurally calibrated using panel data from 35 major economies during 1995-2007. The quantitative results suggest that (i) I-I supply effects are at least comparable to mechanisms in the literature, such as price effects due to sector-biased technological change; (ii) I-I demand effects are less critical due to stable I-I demand intensity; (iii) about half of the structural change attributes to rising comparative advantage of supplying I-I by services relative to by manufacturing.

Keywords: Input-Output Linkages, Structural Change, Domestic Outsourcing, Ricardian Intersector Trade, Nonhomothetic CES, Heterogeneous Firms.

JEL classification: O1, O4, O5, F1, L2, D57.

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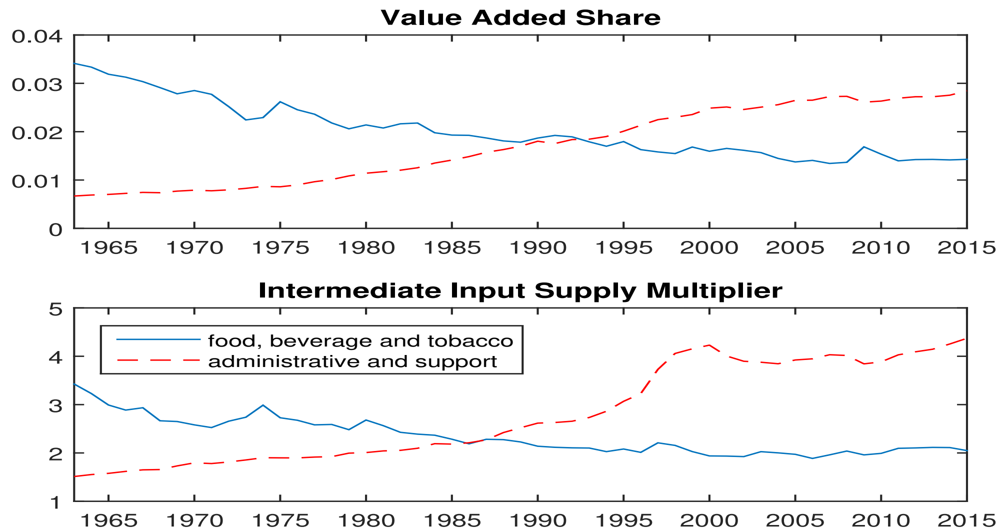
1. Introduction

The transformation of economies from agriculture and manufacturing to services is known as structural change. Existing theories of structural change can be divided into two main categories: (i) price-effect theories, which argue that sector-biased technological change induces different price growth and generates reallocations of production between sectors; (ii) income-effect theories, which argue that heterogeneous income elasticities of demand imply reallocations of sectoral consumption as income grows. In this paper, I provide a new theory of structural change which emphasizes the importance of input-output linkages. I develop a multi-sector general equilibrium model, featuring endogenous input-output linkages, nonhomothetic CES preferences and technology, and heterogeneous firms. The model highlights two essential channels of input-output linkages, which are I-I connections to downstream sectors (I-I supply) and upstream sectors (I-I demand). The quantitative results suggest that I-I supply effects are at least comparable to price effects and income effects, while I-I demand effects are less critical.

Existing theories of structural change usually assume a representative producer, which implicitly assume homogeneous and independent producers. They neglect producer interaction and heterogeneity. This paper sheds light on the role of producer interaction in structural change. Producers are interconnected by input-output linkages. Producers have heterogeneous growth capacity of I-I demand and I-I supply, which induces non-neutral labor and capital mobility and structural change. Empirical evidence in figure 1 supports this argument. The upper panel shows the US value-added share at two-digit sectors: food, beverage, and tobacco products; administrative and support services. During 1963-2015, while value-added share declined in the manufacturing sector, it increased in the service sector. The lower panel demonstrates the I-I supply multiplier of these two sectors. The I-I supply multiplier is an index which formally measures the I-I supply capacity. I show the measurement in subsection 2.2. The I-I supply multiplier of the manufacturing sector dropped, whereas the I-I supply multiplier of the service sector shifted up. Figure 1 suggests a strong positive correlation between the sectoral I-I supply multiplier and value-added share. I present more empirical evidence in section 2.

My model blends features from the existing structural change literature with features from the Ricardian trade literature. In particular, I assume nonhomothetic CES preferences as in Comin, Lashkari and Mestieri (2018). These preferences imply linear price effects and income effects on structural change. Motivated by this setup, I introduce the nonhomothetic CES technology in aggregate gross output production. On top of the price and income effects, the general equilibrium model generates linear I-I supply and I-I demand effects. Moreover, the input-output linkages are endogenous. I borrow the idea of the Ricardian trade to endogenize the input-output linkage intensity, following Boehm (2018). Essentially, the intersectoral trade of I-I

Figure 1: US sectoral value-added share and I-I supply capacity during 1963-2015



is analogous to the international trade of final outputs as in Eaton and Kortum (2002). The equation of input-output linkage intensity mirrors the gravity equation. Furthermore, the sector-level input-output linkages are microfounded by firm-level outsourcing decisions. For each I-I variety, firms have a binary choice between outsourcing and in-house production. The outsourcing decisions depend on relative outsourcing cost which is analogous to trade cost and productivity. I lay out the general equilibrium model in section 3.

The contributions of this paper are threefold. First, I qualitatively illustrate the novel mechanism of input-output linkages in structural change. The mechanism is explained by the following I-I supply and I-I demand channels. For the supply, suppose a sector has growing comparative advantage from productivity and trade cost, it is profitable to supply a relatively larger amount of I-I than other sectors over time. This sector has relatively increasing direct and indirect I-I connections to downstream sectors. It automatically requires relatively more labor and capital to satisfy the external outsourcing demand. As a result, this sector has larger growth of value-added share. This I-I supply channel is supported by evidence in figure 1. On the other hand, for the sector which can take advantage of this relative productivity growth and relative trade cost reduction from the sector with growing comparative advantage, it has the incentive to raise outsourcing. This sector has relatively increasing direct and indirect I-I connections to upstream sectors. It relies relatively more on external outsourcing rather than producing in-house. This sector automatically sheds relatively more labor and capital, resulting in a larger decline of value-added share. Structural change arises as a result of moving economic resources from the sector with larger growth of I-I demand to the sector with larger growth of I-I supply. I show the mechanism in section 4.

Second, I quantify to what extent the new mechanism of external outsourcing accounts for the structural change. In particular, I compare the I-I supply effects and I-I demand effects relative to price effects and income effects. I structurally calibrate the general equilibrium model. I use the World Input-Output Database (WIOD) which contains 35 major economies during 1995-2007. The result suggests that I-I supply effects are significant, comparable to price effects. The I-I supply effects are the dominant effects in my preferable estimate, in which I simulate the general equilibrium mechanisms and decompose the four effects in counterfactual exercise. While I-I supply effects and price effects are critical drivers in both within- and cross-country structural change, income effects are crucial mainly in within-country structural change. The I-I demand effects are significant at 1 percent critical value, but not crucial enough to drive structural change. Because the I-I demand intensity is relatively stable across time, which is consistent with Jones (2011b). I present this quantitative analysis in section 5.

Third, I quantitatively investigate how structural change arises through the I-I supply channel. Compared to manufacturing, services have a higher growth rate in TFP scale and a lower growth rate in outsourcing supply cost. From the point view of Ricardian trade, this implies that services have growing comparative advantage relative to manufacturing for supplying I-I to downstream sectors. Therefore the relative I-I supply multiplier of services to manufacturing increases during this period, resulting in the structural change from manufacturing to services. In the counterfactual study, I shut down these growing comparative advantages. Indeed, the relative value-added share of services to manufacturing declines by more than half, compared to the benchmark case. In addition, the pattern of I-I supply multiplier matches with the value-added share well. It confirms the qualitative mechanism of strong positive I-I supply effects on structural change. I show this quantitative exercise in section 6.

This paper is not the first paper to incorporate input-output linkages into the structural change model. However, this paper is the first paper to endogenize input-output linkages in the structural change model. The input-output linkages are taken as domestic intersectoral trade. This paper explains input-output linkages from the perspective of networks rather than from Leontief model of an input-output matrix. This paper is the first paper formalizing the two channels on structural change through endogenous input-output linkages. This paper emphasizes that firm-level external outsourcing generates sector-level reallocation of labor and capital through input-output linkages. The intensity of input-output linkages is, in turn, recast by external outsourcing.

Two benefits generate from endogenous input-output linkages. First, I take endogeneity bias into account when I identify the I-I supply and I-I demand effects. By contrast, Sposi (2018) takes the input-output linkages as exogenous. The quantitative exercise is subject to the Lucas critique since the variation of input-output linkages is confounded with other critical factors, such as price. Another caveat is reverse-causality bias. Because larger sector can supply more or less proportion of intermediate inputs. Second, the mechanism of input-output linkages is micro-founded by comparative advantage factors, which admits comparison with empirical evidence. As documented by Weil (2014) and Goldschmidt and Schmieder (2017), the advancement of digital technology and the de-unionization reduce the coordination and monitoring cost, which induces external outsourcing of non-core services from manufacturing to services. During the same period, the occupants and value-added share decline in manufacturing and raise in services. The argument of growing comparative advantage of services relative to manufacturing for supplying I-I is consistent with their evidence.

Two related studies of this paper are Berlingieri (2013) and Sposi (2018). Both of them argue that on top of final demand, intermediate demand impacts structural change. This paper independently identifies the mechanism of input-output linkages, whereas their studies cannot isolate the mechanism of input-output linkages from price and income effects. Without isolation, it is hard to identify which mechanism is the key driver of structural change. Thanks to the nonhomothetic CES setup (Comin et al. 2018), this paper emphasizes that it is the I-I supply effects rather than demand effects (Sposi 2018; Xu 2018) driving structural change.

Structural Change This paper contributes to the literature on structural change. The structural change literature mainly focuses on price effects (Ngai and Pissarides 2007) and income effects (Kongsamut et al. 2001).[1] Recent studies such as Herrendorf, Rogerson and Valentinyi (2013b), Boppart (2014) and Comin, Lashkari and Mestieri (2018) combine the two effects in one framework, and compare the importance between the two effects. This paper follows the line of recent studies by qualitatively and quantitatively comparing price effects with income effects. The main contribution is that this paper emphasizes the mechanism of input-output linkages, in addition to price and income effects. This paper complements the literature.

Ricardian Trade In the general equilibrium model, this paper borrows insight from the Ricardian trade literature. This application idea comes from Boehm (2018). Similar to Boehm (2018), this paper applies the Eaton and Kortum (2002) trade framework to every I-I tradable sector pair. Different from Eaton and Kortum (2002) which assumes that consumer has a choice to buy final outputs from many possible countries, in my model every firm has a binary choice between outsourcing and in-house production. While Boehm (2018) studies the contract cost effect on aggregate productivity and welfare through endogenous input-output linkages; this paper studies the implication of outsourcing cost and productivity in structural change through endogenous input-output linkages. This paper, as far as I know, is the first paper extending Eaton and Kortum

[1] I notice that papers are arguing international trade impacts structural change. I concentrate on domestic trade in this paper. See footnote 5 for discussion about why I focus on this type of trade in this paper.

(2002) to domestic outsourcing based structural change.

Domestic Outsourcing The endogenous intermediate input outsourcing on trade cost and technology is consistent with a large literature. There are at least three related costs. The contract cost theory (Coase 1937; Williamson 1985; Boehm 2018) argues that higher contract enforcement cost discourages firm outsourcing decisions. Recently Dustmann, Fitzenberger, Schönberg and Spitz-Oener (2014) and Goldschmidt and Schmieder (2017) argue that the gradually less protection in low-skill service occupants from labor union contributes to the rise of intermediate input outsourcing in Germany manufacturing firms since 1990. Besides, an ineffective institution is likely to hold up comparative advantage (Nunn 2007), which is further likely to hold up intermediate input outsourcing (Boehm 2018). Abramovsky and Griffith (2006) suggests that the development of information and communication technology increases the adaptability and tradability of services across firms.

Macroeconomics with Input-Output Linkages This paper adds to recently growing literature which explores the implication of input-output linkages or production networks in macroeconomic topics.[2] Among others, they argue that input-output linkages or production networks is a prominent element when discussing the following topics: income and productivity difference; industrial distortion and development; trade gain in domestic firms; and shock transmissions.[3] Regarding modeling strategy, many papers take the input-output linkages as exogenous (Jones 2011a,b); other papers endogenize the input-output linkages or the production networks (Oberfield 2017; Acemoglu and Azar 2017). This paper endogenizes the input-output linkages and argues the crucial role of input-output linkages in structural change.[4]

2. Empirical Evidence

In this section I introduce the data in section 2.1 and the empirical evidence in section 2.2. I document the relationship between value-added share and two features of input-output linkages. I define two sufficient statistics: I-I supply multiplier and I-I demand multiplier. Then I depict a positive correlation between sectoral value added share and I-I supply multiplier; and a negative

[2]Though not explicitly exploring, Lucas Jr (1988) and Lucas Jr (1986) directly advocate that application of economic theory to market or group behavior requires assumptions about individual behavior, as well as interaction among agents.

[3]See Fadinger, Ghiglino and Teteryatnikova (2017) for income and productivity difference; see Bartelme and Gorodnichenko (2015) for industrial distortion and development; see Mogstad, Dhyne, Kikkawa, Tintelnot et al. (2017) for trade gain in domestic firms; see Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2012) for shock transmission.

[4]This paper is consistent with Caliendo, Parro and Tsyvinski (2017), Liu (2017) and Baqaee and Farhi (2017), which depart from Cobb-Douglas technologies; and allow the input-output linkages to be endogenous on technology and trade cost.

correlation between sectoral value added share and I-I demand multiplier. I show these associations at 4 one-digit sectors: manufacturing (Manu), market service (MS), non-market service (NMS) and other goods (OG). This sector classification method follows the database. In the appendix section E.1, I show evidence of these associations at two-digit sectors. Other related facts and empirical validation are given in appendix section E.

2.1 Data

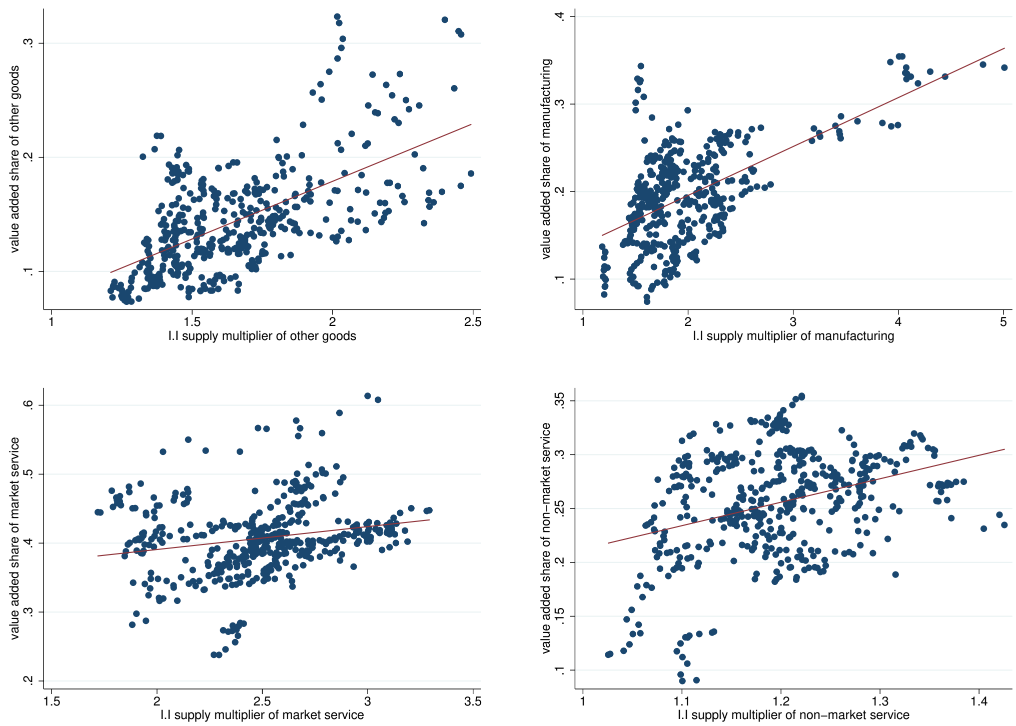
The major database of this paper is WIOD. There are two pertinent datasets under WIOD: Socio Economic Accounts (SEA) and world input-output tables (WIOT). I obtain the nominal value of input-output tables from WIOT. Other nominal values and local price deflators are available in SEA. Since I do not consider international trade in this paper, I ignore the import and export data.[5] I also ignore government consumption, tax/subsidy, and transport margin data. For most major economies, these values are tiny in determining the economic structure and should not affect the result. The sectoral nominal gross output equals the summation of value-added and all of the corresponding I-I demands.

The Sector and Industry Relative Price (SIRP) database from Inklaar and Timmer (2014) is necessary to transfer the local real values into global real values. Specifically, I first use the time series data of price deflators in SEA to calculate the real value of value added, intermediate input and gross output at 2005 local price. The SEA dataset provides all the relevant value-added price deflators and gross-output price deflators. I use the gross-output price delators to deflate the nominal value of intermediate input. Then I aggregate the 35 individual sectors into four sectors following Inklaar and Timmer (2014). Finally, I use the PPP deflators from the SIRP database and the annual exchange rate from the WIOD to calculate the real gross output, real value added and real intermediate input at 2005 global reference prices.

The real primary inputs are calculated similarly. The SEA dataset provides sectoral real capital stock value at 1995 local price. I calculate the real capital stock at the 2005 local price by using the capital price deflators in SEA. Then I use the capital PPP deflators from PWT 8.1 to calculate

[5]There are two reasons for ignoring international trade in this paper. First, regarding intermediate input, domestic trade is far more prominent than international trade. The ratio of domestic I-I to GDP is about 1 in both rich economies like the US and emerging economy like China (Jones 2011b). In contrast, the ratio of foreign intermediate input to GDP is much smaller. Even for rich and open economies, this ratio is small. For the UK and Canada, they are about 0.2 in 1993; for the US and Japan, they are 0.08 and 0.04 respectively (Feenstra 1998). According to on Trade and Development (2013), regarding outsourcing, domestic outsourcing still remarkably dominates particularly for service outsourcing, though we do see a rising in service offshoring. The international trade of final goods is much less comparable than domestic trade of intermediate input as well. According to Jacks and Tang (2018), world exports of 52 major economies to GDP is around 12 percent on average during 1995-2007. Second, the main empirical associations hold even with consideration of international trade of I-I, following my another paper which currently works in progress (Hu 2018). In that paper, given the same database with international trade, I find that the same regression (structural change on I-I supply and demand multipliers, with country and year fixed effects) results are significant at 1 percent level for all 29 two-digit sectors and 40 out of 44 major economies. However, I admit that international trade of I-I still plays a role in structural change, for example through Intra-industry trade in the recent study by Matsuyama (2017), and through global value chains as in Hu (2018).

Figure 2: Sectoral I-I supply multiplier and nominal value-added share



The four panels describe the correlation in the four sectors. The horizontal axis is the value of I-I supply multiplier, and the vertical axis is the value of nominal value added share. Each dot point represents one country at one year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

the real capital stock at the 2005 global price. For the labor input, I use the total employment hours. An alternative choice is the number of employees. Many papers including Fadinger, Ghiglino and Teteryatnikova (2017) argues for the choice of total employment hours. Because data on hours worked allows accounting for differences in working patterns, for instance, full-time and part-time workers.

The final panel data are available for four sectors and 35 countries during 1995-2007.[6] The real capital data are not available in the year 2008 and 2009 for a few European countries in the WIOD 2013 database. Besides, since the SIRP database does not provide PPP price deflator data for Taiwan, I drop out Taiwan from the sample. Given the data, I construct the following useful variables in this paper: nominal input-output table, sectoral gross output price, aggregate real consumption and output, sectoral nominal value-added share and consumption share. Moreover, I use National Accounts Main Aggregate Database (NAMAD) from UN and US input-output table from Bureau of Economic Analysis (BEA). These two databases enable me to track value added and input-output table in a longer period. The long-run time series data are useful for empirical validation, which is given in appendix section E.

[6] See appendix section F for the list of 35 countries; and the sector classification.

2.2 Main Facts

Sufficient Statistics In this section, I present the main facts of this paper. Before I introduce the facts, I formally define the intermediate-input supply and demand multipliers. Suppose matrix B denotes the input-output linkage which we normally observe in input-output table data. The element B_{ij} indicates the intermediate-input share of sector i in producing sector j gross output. From the point view of network, the matrix of input-output linkage illustrates the sector-to-sector intermediate input connections. The *Leontief inverse* matrix L is defined by

$$L \equiv (I - B)^{-1}.$$

Here I denotes the identity matrix. Given Leontief inverse matrix L, I define the sectoral *intermediate-input supply multiplier* and *intermediate-input demand multiplier* as the following:

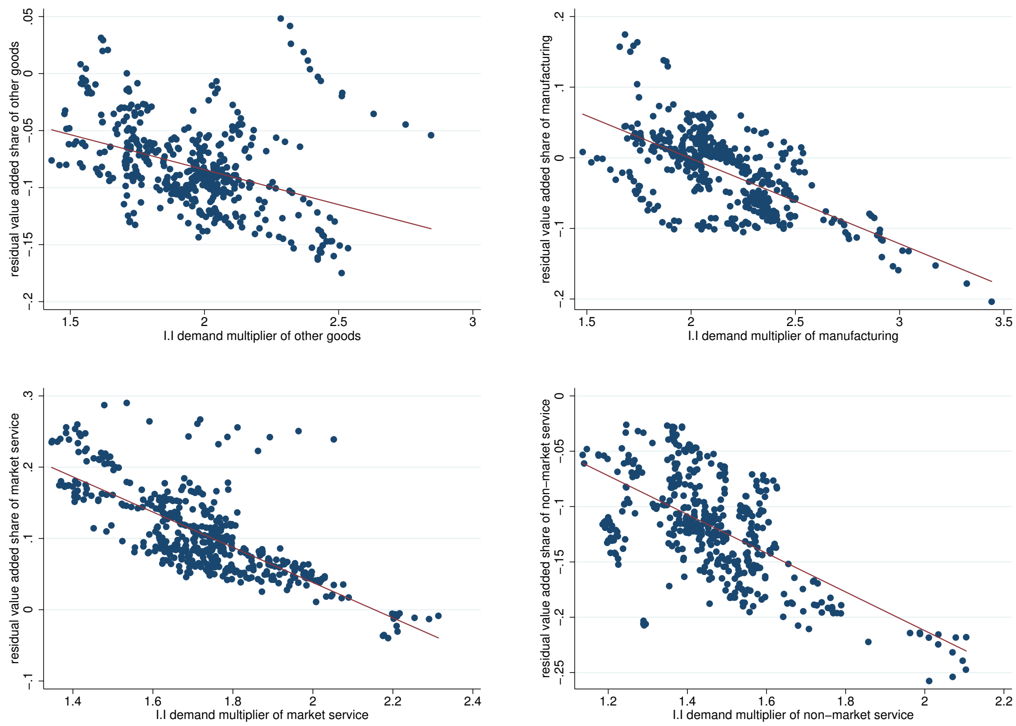
$$\mu_{it}^{s} \equiv \sum_{j=1}^{n} L_{ij},$$
$$\mu_{jt}^{d} \equiv \sum_{i=1}^{n} L_{ij}.$$

The sectoral I-I supply multiplier summarizes the corresponding row vecor of Leontief inverse; the sectoral I-I demand multiplier summarizes the corresponding column vector of Leontief inverse. They measure all the direct and indirect connections between the target sector and all other (including itself) potential sectors, in terms of I-I supply and demand respectively.[7] In Fadinger, Ghiglino and Teteryatnikova (2017), they call the I-I supply multiplier as input-output multiplier following Jones (2011a). So I adopt the name multiplier therein. I extend their original definition to I-I demand multiplier since I-I demand multiplier is related to structural change. In Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2012), they call the intermediate input supply multiplier as forward linkage, and call the vector of supply multipliers as influence vector. In network literature, these two multipliers are special form of Bonacich centrality in terms of I-I supply and I-I demand respectively.[8] Overall the I-I supply and I-I demand multipliers measure how central role a sector plays in supplying intermediate inputs to downstream sectors, and in purchasing intermediate inputs from upstream sectors respectively.

