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Input-Output Linkages in Growth and Development

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This dissertation is submitted for the degree of
Doctor of Philosophy

September 2019

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 100,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

Hang Hu
September 2019

Acknowledgements

I want to express my sincere gratitude to my supervisors Chris Edmond and May Li. I gratefully thank them for their intelligence, critiques, guidance, and encouragement. I am particularly grateful for their patience over the last few years.

I have received many useful comments throughout my PhD research. For their comments and suggestions, I gratefully thank Francisco Buera, Marc Chan, Daeha Cho, Mei Dong, Qingyuan Du, James Hansen, Jingong Huang, Joe Kaboski, Parisa Kamali, Nandita Krishnaswamy, Munseob Lee, Yiliang Li, Jian Lu, Kiminori Matsuyama, Yusuf Mercan, Omid Mousavi, Bruce Preston, Mark Razhev, Terry Roe, Ashish Shenoy, Yongseok Shin, Faisal Sohail, Yong Song, Lawrence Uren, Haikun Zhan and Yahui Zhang.

Conference and seminar participants gave me a lot of helpful feedback. I gratefully thank participants at the following conferences and seminars: Midwest Macro Meeting (Vanderbilt 2018), Economics Graduate Students Conference (Washington University in St. Louis 2018), GEP-China Workshop on Advances in Economic Research (Nottingham Ningbo 2018), Midwest International Economic Development Conference (Minnesota 2018), Pacific Conference for Development Economics (UC Davis 2018), Asian and Australasian Society of Labour Economics Inaugural Conference (ANU 2017) and many Brown Bag seminars (Melbourne 2016-2018).

I have also benefited from the help and advice of many faculty members, professional staffs, colleagues and friends. Among others, I gratefully thank Efrem Castelnuovo, Kalvinder Shields, John Haisken-DeNew, Tom Wilkenning, Christopher Skeels, Ross Garnaut, Lauren Johnston, Graham Richards, Gareth James, Jennifer Decolongon, Imogen Knight, Michelle Best, Victor Andries, Brian Tran, Aaron Blanco, Laxman Bablani, Xianglong Liu.

Finally, I gratefully thank my parents and my sister for their love and support.

Abstract

Do input-output linkages impact growth and development? This dissertation provides three main chapters studying the role of input-output linkages in structural change and productivity measurement. I find that (i) input-output linkages offer a new mechanism to account for structural change, which therefore complements the structural change literature; (ii) input-output linkages affect productivity measurement, particularly impact sector-level productivity measurement.

Chapter 2 presents new evidence and mechanism of input-output linkages in structural change. Sectors with a larger growth of supply (forward) linkages of intermediate inputs absorb more labor to satisfy the rising demand for inputs sourcing from the downstream sectors. Sectors with a larger growth of demand (backward) linkages of intermediate inputs displace more labor, due to the increasing reliance on inputs sourcing rather than in-house production. Manufacturing sector increasingly sources services inputs, such as business services and management services, prompting a rise of services and a decline of manufacturing.

Motivated by the evidence and mechanism in Chapter 2, Chapter 3 develops a general equilibrium model and quantifies the new mechanism of input-output linkages in structural change. The model features endogenous input-output linkages, nonhomothetic constant-elasticity-of-substitution (CES) preferences and technology, and heterogeneous firms. The model is structurally calibrated to the World Input-Output Database which contains 35 major economies through 1995-2007. I find that (i) the supply-linkages effects are at least comparable to other mechanisms in the literature, such as the price effects due to the sector-biased technological change; (ii) the demand-linkages effects are less critical due to the stable use of intermediate inputs across years; (iii) about half of the structural change attributes to the rising comparative advantage for supplying intermediate inputs by the services sector relative to by the manufacturing sector.

Chapter 4 studies the role of input-output linkages in productivity measurement. I construct two hypothetical economies in the model. In the input-output economy, sectors produce gross output by using both intermediate and primary inputs. In the value added economy, sectors produce value added by using only primary inputs. I compare the two economies. I find that (i) aggregate productivity is theoretically equivalent; (ii) sectoral

productivity measurement are different for all sectors and countries; (iii) without taking input-output linkages into account, previous measures of productivity are biased.

Table of contents

List of figures	xiii
List of tables	xv
1 Introduction	1
2 Structural Change and Sectoral Linkages: Evidence and Mechanism	7
2.1 Introduction	7
2.2 Evidence	11
2.2.1 Sufficient Statistics	12
2.2.2 Sector Share in Value Added	14
2.2.3 Domar Weight	15
2.3 Domestic Sourcing	17
2.3.1 A Simple Closed Economy Model	17
2.3.2 Mechanism	18
2.3.3 Example	21
2.4 Global Sourcing	22
2.4.1 Model Extension	24
2.4.2 Empirical Study	26
2.5 Conclusion	30
3 Structural Change with Endogenous Input-Output Linkages	33
3.1 Introduction	33
3.2 Model	38
3.2.1 Preferences	38
3.2.2 Technology	40
3.2.3 Equilibrium	42
3.3 Quantitative Results	47
3.3.1 Benchmark Estimation and Calibration	48

3.3.2	Accounting for Structural Change	53
3.4	Intermediate-Inputs Supply Channel	56
3.4.1	Origins of Structural Change	58
3.4.2	Why Structural Change Arises?	60
3.5	Conclusion	63
4	Input-Output Linkages and Productivity Measurement	65
4.1	Introduction	65
4.2	Model	68
4.2.1	The Input-Output Economy	68
4.2.2	The Corresponding Value Added Economy	70
4.2.3	Aggregate TFP Equivalence	72
4.2.4	Sectoral TFP Measures	73
4.3	Quantitative Analysis	73
4.3.1	Data	73
4.3.2	Measurement Bias in Sectoral TFP	74
4.3.3	Decomposition Bias in Aggregate TFP Growth	77
4.4	Re-examination of Previous Productivity Studies	80
4.4.1	Effect of Structural Change on Aggregate Productivity Growth	80
4.4.2	Sectoral Productivity Convergence	83
4.4.3	“Problem Sectors”	85
4.5	Conclusion	87
5	Conclusion	89
	References	91
	Appendix A Appendix of Chapter 2	97
A.1	Equilibrium Solution of The Closed Economy Model	97
A.2	Additional Evidence	98
A.2.1	Structural Change: Value Added Based	99
A.2.2	Value Added Share and I-I Supply Multiplier	101
A.2.3	Price Effect	103
A.2.4	Intermediate Demand Versus Final Demand: Domestic Sourcing	105
A.2.5	Intermediate Demand Versus Final Demand: Global Sourcing	107
A.3	Main Data Description	110

Appendix B	Appendix of Chapter 3	113
B.1	Proofs of the Propositions	113
B.1.1	Proposition 1: Equilibrium Solution of the Key Variables	113
B.1.2	Proposition 2: Structural Change	115
B.1.3	Proposition 3: Endogenous Input-Output Linkages and Sectoral Prices	116
B.2	Additional Results	120
B.2.1	The US Long Run Data: 1947-2010	120
B.2.2	Developed Countries and Developing Countries	122
B.2.3	Various Parameter Values of ζ and θ	123
B.2.4	Other Two Sectors	124
B.2.5	Imposing $\beta = 1$	125
B.2.6	Employment Share Based Structural Change	125
Appendix C	Appendix of Chapter 4	129
C.1	Proofs of the Propositions	129
C.1.1	Proposition 4: Equilibrium Solution of The IO Economy	129
C.1.2	Proposition 5: Equilibrium Solution of The Value Added Economy	131
C.1.3	Proposition 6: Aggregate TFP Equivalence	132

List of figures

2.1	Sector share in value added and intermediate-inputs supply multiplier in the US	8
2.2	Correlation between value added share and intermediate-inputs supply multiplier	13
2.3	Correlation between residual value added share and intermediate-inputs demand multiplier	14
2.4	Correlation between Domar weight and intermediate-inputs supply multiplier	16
2.5	Crop and animal production, hunting and related services activities	27
2.6	Manufacture of computer, electronic and optical products	27
2.7	Telecommunications	28
3.1	Decomposition under the benchmark estimation	55
3.2	Decomposition under the first counterfactual experiment	57
3.3	Decomposition under the second counterfactual experiment	57
3.4	Sector-to-sector sourcing cost	59
3.5	Relative TFP scale and efficiency	59
3.6	Role of sourcing cost: market services to manufacturing	61
3.7	Role of TFP scale: market services to manufacturing	61
3.8	Role of trade elasticity: market services to manufacturing	62
4.1	The sectoral TFP of the UK relative to the US	75
4.2	The sectoral TFP of China relative to the US	76
4.3	Decomposition of aggregate TFP growth under the IO method	78
4.4	Decomposition of aggregate TFP growth under the DA method	78
4.5	Decomposition of aggregate labour productivity growth under the IO method	81
4.6	Decomposition of aggregate labour productivity growth under the DA method	81
4.7	The standard deviation of sectoral labor productivities across 29 OECD countries	84
4.8	The standard deviation of sectoral TFP across 29 OECD countries	84
A.1	Long run value added share for four developed economies	99

A.2	Long run value added share for four developing economies	100
A.3	Structural change and multipliers: farms	101
A.4	Structural change and multipliers: motor vehicles, bodies and trailers, and parts	102
A.5	Structural change and multipliers: food and beverage and tobacco products .	103
A.6	Value added share and price for four developed economies	104
A.7	Value added share and price for four developing economies	105
A.8	The US sector shares in value added	106
A.9	The UK sector shares in value added	106
A.10	Sector shares in value added in China	108
A.11	Sector shares in value added in India	108
A.12	The US sectoral value added shares relative to manufacturing	109
A.13	The UK sectoral value added share relative to manufacturing	109
A.14	Relative sectoral value added share to manufacturing in China	111
A.15	Relative sectoral value added share to manufacturing in India	111
B.1	Decomposition of the US long run structural change	120
B.2	Decomposition for developed countries and developing countries	121
B.3	Decomposition results with various parameter values of ζ and θ	122
B.4	Decomposition of other goods and non-market service to manufacturing . .	123
B.5	Decomposition with $\beta = 1$	124
B.6	Decomposition of employment share based structural change	126

List of tables

2.1	Structural change and variation of input-output linkages	21
2.2	Trade of intermediate inputs and final output in the global value chains . . .	23
2.3	OLS tests of the two correlations in the global value chains	29
3.1	Estimation of production-side structural change	49
3.2	Parameter estimation and calibration	52
4.1	Summary of the primary decomposition bias (%)	79
4.2	Rankings of structural change and within-sector labor productivity growth .	82
4.3	Regression test of β - convergence: sectoral labour productivity	86
4.4	Regression test of β - convergence: sectoral TFP	86
4.5	Estimation of relative disparity of TFP to income	87
B.1	Estimation of employment share based structural change	125

Chapter 1

Introduction

This dissertation is motivated by a common economic feature: producer *interaction*. The specific interaction I examine in this dissertation is input-output linkages at the sector level. I study the role of input-output linkages in growth and development. I find that input-output linkages are essential in structural change and productivity measurement.

Structural change refers to the reallocations of economic activities from agriculture and manufacturing to services ([Herrendorf et al., 2014](#)). The leading structural change theories attribute the reallocations to final demand factors alone. For instance, the price-effects theories ([Ngai and Pissarides, 2007](#)) argue that the sector-biased technological change induces different price growth and generates the reallocations of final consumption across sectors.

However, the intermediate demand could be as crucial as the final demand in driving structural change from manufacturing to services. In last few decades, the development of information and communication technology (ICT)—internet, software and hardware—constantly transformed the boundary of firms ([Abramovsky and Griffith, 2006](#); [Fort, 2017](#)). The development of ICT reduced transaction cost, coordination cost and monitoring cost, particularly for the procurement of customized intermediate inputs. Cost reduction induced many manufacturers to shift their service tasks—which encompass both medium- to high-skill services such as consulting, accounting, human resources, IT services and low-skill services such as cleaning, logistics, security and food services—to specialized services firms. This rising demand for services inputs by manufacturers was likely to push up the services sector share of value added and attenuate the manufacturing sector share. The growth of business-oriented demand for services inputs outperformed the consumer-oriented demand for services output in the US through 1988-2000 ([Goodman and Steadman, 2002](#)). Surprisingly, these intermediate demand forces are largely overlooked by the leading structural change theories and empirical studies.