[7] For the vector of I-I supply multiplier, $\mu^{s} \equiv (I-B)^{-1}1 = (I+B+B^{2}+...+B^{\infty})1$, where 1 denotes vector of 1s. Here direct connection $B1$ measures the total intensity of I-I supply connection from sector i to all other possible sectors with 1 unit of length. Similar the indirect connection term $B^{2}1$ measures the total intensity of I-I supply connection from sector i to all other possible sectors with 2 unit of length and so on so forth. The similar extension applies to I-I demand multiplier. See Fadinger, Ghiglino and Teteryatnikova (2017), Antras and Chor (2018) and Johnson (2017) for similar discussion.

[8] See Ballester, Calvó-Armengol and Zenou (2006) for an explanation about Bonacich centrality, and the connection between multiplier defined in this paper and the general form of Bonacich centrality in their paper.

Figure 3: Sectoral I-I demand multiplier and residual nominal value-added share

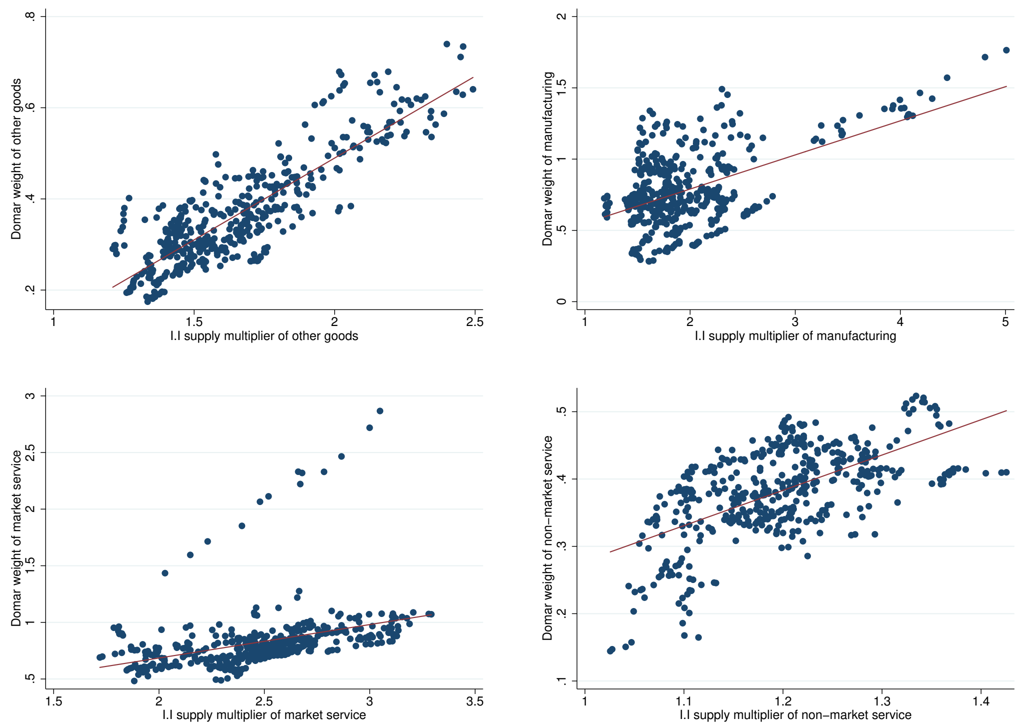


The four panels describe the correlation in the four sectors. The horizontal axis is the value of I-I demand multiplier and the vertical axis is the value of residual nominal value added share after removing the I-I supply effect. Each dot point represents one country at one year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

Value-Added Share and Intermediate-Input Supply and Demand Multipliers There are two empirical associations in this paper: a positive association between sectoral value-added share and the I-I supply multiplier; a negative association between sectoral residual value-added share and the I-I demand multiplier. The two associations are depicted in figure 2 and figure 3 respectively. In both figures, there are four panels. Each panel shows the correlation for a one-digit sector: other good sector; manufacturing; market service and non-market service. The definition and disaggregation of each sector are given in Inklaar and Timmer (2014).[9] The correlations are depicted from the panel data of 35 major economies during 1995-2007. Each dot point in figure 2 and figure 3 stands for a country at a specific year. The horizontal axis of these two figures is intermediate-input supply multiplier and demand multiplier respectively; the vertical axis is sectoral nominal value-added share and residual nominal value-added share respectively. These correlations are also observable in two-digit sectors in the long run, which is given in appendix section E.2. These correlations are general finding, which is true not only for time-series data

[9]See appendix section F for sector classification and description. This classification method follows System of National Account. This classification method is similar to Duarte and Restuccia (2017). The market service sector closes to their modern service sector; and the non-market service sector closes to their traditional service sector, such as including government, health, education, and housing.

Figure 4: Sectoral I-I supply multiplier and nominal Domar weight



The four panels describe the correlation in the four sectors. The horizontal axis is the value of I-I supply multiplier and the vertical axis is the value of sectoral gross output share of GDP (Domar weight). Each dot point represents one country at one year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

but also true across countries. Consistent with Herrendorf, Rogerson and Valentinyi (2013a), structural change is a global phenomenon. It holds across countries at different development stages.

In addition, the strong negative correlation between intermediate-input demand multiplier and sectoral residual value-added share suggests that the demand multiplier also matters. Figure 3 shows that after removing the intermediate-input supply effect, the sectoral value-added share is negatively correlated with intermediate-input demand multiplier. Notice that the sectoral I-I demand intensity is relatively stable over time, which result in less variability in I-I demand multiplier. However, the negative correlation between value-added share and I-I demand multiplier is significant at 1 percent level, in the OLS regression of Value-added share on I-I supply and demand multipliers. The correlations hold with country and year fixed-effects. It suggests that while both associations hold, the positive association between value-added share and I-I supply multiplier is much stronger than the negative association between value-added share and I-I demand multiplier.

Domar weight and Intermediate-Input Supply Multiplier Finally, I show the correlation between Domar weight and the sectoral I-I supply multiplier. *Domar weight* is sectoral gross output share of GDP (Domar 1961). In input-output literature, Domar weight is the relevant sectoral weight to determine the sectoral influence in producing input and output (Balk 2009; Hu 2017). Domar weight is the intermediary term to connect the value-added share and I-I supply multiplier, which is further explored in detail in section 4. I present the correlation in figure 4. The result suggests a positive correlation between Domar weight and I-I supply multiplier in all of the four sectors. This positive association is key to understand the positive I-I supply effect on value-added share, and therefore it is crucial to understand structural change.

3. Model

The economy has a representative consumer with preferences over sectoral consumption. The aggregate gross output and sectoral gross output are produced by competitive producers, using a bundle of differentiated intermediate-input varieties. Each intermediate-input variety is produced by a monopolistically competitive firm. Firms are allowed to have heterogeneous productivity. Firms can produce intermediate-input varieties in-house or by external outsourcing. There is an external outsourcing cost which is analogous to trade cost.

3.1 Preferences

Suppose the time period t is discrete and infinite. A representative consumer consumes final goods and services from n sectors. I assume the following lifetime utility function:

$$U(C_t) = \sum_{t=0}^{\infty} \frac{\delta^t C_t^{1-\phi}}{1-\phi}. \tag{1}$$

Here δ is the discount factor; $1/\phi$ is elasticity of intertemporal substitution of aggregate consumption C_t.

Following Comin, Lashkari and Mestieri (2018), the aggregate consumption C_t has a non-homothetic Constant Elasticity of Substitution (CES) aggregation of sectoral consumption C_{it}, which is

$$\sum_{i=1}^{n} \Omega_i^{\frac{1}{\varepsilon}} C_t^{\frac{\epsilon_i-\varepsilon}{\varepsilon}} C_{it}^{\frac{\varepsilon-1}{\varepsilon}} = 1. \tag{2}$$

Here ε is the elasticity of substitution between sectoral consumption; ϵ_i measures the income elasticity of demand for the consumption good in sector i. I allow heterogeneous income elasticity across sectors.[10] Notice that there are two advantages of choosing this form of nonhomo-

[10] The standard homothetic CES is a special case when I assume unitary income elasticity across sectors. That is, if

thetic CES. First, under this setup, I can independently identify price effects and income effects on consumption. Second, as highlighted by Comin, Lashkari and Mestieri (2018), this assumption implies stable income elasticity, which is consistent with empirical regularities.[11]

Suppose the representative consumer has an initial asset endowment of $\mathcal{A}_0$. The budget constraint equation is given by

$$\sum_{i=1}^{n} P_{it}C_{it} = w_tL_t + (1+r_t)\mathcal{A}_t - \mathcal{A}_{t+1} + \Pi_t. \tag{3}$$

Here Π_t is the aggregate profit; w_tL_t is aggregate labor income. I assume that the representative consumer owns all the profits of firms. According to Herrendorf, Rogerson and Valentinyi (2013a), the consumer's optimization problem could be decomposed by two separate problems. The intertemporal problem optimally allocates aggregate consumption C_t over time. The intratemporal problem optimally allocates sectoral consumption C_{it} within every period. Since only the intratemporal allocation is relevant for structural change study, the focus of this paper is on intratemporal problem.[12]

3.2 Technology

Aggregate Production I introduce a similar nonhomothetic CES aggregation form in aggregate gross output production. I assume time-variant sector weight in the aggregate production:

$$\sum_{i=1}^{n} \Psi_{it}^{\frac{\kappa}{\rho}} Q_t^{\frac{\xi_i-\rho}{\rho}} Q_{it}^{\frac{\rho-1}{\rho}} = 1. \tag{4}$$

Here Q_t is aggregate gross output, and Q_{it} is sectoral gross output. The time-variant sectoral weight plays an additional role to price and income, in determining structural change. Based on the aforementioned fact, *intermediate input supply multiplier* is vital to determine the sectoral weight. Because in the input-output economy, sector weight is Domar weight; and Domar weight positively depends on I-I supply multiplier as illustrated in the next section mecha-

$\epsilon_i = 1, C_t = \left(\sum_{i=1}^{n} \Omega_i^{\frac{1}{\varepsilon}} C_{it}^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$.

[11] Other nonhomothetic CES like Stone-Geary preferences implies asymptotic income elasticity across sectors as income is very high, which is inconsistent with the evidence. Moreover, Matsuyama (2017) argues that other nonhomothetic preferences like constant ratio of income elasticity preferences (Fieler 2011; Caron et al. 2014) cannot isolate the price effect from income effect. Furthermore as mentioned by Matsuyama (2017), the common price elasticity of substitution implied by this assumption cannot be rejected by statistic evidence, according to Deaton (1974).

[12] For the discussion of the intertemporal problem and the related balanced growth path, see Comin, Lashkari and Mestieri (2018) for more detail. A caveat of this paper is that I do not specify the balanced growth path condition as normally did in structural change literature such as in Ngai and Pissarides (2007). The reason is that recent studies suggest that balanced growth path or the Kaldor facts may not be consistent with empirical evidence anymore. We can see much recent evidence, such as the large change in investment rate in the emerging economies like China (Song et al. 2011). For more discussion about structural change with deviation from the balanced growth path, see Garcia-Santana, Pijoan-Mas and Villacorta (2016).

nism. Here I allow a broadly defined sectoral weight. For the aggregate producer's optimization problem, the sector weight is a state variable. However, in the general equilibrium, the sector weight is endogenous. Because the sector level input-output linkages are determined by firm-level trade of I-I varieties.

Sectoral Production Sectoral gross output is a homothetic CES aggregation of intermediate inputs, specifically given by

$$Q_{it} = \left(\sum_{j=1}^{n} X_{ijt}^{\frac{\theta}{1+\theta}} \right)^{\frac{1+\theta}{\theta}}. \tag{5}$$

Here X_{ijt} is the intermediate input potentially from sector j to sector i. Suppose there is a continuum of differentiated intermediate input varieties $\omega \in [0, 1]$. Each variety is produced by a firm. Assume sectoral intermediate input X_{ijt} is a CES aggregation of intermediate-input varieties, such that

$$X_{ijt} = \left[\int_0^1 X_{ijt}(\omega)^{\frac{\nu-1}{\nu}} d\omega \right]^{\frac{\nu}{\nu-1}}. \tag{6}$$

Here $X_{ijt}(\omega)$ is intermediate input variety which could be outsourced to a firm under sector j, and used by another firm under sector i at time t.

Firm Production For the production of intermediate input variety $X_{ijt}(\omega)$, firm can either produces in-house by directly hiring labor and capital; or outsources the production task to another firm which belongs to sector j and can enforce the firm-to-firm outsourcing contract. Each firm produces a differentiated intermediate-input variety. The market structure of producing intermediate input variety is monopolistic competitive.[13] Suppose a firm chooses to produce in-house, the corresponding output and price are given by

$$X_{ijt}^H(\omega) = a_{ijt}^H(\omega) k_{ijt}^{\alpha}(\omega) l_{ijt}^{1-\alpha}(\omega), \tag{7}$$

$$P_{ijt}^H(\omega) = \frac{\nu}{\nu - 1} \frac{\tilde{w}_{it}}{a_{ijt}^H(\omega)}. \tag{8}$$

Here marginal cost composite $\tilde{w}_{it} = \left(\frac{r_{it}}{\alpha}\right)^{\alpha} \left(\frac{w_{it}}{1-\alpha}\right)^{1-\alpha}$; $X_{ijt}^H(\omega)$ and $P_{ijt}^H(\omega)$ are in-house production and price of intermediate-input variety ω; $k_{ijt}(\omega)$ and $l_{ijt}(\omega)$ are firm-level capital and labor demand; $a_{ijt}^H(\omega)$ is in-house productivity. Every firm has a constant markup $\frac{\nu}{\nu-1}$.

On the other hand, the intermediate input variety can be outsourced to sector j. Suppose there is always a firm in sector j can directly use the sectoral gross output as input to producing

[13] Here I follow a large number of studies to assume monopolistic competitive structure at firm production. The model result and quantitative analysis in the next section do not depend on monopolistic competition assumption, so long as firms have constant markup. The result holds even the market structure is competitive.

the outsourced variety. Assume there is sector-to-sector outsourcing cost τ_{ijt} if sector i outsources intermediate input production to sector j at t. Specifically, the production function and the corresponding price equation, in this case, are given by

$$X^X_{ijt}(\omega) = a^X_{ijt}(\omega)Q_{ijt}(\omega), \tag{9}$$

$$P^X_{ijt}(\omega) = \frac{\nu}{\nu - 1}\frac{\tau_{ijt}P_{jt}}{a^X_{ijt}(\omega)}. \tag{10}$$

Here $X^X_{ijt}(\omega)$ and $P^X_{ijt}(\omega)$ are production and price of outsourced intermediate input variety respectively; $a^X_{ijt}(\omega)$ is productivity of outsourcing firm.

Following Eaton and Kortum (2002), I assume that firms draw their productivities from Fréchet distribution:

$$\Pr[a^H_{ijt} \leq a] \equiv F_{it}(a) = e^{-T_{it}a^{-\zeta}}, \tag{11}$$

$$\Pr[a^X_{ijt} \leq a] \equiv F_{jt}(a) = e^{-T_{jt}a^{-\zeta}}. \tag{12}$$

Here T_{it} and T_{jt} are sector specific TFP scale; ζ determines the dispersion of Fréchet distribution. Higher sectoral TFP scale implies larger firm-level productivity draw on average. The dispersion of firm-level productivities declines with ζ. Each intermediate input variety is perfectly substitutable between in-house and outsourcing production. The actual I-I variety price is the minimum price between in-house and outsourcing production:

$$P^*_{ijt}(\omega) = \min(P^H_{ijt}(\omega), P^X_{ijt}(\omega)). \tag{13}$$

Outsourcing firm may be more productive but naturally bears with outsourcing cost. If outsourcing cost is too high, firms are likely to produce in-house. Otherwise, firms may consider outsourcing.

3.3 Equilibrium

At every period, all markets are clear in equilibrium. We have three market clearing conditions. First, the supply of sectoral gross output equals the demand of sectoral gross output. The demand contains final consumption (final demand) and intermediate-input outsourcing (intermediate demand) from all possible sectors. Specifically, we have the following equation:

$$P_{jt}C_{jt} + \sum_{i=1}^{n} P^X_{ijt}X^X_{ijt} = P_{jt}Q_{jt}.$$

Second, capital market and labor market are clear in every period. Capital and labor are supplied inelastically. The market clearing conditions are given by

$$\sum_{i=1}^{n} K_{it} = K_t,$$

$$\sum_{i=1}^{n} L_{it} = L_t.$$

Third, for the production of I-I variety, market clearing conditions are given by the following equations:

$$P^X_{ijt} X^X_{ijt} = \int_0^1 P^X_{ijt}(\omega_X) X^X_{ijt}(\omega_X) d\omega_X,$$

$$P^H_{ijt} X^H_{ijt} = \int_0^1 P^H_{ijt}(\omega_H) X^H_{ijt}(\omega_H) d\omega_H,$$

$$P_{ijt} X_{ijt} = P^X_{ijt} X^X_{ijt} + P^H_{ijt} X^H_{ijt} = \int_0^1 P^*_{ijt}(\omega) X_{ijt}(\omega) d\omega, \tag{14}$$

$$P_{it} Q_{it} = \sum_{j=1}^{n} P_{ijt} X_{ijt}, \tag{15}$$

$$P_t Q_t = \sum_{i=1}^{n} P_{it} Q_{it}. \tag{16}$$

Here ω_X and ω_H are those of varieties which are produced by outsourcing and in-house respectively.

At every period t, the equilibrium is characterized by consumer's optimal allocation of sectoral consumption and producers' optimal allocation of sectoral production, primary inputs, and intermediate inputs. To be specific, the representative consumer maximizes C_t subject to aggregate consumption in equation (2) and budget constraint in equation (3). For the aggregate production, the benevolent social planner maximizes aggregate gross output Q_t by optimally allocating sectoral gross output Q_{it}, subject to aggregate production in equation (4) and aggregate budget constraint in equation (16).

Producer's intratemporal problem can be further divided into two levels: sector level and firm level. At the sector level, assume there is a representative producer who maximizes sectoral gross output as in equation (5) by optimally allocating sectoral intermediate input, subject to sectoral gross output budget constraint in equation (15). Similar at sector level, the representative producer also maximizes sectoral intermediate input according to equation (6), subject to intermediate input budget constraint in equation (14). At firm level for both production in-house and outsourcing, I assume that monopolistically competitive producers draw their productivity from Frechet distribution following equation (11) and equation (12). Then they learn their in-house price and outsourcing price following equation (8) and equation (10). The I-I variety producer always choose the lower price at every period.

After solving the model (all proof of this and other propositions are shown in appendix A), the following proposition summarises the key result of sectoral structure terms, sectoral production, sectoral consumption and aggregate prices:

Proposition 1 (Equilibrium Solution of Key Variables): *In competitive equilibrium the sectoral value added share, Domar weight, and consumption share are solved by the following equations:*

$$\eta_{it} = (1 - \sigma_{it})\gamma_{it}, \tag{17}$$

$$\gamma_t = (I - B_t)^{-1}\lambda_t, \tag{18}$$

$$\lambda_{it} = \Omega_i \left(\frac{P_{it}}{P_t}\right)^{1-\varepsilon} C_t^{\epsilon_i - 1}. \tag{19}$$

In addition, the optimal sectoral consumption, gross output, and the aggregate value-added price $\tilde{P}_t$ and gross-output price P_t are solved by the following equations:

$$C_{it} = \Omega_i \left(\frac{P_{it}}{P_t}\right)^{-\varepsilon} C_t^{\epsilon_i}, \tag{20}$$

$$Q_{it} = \Psi_{it}^{\kappa} \left(\frac{P_{it}}{P_t}\right)^{-\rho} Q_t^{\xi_i}, \tag{21}$$

$$\tilde{P}_t = \left(\sum_{i=1}^{n} \Omega_i P_{it}^{1-\varepsilon} C_t^{\epsilon_i - 1}\right)^{\frac{1}{1-\varepsilon}}, \tag{22}$$

$$P_t = \left(\sum_{i=1}^{n} \Psi_{it}^{\kappa} P_{it}^{1-\rho} Q_t^{\xi_i - 1}\right)^{\frac{1}{1-\rho}}. \tag{23}$$

Here both price effect and income effect contribute to consumption share based structural change, which is discussed in more detail in proposition 2. The sectoral gross output has as similar function form as sectoral consumption. However, the price elasticity and income elasticity are allowed to be different between consumption and production, as illustrated in equation (20) and equation (21) respectively.

Based on proposition 1, I further derive the structural change equations of this paper in the following proposition.

Proposition 2 (Structural Change): *The structural change equations of relative consumption share and value-added share are given by the following equations,*

$$log\frac{\lambda_{it}}{\lambda_{jt}} = log\frac{\Omega_i}{\Omega_j} + (1 - \varepsilon)log\frac{P_{it}}{P_{jt}} + (\epsilon_i - \epsilon_j)logC_t, \tag{24}$$

$$log\frac{\eta_{it}}{\eta_{jt}} = log\frac{1-\sigma_{it}}{1-\sigma_{jt}} + \kappa log\frac{\Psi_{it}}{\Psi_{jt}} + (1-\rho)log\frac{P_{it}}{P_{jt}} + (\xi_i - \xi_j)logQ_t. \quad (25)$$

Notice that since σ_{it} denotes the sectoral I-I demand intensity, the first term on the right hand side of equation (25) represents I-I demand effects. The second term represents the I-I supply effects because the sector weight is Domar weight in the input-output economic landscape. As microfounded by section 2.2, Domar weight positively associates with I-I supply multiplier.

Here the four terms on the right hand side of equation (25) represent I-I demand effects, I-I supply effects, price effects, and income effects respectively. Holding other effects constant, for the I-I supply effects, economic resource moves to the sector with relatively increasing I-I supply multiplier if $\kappa > 0$; economic resource moves to the sector with relatively decreasing I-I supply multiplier if $\kappa < 0$. Holding other effects constant, for the I-I demand effects, economic resource moves to the sector with relatively decreasing I-I demand multiplier. Holding other effects constant, for the price effects, economic resource moves to the sector with relatively increasing price if $\varepsilon \in (0,1)$ and $\rho \in (0,1)$; economic resource moves to the sector with relatively decreasing price if $\varepsilon \in (1,\infty)$ and $\rho \in (1,\infty)$. Holding other effects constant, for the income effect, economic resource moves to the sector with relatively larger income elasticity. The price effect and income effect are consistent with Ngai and Pissarides (2007) and Kongsamut, Rebelo and Xie (2001) respectively.

The structural change mechanisms of this paper nest the literature. If I assume no input-output linkage such that $B = I$, time-invariant sector weight $\Psi_{it} = \Psi_i$ and same elasticities between production and consumption, equation (25) is equivalent to (24) which is the key equation of structural change in Comin, Lashkari and Mestieri (2018). Therefore the structural change equation (25) is a general case with input-output linkages and sectoral heterogeneity of I-I supply and demand.

Price effect and income effect are well studied in the literature, but I-I supply and demand effects are missed. None of them can independently identify I-I supply and I-I demand effects, due to ignorance of input-output linkage, firm heterogeneity, and nonhomothetic CES technology. If I only explore the consumption share based structural change, the ignorance of input-output linkages probably is fine following equation (24). Since I am interested in value-added share based structural change, this ignorance misses out two important channels: I-I demand and I-I supply.

Recent empirical evidence in Goldschmidt and Schmieder (2017), Dustmann, Fitzenberger, Schönberg and Spitz-Oener (2014) and Berlingieri (2013) tend to support the intermediate-input supply and demand effects on structural change. Since the mid-1990s, there has been a dramatic increase in the outsourcing to business service sectors (i.e., cleaning, security, logistics, and food service) from the manufacturing sector in developed countries like US and Germany. During this period, there is a decline of occupations and value-added share in the manufacturing sector and a rise in services. Therefore the important contribution of this paper is that it provides a simple equation (25) to highlight the additionally plausible mechanism of intermediate-input outsourcing.

In addition to the implication of structural change, the equilibrium result of this model implies endogenous input-output linkages and sectoral price. These results are summarized by the following proposition:

Proposition 3 (Endogenous Input-Output Linkages and Sectoral Prices): *The intermediate-input oursourcing share of sector j in sector i is endogenous on sector-to-sector outsourcing supply costs, sectoral TFP scale parameters, trade elasticity and other CES elasticity parameters. Specifically intermediate-input oursourcing share is given by the following equation,*

$$B_{jit} \equiv \frac{P_{ijt}X_{ijt}}{P_{it}Q_{it}} \frac{P^X_{ijt}X^X_{ijt}}{P_{ijt}X_{ijt}} = \left(\frac{P_{ijt}}{P_{it}}\right)^{-\theta} \frac{T_{jt}(P_{jt}\tau_{ijt})^{-\zeta}}{T_{jt}(P_{jt}\tau_{ijt})^{-\zeta} + T_{it}(\tilde{w}_{it}\tau_{iit})^{-\zeta}}. \tag{26}$$

In addition, sectoral gross output price and intermediate-input price are given by the following two equations respectively,

$$P_{it} = \left[\sum_{j=1}^{n}(P_{ijt})^{-\theta}\right]^{-\frac{1}{\theta}}, \tag{27}$$

$$P_{ijt} = \frac{\nu}{\nu-1}\left[\Gamma\left(\frac{1-\nu+\zeta}{\zeta}\right)\right]^{\frac{1}{1-\nu}} \left[T_{jt}(P_{jt}\tau_{ijt})^{-\zeta} + T_{it}(\tilde{w}_{it}\tau_{iit})^{-\zeta}\right]^{-\frac{1}{\zeta}}. \tag{28}$$

If there is no sectoral input-output linkage from j to i, it is a special case of infinitely large outsourcing supply cost τ_{ijt}.

The price equations are consistent with Eaton and Kortum (2002) and Boehm (2018). Proposition 3 suggests that the intermediate-input price P_{ijt} inversely depends on intermediate input efficiency $\Phi_{ijt} = T_{jt}(P_{jt}\tau_{ijt})^{-\zeta} + T_{it}(\tilde{w}_{it}\tau_{iit})^{-\zeta}$. Since I-I efficiency increases with sectoral TFP scale T_{it}; decreases with marginal cost composite $\tilde{w}_{it}$ and outsourcing supply cost τ_{ijt}, it implies that price decreases with sectoral TFP scale; increases with marginal cost composite and outsourcing supply cost. The dispersion parameter ζ determines how substitutable of production technology between in-house and outsourcing.

The input-output linkage intensity equation is also consistent with the gravity equation in Eaton and Kortum (2002). Equation (26) suggests that input-output linkages depend on intermediate-input share and outsourcing share of intermediate input. In particular, intermediate input share adjusts at intensive margin due to standard CES setup, and outsourcing share adjusts at extensive margin as suggested by Eaton and Kortum (2002). According to equation (26), higher TFP scale sector supplies more I-I outsourcing, which corresponds to the absolute advantage argument in Eaton and Kortum (2002). Because higher absolute advantage implies that on average firms under this sector have relatively larger productivity draw. It further implies that firms have comparative advantage to supply a broader range of intermediate inputs.

In addition, this comparative advantage is discounted by marginal cost and outsourcing supply cost. Equation (26) suggests that the dispersion parameter ζ measures the sensitivity of intermediate-input outsourcing to relative outsourcing cost, which is consistent with elasticity of trade share to relative trade cost in Eaton and Kortum (2002). A lower value of ζ implies higher outsourcing intensity, which corresponds to the larger comparative advantage argument in Eaton and Kortum (2002). Because the lower value of ζ, the larger difference in productivity draw between firms, which further implies larger trade scope of intermediate-input variety. Essentially firm-level producers always seek cheaper intermediate-input variety. Furthermore, following proposition 3, the relatively sectoral price inversely depends on relatively sectoral overall efficiency. Here I define the sectoral overall efficiency Φ_{it} by the following: ${\Phi_{it}}^{\frac{\theta}{\zeta}} = \sum_{j=1}^{n} {\Phi_{ijt}}^{\frac{\theta}{\zeta}}$. It is easy to derive $\frac{P_{it}}{P_{jt}} = \left(\frac{\Phi_{it}}{\Phi_{jt}}\right)^{-\frac{1}{\zeta}}$.

4. Key Mechanism

I present the mechanism of input-output linkages in structural change in this section. This mechanism is explained by I-I supply channel and I-I demand channel. I present these two channels, then followed by a complete picture of the whole mechanism.

I-I Supply Channel The I-I supply channel is understood according to equation (17) and equation (18). We can understand the I-I supply channel in two steps. In the first step, we need to understand the positive association between I-I supply multiplier $\mu^s = (I - B)^{-1}1$ and Domar weight γ. This association is implied by equation (18). The intermediate-input supply multiplier is a vector sum of the corresponding row of Leontief inverse. The Domar weight is a weighted average of the corresponding row of Leontief inverse. Here the weight is sectoral consumption share.

Theoretically, both the variation of consumption share and intermediate-input supply multiplier contribute to the variation of Domar weight. If there are no input-output linkages such that $B = I$, Domar weight is equivalent to consumption share: $\gamma = \lambda$. In this case, the variation of Domar weight entirely depends on the heterogeneity of consumer preferences. On the other hand, if consumer has symmetric consumption preferences such that $\lambda_i = \lambda_j$, then the variation of Domar weight depends on the heterogeneity of I-I supply multiplier. In Acemoglu, Ozdaglar and Tahbaz-Salehi (2017), these two extreme cases are called primitive heterogeneity and network heterogeneity. In general, the variation of Domar weight is determined by a linear combination of primitive and network heterogeneity.

This paper focuses on network heterogeneity. I assume symmetric preferences. Domar weight positively depends on I-I supply multiplier, and the mapping is one-on-one in this particular case. In figure 4, there is a strong positive correlation between Domar weight and I-I supply multiplier. It suggests that in our economies, network heterogeneity plays a prominent role in determining Domar weight, which is consistent with Acemoglu, Ozdaglar and Tahbaz-Salehi (2017).[14]

The second step aims for understanding the positive correlation between value-added share and Domar weight. This correlation is implied by equation (17). The economic meaning of Leontief inverse element L_{ij} is that if sector i increases TFP by 1 percent, it would finally raise the gross output of sector j by L_{ij} percent. This final effect summarises all the direct and indirect effect of TFP shock of sector i, through the input-output linkages. Moreover, if the gross output of sector j increases by L_{ij} percent, GDP would increase by γ_i percent. It implies that the Domar weight γ_i is the elasticity of GDP to sectoral gross-output based TFP in sector i. In a corresponding case of value-added economy, the sectoral value-added share η_i is understood as elasticity of GDP to sectoral value-added based TFP in sector i.[15] Essentially value-added share and Domar weight are elasticity of GDP to different types of TFP: value-added based and gross-output based respectively. Equation (17) implies a positive correlation between these two elasticities: value-added share η_i positively depends on Domar weight γ_i, holding intermediate-input demand intensity σ_i constant.

Finally, we can integrate the two steps. That is, conditional on symmetric consumption share, a sector with larger I-I supply multiplier has higher Domar weight. Higher Domar weight implies larger elasticity of aggregate output to sectoral gross-output based TFP, which implies that this sector has a larger sector weight and therefore larger value-added share.

I-I Demand Channel On the other hand, for any sector with larger intermediate-input demand multiplier, it implies larger intermediate-input demand intensity.[16] According to equation (17), this implies smaller value-added share. The sector weight is discounted by I-I demand intensity. In conclusion, if I suppress the mechanism of heterogeneous preferences, structural change arises from the sector with relatively larger intermediate-input demand multiplier to the sector with relatively larger intermediate-input supply multiplier.

[14]In the general equilibrium model in the next section, I allow both heterogeneities. That is, consumer side mechanism and producer side mechanism jointly determine structural change.

[15]See my working paper Hu (2017) for this discussion.

[16]The vector of I-I demand multiplier is derived as $\mu_t^d \equiv 1'(I-B)^{-1} = 1'(I+B+B^2+...+B^{\infty})$. Hence we have $\mu_{jt}^d \approx 1+\sigma_{jt}$, if the element value of input-output matrix B is sufficiently small. Hence we have a positive correlation between I-I demand multiplier and sectoral I-I demand intensity, given relatively small input-output linkage intensity across sectors.

Summary I summarize the whole mechanism as follows. If a sector becomes relatively more productive than other sectors over time, or bears with relatively less outsourcing supply cost over time; this sector gains increasing comparative advantage to supply relatively more intermediate inputs to other sectors. In input-output economic landscape, this sector has relatively larger direct and indirect connections to the downstream sectors, namely relatively larger intermediate-input supply multiplier. In order to satisfy this relatively increasing demand for intermediate inputs, this sector has to hire relatively more labor and capital to produce. On the other hand, for other sectors, they can choose to outsource relatively more intermediate inputs to the sector with growing comparative advantage. Because they can take advantage of relatively lower cost. With relatively more outsourcing, these sectors have relatively larger direct and indirect connections to the upstream sector, namely relatively larger intermediate-input demand multiplier. Since these sectors rely relatively more on outsourcing, they lay off labors and rent out capital. Henceforth, structural change arises from the sector with larger growth of I-I demand to the sector with larger growth of I-I supply. This mechanism is supported by recently documented relationship between digital technological development, deunionization, and labor market outsourcing and labor mobility in the US (Weil 2014; Katz and Krueger 2016; Berlingieri 2013) and Germany (Dustmann et al. 2014; Goldschmidt and Schmieder 2017).

5. Quantitative Results

This section presents the calibration and quantifies the importance of the four effects. For the sake of clear illustration, I focus on the most significant structural change trend: from manufacturing to market service. The results consistently hold to another two sectors. I leave the results of another two sectors in the appendix section D.4. I first show the benchmark calibration result in subsection 5.1. I study which channel is crucial to driving value-added share based structural change in subsection 5.2. I leave a similar case study of employment share based structural change in appendix subsection D.6.

5.1 Benchmark Calibration

Production Side Elasticity I estimate the production side structural change elasticities, following equation (25). Specifically, I run the following OLS regression:

$$\log\frac{\eta_{ict}}{\eta_{jct}} = \beta\log\frac{1-\sigma_{ict}}{1-\sigma_{jct}} + \kappa\log\frac{\mu^s_{ict}}{\mu^s_{jct}} + (1-\rho)\log\frac{P_{ict}}{P_{jct}} + (\xi_i - \xi_j)\log Q_{ct} + f_c + f_t + e_{ct}.$$

Here f_c and f_t are country fixed effect and year fixed effect respectively.[17] The error term is $e_{ct} = \kappa\left(\frac{\Psi_{ict}}{\Psi_{jct}} - \frac{\mu^s_{ict}}{\mu^s_{jct}}\right)$, conditional on sector pair ij. Here c stands for country. I choose manufacturing as the benchmark sector following Comin, Lashkari and Mestieri (2018). The structural change terms are relative value added share of the other three sectors to manufacturing. I present the estimate result in table 1.[18]

The first four columns of table 1 report the estimate with all sampling countries. Column 1 replicates the traditional price effect and income effect on structural change. The result suggests a significantly positive price effect and negative income effect. The positive price effect is consistent with the prediction in Ngai and Pissarides (2007). When sectoral goods are complement ($\rho < 1$), structural change arises from lower price sector to higher price sector. The price effect is still significant when I add intermediate-input demand and supply effects in column 2. But the size is smaller than that in column 1, which suggests that part of the estimate of price effect in column 1 is absorbed by the intermediate-input supply and demand effects. In column 2, the intermediate-input supply and demand effects are significant at 1 percent level. More importantly, their magnitudes are much larger than price effect. It suggests that structural change has a larger correlation with intermediate-input supply and demand channels than with the price channel.

Column 3 and column 4 show similar estimate as in column 2, but controlling with country and year fixed effects. Given the fixed effects, structural change still has larger correlation with intermediate-input supply and demand channels than with price channel. For instance, column 4 suggests that given country and year fixed effects, the elasticity of relative value-added share to relative intermediate-input demand is 0.887; the elasticity of relative value-added share to relative intermediate-input supply is 0.686, and the elasticity of relative value-added share to relative price is 0.503. The first four columns also suggest that income effects are not always significant, particularly not significant when country and year fixed effects are included in column 4.

The larger elasticity of relative value-added share to intermediate-input supply and demand holds in column 5 to column 7 of table 1. These three columns show results of another three estimate strategies, with country and year fixed effects. The intermediate-input demand effect on the right hand side of OLS regression equation contains relative value-added term which also enters the left hand side of OLS. This may introduce bias. To account for this potential bias, I

[17] I control year fixed effect since structural change tends to be cross-country phenomenon as well (Herrendorf et al. 2013a). In Comin, Lashkari and Mestieri (2018), they do not control year fixed effect. They concentrate on within-country structural change. Based on column 3 and column 4 of table 1, my estimate results do not change too much without year fixed effect.

[18] Consistent with Comin, Lashkari and Mestieri (2018), I use linear seemingly unrelated regressions to estimate the above regression equation. This is to ensure equivalent price, I-I supply and demand elasticities between sectors; while allowing sector specific income elasticity.

Table 1: Estimate of production side structural change

	Dependent Variable : $\log\frac{\eta_{it}}{\eta_{jt}}$						
Coefficient	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
β		1.486***	0.896***	0.887***	1.737***	0.970***	0.845***
		(0.065)	(0.045)	(0.042)	(0.083)	(0.053)	(0.056)
κ		1.406***	0.803***	0.686***	0.689***	0.646***	0.802***
		(0.046)	(0.037)	(0.037)	(0.036)	(0.044)	(0.055)
$1-\rho$	0.408***	0.272***	0.472***	0.503***	0.478***	0.547***	0.336***
	(0.028)	(0.026)	(0.030)	(0.029)	(0.029)	(0.043)	(0.037)
$\epsilon_{OG}-\epsilon_{Manu}$	-0.024**	0.020**	-0.073***	-0.059	-0.004	0.682***	0.012
	(0.011)	(0.008)	(0.028)	(0.052)	(0.051)	(0.070)	(0.068)
$\epsilon_{MS}-\epsilon_{Manu}$	-0.049***	-0.050***	0.190***	-0.029	0.044	0.452***	0.124**
	(0.009)	(0.008)	(0.022)	(0.041)	(0.040)	(0.059)	(0.054)
$\epsilon_{NMS}-\epsilon_{Manu}$	-0.050***	-0.008	0.073**	-0.097*	-0.011	0.022	0.291***
	(0.009)	(0.007)	(0.030)	(0.064)	(0.055)	(0.068)	(0.086)
Country FE	NO	NO	YES	YES	YES	YES	YES
Year FE	NO	NO	NO	YES	YES	YES	YES
DE approx.	NO	NO	NO	NO	YES	NO	NO
Sample	ALL	ALL	ALL	ALL	ALL	DC	LDC

$***$, $**$, $*$ denote significant at 1 percent, 5 percent and 10 percent critical values respectively. DC and LDC denote developed countries group and developing countries group respectively.

apply the first order Tayor rule approximation: $\log(1-\sigma_{ict}) \approx -\sigma_{ict}$. The estimate result is shown in column 5. Not surprisingly, now the estimate of demand elasticity is different, but the supply and price elasticities do not change too much. I further show the estimate result on developed countries and developing countries in column 6 and column 7 respectively. Again I find that the intermediate-input demand and supply elasticities are always significant and larger than price elasticity. Column 6 and column 7 also suggest that income elasticities are very different between developed countries and developing countries.

Consumption Side Elasticity Similar to the production side elasticities, I use OLS regression to estimate the consumption side elasticities by the following equation (24):

$$\log\frac{C_{ict}}{C_{jct}} = -\varepsilon\log\frac{P_{ict}}{P_{jct}} + (\epsilon_i - \epsilon_j)\log C_{ct} + f_c + f_t + u_{ct}.$$

Notice that here I use relatively real consumption rather than nominal consumption. Because the relative price also enters to the right hand side of the regression equation. The relatively time-invariant sectoral weight is absorbed by the country fixed effect. All the coefficients are estimated with both country fixed effect and year fixed effect. Here the error term is taken as measurement error. I assume fully exogenous error term in the consumption side OLS.[19]

[19]In the model, price is endogenous on primitives; aggregate consumption is taken as exogenous.

Table 2: Parameter calibration result

Parameter	Benchmark	Simulation 1	Simulation 2
ζ	2.701	2.701	2.701
ν	3.5	3.5	3.5
θ	1.646	1.646	1.646
ε	0.344	0.344	0.344
β	0.887	0.926	1.005
κ	0.686	0.865	1.151
ρ	0.497	0.818	0.532
$\epsilon_{OG} - \epsilon_{Manu}$	0.004	0.004	0.004
$\epsilon_{MS} - \epsilon_{Manu}$	0.004	0.004	0.004
$\epsilon_{NMS} - \epsilon_{Manu}$	-0.316	-0.316	-0.316
$\xi_{OG} - \xi_{Manu}$	-0.059	0.043	-0.016
$\xi_{MS} - \xi_{Manu}$	-0.029	0.031	-0.010
$\xi_{NMS} - \xi_{Manu}$	-0.097	-0.004	-0.097
τ_{ijt}	$\hat{\tau}_{ijt}$	$\hat{\tau}_{ij,1995}$	$\hat{\tau}_{ijt}$
T_{it}	$\hat{T}_{it}$	$\hat{T}_{it}$	$\hat{T}_{i,1995}$

$\hat{\tau}_{ijt}$ and $\hat{T}_{it}$ are calibrated outsourcing cost and TFP scale under the benchmark case. $\hat{\tau}_{ij,1995}$ and $\hat{T}_{i,1995}$ are outsourcing cost and TFP scale in the counterfactual cases, in which they stay at their initial year level over time for all countries and for all sectors and sector-pairs. .

Outsourcing Cost, TFP Scale, and Marginal Cost Composite For the rest of the parameters, I calibrate their values in two steps. First, suppose the trade elasticity ζ, CES elasticity parameter θ and ν are known, I calibrate the trade cost τ_{ijt}, TFP scale T_{it} and marginal cost composite parameter $\tilde{w}_{it}$. Second, I jointly find ζ and θ to minimize the moment gap between the model and the data. The moment I choose is the average growth rate of sectoral wage.

In the first step, I use the non-linear fixed effect method, given the input-output linkage equation (26) and price equations (27) and (28) in proposition 3. I normalize zero distortion in internal (within-sector) outsourcing, such that $\tau_{iit} = 1$. For every country at every year, I have 20 primitives to calibrate.[20] Given the available data on B_{jit} and P_{it}, these 20 values are exactly identified. They are identified by the following recursive fixed-effect method.

1. Given $\tilde{w}_{it}$, T_{it} are estimated from B_{iit} equation (26) and I-I price equation (28).

[20] Since I have 4 sectors, I have 4 parameters to calibrate for T_{it} and $\tilde{w}_{it}$ respectively. In addition, given the normalization of $\tau_{iit} = 1$, now I have 12 parameters to calibrate for τ_{ijt}.

2. Given $\tilde{w}_{it}$ and T_{it}, τ_{ijt} are estimated from B_{jit} equation (26) and I-I price equation (28).
3. Given T_{it} and τ_{ijt}, $\tilde{w}_{it}$ are estimated from P_{it} equation (27) and I-I price equation (28).
4. Repeat the first three steps until T_{it} converges.

This method is applied to every country at every year.[21] This paper offers a different calibration method, and henceforth contributing to the calibration method of Eaton-Kortum trade model (Dekle et al. 2008; Caliendo and Parro 2015; Caliendo et al. 2017).