Despite most structural change studies omit producer interaction and heterogeneity, these are the focus of this dissertation. Do input-output linkages matter for structural change? How do input-output linkages impact structural change? Which features of input-output linkages are critical? To what extent do the input-output linkages account for structural change? How important is the new mechanism of input-output linkages compared with the existing mechanisms in the literature? The next two chapters of this dissertation attempt to answer these questions.

Chapter 2 presents the novel evidence and mechanism on the correlations between sector shares in value added and the relevant features of input-output linkages. I find two useful features of input-output linkages: intermediate-inputs (I-I) supply multiplier and I-I demand multiplier. The I-I supply multiplier and I-I demand multiplier measure the connection intensity of a sector in terms of providing materials to the downstream sectors and purchasing materials from the upstream sectors, respectively.¹ They are forward linkages and backward linkages following [Miller and Blair \(2009\)](#).

I find a positive correlation between the sector share in value added and the I-I supply multiplier. Conditional on the positive correlation, I find a negative correlation between the sector share in value added and the I-I demand multiplier.² I use the World Input-Output Database (WIOD) to test these correlations. These two correlations hold in 44 major economies through 1995-2014. They are robust to different levels of sector aggregation (4 one-digit sectors and 30 two-digit sectors), as well as different patterns of trade (domestically intersectoral trade and international trade in the global value chains).

I use a multi-sector model with input-output linkages following [Jones \(2011b\)](#) to illustrate the mechanism behind the above evidence. The input-output linkages are taken as exogenous. I summarize the insight of the mechanism as follows. On the one hand, for sectors that have a more rapid growth or larger growth of I-I supply multiplier, they increasingly supply intermediate inputs to the downstream sectors. These sectors naturally require more and more labor and capital to satisfy the increasing demand for inputs sourcing. As a result, their value added shares go up. On the other hand, for sectors that have a larger growth of I-I demand multiplier, they increasingly rely on sourcing of intermediate inputs from upstream sectors, rather than in-house production. These sectors naturally displace more and more labor and capital, leading to a decline of value added share. Structural change arises as a consequence

¹In the input-output economy, each sector could be both customer and supplier of inputs given the roundabout production characteristics. In this dissertation, when sector i supplies inputs to sector j , I refer sector i to the upstream sector and sector j to the downstream sector. The concepts of upstream and downstream are used to represent the flow of goods and services.

²In the regression study, the dependent variable is value added share and the independent variables are I-I supply and demand multipliers. After removing the positive correlation in the I-I supply multiplier, there is a strong negative correlation between the residual value added share and the I-I demand multiplier.

of moving economic resource from the sectors with a larger growth of I-I demand multiplier to the sectors with a larger growth of I-I supply multiplier.

While the partial equilibrium model is convenient for illustration of the new mechanism, it is not helpful for evaluating the new mechanism versus the existing mechanisms in the literature. Because the final demand factors are switched off when I illustrate the new mechanism of input-output linkages. Moreover, the input-output linkages are taken as exogenous in the partial equilibrium model. The fundamental factors behind the variation of input-output linkages may be confounded with the final demand factors. Hence, it is challenging to clearly disentangle the new mechanism from the existing mechanisms based on the partial equilibrium model.

To quantify the new mechanism of input-output linkages, I extend the partial equilibrium model to a general equilibrium model in Chapter 3. The model blends features from the recent structural change literature with features from the Ricardian trade literature. In particular, I assume nonhomothetic CES preferences as in [Comin et al. \(2019\)](#). These preferences imply a separation of the price effects from the income effects on structural change. The income-effects theories argue that the nonhomothetic preferences lead to a rise of services consumption and a decline of manufacturing consumption when income grows. I introduce the nonhomothetic CES technology in the aggregate gross output production in the spirit of [Comin et al. \(2019\)](#). On top of the independent price and income effects, the general equilibrium model generates a separation of the intermediate-inputs supply effects from the I-I demand effects. The latter two effects correspond to the channel of I-I supply and the channel of I-I demand in the mechanism described above.

Moreover, the input-output linkages are endogenous in Chapter 3. I borrow the idea of the Ricardian trade to endogenize the intensity of input-output linkages following [Boehm \(2018\)](#). Essentially, the intersectoral trade of intermediate inputs is analogous to the international trade of final outputs as in [Eaton and Kortum \(2002\)](#). The equation of input-output linkages intensity resembles the gravity equation. Furthermore, the sector-level input-output linkages are microfounded by the firm-level sourcing decisions. For each I-I variety, firms have a binary choice between input sourcing and in-house production. The sourcing decisions depend on relative productivity and relative sourcing cost which is analogous to trade cost.

The model is structurally calibrated to the WIOD. I calibrate the parameters of trade costs, productivities, trade elasticity and elasticity of substitution to match the observed sector prices, input-output linkages intensities, and sectoral wage growth rates. The key structural change parameters are estimated by regression. Using the calibrated model, I quantify to what extent the new mechanism of input-output linkages accounts for the structural change. In particular, I compare the I-I supply effects and the I-I demand effects relative to the price

effects and the income effects. The baseline decomposition result suggests that the I-I supply effects are comparable to the price effects. I also find that the income effects and the I-I demand effects are modest. Moreover, the quantitative result reveals that services have growing comparative advantage relative to manufacturing for supplying intermediate inputs to the downstream sectors. Therefore, it activates the I-I supply channel and leads to the structural change from manufacturing to services.

Over the last few years, there are growing interests in studying the macroeconomic implications of input-output linkages or production networks.³ One of the fundamental questions is when input-output linkages matter and when they are irrelevant. [Acemoglu et al. \(2012\)](#) show that microeconomic shocks translate into macroeconomic fluctuation when forward linkages are substantially asymmetric across sectors. On the other hand, the idiosyncratic shocks wash out in the same way as the standard diversification theory predicts when forward linkages are symmetric. Based on a similar model with [Acemoglu et al. \(2012\)](#), [Leal \(2017\)](#) illustrates an equivalent degree of influence between a Cobb-Douglas framework with input-output linkages and a Cobb-Douglas framework without input-output linkages. Chapter 4 uses a similar framework with [Acemoglu et al. \(2012\)](#) and [Leal \(2017\)](#) to study whether input-output linkages matter for productivity measurement.

I compare two hypothetical economies in the model. The input-output economy is described by the same model as in Chapter 2 in which sectors buy and sell intermediate inputs among each other. In the value added economy, I assume that the representative producer directly produces value added. The representative producer only takes the primary inputs into account and ignoring all the input-output linkages. Except for the input-output linkages, these two economies are otherwise equivalent. To make the model as simple as possible, production technology is assumed to be Cobb-Douglas. Labor and capital are inelastically supplied. I solve the competitive equilibrium aggregate productivity in the two economies.

Chapter 4 has three findings. First, aggregate productivity under the input-output economy is equal to that under the value added economy. This result depends on the assumption of Cobb-Douglas production technology. Second, relative to the sectoral productivity which is measured by taking into account the input-output linkages, the sectoral productivity which is measured without considering the input-output linkages is biased. This finding is supported by the empirical investigation in which the measurement biases occur in all the 4 sectors and 39 sampling countries through 1995-2007. Third, a re-examination of several previous studies suggests that the results of the previous productivity studies that ignore input-output linkages could be biased. For instance, without taking the input-output linkages into account,

³[Carvalho and Tahbaz-Salehi \(2018\)](#) provide a recent literature review on the macroeconomic implications of production networks.

we may misinterpret the contribution of structural change in aggregate productivity growth for many countries.

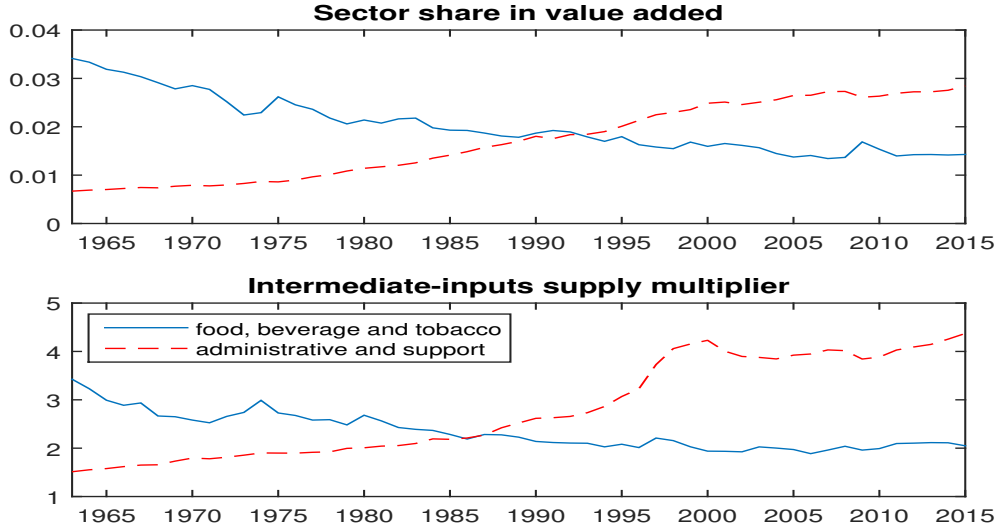
Chapter 2

Structural Change and Sectoral Linkages: Evidence and Mechanism

Do sectoral reallocations of value added depend on input-output linkages? This chapter presents novel evidence and mechanism on the correlations between the sector share in value added and the network characteristics of input-output linkages. Sectors with a larger growth of intermediate-inputs (I-I) supply multiplier increasingly attract labor and capital to satisfy the growing demand for intermediate inputs from the downstream sectors. Sectors with a larger growth of I-I demand multiplier increasingly shed labor and capital due to a rising degree of reliance on inputs sourcing from upstream sectors. Structural change arises from the sectors with a larger growth of I-I demand multiplier to the sectors with a larger growth of I-I supply multiplier. The correlations hold in both domestic trade and global trade of intermediate inputs.

2.1 Introduction

The transformation of economies from agriculture and manufacturing to services is known as structural change. Existing theories of structural change usually assume homogeneous and independent producers. The producer interaction through input-output linkages is overlooked. This chapter shows credible evidence on the relationship between the sector share in value added and the relevant characteristics of sectoral linkages. I find a positive correlation between the sector share in value added and the I-I supply multiplier. Conditional on the positive correlation, I find a negative correlation between the sector share in value added and the I-I demand multiplier. These correlations are robust to various levels of sectoral



Intermediate-inputs supply multiplier measures the connection intensity for supplying intermediate inputs from the target sector to the downstream sectors.

Fig. 2.1 Sector share in value added and intermediate-inputs supply multiplier in the US

aggregation and different patterns of trade. I use a multi-sector partial equilibrium model with input-output linkages to explain these correlations.

This chapter begins with two sufficient statistics which measure the intensity of supply linkages of intermediate inputs and demand linkages of intermediate inputs, respectively. I label them as the *I-I supply multiplier* and the *I-I demand multiplier*. Then I show the correlations between the sector share in value added and the two multipliers. To illustrate the mechanism, I introduce a multi-sector partial equilibrium model with input-output linkages. The input-output linkages are taken as exogenous. This chapter aims to focus on the intermediate demand mechanism.¹ I assume symmetric preferences to separate the new mechanism from the final demand mechanisms in the literature. The model can be extended to contain the global value chains (GVC) which admit the international trade of intermediate inputs and final output. Based on the model result, I undertake an empirical study. The empirical result suggests that the correlations hold in the context of GVC.

I find that the sector share in value added positively correlates with the I-I supply multiplier.² This is a novel and universal empirical finding. For exposition, I show an

¹I use the intermediate demand mechanism, the new mechanism of input-output linkages, and the new mechanism of inputs sourcing interchangeably in this dissertation. This mechanism is conclusive of two channels: I-I supply and I-I demand.

²Berlingieri (2013) finds evidence of the rising sourcing to professional and business services in the US on the one hand, and the increasing employment and value added share of these services industries on the other hand.

example in Figure 2.1. The upper panel displays the US value added shares of two two-digit sectors: food and beverage and tobacco products and administrative and support services. The upper panel of Figure 2.1 suggests that while sector share in value added dropped in the sector of food and beverage and tobacco products, it went up in the sector of administrative and support services through 1963-2015. The lower panel demonstrates the long-run pattern of the I-I supply multiplier of these two sectors. The I-I supply multiplier of the sector of food and beverage and tobacco products declined, whereas the I-I supply multiplier of the sector of administrative and support services shifted up. Figure 2.1 suggests a strong positive correlation between the sector share in value added and the I-I supply multiplier. Conditional on the positive correlation, the sector share in value added negatively correlates with the I-I demand multiplier. I show more evidence on the two correlations in Section 2.2.

Another contribution of this chapter is the discovery of a mechanism behind the correlations. On the one hand, if a sector has a larger growth of intermediate-inputs supply multiplier, this sector increasingly supplies intermediate inputs to the downstream sectors. It naturally requires more and more labor and capital to satisfy the rising demand for input sourcing. As a result, this sector has a rising sector share in value added. This intermediate-inputs supply channel is supported by the evidence in Figure 2.1. On the other hand, if a sector has a larger growth of intermediate-inputs demand multiplier, this sector increasingly purchases intermediate inputs from the upstream sectors. It increasingly relies on input sourcing rather than in-house production. This sector naturally sheds labor and capital, resulting in a decline of value added share. Structural change arises as a result of moving economic resource from the sectors with a more significant growth of intermediate-inputs demand connections to the sectors with a more significant growth of intermediate-inputs supply connections. The detailed mechanism is illustrated in Section 2.3.

Producers trade intermediate inputs not only domestically, but also globally. I extend the domestic model to a global model which admits the global trade of intermediate inputs. Based on the model result, I conduct a regression analysis. I formally test the two correlations by exploiting the World Input-Output Database (WIOD 2016) which contains 44 countries and 30 sectors through 2000-2014. I find that the correlations under the global trade are in line with the corresponding correlations under the domestic trade. I show the evidence under the global trade in Section 2.4.

Moreover, the result of counterfactual study that is based on the new mechanism suggest a comparable effect of intermediate demand with the effect of final demand. The significant intermediate demand mechanism is valid under both the domestic sourcing and the global sourcing. Therefore, the counterfactual study echoes the descriptive evidence and the new

mechanism, which together emphasize the need of contemplating the intermediate demand for the study of structural change.

Two closely related studies of this chapter are [Berlingieri \(2013\)](#) and [Sposi \(2018\)](#). Both of them argue that on top of the final demand, the intermediate demand impacts structural change. According to [Berlingieri \(2013\)](#), the rising services share attributes to the growing requirement for public and business services activities as intermediate inputs by manufacturers in the US economy. [Sposi \(2018\)](#) shows that the variation of intermediate-inputs demand intensity explains the structural change across countries. Compared to [Berlingieri \(2013\)](#), this chapter shows a comprehensive set of evidence for many sectors and many countries. This chapter also provides evidence in the context of global trade of intermediate inputs. Compared to [Sposi \(2018\)](#), this chapter studies structural change not only across the countries but also across the years. While [Sposi \(2018\)](#) emphasises the variation of the intermediate-inputs demand intensity, this chapter highlights the key role of the intermediate-inputs supply multiplier in structural change. In addition, [Sposi \(2018\)](#) and [Berlingieri \(2013\)](#) do not identify the mechanism as in this chapter. [Moro \(2012\)](#) and [Moro \(2015\)](#) mention the amplification of structural change by the divergent use of intermediate inputs between manufacturing and services, though the two papers focus on the impact of structural change on income growth and volatility.

This chapter complements the empirical literature which uses firm- and establishment-level data to document the relationship between structural change and the rise of sourcing of services tasks by manufacturing sector. [Dey et al. \(2012\)](#) estimate that the use of staffing services (mainly temporary help agency services) by US manufacturers increases from 2.3 percent to 8.9 percent of manufacturing employment through 1989-2006. [Dey et al. \(2012\)](#) explicitly point out the correlation between the rising sourcing and the decline of the US manufacturing employment share. Likewise, according to [Goldschmidt and Schmieder \(2017\)](#), while the share of low-skill services occupations (food, cleaning, security and logistics) falls in manufacturing sector, it rises in services sector in Germany between 1975 and 2008. They also suggest that the rising sourcing activities contribute to the increasingly smaller value added share of Germany manufacturing sector. Following [Goodman and Steadman \(2002\)](#), the services division (temporary help agency, business consulting, healthcare) contributed more than half of the US job growth between 1988 and 2000. More importantly, [Goodman and Steadman \(2002\)](#) show that the growth of intermediate demand of services inputs (temporary help agency, computer services and management services) is stronger than the growth of final demand of services output (healthcare and recreation). Therefore, the stronger growth of

intermediate demand of services is the key behind the rise of services and the decline of manufacturing, which is in line with the evidence and mechanism of this chapter.³

2.2 Evidence

The primary database I use in this chapter is the World Input-Output Database (WIOD). I obtain the data of input-output tables from the world input-output tables (WIOT). The WIOD offers two versions of input-output data: the 2013 version and the 2016 version. The 2013 version contains 40 major economies and 35 two-digit sectors through 1995-2011. The 2016 version contains 44 major economies (including the rest of the world) and 56 two-digit sectors through 2000-2014. Without losing generality, I use the 2013 version for the domestic evidence and use the 2016 version for the evidence on global value chains in Section 2.4. Moreover, I use the National Accounts Main Aggregate Database (NAMAD) from the UN and the US input-output tables from Bureau of Economic Analysis (BEA). These two databases are useful to track value added and input-output linkages for a longer period. The long-run time series data are useful for the validation exercises which are given in Appendix A.2.

This section documents the relationship between the sector share in value added and the two network features of input-output linkages. First, I define two sufficient statistics: the intermediate-inputs supply multiplier and the intermediate-inputs demand multiplier. Then I depict a positive correlation between the sector share in value added and the I-I supply multiplier, and a negative correlation between the sector share in value added and the I-I demand multiplier, conditional on the positive effect of I-I supply. I show these correlations in four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG).⁴ In Appendix A.2.2, I show evidence of the two correlations at two-digit sectors. Other related evidence and validation exercises are given in Appendix A.2.

³Though not explicitly present the correlation between sourcing and structural change, [Abraham and Taylor \(1996\)](#) show evidence of the rising outsourcing of services activities (janitorial services, machine maintenance services, engineering and drafting services, accounting services and computer services) by the US manufacturing plants through 1979-1987.

⁴Two reasons to decompose the services sector into the market services and the non-market services. First, Chapter 4 uses the price data from The Sector and Industry Relative Price database. In that database, they aggregate the 35 two-digit sectors into four sectors. I adopt their approach of sector aggregation. Second, four sectors admit a greater degree of variation of input-output linkages than three sectors. Since all evidence are similar between market service and non-market service, the sectoral classification method is irrelevant for all the results.

2.2.1 Sufficient Statistics

Before introduce the evidence, I formally define the intermediate-inputs supply and demand multipliers. Suppose matrix B denotes the input-output linkages which we normally observe in the data of input-output table. The element B_{ij} indicates the intermediate-inputs share of sector i in producing sector j gross output. From the standpoint of the input-output literature, the matrix B is the direct requirement matrix. It shows how much intermediate inputs are directly required from all industries to produce a dollar amount of gross output for each commodity at the bottom of the input-output table. Put it differently, from the point view of the network literature, the matrix B indicates the direct connection intensity for supplying intermediate inputs from the upstream industries in the row to all the downstream industries in the column. The *Leontief inverse* matrix L is defined by

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

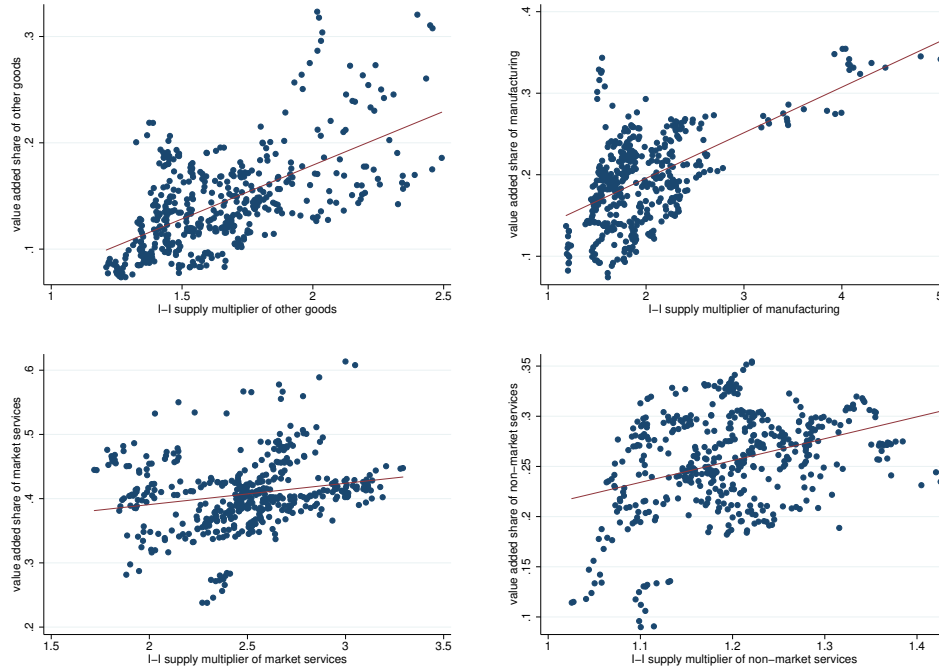
Here I is the identity matrix. In the input-output literature, matrix L is the total requirement matrix which shows how much intermediate inputs are—directly and indirectly—required from all industries to produce a dollar amount of gross output for each commodity at the bottom of the input-output table. Likewise, from the point view of the network literature, the Leontief inverse matrix L represents the total (direct and indirect) connection intensity for supplying intermediate inputs from the upstream industries in the row to all the downstream industries in the column.