Trade Elasticity and Other CES Elasticities Finally, I jointly calibrate ζ, θ and ν. The first two are calibrated to matching the model-generated moment with data-generated moment on marginal cost composite parameter: $\tilde{w}_{it} = \left(\frac{r_{it}}{\alpha}\right)^{\alpha}\left(\frac{w_{it}}{1-\alpha}\right)^{1-\alpha}$. To be specific, I begin with assumption of common capital share and constant rental rate: $\alpha = \frac{1}{3}$ and $r_{it} = r$. For the second assumption, I ignore the time-variant rental rate and assume a globally constant rental rate for every country at every sector. Hence the implied assumption is perfect capital mobility across countries and across sectors. In addition, I normalize $\tilde{w}_{it} = 1$ for US manufacturing at year 2005. Therefore the marginal cost composite parameter now is determined mainly by wage. I estimate wage with annual labor compensation data and annual working hour data from SEA dataset: $w_{it} = \frac{w_{it}L_{it}}{L_{it}}$. Let model generated average growth rate of sectoral marginal cost parameter as $\Delta_M(\tilde{w}_i)$ from the last calibration component; the data estimated counterpart as $\Delta_D(\tilde{w}_i)$. Jointly find ζ and θ to minimizes the moment gap such that

$$(\zeta, \theta) = \arg\min \sum_c \sum_i [\Delta_M(\tilde{w}_i) - \Delta_D(\tilde{w}_i)]^2.$$

Here c stands for country. Since ν only enters the constant term, it does not affect the relative values in this paper. I calibrate $\nu = 3.5$ to allow 40 percent markup following Boehm (2018). The benchmark calibration result is summarized in column 2 of table 2.

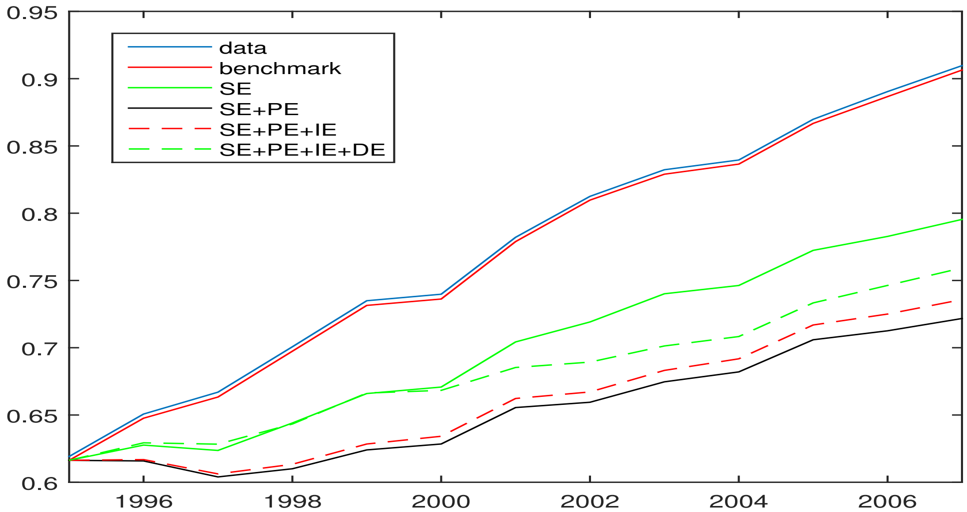
5.2 Accounting for Structural Change

In this subsection, I explore to what extent the intermediate-input supply and demand effects account for the structural change, from manufacturing to market service. I leave the similar results of another two sectors relative to manufacturing in appendix subsection D.4.

Benchmark Decomposition With structural change equation (25) and primitive values in hand, I decompose structural change from manufacturing to market service into the four ef-

[21]To solve a model, we have at least two methods: quantitative method and analytic method. While quantitative method could be highly productive in computation, it may lose the degree of freedom; and vice versa for the analytic method. In this paper, I use a quantitative method to calibrating the model primitives to observable variables, in the line of Caliendo, Parro and Tsyvinski (2017). For the correspondingly analytic method in this context, Dekle, Eaton and Kortum (2008) provides a good discussion.

Figure 5: Decomposition under benchmark estimation

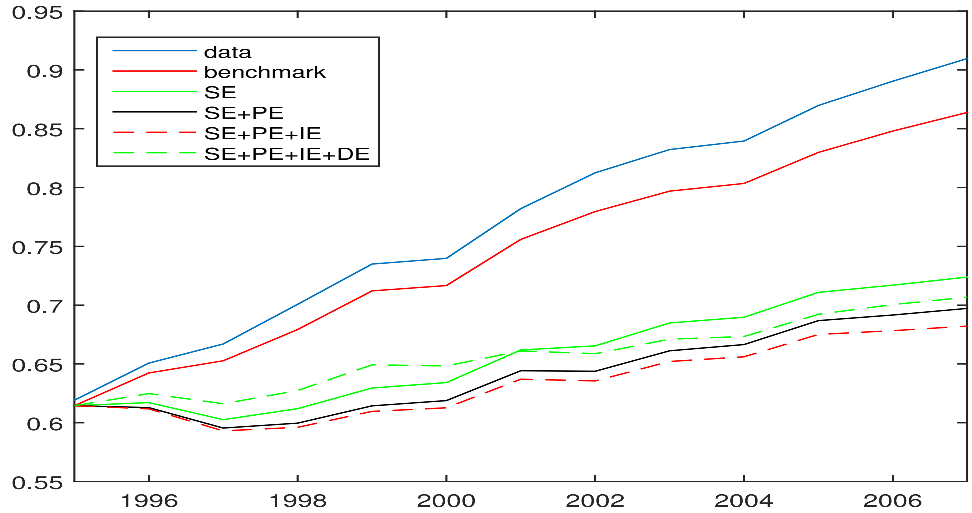


The horizontal axis denotes year; vertical axis shows the value of the relative value-added share of market service to manufacturing in log level. The solid blue and red line show the actual data and OLS predicted value respectively. The rest of the four lines are simulated values when I shut down the four effects one by one. See detail in the main text.

fects. Figure 5 shows the decomposition result under the benchmark calibration. The horizontal axis is year, and the vertical axis is value of relative value-added share of market service to manufacturing. In figure 5, the solid blue line shows the relative value added share in the data. This is the time series pattern of the relative value-added share of market service to manufacturing for the 35 major economies on average. From 1995 to 2007, the monotonic rise in relative value-added share implies the structural change from manufacturing to market service. The solid red line shows the relative value-added share under the regression prediction with country and year fixed effects. Figure 5 suggests that the prediction of OLS regression is very consistent with data. It implies that the model does a good job to match with structural change fact, under the benchmark calibration.

Figure 5 suggests that intermediate-input supply effect is the dominant effect on structural change. To account for the size of each effect, I turn to counterfactual study. First, suppose the relative intermediate-input supply multiplier stays at the initial-year values for all countries, I simulate the relative value-added share under the OLS regression equation with fixed effects. The solid green line shows the simulated relative value-added share without intermediate-input supply effect. The gap between the solid red line and solid green line, therefore, represents the magnitude of the I-I supply effect on structural change. I continue on this simulation exercise by switching off the price effect, income effect and intermediate-input demand effect sequentially. The black line, red dash line, and the green dash line show the simulated relative value-added

Figure 6: Decomposition under model simulation case 1



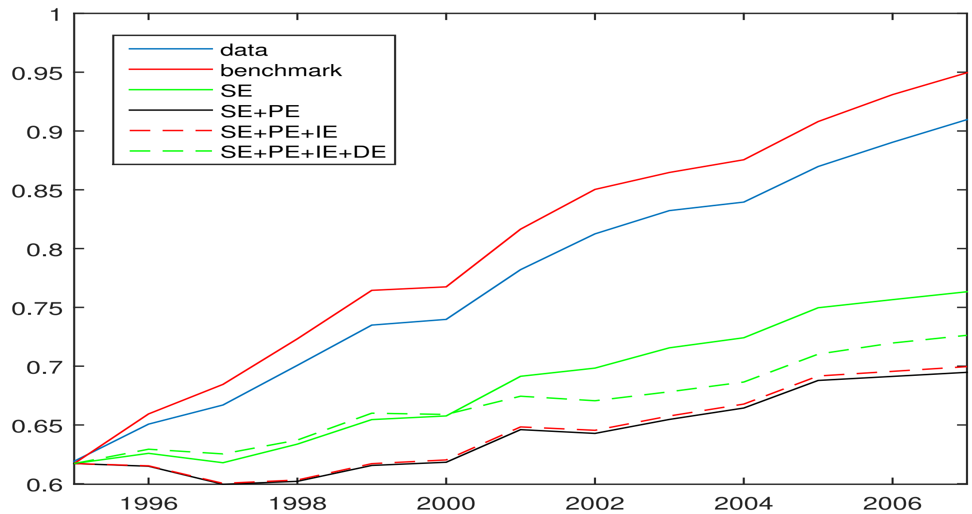
The horizontal axis denotes year; vertical axis shows the value of the relative value-added share of market service to manufacturing in log level. The solid blue and red line show the actual data and OLS predicted value respectively. The rest of the four lines are simulated values when I shut down the four effects one by one. See detail in the main text.

share under the three simulation scenarios respectively. As a result, the gap between the solid green line and the solid black line shows the price effect; the gap between the solid black line and red dash line indicates the income effect, and finally, the gap between red dash line and green dash line shows the intermediate-input demand effect. According to figure 5, I-I supply effect is the largest. Then it is followed by the price effect. The income effect and I-I demand effect are trivial, compared with I-I supply effect and price effect.

Decomposition under Model Simulation Though the benchmark estimation is simple and straight forward, it does not exploit the general equilibrium result and the fundamental primitives. In this subsection, I fully exploit the general equilibrium mechanism. I simulate the model and use the model simulated data to re-estimate the four effects. Then I re-do the decomposition exercise.

I show more specific steps as follows. First, suppose there is a shock to the outsourcing supply cost or TFP scale. It implies value change in outsourcing supply cost or TFP scale. Second, given the new primitives, I use the pertinent equations to simulate price, consumption share, input-output tables, then I-I supply multiplier, I-I demand intensity and finally relative value-added share. Third, I use the same OLS regression equation to re-estimate the coefficients using the simulated data. Finally, given the newly estimated coefficients, I re-do the decomposition exercise.

Figure 7: Decomposition under model simulation case 2

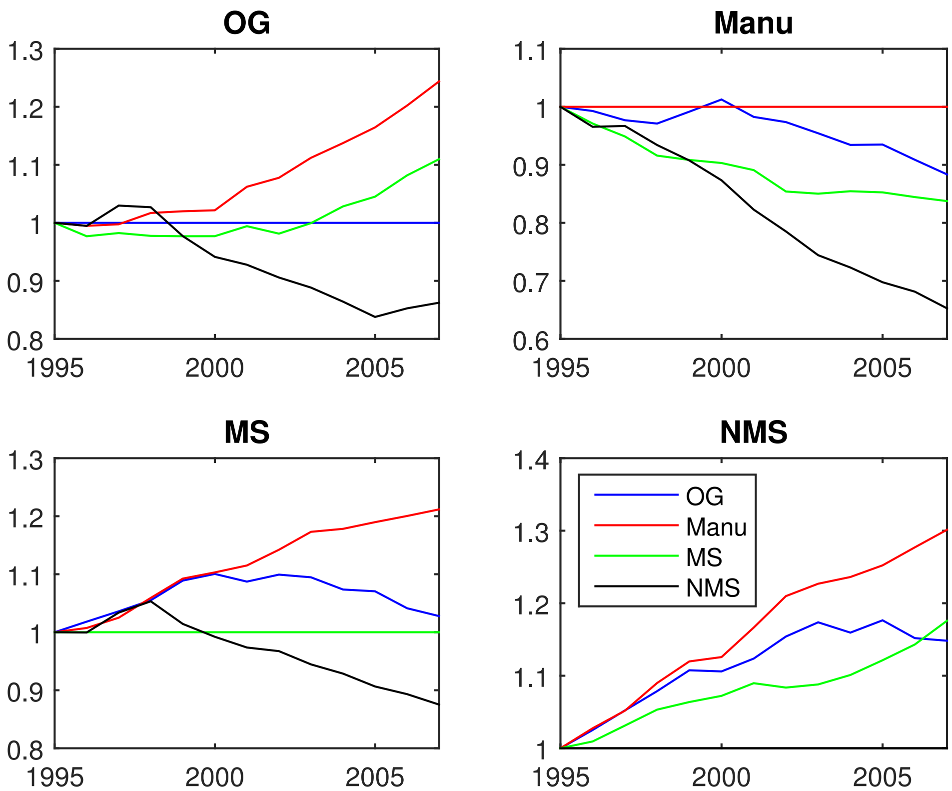


The horizontal axis denotes year; vertical axis shows the value of the relative value-added share of market service to manufacturing in log level. The solid blue and red line show the actual data and OLS predicted value respectively. The rest of the four lines are simulated values when I shut down the four effects one by one. See detail in the main text.

The simulation exercise is conducted through two counterfactual studies. In the first counterfactual study, I assume that outsourcing supply cost τ_{ijt} stays at the first year level for all sectors and for all countries. In the second counterfactual study, I assume that TFP scale parameter T_{it} stays at the first year level for all sectors and for all countries. The calibration results under the two counterfactual cases are presented in column 3 and column 4 of table 2. In column 3, I assume $\tau_{ijt} = \hat{\tau}_{ij,1995}$, and assume other parameters do not change except for production side structural change elasticities. Column 3 of table 2 suggests that the elasticities of I-I supply, I-I demand and price are slightly larger than the benchmark calibration result; and the difference of income elasticities are still trivial. In column 4, I assume $T_{it} = \hat{T}_{i,1995}$ and the rest of the study follows the first counterfactual study. I find as similar estimate results as in the first counterfactual study.

Following the new calibration results in column 3 and column 4 of table 2, I decompose the four effects in the same way as in the benchmark decomposition. I illustrate the result in figure 6 under the calibration in column 3; and illustrate the result in figure 7 under the calibration in column 4. Both figures suggest that the intermediate-input supply effect is the dominant effect on structural change. While the price effect is significantly large, it is much smaller than intermediate-input supply effect. According to the result, intermediate-input supply effect is more than twice as large as the price effect. Besides, the intermediate-input demand effect and income effect are trivial, compared to the two effects mentioned above. This result is qualita-

Figure 8: Outsourcing supply cost at sector-pair



The horizontal axis denotes year; the vertical axis shows the value of outsourcing supply cost. The values are normalized into 1 in the initial year. The four panels represent the outsourcing supply cost to the four sectors respectively. At each panel, the four curves show the outsourcing supply cost from the four sectors respectively.

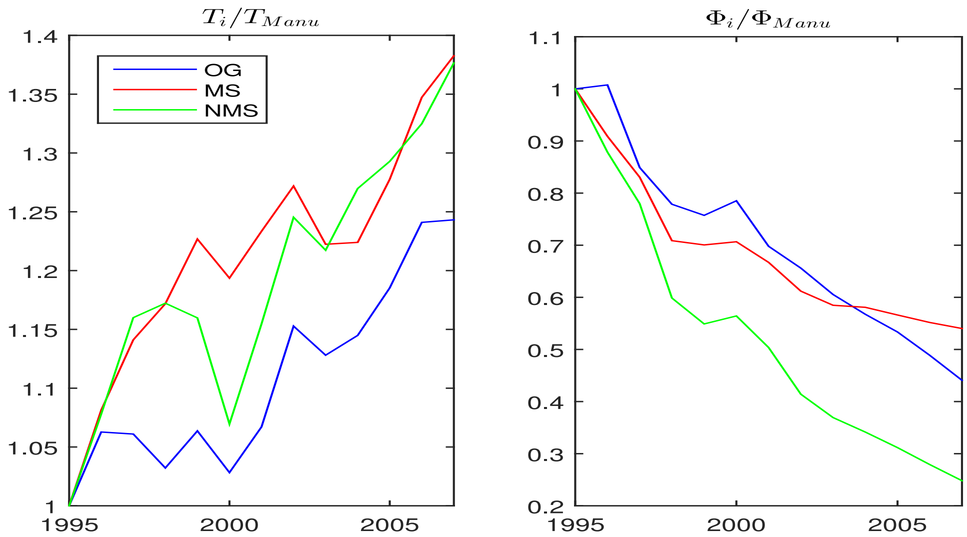
tively consistent with the benchmark decomposition result in figure 5.

In summary, the intermediate-input supply effects dominate the structural change from manufacturing to market service, under both the benchmark and the two simulation cases. The price effects are always significant, have a smaller magnitude than I-I supply effects. The intermediate-input demand elasticity is large and significant, but the demand effects on structural change are trivial. The income effects, however, are not always significant and they are trivial.

6. Quantifying the Intermediate-Input Supply Channel

Given the crucial intermediate input supply effect behind structural change, I quantify the intermediate-input supply channel in this section. I study two fundamental forces: outsourcing supply cost and TFP scale growth. I show how divergent of outsourcing supply cost and TFP scale growth

Figure 9: Relative TFP scale and efficiency



The horizontal axis denotes year; the vertical axis shows the value of relative TFP scale (left panel) and relative sectoral overall efficiency (right panel) over time. The values are normalized into 1 in the initial year. In both panels, the three lines show the relative values of another three sectors to manufacturing.

between the four sectors in section 6.1. Given these divergences, I show their quantitative implications in structural change from manufacturing to market service in section 6.2.

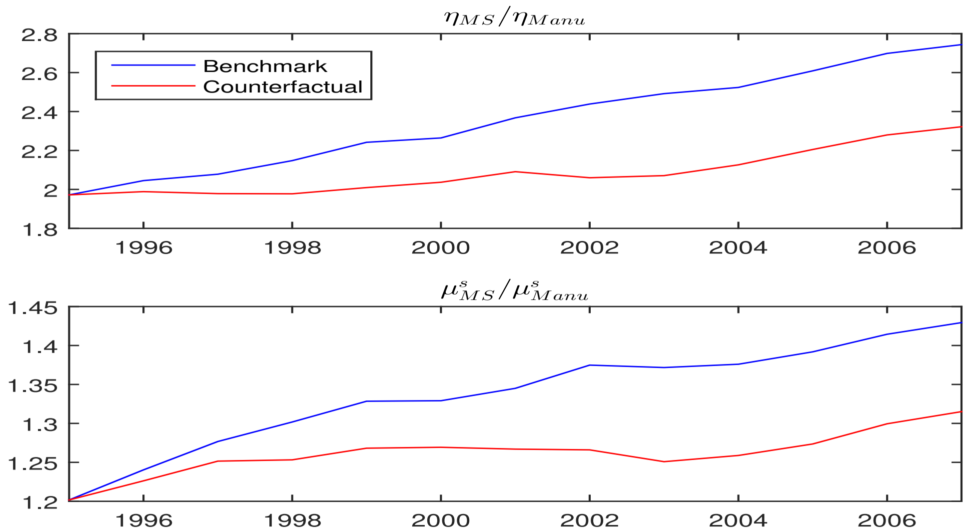
6.1 Source of Comparative Advantage

I examine the fundamental factors in this subsection. Given structural change from manufacturing to market service, it is crucial to know why this happens according to the model result. By examining the model generated primitives, it is readily to see how divergent are these primitives between manufacturing and market service. In the next subsection, I further explore whether these disparities generate structural change from manufacturing to market service.

I focus on trade and productivity primitives: outsourcing supply cost τ_{jit} and sectoral TFP scale T_{it} respectively. Lower outsourcing supply cost τ_{jit}, implies comparative advantage of broader outsourcing supply which further push up the I-I supply share of sector i in sector j. On the other hand, higher TFP scale T_{it}, implies a larger absolute advantage of outsourcing supply which further increase the I-I supply share of sector i in sector j. Therefore a sector with relatively decreasing outsourcing supply cost and relatively increasing TFP scale over time would increasingly supply I-I, which result in rising value-added share through the I-I supply channel.

Outsourcing Supply Cost I illustrate the time series pattern of outsourcing supply cost in figure 8. The four panels show the outsourcing supply cost to the four sectors respectively. In every panel, the curves show the average outsourcing supply cost of the 35 economies during 1995-

Figure 10: Role of outsourcing supply cost: market service to manufacturing



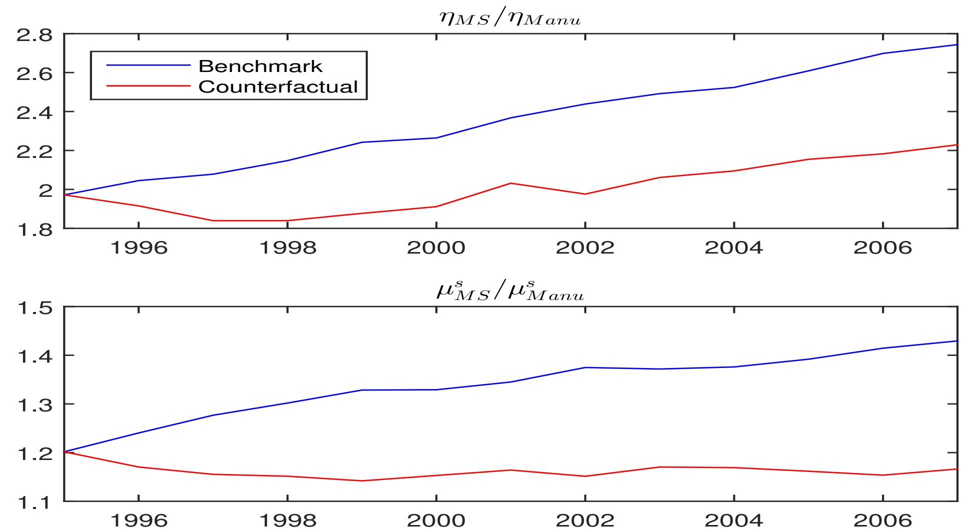
The horizontal axis denotes year, and the vertical axis shows the value of relative value added share in the upper panel and relative I-I supply multiplier in the lower panel. The blue line shows the actual data, and the red line shows the counterfactual values. At every year, the values are averaged on 35 economies.

2007. At each panel, the four curves show the outsourcing supply cost from the four sectors respectively. All the outsourcing supply costs are normalized to be 1 at the beginning year 1995. If I compare manufacturing and market service, the outsourcing supply cost of market service grows much more slowly than manufacturing. Actually, during the most period, the outsourcing supply cost of manufacturing grows faster than the other three sectors. It implies that compared to manufacturing, the other three sectors in particular service sectors, have an increasing comparative advantage for supplying I-I to downstream sectors.

TFP Scale I show the time series pattern of TFP scale in figure 9. The left hand panel shows the trend of relative TFP scale T_{it} of the other three sectors to manufacturing during 1995-2007; the right hand panel shows the trend of the relative overall efficiency Φ_{it}. By definition, the relative efficiency in log level is inversely proportional to relative price in log level: $\frac{\Phi_{it}}{\Phi_{it}} = \left(\frac{P_{it}}{P_{jt}}\right)^{-\zeta}$. At every year, the relative value is averaged over the 35 economies. The right hand panel suggests that the overall efficiency growth of manufacturing sector is larger than the other three sectors. This is consistent with many studies which find larger productivity growth in manufacturing than in service.[22] Surprisingly the left hand panel shows a very different picture for TFP scale growth. It suggests that the growth of manufacturing TFP scale is the slowest. Figure 9 suggests that the higher growth rate of manufacturing overall efficiency is probably due to access to higher TFP scale growth in the other three sectors. Because manufacturing becomes increasingly out-

[22] See evidence in Bernard and Jones (1996), Duarte and Restuccia (2010) and Uy, Yi and Zhang (2013).

Figure 11: Role of within-sector TFP: market service to manufacturing



The horizontal axis denotes year, and the vertical axis shows the value of relative value added share in the upper panel and relative I-I supply multiplier in the lower panel. The blue line shows the actual data, and the red line shows the counterfactual values. At every year, the values are averaged on 35 economies.

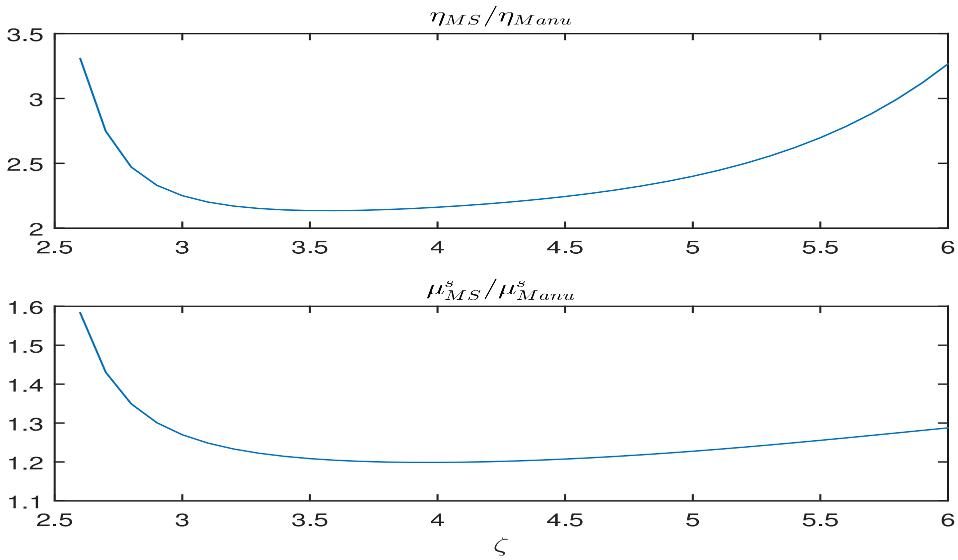
sources their non-core tasks to other sectors particularly services, and then buy back these I-I to manufacturing. Those outsourced intermediate inputs may convey higher productivity growth to manufacturing.

6.2 Why Structural Change Arises?

In this subsection, I illustrate the intermediate-input supply effect from the two comparative advantage forces following subsection 6.1. In particular, given the relatively rising comparative advantage of supplying I-I, the model implies that market service sector has larger growth in I-I supply multiplier and therefore growing value-added share relative to manufacturing. I quantify the I-I supply channel by constructing the following two counterfactual studies.

Counterfactual Setup In the first counterfactual study, I quantify the role of outsourcing supply cost. Suppose market service has as same growth path of outsourcing supply cost as manufacturing, I track the relative I-I supply multiplier and relative value-added share of market service to manufacturing. In the second counterfactual study, I quantify the role of TFP scale. In this case, suppose market service has as same growth path of TFP scale as manufacturing, I track the relative I-I supply multiplier and relative value-added share of market service to manufacturing. Given the disparity of the forces of comparative advantage in section 6.1, I show how important of these disparities for determining the growth pattern of relative I-I supply multiplier and relative value added share. In the counterfactual study, if market service has no growth in

Figure 12: Role of trade elasticity: market service to manufacturing



The horizontal axis shows values of trade elasticity ζ; the vertical axis shows the value of relative value added share in the upper panel, and relative I-I supply multiplier in the lower panel. The values are averaged on 35 economies at the final year 2007.

comparative advantage, the relative I-I supply multiplier and relative value-added share of market service to manufacturing are expected increase by a smaller proportion, compared to the benchmark case.

Role of Outsourcing Supply Cost and Role of TFP Scale I present the results of these two counterfactual studies in figure 10 and figure 11. The results are consistent with my expectation. Without the increasing comparative advantage, the relative I-I supply multiplier and value-added share of market service to manufacturing increases by a much smaller proportion than in the benchmark case. These results have two implications. First, the results suggest that one of the reasons that structural change arises from manufacturing to market service is due to larger growth in TFP scale and smaller growth in outsourcing supply cost in market service than manufacturing. As far as I know, this implication has not been explored by other structural change studies. Second, these results are consistent with the model. The model suggests that one of the critical channels driving the structural change is through I-I supply effect. Figure 10 and figure 11 suggest that relative I-I supply multiplier mainly moves in the same way as relative value-added share.

Role of Trade Elasticity Finally, I study the role of trade elasticity. Holding other parameters constant, I study how relative I-I supply multiplier and relative value-added share response to the parameter value of ζ. I present this result in figure 12. When trade elasticity is smaller than around 4.5, the result suggests that the smaller the trade elasticity the larger value of relative I-I supply multiplier and relative value-added share of market service to manufacturing. Smaller trade elasticity implies larger TFP heterogeneity between firms, which further implies more trade incentives. Since market service has growing comparative advantage relative to manufacturing, smaller trade elasticity amplifies the comparative advantage of market service. When trade elasticity is larger than 4.5, the relative I-I supply multiplier is almost stable, but the relative value-added share increases with trade elasticity. The relative price becomes larger as trade elasticity raises. The price effect supports the rising relative value-added share at a higher value of trade elasticity.

7. Conclusion

While the idea of producer interaction and the implication of input-output linkages has been discussed since at least Alfred Marshall, it has been ignored in most of the subsequent growth studies. Growth literature mainly discusses externalities of technological interaction as in Romer (1986) and Romer (1990). This paper recasts the great insight of Marshall, and follows the discussion line of Hirschman (1958) and Leontief (1974). I show that input-output linkages play a critical role in one of the most salient growth fact: structural change.

This paper underscores the mechanism of input-output linkages in driving structural change. In particular, the primary reason value-added share drops in manufacturing and raises in market service in this paper is due to growing comparative advantage in market service relative to manufacturing. Since both growth of outsourcing supply cost and TFP scale favors market service, this sector can supply increasingly more outsourced tasks than the manufacturing sector. In order to meet this increasing growth of outsourcing demand, economic resources transfer from manufacturing to market service. Recently rising external outsourcing activities support this mechanism as comprehensively documented by Weil (2014).

The mechanism of input-output linkages in this paper complements the structural change literature which mainly focuses on price and income effects. In this paper, I do not destroy price effects and income effects. In particular, for the price effects, this paper shows that the price effects is one of the essential effects on structural change. On top of final demand, I highlight the crucial role of intermediate-input supply and demand for determining structural change. In contrast, these interdependent associations between producers are ignored by most structural change studies. Hence I take this paper making an important contribution to extending the structural change literature to the producer interaction mechanism.

Given structural change reflecting intersector outsourcing, this paper has different implication on TFP growth. That is, the TFP growth slow-down as many people worry about through structural change may be overstated. According to price effects, structural change generally implies that economy transfers from higher TFP growth sector (manufacturing) to lower TFP growth sector (services). However, if structural change partially reflects outsourced economic activities from manufacturing to services, the TFP growth slowdown should be less worrisome. Because the same labor and capital should have similar productivity no matter whether they are employed in manufacturing or services. Essentially, the outsourced servicing tasks do not change too much, from manufacturing to services. On the other hand, as highlighted in section 6.1, the TFP scale growth rate of services is higher than manufacturing, though the overall efficiency growth is most abundant in manufacturing. It implies that services firm can have higher TFP growth, compared to the manufacturing firm. The outsourced labor and capital may benefit from the higher growth rate of firm-level TFP in services. The detail of this implication is obviously beyond the scope of this paper. It opens an interesting question to future study.

References

Abramovsky, Laura and Rachel Griffith, "Outsourcing and offshoring of business services: How important is ICT?," *Journal of the European Economic Association*, 2006, *4* (2-3), 594–601.

Acemoglu, Daron and Pablo D Azar, "Endogenous Production Networks," Technical Report, National Bureau of Economic Research 2017.

_ , Asuman Ozdaglar, and Alireza Tahbaz-Salehi, "Microeconomic origins of macroeconomic tail risks," *American Economic Review*, 2017, *107* (1), 54–108.

_ , Vasco M Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi, "The network origins of aggregate fluctuations," *Econometrica*, 2012, *80* (5), 1977–2016.

Antras, Pol and Davin Chor, "On the Measurement of Upstreamness and Downstreamness in Global Value Chains," Technical Report, National Bureau of Economic Research 2018.

Balk, Bert M, "On the relation between gross output–and value added–based productivity measures: The importance of the Domar factor," *macroeconomic dynamics*, 2009, *13* (S2), 241–267.

Ballester, Coralio, Antoni Calvó-Armengol, and Yves Zenou, "Who's who in networks. Wanted: The key player," *Econometrica*, 2006, *74* (5), 1403–1417.

Baqaee, David Rezza and Emmanuel Farhi, "The Macroeconomic Impact of Microeconomic Shocks: Beyond Hulten's Theorem," Technical Report, National Bureau of Economic Research 2017.

Bartelme, Dominick and Yuriy Gorodnichenko, "Linkages and economic development," Technical Report, National Bureau of Economic Research 2015.

Berlingieri, Giuseppe, "Outsourcing and the rise in services," 2013.

Bernard, Andrew B and Charles I Jones, "Comparing apples to oranges: productivity convergence and measurement across industries and countries," *The American Economic Review*, 1996, pp. 1216–1238.

_ , Teresa C Fort, Valerie Smeets, and Frederic Warzynski, "Offshoring and Reorganization," Technical Report, Technical Report, Tuck School of Business 2017.

Boehm, Johannes, "The Impact of Contract Enforcement Costs on Value Chains and Aggregate Productivity," 2018.

Boppart, Timo, "Structural change and the Kaldor facts in a growth model with relative price effects and non-Gorman preferences," *Econometrica*, 2014, *82* (6), 2167–2196.

Caliendo, Lorenzo and Fernando Parro, “Estimates of the Trade and Welfare Effects of NAFTA,” *The Review of Economic Studies*, 2015, *82* (1), 1–44.

_ , _ , and Aleh Tsyvinski, “Distortions and the Structure of the World Economy,” Technical Report, National Bureau of Economic Research 2017.

Caron, Justin, Thibault Fally, and James R Markusen, “International trade puzzles: A solution linking production and preferences,” *The Quarterly Journal of Economics*, 2014, *129* (3), 1501–1552.

Coase, Ronald H, “The nature of the firm,” *economica*, 1937, *4* (16), 386–405.

Comin, Diego A, Danial Lashkari, and Martí Mestieri, “Structural change with long-run income and price effects,” Technical Report, National Bureau of Economic Research 2018.

Deaton, Angus, “A reconsideration of the empirical implications of additive preferences,” *The Economic Journal*, 1974, *84* (334), 338–348.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum, “Global rebalancing with gravity: measuring the burden of adjustment,” *IMF Staff Papers*, 2008, *55* (3), 511–540.

Domar, Evsey D, “On the measurement of technological change,” *The Economic Journal*, 1961, *71* (284), 709–729.

Duarte, Margarida and Diego Restuccia, “The role of the structural transformation in aggregate productivity,” *The Quarterly Journal of Economics*, 2010, *125* (1), 129–173.

_ and _ , “Relative Prices and Sectoral Productivity,” Technical Report, National Bureau of Economic Research 2017.

Dustmann, Christian, Bernd Fitzenberger, Uta Schönberg, and Alexandra Spitz-Oener, “From sick man of Europe to economic superstar: Germany’s resurgent economy,” *The Journal of Economic Perspectives*, 2014, *28* (1), 167–188.

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

Fadinger, Harald, Christian Ghiglino, and Mariya Teteryatnikova, “Income Differences, Productivity and Input-Output Networks,” 2017.

Feenstra, Robert C, “Integration of trade and disintegration of production in the global economy,” *Journal of economic Perspectives*, 1998, *12* (4), 31–50.

Fieler, Ana Cecilia, "Nonhomotheticity and bilateral trade: Evidence and a quantitative explanation," *Econometrica*, 2011, *79* (4), 1069–1101.

Garcia-Santana, Manuel, Josep Pijoan-Mas, and Lucciano Villacorta, "Investment demand and structural change," 2016.

Goldschmidt, Deborah and Johannes F Schmieder, "The rise of domestic outsourcing and the evolution of the German wage structure," *The Quarterly Journal of Economics*, 2017, p. qjx008.

Herrendorf, Berthold, Richard Rogerson, and Ákos Valentinyi, "Growth and structural transformation," Technical Report, National Bureau of Economic Research 2013.

_ , _ , and Akos Valentinyi, "Two perspectives on preferences and structural transformation," *The American Economic Review*, 2013, *103* (7), 2752–2789.

Hirschman, Albert O, "The strategy of economic development," Technical Report 1958.

Hu, Hang, "Input-Output Linkage and Productivity Measurement," *Working Paper*, 2017.

_ , "Structural Change in Global Value Chains," *Working Paper*, 2018.

Inklaar, Robert and Marcel P. Timmer, "The Relative Price of Services," *Review of Income and Wealth*, 2014, *60* (4), 727–746.

Jacks, David S and John P Tang, "Trade and Immigration, 1870-2010," Technical Report, National Bureau of Economic Research 2018.

Johnson, Robert C, "Measuring Global Value Chains," Technical Report, National Bureau of Economic Research 2017.

Jones, Charles I, "Intermediate goods and weak links in the theory of economic development," *American Economic Journal: Macroeconomics*, 2011, *3* (2), 1–28.

_ , "Misallocation, economic growth, and input-output economics," Technical Report, National Bureau of Economic Research 2011.

Jr, Robert E Lucas, "Adaptive behavior and economic theory," *Journal of Business*, 1986, pp. S401–S426.

_ , "On the mechanics of economic development," *Journal of monetary economics*, 1988, *22* (1), 3–42.

Katz, Lawrence F and Alan B Krueger, "The rise and nature of alternative work arrangements in the United States, 1995-2015," Technical Report, National Bureau of Economic Research 2016.

Kehoe, Timothy J, Kim J Ruhl, and Joseph B Steinberg, "Global imbalances and structural change in the United States," *Journal of Political Economy*, 2018, *126* (2), 000–000.

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

Leontief, Wassily, "Sructure of the world economy: outline of a simple input-output formulation," *The American Economic Review*, 1974, pp. 823–834.

Liu, Ernest, "Industrial policies and economic development," 2017.

Matsuyama, Kiminori, "Engel's Law in the Global Economy: Demand-induced Patterns of Structural Change, Innovation, and Trade," 2017.

Mogstad, Magne, Emmanuel Dhyne, Ayumu Kikkawa, Felix Tintelnot et al., "Trade and Domestic Production Networks," in "2017 Meeting Papers" number 381 Society for Economic Dynamics 2017.

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

Nunn, Nathan, "Relationship-specificity, incomplete contracts, and the pattern of trade," *The Quarterly Journal of Economics*, 2007, *122* (2), 569–600.

Oberfield, Ezra, "A theory of input-output architecture," *Unpublished manuscript*, 2017.

on Trade, United Nations Conference and Development, *World investment report 2013: Global value chains: Investment and trade for development*, UN, 2013.

Rodrik, Dani, "Premature deindustrialization," *Journal of Economic Growth*, 2016, *21* (1), 1–33.

Romer, Paul M, "Increasing returns and long-run growth," *Journal of political economy*, 1986, *94* (5), 1002–1037.

_ , "Endogenous technological change," *Journal of political Economy*, 1990, *98* (5, Part 2), S71–S102.

Song, Zheng, Kjetil Storesletten, and Fabrizio Zilibotti, "Growing like china," *American economic review*, 2011, *101* (1), 196–233.

Sposi, Michael, "Evolving comparative advantage, sectoral linkages, and structural change," *Journal of Monetary Economics*, 2018.

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

Weil, David, *The fissured workplace*, Harvard University Press, 2014.

Williamson, Oliver E, *The economic institutions of capitalism: firms, markets, relational contracting*, Free Press, 1985.

Xu, Yang, “Structural Change and the Skill Premium in a Global Economy,” 2018.

Appendix

A. Proofs of the Propositions

A.1 Proposition 1

Proof of Proposition 1. Equilibrium Solution of Key Variables

I start with consumer's problem. The two constraint equations (2) and (3) are transformed to become the following equations:

$$\sum_{i=1}^{n} \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\epsilon_i - \varepsilon}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}} = 1 \tag{A.1}$$

$$\sum_{i=1}^{n} P_{it} C_{it} = E_t; \text{ where } E_t = w_t L_t + (1+r_t)\mathcal{A}_t - \mathcal{A}_{t+1} \tag{A.2}$$

The Lagrangian equation is given by

$$\mathcal{L} = C_t + \rho_t \left[1 - \sum_{i=1}^{n} \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\epsilon_i - \varepsilon}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}} \right] + \omega_t \left(E_t - \sum_{i=1}^{n} P_{it} C_{it} \right)$$

The corresponding first order condition with respect to sectoral consumption is given by

$$P_{it} C_{it} = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon} \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\epsilon_i - \varepsilon}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}} \tag{A.3}$$

Given equation (A.3), I have the following equation:

$$\sum_{i=1}^{n} P_{it} C_{it} = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon} \sum_{i=1}^{n} \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\epsilon_i - \varepsilon}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}} = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon}$$

The second equality holds by applying the fact from equation (A.1). Define $P_t C_t = \sum_{i=1}^{n} P_{it} C_{it}$, then I have

$$P_t C_t = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon} \tag{A.4}$$

Substitute equation (A.4) to equation (A.3), I have the following

$$\frac{P_{it} C_{it}}{P_t C_t} = \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\epsilon_i - \varepsilon}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}}$$

Therefore the optimal intratemporal sectoral consumption allocation C_{it} is solved as in equation (20)

Based on equation (20), I derive the consumption share as in equation (19). Then given equation (19), we have the following:

$$\sum_{i=1}^{n} \frac{P_{it}C_{it}}{P_t C_t} = \sum_{i=1}^{n} \Omega_i \left(\frac{P_{it}}{P_t}\right)^{1-\varepsilon} C_t^{\epsilon_i - 1} = 1$$

Accordingly the aggregate price index is derived as in equation (22).

Next I turn to the producer's problem at sectoral level. The derivation of sectoral gross output equation (21) and the corresponding aggregate price index equation (23) follow exactly the same way as solving the optimal sectoral consumption and aggregate price above. We could think of a social planner which maximizes intratemporal aggregate gross output at every time period t.

Given the input-output linkage matrix B, $B_{jit} \equiv \frac{P_{ijt}^X X_{ijt}^X}{P_{it}Q_{it}}$, the sectoral gross production budget constraint equation in section 3.3 becomes to

$$P_{jt}C_{jt} + \sum_{i=1}^{n} B_{jit}P_{it}Q_{it} = P_{jt}Q_{jt} \tag{A.5}$$

Divide both sides of the equation (A.5) by nominal GDP or aggregate value added $P_{Yt}Y_t$, the budget constraint could be transformed by the following equation.

$$\gamma_{jt} \equiv \frac{P_{jt}Q_{jt}}{P_{Yt}Y_t} = \frac{P_{jt}C_{jt}}{P_{Yt}Y_t} + \sum_{i=1}^{n} B_{jit}\frac{P_{it}Q_{it}}{P_{Yt}Y_t}$$

Following the equation above, we can further derive budget constraint as

$$\gamma_t = \lambda_t + B_t \gamma_t \tag{A.6}$$

Then we can easily solve equation (A.6), and get the vector result of Domar weight as in equation (18). Given the solution of Domar weight, the value added share is simply solved by following the fact that $\eta_{it} = (1 - \sigma_{it})\gamma_{it}$, where $\sigma_{it} \equiv \sum_{j=1}^{n} \frac{P_{ijt}^X X_{ijt}^X}{P_{it}Q_{it}}$.

Assume there is a representative producer which maximizes the sectoral gross profit by optimally allocate sectoral labor and capital. Given the Cobb-Douglas assumption of sectoral gross output equation (C.1), the first order condition of capital and labor are given by

$$(1 - \sigma_{it})\alpha \frac{P_{it}Q_{it}}{K_{it}} = r \tag{A.7}$$

$$(1 - \sigma_{it})(1 - \alpha)\frac{P_{it}Q_{it}}{L_{it}} = w \tag{A.8}$$

Equation (A.7) and (A.8), together with the fact that $\sum_{i=1}^{n}(1-\sigma_{it})\gamma_{it}=1$ implies that

$$K_{it} = (1-\sigma_{it})\gamma_{it}K_t \tag{A.9}$$

$$L_{it} = (1-\sigma_{it})\gamma_{it}L_t \tag{A.10}$$

Therefore the employment share is solved as in equation (17).

QED.

A.2 Proposition 2

Proof of Proposition 2. Structural Change

Equation (24) follows the logarithm transformation of equation (20) with respect to sector i and sector j. Make a logarithm transformation of equation (20) and (21), I have the following two equations:

$$\log\frac{C_{it}}{C_{jt}} = \log\frac{\Omega_i}{\Omega_j} - \varepsilon\log\frac{P_{it}}{P_{jt}} + \log\frac{C_t^{\epsilon_i}}{C_t^{\epsilon_j}} \tag{A.11}$$

$$\log\frac{Q_{it}}{Q_{jt}} = \kappa\log\frac{\Psi_{it}}{\Psi_{jt}} - \rho\log\frac{P_{it}}{P_{jt}} + \log\frac{Q_t^{\xi_i}}{Q_t^{\xi_j}} \tag{A.12}$$

Based on equation (A.11) and equation (A.12), I have the following equations:

$$\log\frac{\lambda_{it}}{\lambda_{jt}} = \log\frac{\Omega_i}{\Omega_j} + (1-\varepsilon)\log\frac{P_{it}}{P_{jt}} + (\epsilon_i - \epsilon_j)\log C_t$$

$$\log\frac{\gamma_{it}}{\gamma_{jt}} = \kappa\log\frac{\Psi_{it}}{\Psi_{jt}} + (1-\rho)\log\frac{P_{it}}{P_{jt}} + (\xi_i - \xi_j)\log Q_t$$

Equation (17) implies that I can transform the relative employment share and value added share in logarithm as the following way

$$\begin{aligned}\log\frac{l_{it}}{l_{jt}} = \log\frac{\eta_{it}}{\eta_{jt}} &= \log\frac{1-\sigma_{it}}{1-\sigma_{jt}} + \log\frac{\gamma_{it}}{\gamma_{jt}} \\ &= \log\frac{1-\sigma_{it}}{1-\sigma_{jt}} + \kappa\log\frac{\Psi_{it}}{\Psi_{jt}} + (1-\rho)\log\frac{P_{it}}{P_{jt}} + (\xi_i - \xi_j)\log Q_t\end{aligned}$$

Therefore I arrive at equation (25).