Given the Leontief inverse matrix $L = [L_{ij}]$, I define the sectoral *intermediate-inputs supply multiplier* and *intermediate-inputs demand multiplier* as the following:

$$\mu_i^s \equiv \sum_{j=1}^J L_{ij},$$

$$\mu_j^d \equiv \sum_{i=1}^J L_{ij}.$$

The sectoral I-I supply multiplier μ_i^s is a horizontal sum of the corresponding row vector of the Leontief inverse. It measures the total connection intensity of a target sector that provides intermediate inputs to the downstream sectors. The sectoral I-I demand multiplier μ_j^d is a vertical sum of the corresponding column vector of the Leontief inverse. It measures the total connection intensity of a target sector that purchases intermediate inputs from the



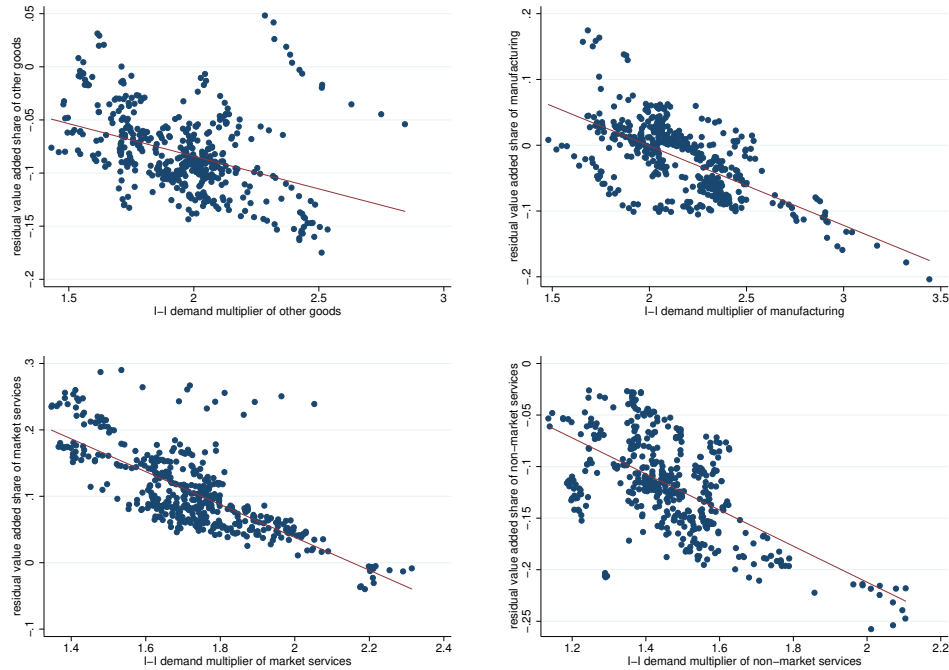
The horizontal axis denotes the values of I-I supply multiplier, and the vertical axis denotes the values of nominal value added share. Each dot point represents a country at a year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

Fig. 2.2 Correlation between value added share and intermediate-inputs supply multiplier

upstream sectors.⁵ Jones (2011a) and Fadinger et al. (2017) call the I-I supply multiplier as the input-output multiplier. I extend their original definitions to the I-I demand multiplier since the I-I demand multiplier is related to structural change as well.⁶ Overall, the I-I supply and I-I demand multipliers measure the degree of centrality of a sector for supplying intermediate inputs to the downstream sectors and purchasing intermediate inputs from the upstream sectors, respectively.

⁵For the vector of I-I supply multipliers, $\mu^s \equiv (I - B)^{-1}1 = (I + B + B^2 + \dots + B^\infty)1$, where 1 denotes a column vector with all entries of ones. Here the direct connection $B1$ measures the intensity of I-I supply connection from the target sectors to the downstream sectors with 1 unit of length. Similar, the indirect connection term B^21 measures the intensity of I-I supply connection from the target sectors to the downstream sectors with 2 units of length and so on so forth. The similar extension applies to the I-I demand multipliers. See Fadinger et al. (2017), Antras and Chor (2018) and Johnson (2018) for similar discussions.

⁶Acemoglu et al. (2012) call the vector of I-I supply multipliers as the influence vector. In the input-output literature, the I-I supply multiplier and I-I demand multiplier are forward linkages and backward linkages, respectively (Miller and Blair 2009). In the network literature, these two multipliers are a special form of Bonacich centrality in terms of the I-I supply and the I-I demand, respectively. See Ballester et al. (2006) for an explanation about Bonacich centrality, and the connection between multipliers defined in this chapter and the general form of Bonacich centrality in their paper.



The horizontal axis denotes the values of I-I demand multiplier, and the vertical axis denotes the values of residual nominal value added share. Here residual means the value added share after accounting for the positive correlation in the I-I supply multiplier. Each dot point represents a country at a year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

Fig. 2.3 Correlation between residual value added share and intermediate-inputs demand multiplier

2.2.2 Sector Share in Value Added

Structural change refers to a decline of sector share in agriculture and especially manufacturing and a rise in services. I show the long run pattern of structural change for a few developed countries in Figure A.1 and for a few developing countries in Figure A.2. Herrendorf et al. (2013) and Herrendorf et al. (2014) provide detailed evidence on structural change.

This chapter highlights two key correlations: a positive correlation between the sector share in value added and the I-I supply multiplier, and a negative correlation between the sector share in value added and the I-I demand multiplier conditional on the positive correlation in the supply side. The two correlations are depicted in Figure 2.2 and Figure 2.3, respectively. In both figures, the four panels display the correlations for four one-digit sectors: other good; manufacturing; market services and non-market services. The definition of each sector is given in Inklaar and Timmer (2014).⁷ These correlations are based on the World Input-Output Database which contains 35 major economies through 1995-2007. Each dot point stands for a

⁷See Appendix A.3 for sector classification and description. This classification approach follows the System of National Account. This classification approach is similar to Duarte and Restuccia (2017). The market services

country at a specific year in Figure 2.2 and Figure 2.3. The horizontal axis of these two figures denotes the intermediate-inputs supply multiplier and demand multiplier, respectively. The vertical axis denotes the nominal sector share in value added and the residual nominal sector share in value added, respectively. These correlations are also observable at the two-digit sectors in the long run, which are given in Appendix A.2.2. These correlations hold not only in time series data but also hold across countries. Consistent with Herrendorf et al. (2014), structural change is a global phenomenon which holds across countries at different stages of development.

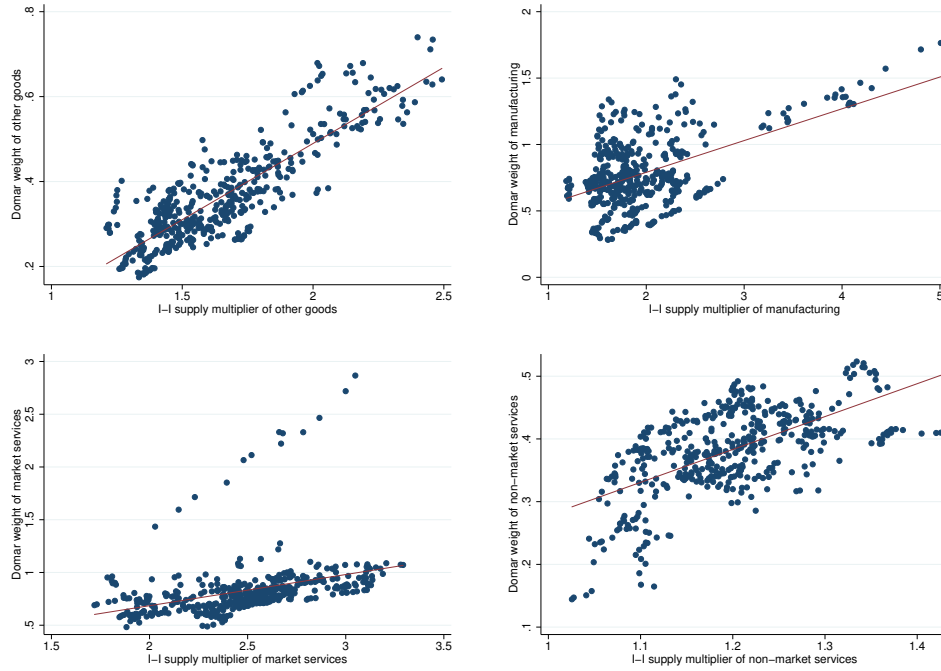
Besides, the strong negative correlation between the residual sector share in value added and the intermediate-inputs demand multiplier implies that the demand multiplier also matters. Figure 2.3 suggests that after removing the positive correlation in the intermediate-inputs supply multiplier, the residual sector share in value added negatively correlates with the intermediate-inputs demand multiplier. Notice that the sectoral use of intermediate inputs is relatively stable over time, which result in less variation in the I-I demand multiplier.⁸ However, the negative correlation between the value added share and the I-I demand multiplier is significant at 1 percent level, in the OLS regression of Value added share on the I-I supply and I-I demand multipliers. Conditional on the positive correlation between the value added share and the I-I supply multiplier, the value added share negatively correlates with the I-I demand multiplier. The correlations hold with country and year fixed effects. Though both correlations hold, the positive correlation between the value added share and the I-I supply multiplier is much stronger than the negative correlation between the value added share and the I-I demand multiplier. I show the detailed regression evidence in Section 2.4.

2.2.3 Domar Weight

Finally, I show the correlation between the Domar weight and the I-I supply multiplier. *Domar weight* is defined as the sectoral gross output share of GDP (Domar 1961). In the input-output literature, Domar weight is the relevant sector weight to determine the sectoral influence in the sale of gross output (Balk 2009). I present the correlation in Figure 2.4. It suggests a positive correlation between the Domar weight and the I-I supply multiplier in all the four sectors. This positive correlation is the key to understand the positive correlation between the sector share in value added and the I-I supply multiplier, and therefore crucial to understand

sector closes to their modern services sector; and the non-market services sector closes to their traditional services sectors, such as government, health, education, and housing.

⁸Acemoglu et al. (2012) find that 71 percent of the US four-digit sectors are within one standard deviation of the mean demand intensity of intermediate inputs. More importantly, the distribution is stable between 1972 and 2002.



The horizontal axis denotes the values of I-I supply multiplier, and the vertical axis denotes the values of Domar weight (gross output share of GDP). Each dot point represents a country at a year. The data contain 35 major economies between 1995 and 2007. The solid line shows the OLS fitted values.

Fig. 2.4 Correlation between Domar weight and intermediate-inputs supply multiplier

structural change. Domar weight is the intermediary term to connect the value-added share and the I-I supply multiplier. I illustrate the connection in the following section.

In addition, the result of the counterfactual study suggests a comparative role of intermediate demand versus the final demand in structural change. The detail of the counterfactual study are given in Appendix A.2.4 and Appendix A.2.5. First, I hold the input-output linkages constant. Second, I assume no change of consumption shares. Under both cases, I calculate the counterfactual value added shares based on equations (2.1) and (2.2) that are introduced in the following section. The result suggests that both intermediate demand and final demand are crucial for structural change. The magnitude of the two mechanisms are close.

In effect, the evidence implies that input-output linkages are of use for considering structural change. Structural change is driven not only by final demand, but also potentially affected by intermediate demand. In the next section, the new mechanism of intermediate demand is analyzed comprehensively.

2.3 Domestic Sourcing

This section explores the mechanism behind the evidence in the last section. I introduce a multi-sector partial equilibrium model with input-output linkages following Jones (2011b). In this model, the input-output linkages are taken as exogenous. Consumption is exogenous as well. I use this simple model to illustrate the implication of input-output linkages for structural change. This section aims to explain the intermediate demand mechanism through a simple model and a simple example.

2.3.1 A Simple Closed Economy Model

In this subsection, I consider a closed economy model without international trade of intermediate inputs and final output.

There are finite number (J) of sectors in an economy. Let i and j denote sectors. In each sector, there is a representative producer. The production function of the sectoral gross output features constant return to scale Cobb-Douglas:

$$Q_i = A_i K_i^{(1-\sigma_i)\alpha_i} L_i^{(1-\sigma_i)(1-\alpha_i)} \prod_{j=1}^J X_{ij}^{\sigma_{ij}}.$$

Here $\sigma_i \equiv \sum_{j=1}^J \sigma_{ij}$; K_i and L_i stand for capital and labor demand of sector i , respectively; X_{ij} represents the intermediate input produced by sector j and used by sector i ; A_i is total factor productivity (TFP) of sector i . The exponent σ_{ij} denotes the intermediate-input share of sector j in producing the gross output of sector i , and by construction we have $\sigma_{ij} = B_{ji}$. Hence, σ_i indicates the intermediate-inputs demand intensity of sector i . Capital share of value added is α_i . The gross output is either consumed as the final good or supplied to other sectors as the intermediate inputs:

$$C_j + \sum_{i=1}^J X_{ij} = Q_j.$$

The aggregate value added (real GDP) Y is assumed to be a Cobb-Douglas aggregation of sectoral consumption C_i , such that

$$Y = \prod_{i=1}^J C_i^{\lambda_i}.$$

Here λ_i is the consumption share of sector i and $\sum_{i=1}^J \lambda_i = 1$.