QED.

A.3 Proposition 3

Proof of Proposition 3. Endogenous Input-Output Linkage and Sectoral Prices

The probability of in-house price larger and equal to a constant value p is given by

$$\begin{aligned}\Pr(P^H_{ijt}(\omega) \geq p) &= \Pr\left(\frac{\nu}{\nu-1}\frac{\tilde{r}}{a^H_{ijt}(\omega)} \geq p\right)\\ &= \Pr\left(a^H_{ijt}(\omega) \leq \frac{\nu}{\nu-1}\frac{\tilde{r}}{p}\right)\end{aligned}$$

The above inequality together with equation (11) implies that the CDF of in-house price is derived by

$$G^H_{ijt}(p) \equiv \Pr(P^H_{ijt}(\omega) \leq p) = 1 - \exp\left[-A_{it}\left(\frac{\nu}{\nu-1}\frac{\tilde{r}}{p}\right)^{-\zeta}\right] \tag{A.13}$$

Similar the CDF of outsourcing price from sector j at time period t is derived as

$$G^X_{ijt}(p) \equiv \Pr(P^X_{ijt}(\omega) \leq p) = 1 - \exp\left[-A_{jt}\left(\frac{\nu}{\nu-1}\frac{\tau_{ijt}P_{jt}}{p}\right)^{-\zeta}\right] \tag{A.14}$$

According to equation (13), the probability of intermediate input variety price which is not larger than p the producer of sector i actually pay is given by

$$\begin{aligned}\Pr(P^*_{ijt}(\omega) \leq p) &= 1 - \Pr(P^*_{ijt}(\omega) \geq p)\\ &= 1 - \Pr(P^H_{ijt}(\omega) \geq p, P^X_{ijt}(\omega) \geq p)\\ &= 1 - (1 - \Pr(P^H_{ijt}(\omega) \leq p))(1 - \Pr(P^X_{ijt}(\omega) \leq p))\end{aligned}$$

Substitute equation (A.13) and equation (A.14) to the above inequality, we can derive the CDF of intermediate input variety price producer of sector i actually pay, which is given by

$$G_{ijt}(p) \equiv \Pr(P^*_{ijt}(\omega) \leq p) = 1 - \exp(-\Phi_{ijt}p^{\zeta}) \tag{A.15}$$

Here $\Phi_{ijt} = \left(\frac{\nu}{\nu-1}\right)^{-\zeta}(A_{it}\tilde{r}^{-\zeta} + A_{jt}(\tau_{ijt}P_{jt})^{-\zeta})$.

Let $\pi_{ijt}(\omega)$ be the unconditional probability of variety ω which is sourced from sector j to sector i. This probability is solved as following:

$$\begin{aligned}
\pi_{ijt}(\omega) &= \text{Pr}(P^X_{ijt}(\omega) \leq P^H_{ijt}(\omega)) \\
&= \int_0^\infty \text{exp}\left[- A_{it}\left(\frac{\tilde{r}}{p}\right)^{-\zeta}\left(\frac{\nu}{\nu-1}\right)^{-\zeta}\right] dG^X_{ijt}(p) \\
&= \int_0^\infty \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}\zeta p^{\zeta-1}\text{exp}(-\Phi_{ijt}p^\zeta)dp \\
&= \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}\frac{1}{\Phi_{ijt}}\int_0^\infty \zeta p^{\zeta-1}\Phi_{ijt}\text{exp}(-\Phi_{ijt}p^\zeta)dp \\
&= \frac{A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}}{A_{it}\tilde{r}^{-\zeta} + A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}} \qquad \text{(A.16)}
\end{aligned}$$

This is the probability that sector i outsources from sector j with any randomly chosen variety ω. This is also the fraction of $\omega \in [0,1]$ which sector i outsources from sector j rather than produce in house. Moerover equation (A.15) also implies that the probability does not depend on intermediate input variety, that is, equation (A.15) suggests that

$$\pi_{ijt}(\omega) = \pi_{ijt}$$

The conditional CDF of price that producer of sector i outsources from producer of sector j is given by

$$\begin{aligned}
G_{ijt|X}(p) &= \text{Pr}(P^X_{ijt}(\omega) \leq p | P^X_{ijt}(\omega) \leq P^H_{ijt}(\omega)) \\
&= \frac{1}{\pi_{ijt}}\int_0^p \text{Pr}(z \leq P^H_{ijt}(\omega))dG^X_{ijt}(z) \\
&= \frac{1}{\pi_{ijt}}\int_0^p \text{exp}\left[- A_{it}\left(\frac{\tilde{r}}{z}\right)^{-\zeta}\left(\frac{\nu}{\nu-1}\right)^{-\zeta}\right] dG^X_{ijt}(z) \\
&= \frac{1}{\pi_{ijt}}\int_0^p \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}\zeta z^{\zeta-1}\text{exp}(-\Phi_{ijt}z^\zeta)dz \\
&= \left(\frac{\nu}{\nu-1}\right)^{-\zeta} \frac{A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}}{\pi_{ijt}}\frac{1}{\Phi_{ijt}}\int_0^p \zeta z^{\zeta-1}\Phi_{ijt}\text{exp}(-\Phi_{ijt}z^\zeta)dz \\
&= \int_0^p \zeta z^{\zeta-1}\Phi_{ijt}\text{exp}(-\Phi_{ijt}z^\zeta)dz \\
&= \text{Pr}(P^*_{ijt}(\omega) \leq p) \\
&= G_{ijt}(p) \qquad \text{(A.17)}
\end{aligned}$$

Therefore the distribution of intermediate input outsourcing price of sector i from sector j is exactly the same as the general price distribution in sector i.

Assume the representative producer minimizes the total intermediate input cost at every sector pair ij, subject to the intermediate input pair equation (6). Given the aggregate intermediate input of sector i from sector j is a CES sum of individual intermediate input variety as in equation (6), the equilibrium quantity and aggregate price of individual intermediate input variety are derived by the following two equations.

$$X_{ijt}(\omega) = \left(\frac{P_{ijt}(\omega)}{P_{ijt}}\right)^{-\nu} X_{ijt} \tag{A.18}$$

$$P_{ijt} = \left(\int_0^1 P_{ijt}(\omega)^{1-\nu} d\omega\right)^{\frac{1}{1-\nu}} \tag{A.19}$$

Based on equation through (A.17) to (A.19), the total spending of outsourcing of sector i from sector j at time period t is given by

$$\begin{aligned}
P^X_{ijt} X^X_{ijt} &= \int_0^1 P^X_{ijt}(\omega) X^X_{ijt}(\omega) d\omega \\
&= \int_{1\{P^X_{ijt}(\omega) = P^*_{ijt}(\omega)\}} P^*_{ijt}(\omega) X_{ijt}(\omega) d\omega \\
&= \int_{1\{P^X_{ijt}(\omega) = P^*_{ijt}(\omega)\}} \left(\frac{P^*_{ijt}(\omega)}{P_{ijt}}\right)^{1-\nu} P_{ijt} X_{ijt}(\omega) d\omega \\
&= P^{\nu-1}_{ijt} P_{ijt} X_{ijt} \int_{1\{P^X_{ijt}(\omega) = P^*_{ijt}(\omega)\}} P^{*(1-\nu)}_{ijt}(\omega) d\omega \\
&= P^{\nu-1}_{ijt} P_{ijt} X_{ijt} E\Big[P^{*(1-\nu)}_{ijt}(\omega) | \omega \in 1\{P^X_{ijt}(\omega) = P^*_{ijt}(\omega)\}\Big] \Pr(\omega \in 1\{P^X_{ijt}(\omega) = P^*_{ijt}(\omega)\}) \\
&= P^{\nu-1}_{ijt} P_{ijt} X_{ijt} E\Big[P^{*(1-\nu)}_{ijt}(\omega)\Big] \pi_{ijt} \\
&= P^{\nu-1}_{ijt} P_{ijt} X_{ijt} P^{1-\nu}_{ijt} \pi_{ijt} \\
&= P_{ijt} X_{ijt} \pi_{ijt}
\end{aligned} \tag{A.20}$$

Equation (A.20) implies that the outsourcing share of intermediate input of sector i from sector j equals the unconditional probability of outsourcing variety from sector j by sector i. That is,

$$\frac{P^X_{ijt} X^X_{ijt}}{P_{ijt} X_{ijt}} = \pi_{ijt} = \frac{A_{jt}(\tau_{ijt} P_{jt})^{-\zeta}}{A_{it} \tilde{r}^{-\zeta} + A_{jt}(\tau_{ijt} P_{jt})^{-\zeta}} \tag{A.21}$$

Assume the representative producer of every sector also minimizes the total matrial cost or total intermediate input cost from all other sectors, subject to the sectoral gross output function (5). Given the CES sum of sectoral gross output, the equilibrium quantity of intermediate input is given by

$$X_{ijt} = \left(\frac{P_{ijt}}{P_{it}}\right)^{-(1+\theta)} Q_{it} \tag{A.22}$$

The corresponding equilibrium price of sector i is given by equation (27). Equation (A.22) implies that the equilibrium share of intermediate input of sectoral piar ij to sector i is given by

$$\frac{P_{ijt}X_{ijt}}{P_{it}Q_{it}} = \left(\frac{P_{ijt}}{P_{it}}\right)^{-\theta} \tag{A.23}$$

Therefore equation (A.21) and equation (A.23) together imply that equation (26) holds in equilibrium.

We can derive the intermediate input price P_{ijt} by following equation (A.19) and the CDF formula of P_{ijt} from equation (A.15). Specifically we have the following solution:

$$\begin{aligned} P_{ijt}^{1-\nu} &= \int_0^1 P_{ijt}(\omega)^{1-\nu} d\omega \\ &= \int_0^\infty p^{1-\nu} dG_{ijt}(p) \\ &= \int_0^\infty p^{1-\nu} \Phi_{ijt} \zeta p^{\zeta-1} \text{exp}(-\Phi_{ijt} p^{\zeta}) dp \end{aligned}$$

Denote $z = \Phi_{ijt} p^{\zeta}$, then we have $dz = \Phi_{ijt} \zeta p^{\zeta-1} dp$. Use this definition, we can further solve P_{ijt} by following the above equation.

$$\begin{aligned} P_{ijt}^{1-\nu} &= \int_0^\infty p^{1-\nu} \text{exp}(-\Phi_{ijt} p^{\zeta}) dz \\ &= \int_0^\infty \left(\frac{z}{\Phi_{ijt}}\right)^{\frac{1-\nu}{\zeta}} \text{exp}(-z) dz \\ &= \Phi_{ijt}^{-\frac{1-\nu}{\zeta}} \int_0^\infty z^{\frac{1-\nu}{\zeta}+1-1} \text{exp}(-z) dz \\ &= \Phi_{ijt}^{-\frac{1-\nu}{\zeta}} \Gamma\left(\frac{1-\nu}{\zeta} + 1\right) \end{aligned} \tag{A.24}$$

Equation (A.24) with definition of Φ_{ijt} from equation (A.15) implies that equation (28) holds in equilibrium.

QED.

B. Producer Side Mechanism in a Simple Example

In this subsection I illustrate the intermediate input supply and demand mechanism through a simple example. This example is capable of explaining the mechanism.

Assume an economy has two sectors: sector 1 and sector 2. Each sector has a representative producer who produces sector specific gross output. The gross output is either supplied to consumer as final consumption, or is supplied to another sector as intermediate input. For

Benchmark					Structural change				
	IIS1	IIS2	C	Q		IIS1	IIS2	C	Q
IID1	1	1	2	4	IID1	1	**2**	2	**5**
IID2	1	1	2	4	IID2	1	1	2	4
VA	2	2			VA	**3**	**1**		
Q	4	4			Q	**5**	4		

Table 3: Intermediate input mechanism in structural change

instance, we can think about these two sectors as electronic product sector and accounting service sector. On one hand electronic manufacturer requires accounting service to produce; on the other hand accounting service company also requires electronic product to provide accounting service. Their product or service are consumed by consumer as well.

Table 3 summarizes one example of structural change. In the benchmark panel, I show the gross output (Q), consumption (C), value added (VA), intermediate input supply (IIS) and intermediate input demand (IID) before the structural change. This table mimics a two sector input-output table. The first two columns show the demand side of production; and the first two rows show the supply side of production. On demand side, each sector outsources 1 unit of intermediate input within the sector;[23] outsources 1 unit of intermediate input to another sector; and produces 2 units of value added. On supply side, each sector supplies 1 unit of intermediate input to itself; supplies 1 unit of intermediate input to another sector; and supply 2 units of final goods to consumer. Both sectors produce 4 units of gross output in the benchmark case.

Suppose there is a shock in outsourcing supply cost, such that producer of sector 1 supplies I-I to sector 2 at lower cost than before.[24] After the shock, producer of sector 2 has incentive to buy 1 more unit of intermediate input from sector 1; simultaneously producer of sector 1 is more profitable to supply 1 more unit of intermediate input to sector 2. For instance, the de-unionization policy in European manufacturing sector substantially reduce the outsourcing cost from service sector, which induces manufacturers to outsource some of their traditional service activities, such as janitorial service, security and logistics, to specialized service companies.

In this case, sector 2 now relies more on intermediate input outsourcing, therefore does not

[23]If there are many disaggregated industries under the broad sector, the interindustrial trade of I-I is taken as within broad sector outsourcing.

[24]Here I hold constant income and producer basic price. Constant income is easy to see since aggregate value added is 4 in both cases. Since there is only trade cost shock, the producer basic receiving price should not change given everything else exactly the same as before. But the consumer price and producer purchasing price definitely change in this case. Hence here I try to partially turn off consumer side mechanisms.

need to produce as much value added as in the benchmark case. We could argue that producer in sector 2 substitutes the low skill service production, from production in house to outsourcing. Sector 2 shifts out some of her labor and capital. Sector 2 outsources the service activities to sector 1, and focus on the core manufacturing production which produces value added in 1 unit. In contrast, sector 1 now is responsible for supplying more intermediate inputs to sector 2. Sector 1 accepts the outsourcing activities from sector 2, therefore sector 1 now needs to produce more value added in order to meet the additional I-I supply responsibility. Not surprisingly, labor and capital would shift out from sector 2 to sector 1, to meet the relative change of value added production between these two sectors.

In effect, the shock of outsourcing supply cost leads to change pattern of intersectoral trade of intermediate input, which finally results in structural change of primary input and value added. This example has three implications. First, the simple mechanism in this example is consistent with the general mechanism in section **??**. That is, since sector 2 becomes relatively more intermediate input demandable; and sector 1 becomes relatively more intermediate input suppliable, the structural change happens from sector 2 to sector 1 at the end. Second and not surprisingly, this example is consistent with the main fact in section 2.2. That is, when sector 1 becomes more I-I suppliable (larger I-I supply multiplier), sector 1 has larger value added share; when sector 2 becomes more I-I demandable (larger I-I demand multiplier), sector 2 has smaller value added share. Third, this example motivates the model set-up in the next section. That is, the shock of outsourcing supply cost is an important factor to generate change in intersectoral trade of intermediate input. In the next section, I directly model the endogenous path of intersectoral trade of intermediate input on outsourcing cost.

C. Two Notions of Equivalent Sectoral Production

There are two different notions about how sectoral gross outputs are produced. In the first notion, sectoral value added and the corresponding composite of material together contribute to production of sectoral gross output. The value added attributes to primary input, such as capital and labor. Based on the first notion, people normally assume that sectoral gross output is produced in a constant return to scale Cobb-Douglas function form

$$Q_{it} = A_{it} K_{it}^{(1-\sigma_{it})\alpha} L_{it}^{(1-\sigma_{it})(1-\alpha)} M_{it}^{\sigma_{it}} \tag{C.1}$$

The term M_{it} represents the composite of outsourced intermediate inputs or material good from all potential sectors.

In the second notion, sectoral gross output is directly taken as composite of individual sectoral intermediate inputs from all sectors. Here I need to differentiate the source of intermediate input between from outsourcing and production in-house (insourcing). If producers in sector i directly buy intermediate input from sector j, I define it as intermediate input outsourcing. For the same intermediate input which sector j is able to produce, but producer in sector i chooses to produce it by hiring labor and capital without buying from sector j I define this situation as intermediate input production in-house.[25] In the first notion, the intermediate input outsourcing is summarised by M_{it}; and the intermediate input production in-house is summarised by value added terms: K_{it} and L_{it}. In the second notion we skip this intermediary terms, and directly mapping outsourcing and in-house production of intermediate inputs into sectoral gross output Q_{it}.

The upshot is that the two notions are essentially equivalent at nominal terms. For the same production process, people have two angles to see the production. For the first notion, people see the production process in a very aggregate way. The gross output is produced by material and value added. For the second notion, people see the production process in a disaggregate way. The whole production process of gross output is taken as aggregation of firm level input variety. Every variety is either outsourced to the corresponding sector, or is being produced in-house. Finally all the outsourced tasks are summarized as matrial; and all the production in-house are summarized as value added.

Equation (C.1) under the first notion is also equivalent to the sectoral production equation in the last section. Actually the partial equilibrium model holds if I turn off all the endogenous structure below, and aggregate production in-house into value added. Therefore the general equilibrium model in this section only extends the partial equilibrium model in the last section, from the point view of sectoral nominal value at every term. I do not deviate from the partial equilibrium model. The first notion is comprehensive at sector level, which is useful to depict sectoral level variables. In this model, the first notion is mainly used to depict sector level structural term as summarized in proposition 1. The second notion is specific at individual sectoral level intermediate input production, which could be further extended to study firm level decision of intermediate input outsourcing and production in-house.

Actually the two notions of sectoral gross output production are connected by the following equations:

$$\sum_{j=1}^{n} P^H_{ijt} X^H_{ijt} = w_{it} L_{it} + r_{it} K_{it}$$

$$\sum_{j=1}^{n} P^X_{ijt} X^X_{ijt} = P_{Mit} M_{it}$$

[25]Here the producer decision is whether outsourcing or production in-house (Boehm 2018). In trade literature, the decision is whether offshoring (including FDI and foreign outsourcing) or producing domestically (including production in-house and domestic outsourcing (Bernard et al. 2017). In firm producing organization literature, the decision is make-or-buy (Williamson 1985).

Again these two notions of production are exactly the same since we have the following equivalence:

$$P_{it}Q_{it} = \sum_{j=1}^{n} P_{ijt}X_{ijt} = \sum_{j=1}^{n} P_{ijt}^{X}X_{ijt}^{X} + \sum_{j=1}^{n} P_{ijt}^{H}X_{ijt}^{H} = P_{Mit}M_{it} + w_{it}L_{it} + r_{it}K_{it} = P_{it}Q_{it}$$

D. Additional Results

This section shows the additional results to section 5. The main object is to check the robustness of the headline results in the following contexts.

D.1 US Long Run Data: 1947-2010

The quantitative result in section 5 is based on panel data of 35 major economies during short time period 1995-2007. A natural question would be whether the headline result holds in long run time series data. I seek to answer this question based on US long run data.

The input-output linkage data come from Input-Output Accounts Data in Bureau of Economic Analysis (BEA). I can find long run linkage data since 1947 in BEA. Following Herrendorf, Rogerson and Valentinyi (2013b), the individual industries are aggregated into three broad sectors: Agriculture, manufacturing and service. The sectoral price data come from Herrendorf, Rogerson and Valentinyi (2013b) which compute the three sectoral prices mainly based on data from National Income and Product Accounts (NIPA) and BEA.[26]

Given the US data, I replicate the benchmark decomposition exercise in upper panel of figure 13; and replicate the decomposition under counterfactual study 1 in lower panel of figure 13.[27] Given the long run time series data, I take the first difference to relative value added share and the four individual effects. Because the unit root test[28] suggests that these relevant variables in particular aggregate income are non-stationary. In both cases, the elasticity on I-I supply is significant at 1 percent level. The benchmark decomposition suggests that the I-I supply effet is not as big as the price effect. But the counterfactual decomposition suggests a very strong I-I supply effect on structural change from manufacturing to service. It implies that the endogeneity problem bias the OLS estimate in the benchmark case.

Very interestingly, the income effect is negative and sizable in both cases. In contrast, Herrendorf, Rogerson and Valentinyi (2013b) finds positive and small income effect. The main difference between Herrendorf, Rogerson and Valentinyi (2013b) and this paper is that, the con-

[26]See Herrendorf, Rogerson and Valentinyi (2013b) for the price data and the exact data sources.

[27]For the decomposition under counterfactual study, I keep the parameter values of ζ, θ and ν as same as in section 5.

[28]Here I use DickeyFuller test.

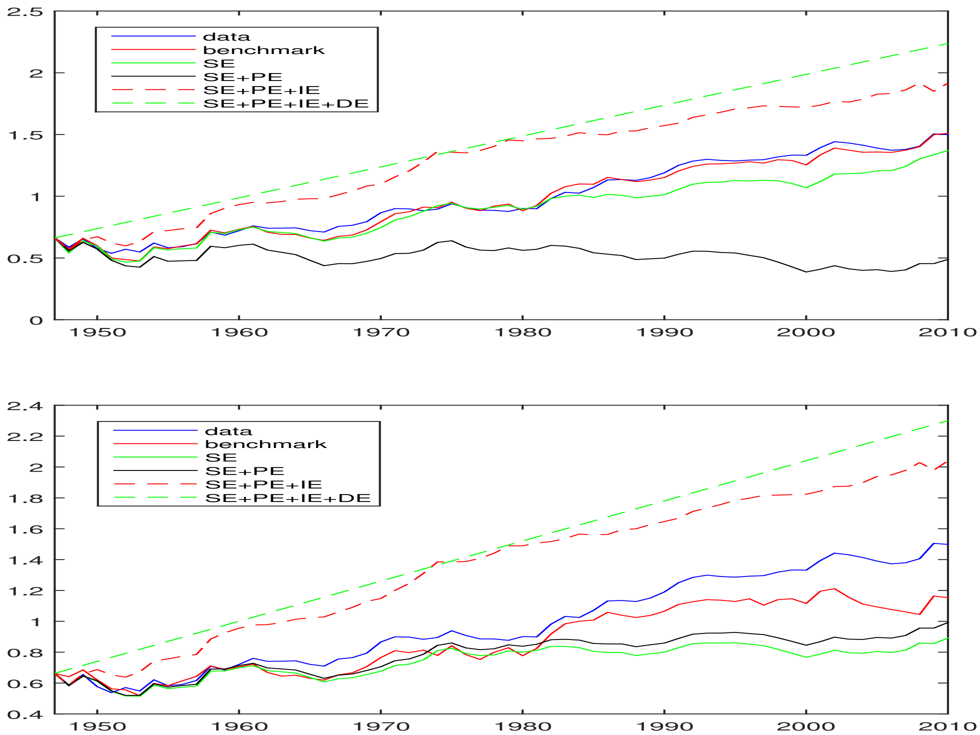


Figure 13: Relative VA share of service to manufacturing in US during 1947-2010

Horizontal axis denotes year; vertical axis shows the value of relative VA share of service to manufacturing in log level. Upper panel shows the benchmark decomposition; Lower panel shows decomposition under counterfactual study 1.

sumption expenditure in this paper actually is aggregate expenditure in final demand[29] whereas consumption expenditure in Herrendorf, Rogerson and Valentinyi (2013b) is per capita consumption expenditure. If I use per capita consumption expenditure in my research, I got very similar result with Herrendorf, Rogerson and Valentinyi (2013b). For consumption side structural change per capita income effect is positive. But the results of magnitude are mixed in literature. Income effect is large in Comin, Lashkari and Mestieri (2018); small in Herrendorf, Rogerson and Valentinyi (2013b) and equal to price effect in Boppart (2014). In my research, I find that aggregate income effect is negative and large in US structural change; and is trivial in the 35 economies cross-country structural change as illustrated in table 1.

D.2 Developed Countries and Developing Countries

Rather than pool all countries together, I show the decomposition under counterfactual case 1 for developed countries in upper panel of figure 14; and for developing countries in lower panel of figure 14. The definition and lists of developed country and developing country follow The

[29]Final demand includes not only private consumption, but also government consumption, investment, inventories and so on. I uses final demand rather than just private consumption because the model is constructed on aggregate final demand. See the gross output production budget constraint equation in section 3.3.

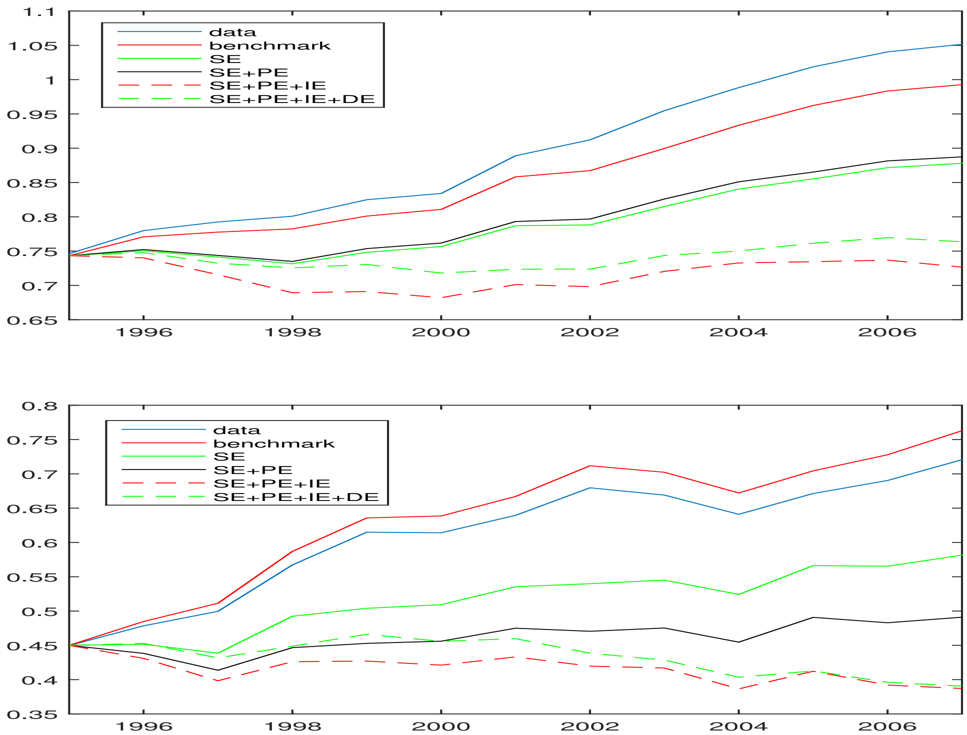


Figure 14: Relative VA share of MS to Manu in developed and developing countries

Horizontal axis denotes year; vertical axis shows the value of relative VA share of market service to manufacturing in log level. Upper and lower panel show the decomposition result under counterfactual case 1 in developed countries and developing countries respectively.

World Factbook.[30] In both groups, figure 14 suggests that I-I supply effect is significant and comparable to price and income effect; I-I demand effect is significant but again small. For both groups, income effect is significantly positive and large. It implies that the overall trivial income effect probably is due to mixed income effects between rich countries and poor countries. In this case, price effect is very small in developed countries and large in developing countries.

D.3 Other Values of ζ and θ

One of the most important concern about the parameter calibration is at ζ and θ. Since the calibration of primitives are conditional on ζ and θ, a natural question is how robust of the headline decomposition result to other values of them. It turns out that the decomposition result qualitatively holds if I use other values of ζ and θ. Given the smooth calibration with developed countries data, I do this exercise based on developed countries data. I show this decomposition result under counterfactual case 1 in figure 15. In the three panels of figure 15 from left to right, I show the result with $\zeta = 4; \theta = 3$, $\zeta = 4; \theta = 4$ and $\zeta = 1.2; \theta = 1.2$ respectively. Apparently the decomposition result only varies very marginally though the values of ζ and θ switch substan-

[30] Finally there are 20 developed countries and 15 developing countries in the panel data.

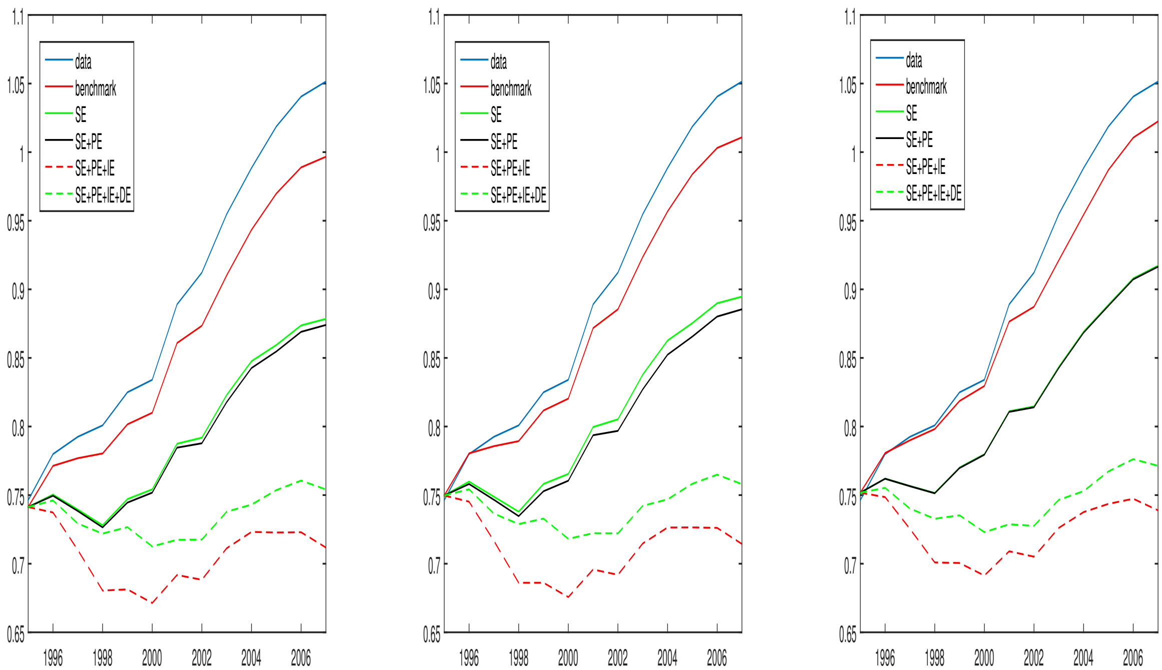


Figure 15: Relative VA share of MS to Manu at different values of ζ and .

Horizontal axis denotes year; vertical axis shows the value of relative VA share of market service to manufacturing in log level. The decomposition is based on developed countries. Left panel has $\zeta = 4; \theta = 3$; middle panel has $\zeta = 4; \theta = 4$ and right panel has $\zeta = 1.2; \theta = 1.2$.

tially. This is true when I compare the result of figure 15 with upper panel of figure 14. The result suggests that even though both relative VA share and the individual effects response to ζ and θ; the ratio of relative VA share to individual effects largely is fixed. This is consistent with figure 10 to figure 12.

D.4 Another Two Sectors

In section 5, I mainly focus on relative value added share of market service to manufacturing. I show the decomposition result of relative VA share of other good to manufacturing in upper panel of figure 16; and show the result of non-market service to manufacturing in lower panel of figure 16. For both panels, the decomposition is based on parameters from counterfactual case 1. For both panels, the benchmark simulation largely matches with data, in particular for relative VA share of other good to manufacturing. While the relative VA share of non-market service to manufacturing generally rises in this period; there is a invert-U shape in relative VA share of other good to manufacturing. This reflects the overall structural change from manufacturing to services during this period; from manufacturing to other good since 2000. Both panels of figure 16 suggest a strong I-I supply effect on structural change, which is again comparable to

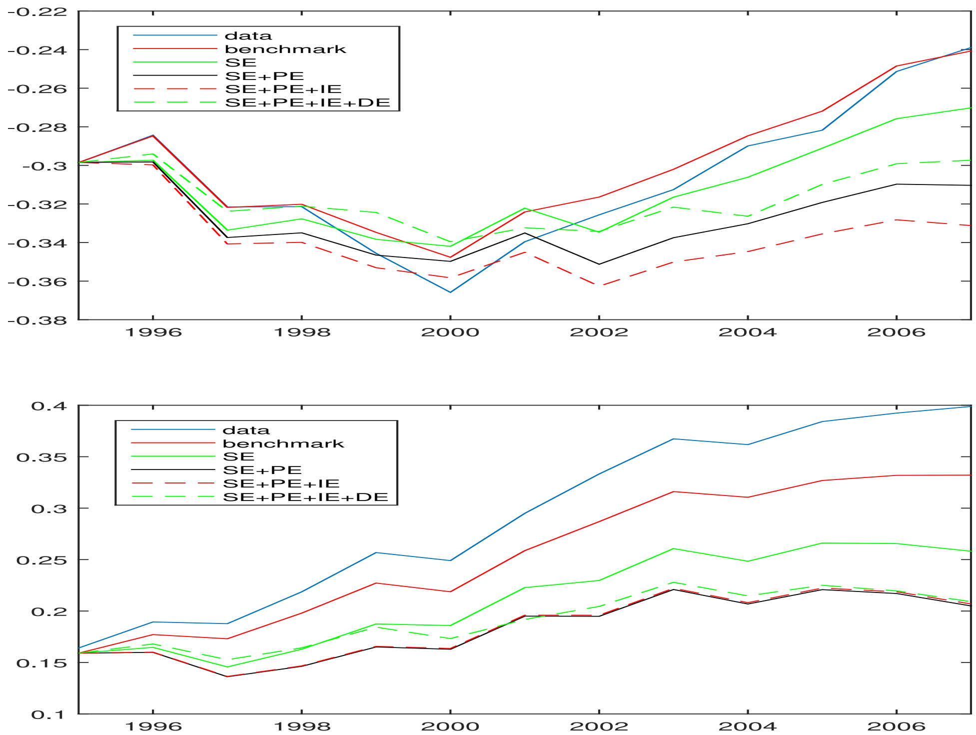


Figure 16: Relative VA share of OG and NMS to Manu

Horizontal axis denotes year; vertical axis shows the value of relative VA share of other good and non-market service to manufacturing in log level. Upper and lower panel show the decomposition result under counterfactual case 1 in other good and non-market service respectively.

the price effect. Income effect is relatively large in other good sector, but trivial in non-market service. Surprisingly I-I demand effect is negative and large in other good sector; and trivial in non-market service.

D.5 Imposing $\beta = 1$

The model implies a unitary elasticity of relative value added share to I-I demand effect. When I use OLS to estimate the elasticity in the main text of section 5, I do not impose this constraint. Though the estimate is very close to 1 in section 5, it is worth to check how the decomposition result responses to this strict constraint. I show the result of decomposition with this constraint in figure 17. This decomposition result is conducted through benchmark decomposition, with the addition constraint of imposing $\beta = 1$. Compare figure 17 with figure 5 where I do not impose this constraint, they are almost the same. The only slight difference is that the I-I demand effect is modestly larger in figure 17 than figure that in figure 5. The other three effects on structural change do not change.

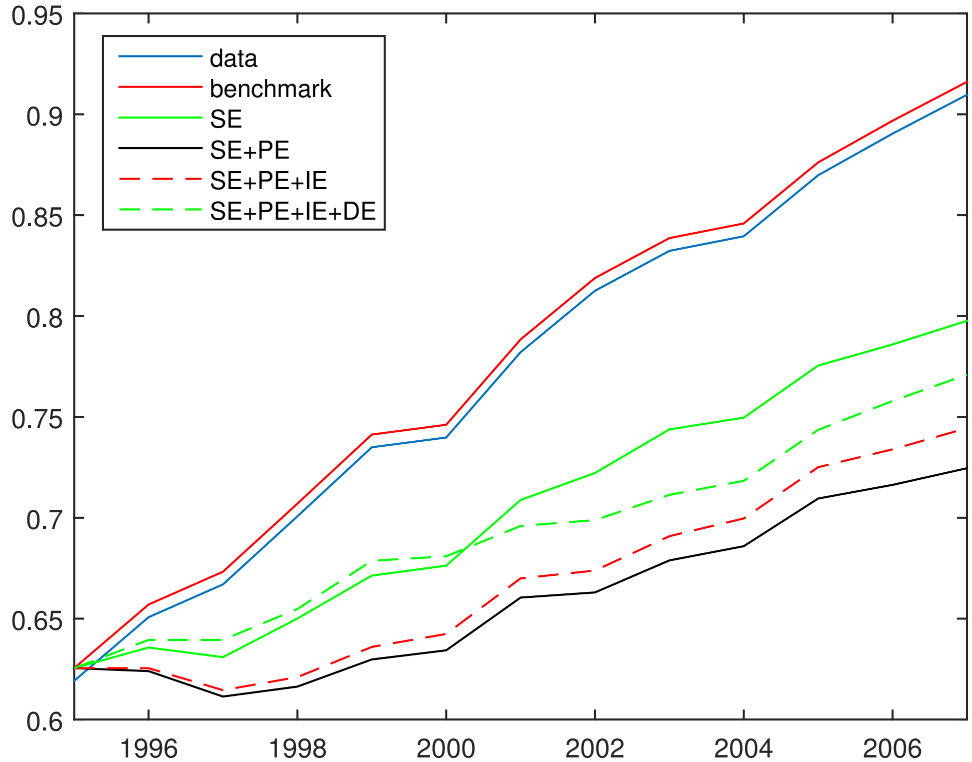


Figure 17: Relative VA share of MS to Manu with constraint of $\beta = 1$

Horizontal axis denotes year; vertical axis shows the value of relative VA share of market service to manufacturing in log level. The result is based on benchmark decomposition with additional constraint of $\beta = 1$.

D.6 Employment Share Based Structural Change

In the main body of this paper, I only discuss the structural change with value added share and consumption share. Another interesting structure term is employment share.[31] As argued in section **??**, sectoral employment share equals value added share when I assume equivalent capital share across sectors. This equivalence is shown in equation (**??**). Therefore I estimate the elasticities of the four individual effects on employment share based structural change as analogous as I do for value added share based structural change in section 5.1.

I show the estimate result in table 4. Compare with the estimate result in table 1, the elasticity of I-I demand effect, I-I supply effect and price effect are smaller on employment share based structural change than in value added share based structural change. Except for column (7), the OLS estimated coefficients are significant in these three effects. In particular for I-I supply effect, they are always significant at 1 percent level. In column 3 when I control country fixed effect, the income effect and I-I supply effect are relatively larger than price effect and I-I

[31]See Comin, Lashkari and Mestieri (2018), Rodrik (2016), and Kehoe, Ruhl and Steinberg (2018) for discussion about employment share based structural change.

$Dependent\ Variable : \log\frac{l_{it}}{l_{jt}}$							
0 **Coefficient**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
β		0.568***	0.112**	0.116***	0.264***	0.234***	0.029
		(0.079)	(0.050)	(0.043)	(0.087)	(0.050)	(0.067)
κ		0.861***	0.356***	0.160***	0.165***	0.319***	-0.065
		(0.053)	(0.042)	(0.038)	(0.037)	(0.040)	(0.063)
$1-\rho$	0.281***	0.198***	0.031	0.071**	0.066**	0.245***	0.034
	(0.034)	(0.033)	(0.033)	(0.028)	(0.028)	(0.039)	(0.040)
$\epsilon_{OG}-\epsilon_{Manu}$	0.004	0.049***	-0.080**	-0.349***	-0.341***	0.484***	-0.331***
	(0.013)	(0.012)	(0.033)	(0.061)	(0.061)	(0.064)	(0.083)
$\epsilon_{MS}-\epsilon_{Manu}$	0.031***	0.048***	0.417***	-0.080**	-0.071**	0.174***	-0.129**
	(0.009)	(0.009)	(0.023)	(0.034)	(0.034)	(0.047)	(0.061)
$\epsilon_{NMS}-\epsilon_{Manu}$	-0.023**	0.017*	0.340***	-0.274***	-0.263***	0.083	-0.320***
	(0.010)	(0.009)	(0.032)	(0.048)	(0.047)	(0.061)	(0.079)
Country FE	NO	NO	YES	YES	YES	YES	YES
Year FE	NO	NO	NO	YES	YES	YES	YES
IS approx.	NO	NO	NO	NO	YES	NO	NO
Sample	ALL	ALL	ALL	ALL	ALL	DC	LDC

Table 4: Estimate of employment share based structural change

demand effect. It implies that Income effect and I-I supply effect are two important effect on employment share based within-country structural change from manufacturing to market service.[32] In column 4 when I further control year fixed effect, both effects attenuate by more than half. Given the four effects are small in cross-country structural change from manufacturing to market service, it implies that there are other important factors which are important to affect cross-country structural change but not yet been explored by this paper.

I do a similar benchmark decomposition exercise with employment share based structural change. The coefficients are based on the column 4 estimate of table 4. The result of relative employment share of market service to manufacturing is presented in figure 18. Consistent with the argument above, all of the four effects are small. But we still can observe the relatively larger I-I supply effect and income effect in this case. Overall the result of table 4 and figure 18 suggest that the I-I supply effect and income effect are important for within-country employment share based structural change. They are less important for cross-country employment share based structural change.

E. Additional Facts

In this section, I present three additional facts. First, for major economies, Value added share drops in manufacturing and rises in service since 1970. If any, this trend is more obvious in the

[32]The positive and relatively large income effect on within-country structural change from manufacturing to services, is consistent with Comin, Lashkari and Mestieri (2018).

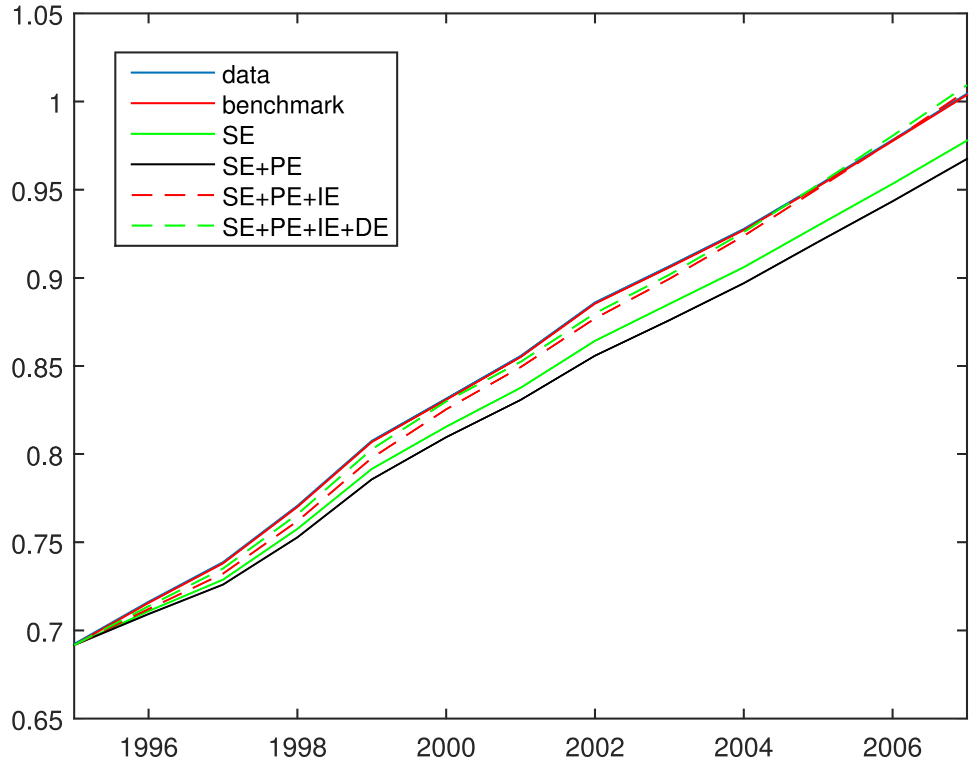


Figure 18: Relative employment share of MS to Manu

Horizontal axis denotes year; vertical axis shows the value of relative employment share of market service to manufacturing in log level. The result is based on benchmark decomposition.

last two decades. Second, VA share increases with intermediate input supply multiplier for US two-digit industries during 1963-2015. Last, relative price of manufacturing to service matches very well with relative nominal value added share.

E.1 Additional Fact 1

The first fact is not new to this paper. It has been documented by many structural change studies. I show this fact for 4 developed economies in figure 19: US, UK, Japan and Canada; and for 4 emerging economies in figure 20: Brazil, India, South Afirca and Turkey.[33] These two figures present the long run time series pattern of value added share for manufacturing sector and service sector since 1970. The horizontal axis is year; and vertical axis is value added share at percentage point.

Figure 19 and figure 20 suggest that in these sampling countries, value added share declines in manufacturing sector and surges in service sector since 1970. This fact is evident in both developed economies and emerging economies. These economies not only have very different

[33]The long run data is not available for China in NAMAD.