Output and inputs markets are competitive, and capital and labor are inelastically supplied. A representative producer maximizes aggregate profit and sectoral profit, by optimally allocating primary inputs, intermediate inputs, and consumption (See Appendix A.1 for solution). In equilibrium, the value added share η_i and the employment share l_i are dependent on the structure of the input-output linkages, which are given by

$$\eta_i \equiv \frac{P_{Yi}Y_i}{P_Y Y} = (1 - \sigma_i)\gamma_i,$$

$$l_i \equiv \frac{L_i}{L} = \frac{(1 - \sigma_i)(1 - \alpha_i)\gamma_i}{\sum_{i=1}^J (1 - \sigma_i)(1 - \alpha_i)\gamma_i}.$$

Here P_{Yi} and P_Y are the sectoral output price and aggregate output price, Y_i is the sectoral value added, and L is the aggregate labor supply. The term γ is the column vector ($J \times 1$) of Domar weights: $\gamma = (I - B)^{-1}\lambda$, where λ is the column vector ($J \times 1$) of consumption share and $\gamma_i \equiv \frac{P_i Q_i}{P_Y Y}$. I assume the same capital share across sectors hereafter such that $\alpha_i = \alpha_j$.⁹ Then I derive an equivalence between the value added share and the employment share, which is given by

$$l = \eta = (I - \Sigma)\gamma = (I - \Sigma)(I - B)^{-1}\lambda. \quad (2.1)$$

Here Σ is a diagonal matrix with $\Sigma_{ii} = \sigma_i$ and zero otherwise, η and l are column vectors ($J \times 1$) of value added shares and employment shares, respectively.

2.3.2 Mechanism

This subsection illustrates the mechanism of input-output linkages behind structural change. The mechanism is jointly determined by two channels: the intermediate-inputs supply channel and the intermediate-inputs demand channel. I show the two channels individually, followed by a summary of the whole mechanism. The mechanism is illustrated in the light of equation (2.1).

I-I Supply Channel

We can see the I-I supply channel following two steps. In the first step, we need to understand the positive correlation between the I-I supply multipliers $\mu^s = (I - B)^{-1}1$ and the Domar weights $\gamma = (I - B)^{-1}\lambda$. This correlation is implied by the third equality in equation (2.1). The intermediate-inputs supply multiplier is a vector sum of the corresponding row of the

⁹Another implicit assumption of this chapter is equal wages across sectors.

Leontief inverse. The Domar weight is a weighted average of the corresponding row of the Leontief inverse. Here the weights are sectoral consumption shares.

In principal, both the variation of the consumption shares λ and the intermediate-inputs supply multipliers μ^s contribute to the variation of the Domar weights γ . If there is no input-output linkage such that $B = 0$, Domar weights are equivalent to consumption shares: $\gamma = \lambda$. In this case, the variation of Domar weight depends only on the consumer preferences heterogeneity. On the other hand, if the consumer has symmetric consumption preferences such that $\lambda_i = \lambda_j$, then the variation of the Domar weight depends only on the heterogeneity of I-I supply multiplier. In [Acemoglu et al. \(2017\)](#), these two extreme cases are called the *primitive heterogeneity* and the *network heterogeneity*, respectively. Input-output linkages are overlooked by the conventional structural change literature which attributes structural change only to the primitive heterogeneity. Structural change literature omits the network heterogeneity which is the focus of this chapter.

In this chapter, since I focus on the network heterogeneity, this is the second extreme case. I assume symmetric preferences. The Domar weight positively depends on the I-I supply multiplier, and the mapping is one-on-one in this special case. In [Figure 2.4](#), there is a strong positive correlation between the Domar weight and the I-I supply multiplier. It suggests that the network heterogeneity plays a critical role in determining the Domar weight, which is consistent with [Acemoglu et al. \(2017\)](#). This chapter identifies the *network origins* of structural change in the spirit of [Acemoglu et al. \(2012\)](#).

The second step aims to understand the positive correlation between the value added share and the Domar weight. This correlation is implied by the second equality in equation (2.1). The economic meaning of the 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 aggregates all the direct and indirect effects of the TFP shock to 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_j percent. It implies that the Domar weight γ_i is the elasticity of GDP to the TFP (sectoral gross output based) shock of sector i . In a corresponding case of value added economy, the sectoral value added share η_i is also the elasticity of GDP to the TFP (sectoral value added based) shock of sector i .¹⁰ Essentially, the value added share and the Domar weight are elasticities of GDP to different types of TFP: value added based and gross output based, respectively. Equation (2.1) suggests a positive correlation between the two elasticities, holding the intermediate-inputs demand intensity σ_i constant.

Eventually, we can integrate the two steps together. That is, conditional on the assumption of symmetric preferences, a sector with a larger I-I supply multiplier has a higher Domar

¹⁰See this implication in Proposition 5 of Chapter 4.

weight. A higher Domar weight implies a larger elasticity of aggregate output to sectoral gross output based TFP, which means that this sector has a larger weight in the input-output economic landscape. As a result, this sector also has a larger weight in the value added economic landscape, namely a larger value added share. As intuitively summarized by [Leal \(2017\)](#), when a sector plays a central role in the input-output network, it also has a large value added share.

I-I Demand Channel

On the other hand, for any sector with a larger intermediate-inputs demand multiplier μ_i^d , it implies a larger intermediate-inputs demand intensity σ_i .¹¹ Based on equation (2.1), this implies a smaller value added share. The large sector weight is offset by the more intensive use of intermediate inputs, holding constant the Domar weight. In aggregate, if I suppress the mechanisms of final demand by assuming symmetric preferences, structural change arises from the sectors with a larger growth of intermediate-inputs demand multiplier to the sectors with a larger growth of intermediate-inputs supply multiplier.¹²

Summary

I summarize the insight of the new mechanism as follows. In the input-output economic landscape, if sectors have increasingly more intensive direct and indirect supply connections of intermediate inputs to the downstream sectors, these sectors have a larger growth of intermediate-inputs supply multiplier. To satisfy the rising demand for intermediate inputs, these sectors have to employ more and more labor and capital than other sectors. On the other hand, if sectors have increasingly more intensive direct and indirect demand connections of intermediate inputs to the upstream sectors, these sectors increasingly rely on inputs sourcing rather than in-house production. These sectors displace a growing amount of labor and capital. Consequently, structural change arises from the sectors with a larger growth of I-I demand connections to the sectors with a larger growth of I-I supply connections. I further illustrate the new mechanism through a simple example in the next subsection.

¹¹The vector of I-I demand multipliers is extended as $\mu^d \equiv 1'(I - B)^{-1} = 1'(I + B + B^2 + \dots + B^\infty)$. We have $\mu_j^d \approx 1 + \sigma_j$, if the element values of the input-output matrix B are sufficiently small. Hence, we have a positive correlation between the I-I demand multiplier and the sectoral I-I demand intensity, given sufficiently small input-output linkages intensities between sectors.

¹²In this chapter, I turn off the mechanisms of final demand. This is the key departure of this chapter from the conventional structural change literature. In the next chapter, I allow both mechanisms—the final demand mechanisms and the intermediate demand mechanism—jointly determining structural change.

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		

This table shows a 2×2 input-output table. The first two main columns display the production of gross output (Q) by demanding intermediate inputs (IID) and making value added (VA). The first two main rows display the supply of gross output to either producers as intermediate inputs (IIS) or consumer as final goods (C).

Table 2.1 Structural change and variation of input-output linkages

2.3.3 Example

Suppose an economy has two sectors: sector 1 and sector 2. Each sector has a representative producer who produces a sector-specific gross output. The gross output is either supplied to the consumer as the final consumption or to the two producers as the intermediate input. For instance, we can think of these two sectors as the manufacturing sector and services sector. On the one hand, the manufacturer requires the services activities to produce. On the other hand, the services provider uses the manufacturing product as input when providing services. Their product and services are consumed by customer as well.

Table 2.1 presents an example of structural change as the sectoral linkages vary. In the benchmark panel, I show the gross output (Q), consumption (C), value added (VA), the supply of intermediate inputs (IIS) and the demand of intermediate inputs (IID). Table 2.1 mimics an input-output table with two sectors.¹³ The first two main columns show the demand-side production, and the first two main rows show the supply-side production. On the demand side, each sector sources 1 unit of intermediate input within the sector,¹⁴ sources 1 unit of intermediate input from the other sector, and produces 2 units of value added. On the supply side, each sector supplies 1 unit of intermediate input to itself, supplies 1 unit of intermediate input to the other sector, and supplies 2 units of final good to the consumer. Both sectors produce 4 units of gross output in the benchmark case.

Suppose there is a shock to the sourcing cost, such that sector 1 supplies intermediate input to sector 2 at a lower cost than before.¹⁵ After the shock, suppose sector 2 has an

¹³The input-output matrix B in the benchmark case is $\begin{bmatrix} 0.25 & 0.25 \\ 0.25 & 0.25 \end{bmatrix}$.

¹⁴If there are many disaggregated industries under the broadly defined sector, the interindustrial trade of intermediate inputs is taken as sourcing within the broadly defined sector.

¹⁵Here I fix the income and the producer basic price. Constant income is easy to see since the aggregate value added is 4 in both cases. There is only a shock to the trade cost. The producer basic receiving price should not change given everything else the same as before. But the consumer price and the producer purchasing price change after the shock. Hence, here I try to partially turn off the final demand mechanisms (income and prices).

incentive to buy 1 more unit of intermediate input from sector 1. Simultaneously, sector 1 is more profitable to supply 1 more unit of intermediate input to sector 2. For instance, the European de-unionization policy significantly reduces the sourcing cost from the services sector, which induces manufacturers to source some of their traditional services activities, such as janitorial services, security and logistics, from the specialized services companies (Goldschmidt and Schmieder 2017).

In this case, sector 2 now relies more on input sourcing, therefore sector 2 does not need to produce as much value added as in the benchmark case. Sector 2 may substitute the low-skill services activities from production in-house to sourcing, hence displacing some of her labor and capital. Sector 2 sources part of the services tasks from sector 1 and focusing on the core manufacturing production which produces 1 unit of value added. In contrast, sector 1 now is responsible for supplying more intermediate inputs to sector 2. Sector 1 accepts the incremental sourcing tasks from sector 2, thus producing more value added to satisfy the extra demand for intermediate input. Not surprisingly, labor and capital are transferred from sector 2 to sector 1, due to the relative change of value added production between the two sectors.

In aggregate, the shock to the sourcing cost leads to a change pattern of intersectoral trade of intermediate input, which further implies the structural change of primary inputs and value added. This example has three implications. First, this example illustrates the novel mechanism in the previous subsection. Since sector 2 has a growing I-I demand multiplier, and sector 1 has an increasing I-I supply multiplier, it gives rise to the structural change from sector 2 to sector 1. Second, this example matches the evidence in Section 2.2. When sector 1 has a larger I-I supply multiplier, value added share of sector 1 rises. When sector 2 has a larger I-I demand multiplier, value added share of sector 2 falls. Third, this example motivates the model setup in the next chapter. The shock to the sourcing cost is an essential factor generating variation in the intersectoral trade of intermediate inputs. In Chapter 3, I directly model the endogenous path of intersectoral trade of intermediate inputs on sourcing cost.