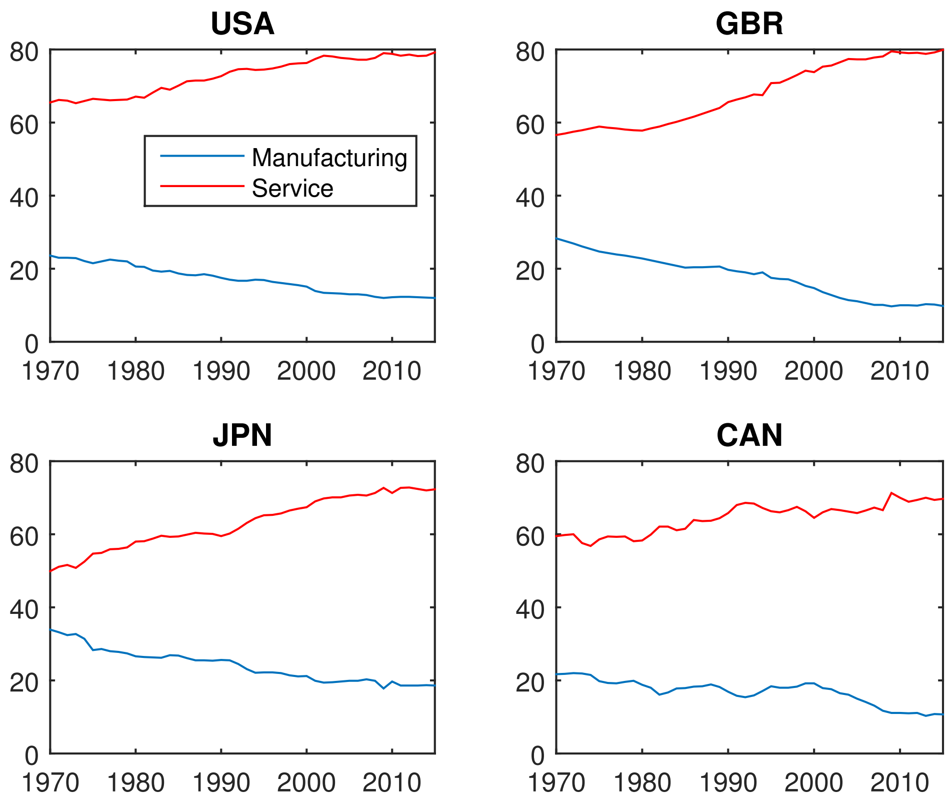


Figure 19: Long run VA share pattern of four developed economies

Horizontal axis denotes year; vertical axis shows value of value added share of manufacturing and service at percentage point. The four countries are US, UK, Japan and Canada. Computation is based on National Accounts Main Aggregate Database from UN.

development process, but also very different culture, history, population size and geography. Actually I find similar structural change fact in other major economies as well. It suggests that at least since 1970 the major economies experience significant structural change from manufacturing to service.

In addition, structural change is more obvious to see after 1990, in particular true for emerging economies. We can see that structural change tend to accelerate in UK and Canada after 1990. The value added share of manufacturing sector declines more significantly since 1990 than before; on the other hand value added share of service sector shifts up more significantly since 1990 than before. For emerging economies, structural change is not obvious before 1990. Since 1990, we can see rapid structural change in all of the emerging economies in figure 20. This fact has two implications. First, Value added share is one of the important structure term which depicts the structural change fact in major economies.[34] Second, I do not miss out the

[34]For description and discussion of value added share based structural change, see Herrendorf, Rogerson and Valentinyi (2013a) and Rodrik (2016).

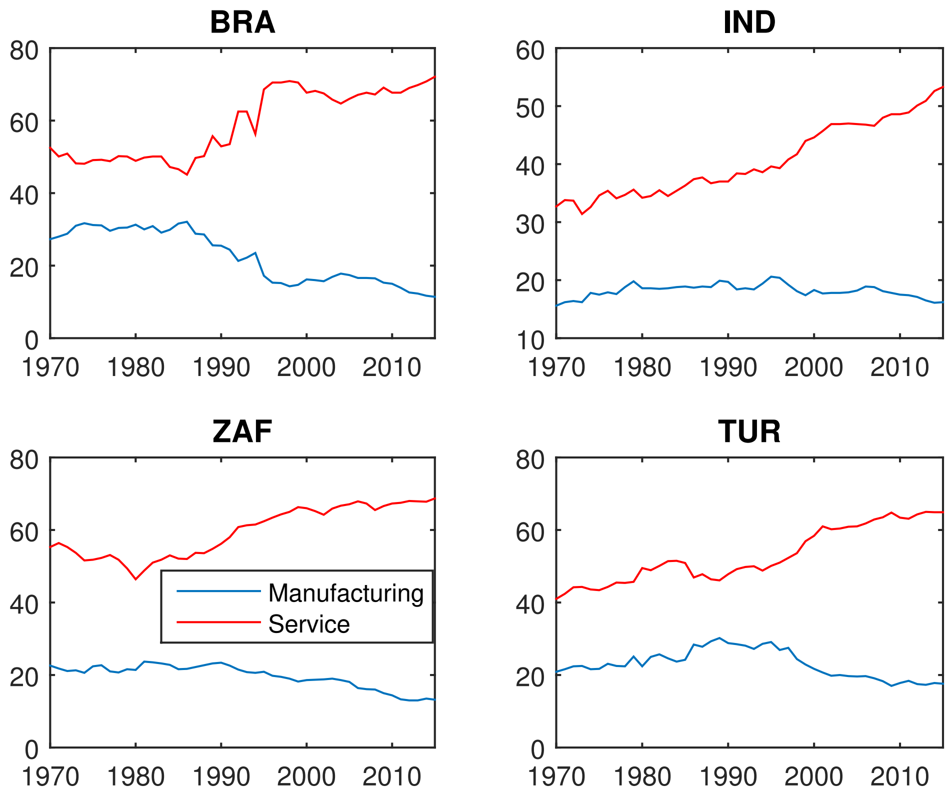


Figure 20: Long run VA share pattern of four emerging economies

Horizontal axis denotes year; vertical axis shows value added share of manufacturing and service at percentage point. The four countries are Brazil, India, South Africa and Turkey. Computation is based on National Accounts Main Aggregate Database from UN.

structural change fact by using the main panel data WIOD which contains data between 1995 and 2007.

E.2 Additional Fact 2

The second additional fact complements the main fact in section 2.2. I show the positive correlation between value added share and intermediate input supply multiplier for US two-digit sector. I show this fact for farm sector in figure 21; for sector of motor vechcles, bodies and trailers, and parts in figure 22; and for sector of miscellaneous professional, scientific and technical services in figure 23. Basically each figure shows one example of agriculture sector, manufacturing sector and service sector respectively. In every figure, the top panel shows the long run pattern of value added share; the middle panel shows the long run pattern of intermediate input supply multiplier; and the bottom panel shows the long run pattern of relative intermediate input supply multiplier to demand multiplier.

Figure 21 to figure 23 suggest a strong positive correlation between US sectoral value added

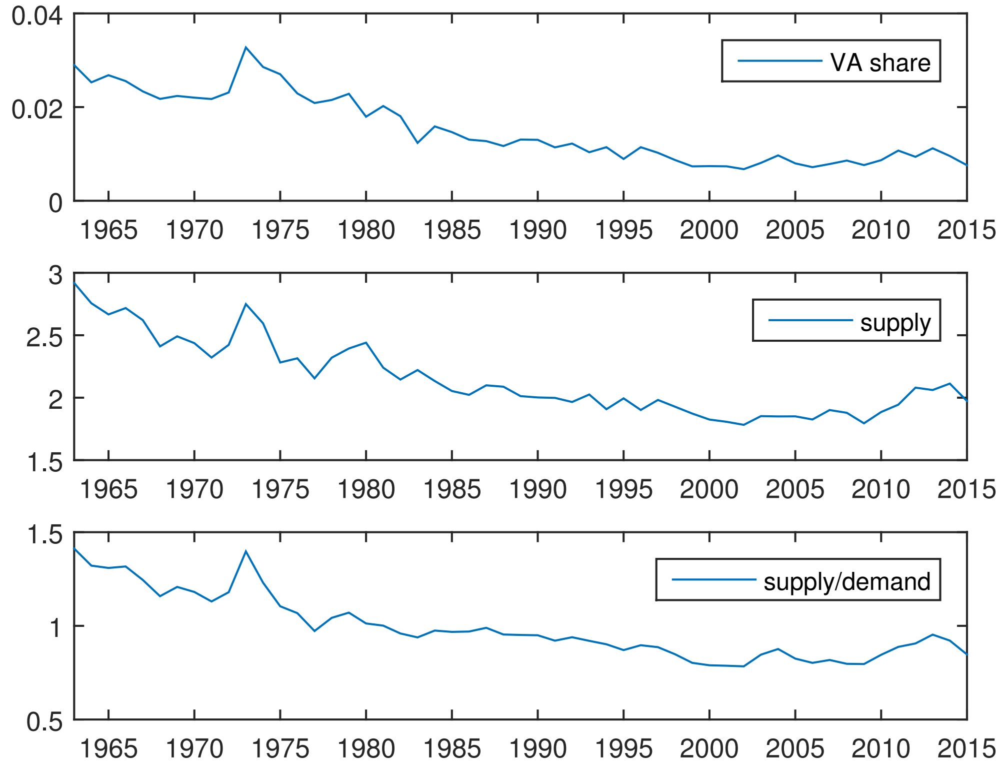


Figure 21: Farms

Horizontal axis denotes year; vertical axis shows value added share. Computation is based on Industry Input-Output Accounts Data from BEA. The three panels depict VA share, I-I supply multiplier and relative I-I supply to I-I demand multiplier respectively.

share and the corresponding intermediate input supply multiplier during 1963-2015. For the agriculture and manufacturing sector, the declining value added share pattern largely matches with decreasing intermediate input supply multiplier; for the service sector, the rising value added share pattern also largely matches with increasing intermediate input supply multiplier. In addition, these figures suggest that the pattern of I-I supply multiplier is very consistent with the pattern of relative I-I supply to I-I demand multiplier. This finding implies that intermediate input demand multiplier is relatively stable, compared with supply multiplier. The stable intermediate input demand multiplier is consistent with Jones (2011b) and Duarte and Restuccia (2017), in which they find that US sectoral intermediate input demand intensity is stable over time. Furthermore, figure 22 suggests that the relative I-I supply to I-I demand multiplier matches with value added share better than I-I supply multiplier only. This implies that I-I demand multiplier is also important to determine value added share.

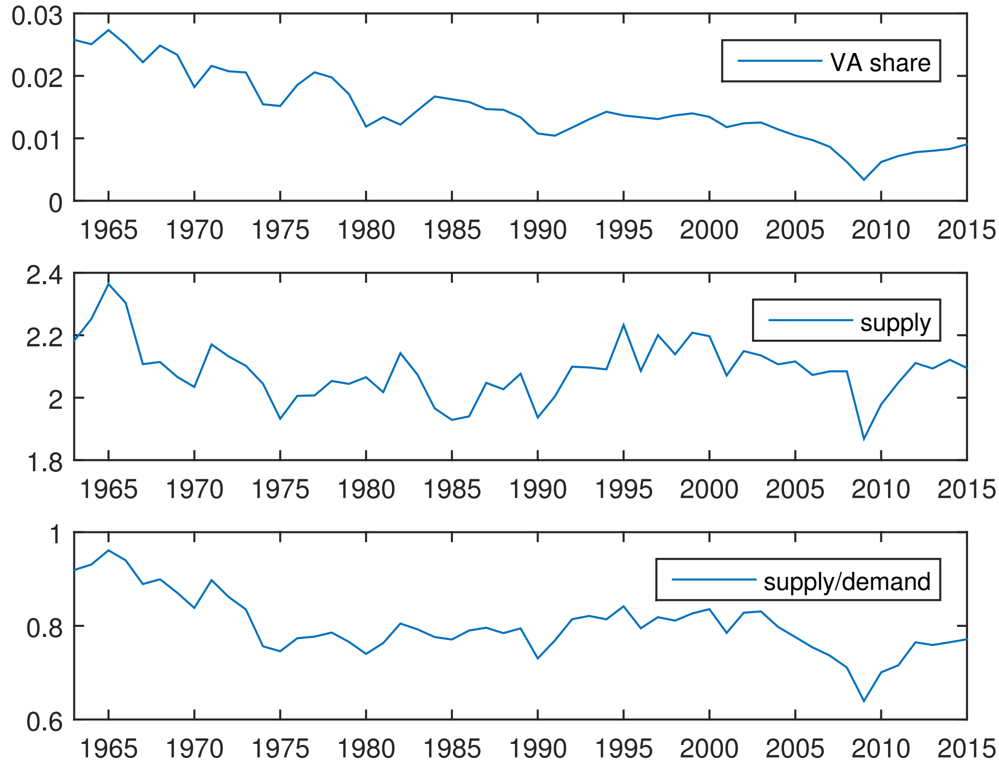


Figure 22: Motor vehicles, bodies and trailers, and parts

Horizontal axis denotes year; vertical axis shows value added share. Computation is based on Industry Input-Output Accounts Data from BEA. The three panels depict VA share, I-I supply multiplier and relative I-I supply to I-I demand multiplier respectively.

E.3 Additional Fact 3

The last fact documents the correlation between relative sectoral price and structural change. According to Ngai and Pissarides (2007), if manufacturing and service are complement to consumption, structural change happens from relatively lower price sector to relatively higher price sector. It implies that we should see a positive correlation between relative price and relative value added share of manufacturing to service. I present this correlation for four developed economies and four emerging economies in figure 24 and figure 25 respectively. The sampling countries and time period are exactly the same as in section E.1. In both figures, the horizontal axis is year; the vertical axis is the index of relative value added share and relative price of manufacturing to service. The index is normalized to be 1 in year 1970.

Figure 24 and figure 25 suggest that relative price tracts with relative value added share very well. In this time period, relative value added share of manufacturing to service falls particularly for developed countries. This is consistent with fact 1. At the same time we observe that the relative price of manufacturing to service also decreases. There is a strong positive correlation

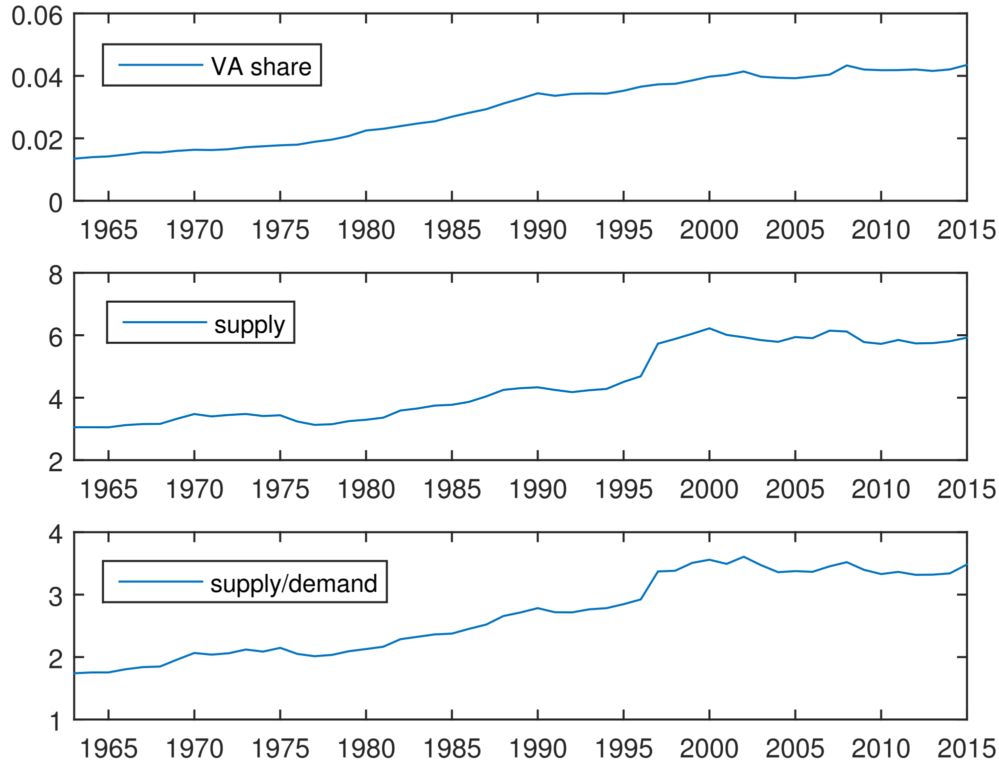


Figure 23: Food and beverage and tobacco products

Horizontal axis denotes year; vertical axis shows value added share. Computation is based on Industry Input-Output Accounts Data from BEA. The three panels depict VA share, I-I supply multiplier and relative I-I supply to I-I demand multiplier respectively.

between relative price and relative value added share, which is consistent with the prediction in Ngai and Pissarides (2007).

F. Main Data Description

In this paper, the main database is World Input-Output Database (WIOD) 2013. In WIOD, there are 35 two-digit sectors. In the main body, there are 4 one-digit sectors. The classification of these 35 initial two-digit sectors into 4 one-digit sectors borrows from Inklaar and Timmer (2014).

Manufacturing sector contains the following two-digit sectors: food, beverage and tobacco; textile products; leather and footwear; wood products; paper, printing and publishing; coke and refined petroleum; chemical products; rubber and plastics; non-metallic mineral products; basic and fabricated metal; machinery; electrical and optical equipment; transport equipment; other manufacturing.

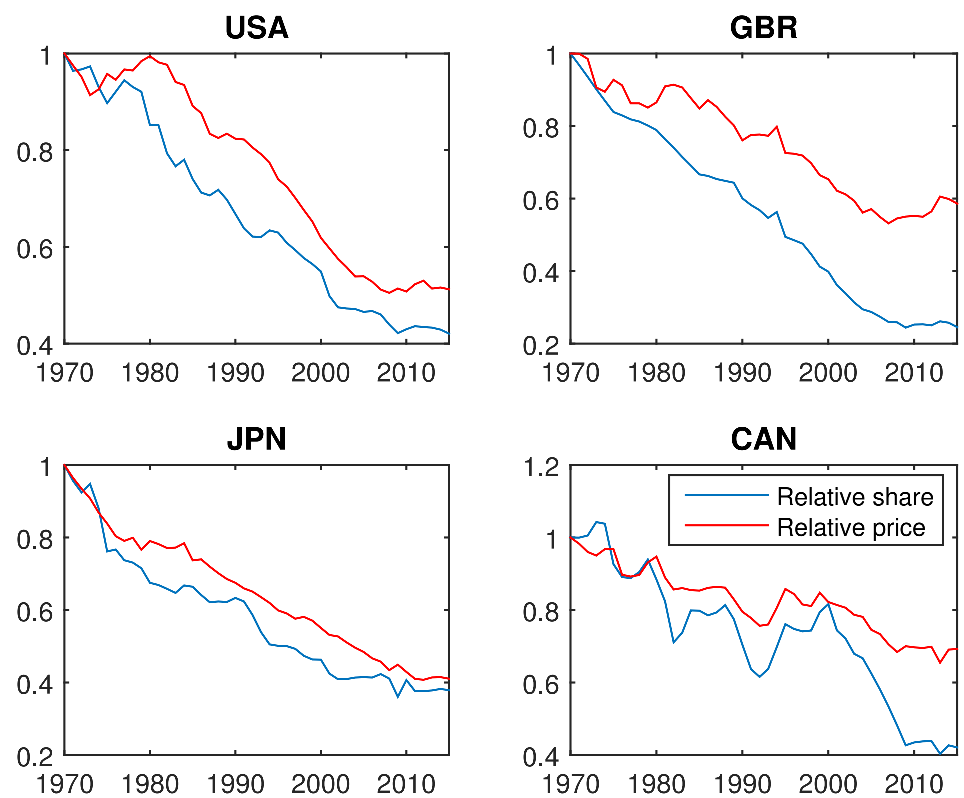


Figure 24: Correlation between relative VA share and relative price for 4 developed economies

Horizontal axis denotes year; vertical axis shows index of relative value added share and relative price of manufacturing to service. Computation is based on National Accounts Main Aggregate Database from UN.

Market services sector contains the following two-digit sectors: motor vehicle and fuel trade; wholesale trade; retail trade; hotels and restaurants; land transport; water transport; air transport; transport services; post and telecommunications; financial services; business services; other services.

Non-market services sector contains the following: real estate; government; education; health; Other good sector contains the following: agriculture, forestry and fishing; mining and quarrying; utilities; construction.

In the panel data, I have 35 countries. There are 20 developed countries and 15 developing countries. This classification follows CIA The World Factbook. The developed countries include the following countries: Australia; Austria; Belgium; Canada; Germany; Denmark; Spain; Finland; France; UK; Greece; Ireland; Italy; Japan; Malta; Netherlands; Portugal; Sweden; US; Luxembourg. The developing countries include the following countries: Brazil; China; Cyprus; Czech; Estonia; Hungary; Korea; Latvia; Lithuania; Mexico; Poland; Romania; Slovak; Slovenia; Turkey.

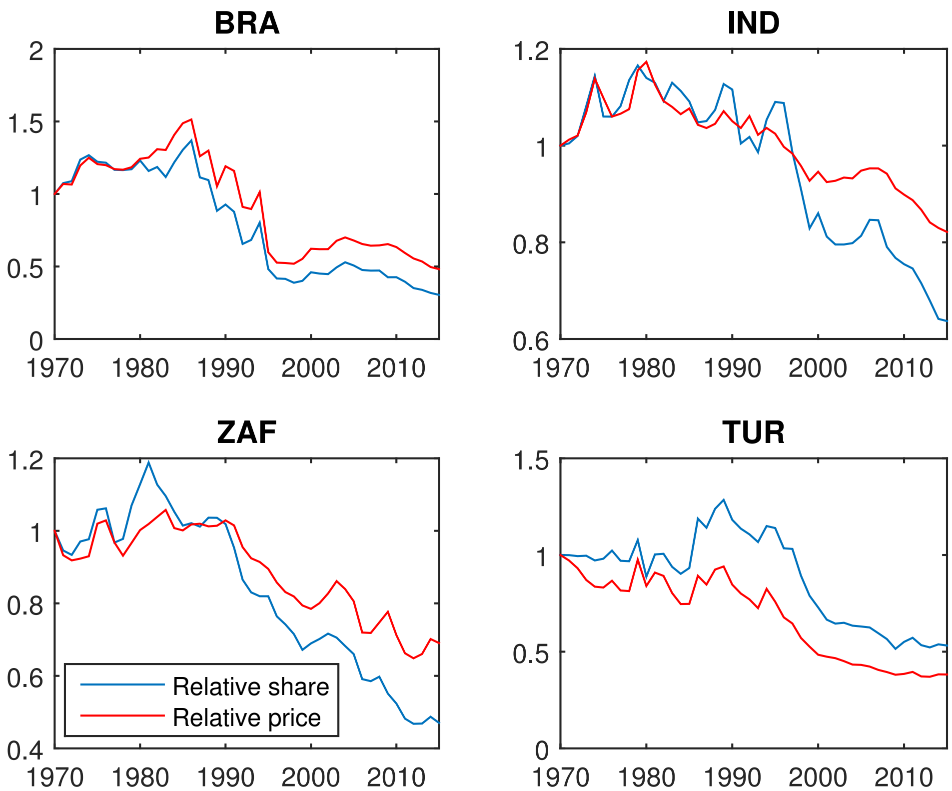


Figure 25: Correlation between relative VA share and relative price for 4 emerging economies

Horizontal axis denotes year; vertical axis shows index of relative value added share and relative price of manufacturing to service. Computation is based on National Accounts Main Aggregate Database from UN.