2.4 Global Sourcing

Sectors buy and sell intermediate inputs through the global value chains in which the trade of intermediate inputs occurs not only across sectors but also across countries. I show the global trade of intermediate inputs and final output in Table 2.2, an abstract world input-output table with J sectors and N countries. For the main columns, Table 2.2 displays the value added and the requirement of intermediate inputs from all country-sector pairs to produce the dollar amount of gross output at the bottom of the table. For the main rows, Table 2.2 displays the

		Input use & value added										Final use		Total use
		Country 1				Country N				Country 1		Country N		
Inputs supplied	Country 1	Sector 1	...	Sector J	...	Sector 1	...	Sector J	...	C_1^1	...	C_1^{N1}	...	Q_1^1
		X_{11}^1	...	X_{J1}^1	...	X_{11}^{N1}	...	X_{J1}^{N1}	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	C_1^1	...	...	...	...
	Country N	Sector 1	...	Sector J	...	Sector 1	...	Sector J	...	C_1^1	...	C_1^{N1}	...	Q_1^1
		X_{11}^1	...	X_{J1}^1	...	X_{11}^{N1}	...	X_{J1}^{N1}	...	...	...	...	...	...
	Value added	X_{11}^{mn}	...	X_{J1}^{mn}	...	X_{11}^{NN}	...	X_{J1}^{NN}	...	C_1^{mn}	...	C_1^{NN}	...	Q_1^N
Gross output		Y_1^1	...	Y_1^J	...	Y_1^N	...	Y_1^N	...	C_1^{1N}	...	C_1^{NN}	...	Q_1^N
		Q_1^1	...	Q_1^J	...	Q_1^N	...	Q_1^N	...	C_1^{1N}	...	C_1^{NN}	...	Q_1^N

This table presents an arbitrary input-output table in the context of the global value chains. Here the trading unit is a country-sector pair. For a particular column, the table shows the production of gross output Q_i^m in sector i of country m. The gross output is produced by making value added Y_i^m and using intermediate inputs X_{ij}^{mn} which is produced by sector j in country n and used by sector i in country m. For a particular row, the table shows that the gross output Q_j^n could be consumed as final goods C_j^{mn} to country m or supplied to producers as intermediate inputs X_{ij}^{mn} which is supplied by sector j in country n and used by sector i in country m.

Table 2.2 Trade of intermediate inputs and final output in the global value chains

flow of the gross output in the last column to all country-sector pairs as intermediate inputs and to all countries as final consumption. The domestically intersectoral trade of intermediate inputs in Section 2.3 is a special case to the global value chains in this section.

2.4.1 Model Extension

The world economy contains N countries. In each country, there are J sectors. The sectoral gross output production function in Section 2.3 extends to

$$Q_i^m = A_i^m (K_i^m)^{(1-\sigma_i^m)\alpha_i^m} (L_i^m)^{(1-\sigma_i^m)(1-\alpha_i^m)} \prod_{n=1}^N \prod_{j=1}^J (X_{ij}^{mn})^{\sigma_{ij}^{mn}}.$$

Here the superscript denotes country. The country-sector pair sources intermediate inputs X_{ij}^{mn} globally from sector j in country n to sector i in country m . Except for the extra country dimension, all the variables follow the same economic meanings as in the sectoral production equation in Section 2.3. The global resource constraint is given by the following equation:

$$Q_i^m = \sum_{n=1}^N \sum_{j=1}^J X_{ji}^{nm} + \sum_{n=1}^N C_i^{nm}.$$

In contrast to the definition of the national aggregate value added in Section 2.3, it is useful to define the global aggregate value added in this subsection. The global GDP $\tilde{Y}$ is defined by

$$\tilde{Y} = \prod_{m=1}^N \prod_{i=1}^J (C_i^m)^{\lambda_i^m},$$

$$C_i^m = \prod_{n=1}^N (C_i^{nm})^{\lambda_i^{nm}}.$$

Here we have $\sum_{m=1}^N \sum_{i=1}^J \lambda_i^m = 1$ and $\sum_{n=1}^N \lambda_i^{nm} = 1$.

All markets are competitive, and capital and labor are inelastically supplied. In the global value chains, the representative producer maximizes the aggregate profit and sectoral profit by globally sourcing intermediate inputs, otherwise the equilibrium solution follows the same way as in the closed economy model. In equilibrium, we have the following key equilibrium

condition:

$$P_i^m Q_i^m = \sum_{n=1}^N \sum_{j=1}^J B_{ij}^{mn} P_j^n Q_j^n + \sum_{n=1}^N P_i^m C_i^{nm};$$

$$\gamma_i^m \equiv \frac{P_i^m Q_i^m}{P_{\tilde{Y}} \tilde{Y}} = \sum_{n=1}^N \sum_{j=1}^J B_{ij}^{mn} \frac{P_j^n Q_j^n}{P_{\tilde{Y}} \tilde{Y}} + \sum_{n=1}^N \frac{P_i^m C_i^{nm}}{P_{\tilde{Y}} \tilde{Y}}.$$

Here B denotes the global input-output matrix ($NJ \times NJ$) with $B_{ij}^{mn} = \frac{P_i^m X_{ji}^{nm}}{P_j^n Q_j^n}$, and $P_{\tilde{Y}} \tilde{Y}$ is the world nominal GDP, and γ_i^m is the Domar weight in terms of the world GDP. Then we can solve the global version of Domar weights in a similar equation as in Section 2.3:

$$\gamma = (I - B)^{-1} \lambda.$$

Here λ is the column vector ($NJ \times 1$) of consumption shares in terms of the world GDP:

$$\lambda_i^m = \frac{P_i^m C_i^m}{P_{\tilde{Y}} \tilde{Y}}.$$

I construct the sector share in value added in the following equation:

$$\begin{aligned} \eta_i^m &= \frac{P_{Yi}^m Y_i^m}{P_Y^m Y^m} \\ &= \frac{P_{Yi}^m Y_i^m}{P_i^m Q_i^m} \frac{P_i^m Q_i^m}{P_{\tilde{Y}} \tilde{Y}} \frac{P_{\tilde{Y}} \tilde{Y}}{P_Y^m Y^m} \\ &= (1 - \sigma_i^m) \gamma_i^m \frac{P_{\tilde{Y}} \tilde{Y}}{P_Y^m Y^m}. \end{aligned}$$

Here $P_{Yi}^m Y_i^m$ is the nominal sectoral value added, and $P_Y^m Y^m$ is the nominal national GDP. The term σ_i^m denotes the demand intensity of intermediate inputs in sector i of country m . Finally, I derive the relative sector share in value added, which is given by

$$\frac{\eta_i^m}{\eta_j^m} = \frac{1 - \sigma_i^m}{1 - \sigma_j^m} \frac{\gamma_i^m}{\gamma_j^m}. \quad (2.2)$$

Equation (2.2) suggests a positive correlation between the value added share and the Domar weight, which further implies that the value added share positively correlates with the I-I supply multiplier. Besides, equation (2.2) suggests a negative correlation between the value added share and the sectoral demand intensity of intermediate inputs, which further implies that the value added share negatively correlates with the I-I demand multiplier. As a result, the implications in this subsection are consistent with Section 2.3. The closed economy mechanism holds in the global value chains.

2.4.2 Empirical Study

In this subsection, I undertake an empirical study to test the model predictions in the context of global sourcing. I use the 2016 version of input-output table data. To keep more information about the global trade of intermediate inputs, I conduct the empirical study at a two-digit sector level.

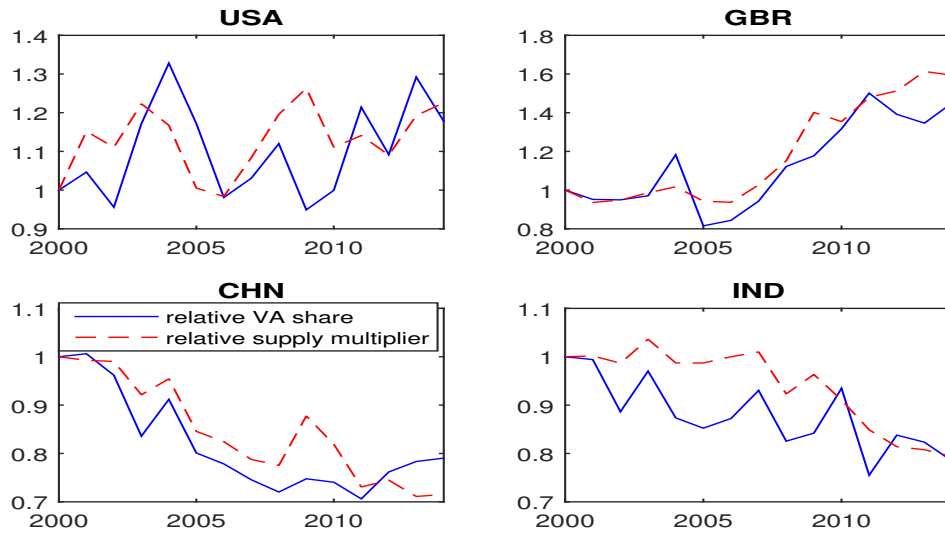
The balanced dataset of the WIOT 2016 contains the input-output tables for 44 countries, 30 sectors and 15 years (2000-2014).¹⁶ At every year, I have 1320 trading nodes, a comprehensive trade network. For each sector, I have a country-year panel (44×15) dataset, and for each country, I have a sector-year panel (30×15) dataset. I use these comprehensive datasets to test whether the sectors with a larger growth of I-I supply multiplier have a rising sector share in value added, and the sectors with a larger growth of I-I demand multiplier have a reducing sector share in value added.

I begin with three examples demonstrating the evidence of the positive correlation between the sector share in value added and the intermediate-inputs supply multiplier. I present the positive correlations in three principal sectors: crop and animal production, hunting and related services activities; manufacture of computer, electronic and optical products; and telecommunications. They represent one of the primary agriculture, manufacturing and services sectors, respectively.

Figure 2.5 to Figure 2.7 present the trends of the relative sector share in value added and the relative intermediate-inputs supply multiplier of the three representative sectors to the benchmark sector: manufacture of chemicals and chemical products. I show the results in relative values following equation (2.2). I follow Comin et al. (2019) to choose a major manufacturing sector as the benchmark sector. Note that the qualitative correlations do not depend on the choice of the benchmark sector. Each figure plots the two curves for two rich economies: the US and the UK; and two emerging economies: China and India.

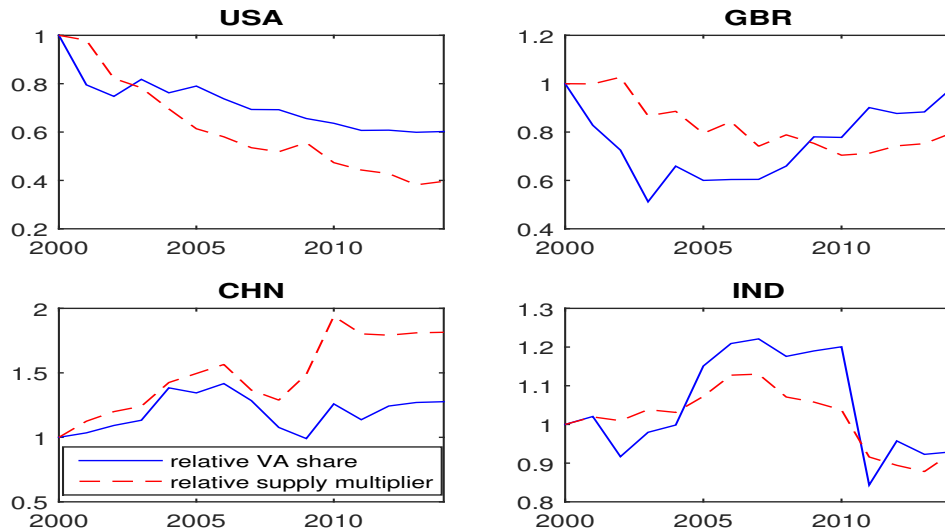
Figure 2.5 to Figure 2.7 suggest a strong positive correlation between the relative sector share in value added and the relative I-I supply multiplier. The two trends move closely throughout the period, though the movement differs substantially across countries and across industries. Figure 2.5 to Figure 2.7 suggest that the sectors with a growing I-I supply multiplier have an increasing sector share in value added. The positive correlation is in line with the domestic evidence in Section 2.2.

¹⁶I remove any sector with missing data for all countries. Eventually, 26 out of 56 sectors are removed from the original database.



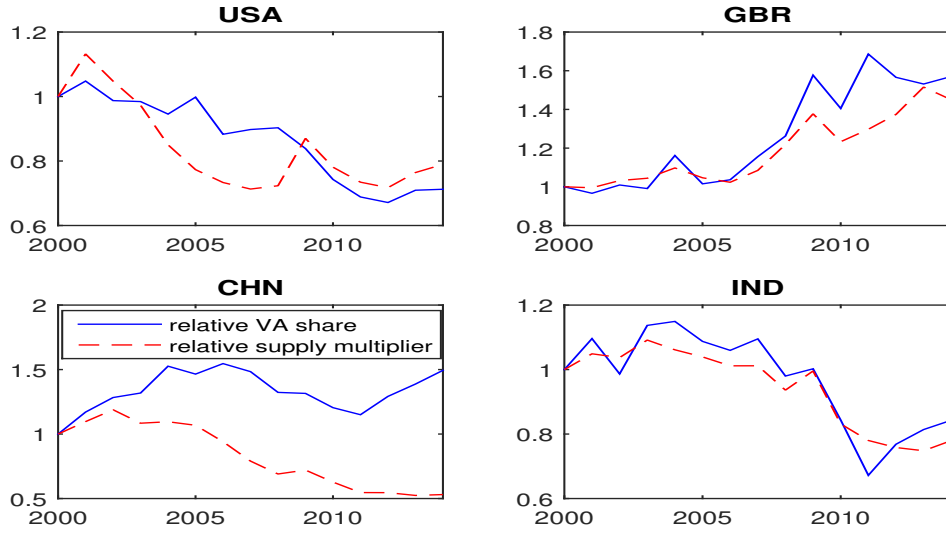
This figure plots the relative sector share in value added (VA) and the relative I-I supply multiplier of the agricultural industry to the benchmark industry: manufacture of chemicals and chemical products. The chosen agricultural industry is crop and animal production, hunting and related services activities. The four panels stand for the four countries: United State (USA), United Kingdom (GBR), China (CHN) and India (IND). The initial year values are normalized to 1.

Fig. 2.5 Crop and animal production, hunting and related services activities



This figure plots the relative sector share in value added and the relative I-I supply multiplier of the manufacturing industry to the benchmark industry: manufacture of chemicals and chemical products. The chosen manufacturing industry is manufacture of computer, electronic and optical products. The four panels stand for the four countries: United State (USA), United Kingdom (GBR), China (CHN) and India (IND). The initial year values are normalized to 1.

Fig. 2.6 Manufacture of computer, electronic and optical products



This figure plots the relative sector share in value added and the relative I-I supply multiplier of the services industry to the benchmark industry: manufacture of chemicals and chemical products. The chosen services industry is telecommunications. The four panels stand for the four countries: United State (USA), United Kingdom (GBR), China (CHN) and India (IND). The initial year values are normalized to 1.

Fig. 2.7 Telecommunications

Now I proceed to formally test the two correlations in a pooled regression study. I treat the country-sector pair as a panel. I use the following regression equation:

$$\hat{\eta}_{mi,t} = \alpha + \beta_s \hat{\mu}_{mi,t}^s + \beta_d \hat{\mu}_{mi,t}^d + f_m \times f_i + f_t + e_{mi,t}.$$

Here the variable with a hat means the relative value to the benchmark sector. The term f_m , f_i , and f_t are country, sector and year fixed effects. I use the country-sector fixed effect in this regression study. The error term $e_{mi,t}$ contains the effects of final demand factors, such as the price effects and the income effects. The objective of this regression study is testing the positive correlation in the I-I supply channel: $\beta_s > 0$ and testing the negative correlation in the I-I demand channel: $\beta_d < 0$.

Table 2.3 reports the estimation results. Column (1) to column (3) of Table 2.3 suggest a positive correlation between the relative value added share and the relative I-I supply multiplier, and a negative correlation between the relative value added share and the relative I-I demand multiplier. All the correlations are significant at one percent critical value. The correlations hold with fixed effects as well. Given the fixed effects, the estimation result suggests a stronger absolute magnitude in the I-I supply channel than the I-I demand channel.

I perform a few validation tests. Within each country, I run the regression based on the sector $\times$ year panel dataset. I find that the positive correlation is significant at five percent

Coefficient	Dependent Variable : $\hat{\eta}_{mi,t}$								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
β_s	4.339*** (0.049)	5.287*** (0.113)	5.092*** (0.114)	4.089*** (0.052)	5.195*** (0.112)	5.026*** (0.112)			
β_d	-8.852*** (0.175)	-1.855*** (0.335)	-1.160*** (0.340)				-7.279*** (0.207)	0.431 (0.351)	1.380*** (0.353)
Country× Sector FE	NO	YES	YES	NO	YES	YES	NO	YES	YES
Year FE	NO	NO	YES	NO	NO	YES	NO	NO	YES
N	19140	19140	19140	19140	19140	19140	19140	19140	19140
R^2	0.335	0.810	0.812	0.246	0.809	0.812	0.061	0.786	0.791

This table shows the results of OLS estimation of relative value added share on relative I-I supply multiplier and I-I demand multiplier. Here the benchmark sector is manufacture of chemicals and chemical products. All estimation results are based on the World Input-Output Database 2016 which contains 44 countries and 30 sectors through 2000-2014. The β_s estimates the magnitude on the I-I supply multiplier, and β_d estimates the magnitude on the I-I demand multiplier. Standard errors are reported in the parentheses. *** denotes significance at one percent critical value.

Table 2.3 OLS tests of the two correlations in the global value chains

critical value for 39 out of 44 countries, and the negative correlation is significant at five percent critical value for 41 out of 44 countries. Within each sector, I run the regression based on the country $\times$ year panel dataset. I find that the positive correlation is significant at five percent critical value for 28 out of 29 sectors, and the negative correlation is significant at five percent critical value for 13 out of 29 sectors. The positive supply-side correlation appears more robust than the negative demand-side correlation.

I also test the correlations individually. I present the estimation results of the supply-side correlations in column 4 to column 6 and the demand-side correlations in column 7 to column 9 of Table 2.3. The results suggest that the positive correlation is always significant. The negative correlation disappears when I run the regression just on the relative I-I demand multiplier with fixed effects. Table 2.3 suggests that while the I-I supply and I-I demand channels jointly determine the structural change, the I-I supply channel is stronger and more independent. The negative I-I demand channel appears conditional on the positive I-I supply channel.

2.5 Conclusion

I present new evidence on structural change in this chapter. The evidence features a positive correlation between the sector share in value added and the intermediate-inputs supply multiplier. Conditional on the positive supply-side correlation, sector share in value added negatively correlates with the intermediate-inputs demand multiplier. These correlations are significant under both the domestic trade and the global trade of intermediate inputs.

The evidence could be explained by a simple multi-sector model with input-output linkages. The intuition is that when sectors have a stronger growth of supply linkages of intermediate inputs, they increasingly employ more labour and capital to satisfy the rising demand for inputs sourcing. In contrast, for the sectors with a stronger growth of demand linkages of intermediate inputs, they increasingly rely on inputs sourcing rather than in-house production, therefore displacing more and more labor and capital. As a result, structural change arises from the sectors with a larger growth of demand linkages to the sectors with a larger growth of supply linkages of intermediate inputs.

This chapter sheds light on the critical role of input-output linkages in structural change. The structural change literature primarily concentrates on the final demand factors, in which the input-output linkages are usually absent. This chapter makes a first step toward studying the correlation between structural change and the input-output linkages. Based on the evidence and the mechanism in this chapter, I further consider the fundamental factors behind the structural change and the trade of intermediate inputs in the next chapter. I attempt

to quantify the new mechanism of input-output linkages and compare it with the existing mechanisms in the literature in the next chapter.

Chapter 3

Structural Change with Endogenous Input-Output Linkages

Motivated by the evidence and mechanism in the last chapter, I build a multi-sector general equilibrium model to quantify the mechanism of input-output linkages for structural change. The model features endogenous input-output linkages, nonhomothetic CES preferences and technology, and heterogeneous firms. As relative sourcing cost changes, sectors with a rising demand of inputs sourcing (I-I demand) shed labor, while sectors with a growing supply of inputs sourcing (I-I supply) absorb labor. The model is structurally calibrated using the panel data with 35 major economies through 1995-2007. The quantitative results suggest that (i) the I-I supply effects are at least comparable to the existing mechanisms in the literature, such as the price effects due to the sector-biased technological change; (ii) the I-I demand effects are modest due to the stable I-I demand intensity; (iii) about half of the structural change attributes to the rising comparative advantage for supplying intermediate inputs by services relative to by manufacturing.

3.1 Introduction

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. Motivated by the evidence and mechanism in Chapter 2, I

provide a new theory for structural change in this chapter which emphasizes the importance of input-output linkages. This chapter attempts to quantify the role of input-output linkages in structural change. I develop a multi-sector general equilibrium model which features endogenous input-output linkages, nonhomothetic CES preferences and technology, and heterogeneous firms. The model highlights two essential channels of input-output linkages: the supply linkages of intermediate inputs (I-I supply) and the demand linkages of intermediate inputs (I-I demand). The quantitative results suggest that the I-I supply effects are at least comparable to the price effects and the income effects, while the I-I demand effects are modest.

My model blends features from the recent structural change literature with features from the Ricardian trade literature. In particular, I assume nonhomothetic CES preferences *à la* [Comin et al. \(2019\)](#). The preferences imply a separation of the price effects from the income effects on structural change. Motivated by this setup, I introduce the nonhomothetic CES technology in the aggregate gross output production. On top of the independent price and income effects, the model generates a separation of the I-I supply effects from the I-I demand effects.

Moreover, the intensities of input-output linkages are endogenous in this chapter. I borrow the idea of the Ricardian trade to endogenize the input-output linkages intensities following [Boehm \(2018\)](#). Essentially, the intersectoral trade of intermediate inputs is analogous to the international trade of final output as in [Eaton and Kortum \(2002\)](#). The equation of input-output linkages intensity resembles the gravity equation. Furthermore, the sector-level input-output linkages are microfounded by the firm-level sourcing decisions. For each I-I variety, firms have a binary choice between sourcing and in-house production. The sourcing decisions depend on the relative productivity and the relative sourcing cost which is analogous to the trade cost. Section [3.2](#) outlines the model.

The contribution of this chapter are twofold. First, I quantify to what extent the new mechanism of inputs sourcing accounts for the structural change. In particular, I compare the I-I supply effects and the I-I demand effects relative to the price effects and the income effects. I structurally calibrate the general equilibrium model. I use the World Input-Output Database (WIOD) which contains 35 major economies through 1995-2007. The result suggests that the I-I supply effects are significant, comparable to the price effects. The I-I supply effect dominates the structural change from manufacturing to market services in both of the baseline decomposition and the counterfactual decomposition in which I use the counterfactual primitives to simulate the general equilibrium mechanisms.

While the I-I supply effects and the price effects are critical drivers behind both within- and cross-country structural change, the 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, a feature that is in line with [Jones \(2011b\)](#) and [Acemoglu et al. \(2012\)](#). I present the quantitative analysis in Section 3.3.

Second, 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 sourcing cost from services to the downstream sectors, which is supported by recent evidence from [Eckert \(2019\)](#). Higher TFP scale implies that firms are more likely to draw a larger productivity. From the standpoint of Ricardian trade, services have growing comparative advantages relative to manufacturing for supplying intermediate inputs. Therefore, the relative I-I supply multiplier of services to manufacturing increases throughout this period, leads to the structural change from manufacturing to services. In the counterfactual study, I shut down the growing comparative advantage. Indeed, the relative value added share of services to manufacturing increases by a much smaller proportion versus the benchmark case. In addition, the pattern of the I-I supply multiplier matches the pattern of the value added share well. It confirms the qualitative mechanism which suggests the strong positive I-I supply effects on structural change. I show this quantitative exercise in Section 3.4.

The inputs sourcing contains the within-firm insourcing and the cross-firm outsourcing. This chapter identifies inputs sourcing using the data of input-output table which are constructed on establishment-level trade flow of intermediate inputs. A firm could have more than one establishment, and the multiple establishments may be assigned more than one sector. The sector-level input-output flows that we observe may occur within the boundary of a firm, namely within-firm insourcing. On the one hand, the proportion of firms with multiple establishments is small ([Abramovsky and Griffith 2009](#)), hence the within-firm insourcing is not common ([Abramovsky and Griffith 2006](#)). On the other hand, [Ding et al. \(2019\)](#) point out that about 28 percent of the growth of the US services employment took place within manufacturing firms between 1977 and 2012. The within-firm insourcing activities was likely to increase in the last few decades. In this chapter, I take a conservative view about the formation of input-output linkages which allows not only cross-firm outsourcing activities but also within-firm insourcing activities. This is converse to [Boehm \(2018\)](#) who attributes the formation of input-output linkages only to outsourcing.

This chapter is not the first one incorporating the input-output linkages into a structural change model. However, this chapter is the first one incorporating the endogenous input-output linkages into a structural change model. The input-output linkages are taken as domestically intersectoral trade of intermediate inputs. This chapter explains the input-output linkages

from the perspective of networks rather than from the Leontief perspective of an input-output matrix. This chapter is the first one formalizing the two intermediate-inputs channels that are described in the previous chapter, through the endogenous input-output linkages. This chapter emphasizes that the firm-level inputs sourcing gives rise to the sector-level reallocations of labor and capital through the input-output linkages. The intensities of input-output linkages are, in turn, modified by the inputs sourcing activities.

Two advantages are generated from the endogenous input-output linkages. First, all the quantitative exercises in this chapter are performed based on the fundamental primitives. These fundamental primitives are plausibly exogenous which can be utilised for quantitative investigation, particularly for counterfactual exercises. By contrast, [Sposi \(2018\)](#) takes the input-output linkages as exogenous. His quantitative exercise is subject to the Lucas critique since the variation of input-output linkages may be confounded by other critical factors, such as price.

Second, the new mechanism of inputs sourcing is microfounded by the comparative advantage forces, which admits a comparison with the existing empirical evidence. As documented by [Weil \(2014\)](#) and [Goldschmidt and Schmieder \(2017\)](#), the advancement of digital technology and the de-unionization policy reduce the coordination and the monitoring costs, which induces the sourcing of non-core service activities from services sector to manufacturing sector. Throughout the same period, the employment share and value added share fall in manufacturing and rise in services. Their evidence tend to support the argument of a growing comparative advantage of services relative to manufacturing for supplying intermediate inputs.

Two related studies of this chapter are [Berlingieri \(2013\)](#) and [Sposi \(2018\)](#). Both of them argue that on top of the final demand, the intermediate demand impacts structural change. This chapter independently identifies the mechanism of input-output linkages, whereas their studies cannot isolate the mechanism of input-output linkages from the final demand mechanisms. Without isolation, it is hard to identify which mechanism is a key driver for structural change. Thanks to the nonhomothetic CES setup ([Comin et al. 2019](#)), this chapter emphasizes that it is the I-I supply effects rather than the I-I demand effects ([Sposi 2018](#); [Xu 2018](#)) driving structural change.

This chapter contributes to the literature on structural change. The structural change literature mainly focuses on the final demand factors: price effects ([Ngai and Pissarides 2007](#)) and income effects ([Kongsamut et al. 2001](#)). Recent studies such as [Herrendorf et al. \(2013\)](#), [Boppart \(2014\)](#) and [Comin et al. \(2019\)](#) combine the two effects in one framework, and compare the importance between the two effects. This chapter follows the line of the recent studies by qualitatively and quantitatively comparing price effects with income effects. The

main contribution is that this chapter emphasizes the mechanism of input-output linkages, in addition to the price and the income effects. This chapter complements the structural change literature.

Regarding the formation of input-output linkages, this chapter borrows insight from the Ricardian trade literature in a similar manner with [Boehm \(2018\)](#). Similar to [Boehm \(2018\)](#), this chapter applies the [Eaton and Kortum \(2002\)](#) trade framework to each sector pair. Different to [Eaton and Kortum \(2002\)](#) who assume that consumer has a choice of final output from many possible countries, in my model, each firm has a binary choice between sourcing and in-house production. While [Boehm \(2018\)](#) studies the effect of contract cost distortion on aggregate productivity and welfare through the endogenous input-output linkages, this chapter studies the implication of sourcing cost for structural change through the endogenous input-output linkages. This chapter, as far as I know, provides the first study extending [Eaton and Kortum \(2002\)](#) to domestic sourcing based structural change.

The endogenous inputs sourcing on trade cost and technology is consistent with a large literature. There are at least three types of related costs. The contract cost theory ([Coase 1937](#); [Williamson 1985](#)) argues that a higher contract enforcement cost discourages firm sourcing decisions. Recently [Dustmann et al. \(2014\)](#) and [Goldschmidt and Schmieder \(2017\)](#) argue that the gradually less protection in low-skill services occupants from labor union contributes to the rise of inputs 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 the inputs sourcing ([Boehm 2018](#)). This chapter is agnostic about which specific cost impacts inputs sourcing. The development of information technology and digital technology prompts the fragmentation of firm production. [Abramovsky and Griffith \(2006\)](#) suggest that the development of information and communication technology increases the adaptability and tradability of services across firms. [Fort \(2017\)](#) shows that the adoption of communication technology increases the probability of production fragmentation, particularly for domestic sourcing. Likewise, according to [Eckert \(2019\)](#), the reduction of communication cost facilitated the use of business services as intermediate inputs by goods sector in the US since 1980.

Finally, this chapter adds to a recently growing literature which explores the implication of input-output linkages or production networks for macroeconomic issues.¹ Among others, they argue the prominent role of input-output linkages or production networks in the following topics: income and productivity difference; industrial distortion and development; trade gain

¹Though not explicitly studies, [Lucas Jr \(1988\)](#) and [Lucas Jr \(1986\)](#) advocates that the application of economic theory to market or group behavior requires assumptions about individual behavior, as well as interaction among agents.

in domestic firms; and shock transmissions.² Regarding the modeling strategy, many papers take the input-output linkages as exogenous (Jones 2011a,b), while other papers endogenize the input-output linkages or the production networks (Acemoglu and Azar 2019; Oberfield 2018). This chapter endogenizes the input-output linkages and quantifies the crucial role of input-output linkages in structural change.³

3.2 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-inputs varieties. Each intermediate-inputs variety is produced by a monopolistically competitive firm. Firms are allowed to have heterogeneous productivity. Firms can either produce intermediate-inputs varieties in house or by inputs sourcing. There is a sourcing cost which is analogous to the trade cost.

3.2.1 Preferences

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

$$U(C_t) = \sum_{t=0}^{\infty} \frac{\delta^t C_t^{1-\phi}}{1-\phi}. \quad (3.1)$$

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

Following Comin et al. (2019), the aggregate consumption C_t has a nonhomothetic CES aggregation of sectoral consumption C_{it} , which is

$$\sum_{i=1}^J \Omega_i^{\frac{1}{\varepsilon}} C_t^{\frac{\varepsilon_i - \varepsilon}{\varepsilon}} C_{it}^{\frac{\varepsilon - 1}{\varepsilon}} = 1. \quad (3.2)$$

Here ε is the elasticity of substitution across the sectoral consumption goods and services, ε_i measures the income elasticity of demand for consumption goods or services of sector i , Ω_i is

²See Fadinger et al. (2017) for income and productivity difference; see Bartelme and Gorodnichenko (2015) for industrial distortion and development; see Tintelnot et al. (2018) for trade gain in domestic firms; see Acemoglu et al. (2012) for shock transmission.

³This chapter is broadly in line with Caliendo et al. (2017), Liu (2017) and Baqaee and Farhi (2017) who depart from the Cobb-Douglas technologies by allowing the endogenous input-output linkages intensities on productivity and trade cost.

the sector weight. I allow heterogeneous income elasticities across sectors.⁴ Notice that there are two advantages for choosing this form of nonhomothetic CES. First, under this setup, I can independently identify the price effects and the income effects on consumption share based structural change. Second, as highlighted by [Comin et al. \(2019\)](#), this assumption implies asymptotically stable income elasticities as income rises, which is consistent with the empirical evidence.⁵

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

$$\sum_{i=1}^J P_{it} C_{it} = w_t L_t + (1 + r_t) \mathcal{A}_t - \mathcal{A}_{t+1} + \Pi_t. \quad (3.3)$$

Here Π_t is the aggregate profit, and $w_t L_t$ is the aggregate labor income. I assume that the representative consumer owns all the profits of the firms. According to [Herrendorf et al. \(2014\)](#), the consumer's optimization problem could be decomposed by two separate problems. The intertemporal problem optimally allocates the aggregate consumption C_t over time. The intratemporal problem optimally allocates the sectoral consumption C_{it} within each period. Since only the intratemporal allocation is relevant for the structural change study, the focus of this chapter is on the intratemporal problem.⁶

⁴The standard CES is a special case when I assume the unitary income elasticities across sectors. That is, if $\epsilon_i = 1$, $C_t = \left(\sum_{i=1}^J \Omega_i^{\frac{1}{\epsilon}} C_{it}^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$.

⁵Other nonhomothetic CES like Stone-Geary preferences imply the asymptotically equivalent income elasticity across sectors as income increases, which is inconsistent with empirical evidence. Moreover, [Matsuyama \(2019\)](#) argues that other nonhomothetic preferences like the constant ratio of income elasticity preferences ([Caron et al. 2014](#); [Fieler 2011](#)) cannot isolate the price effects from the income effects. Furthermore, as mentioned by [Matsuyama \(2019\)](#), the common elasticity of substitution implied by this assumption cannot be rejected by statistic evidence, according to [Deaton \(1974\)](#).

⁶For the discussion of the intertemporal problem and the related balanced growth path, see [Comin et al. \(2019\)](#) for more details. A caveat of this chapter is that I do not specify the balanced growth conditions as normally do in the structural change theories such as in [Ngai and Pissarides \(2007\)](#). Recent studies suggest that the balanced growth or the Kaldor facts may not hold well. We can see many recent evidence, such as the large change in investment rate in China ([Song et al. 2011](#)), or the global decline of labor share ([Karabarbounis and Neiman 2013](#)). For more discussion about structural change with an absence of balanced growth path, see [Garcia-Santana et al. \(2016\)](#).

3.2.2 Technology

Aggregate Production

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

$$\sum_{i=1}^J \Psi_{it}^{\frac{\kappa}{\rho}} Q_t^{\frac{\xi_i - \rho}{\rho}} Q_{it}^{\frac{\rho-1}{\rho}} = 1. \quad (3.4)$$

Here Q_t is the aggregate gross output, and Q_{it} is the sectoral gross output. The time-variant sector weights play an additional role to the price effects and the income effects in determining structural change. I give more discussions about the role of the sector weights following Proposition 2. For the aggregate producer's optimization problem, the sector weights are state variables. However, the sector weights are endogenously determined by firm production decisions that are described below.

Sectoral Production

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

$$Q_{it} = \left(\sum_{j=1}^J X_{ijt}^{\frac{\theta}{1+\theta}} \right)^{\frac{1+\theta}{\theta}}. \quad (3.5)$$

Here X_{ijt} is the intermediate input which sector i could source from sector j , and θ refers to the elasticity of substitution across the intermediate inputs. Suppose there is a continuum of differentiated intermediate-inputs varieties $\omega \in [0, 1]$. Each variety is produced by a firm.⁷ Assume the intermediate input X_{ijt} is a CES aggregation of the intermediate-inputs varieties, such that

$$X_{ijt} = \left[\int_0^1 X_{ijt}(\omega)^{\frac{\nu-1}{\nu}} d\omega \right]^{\frac{\nu}{\nu-1}}. \quad (3.6)$$

Here $X_{ijt}(\omega)$ is the output of the intermediate-inputs variety. The parameter ν denotes the elasticity of substitution across the intermediate-inputs varieties.

⁷In the model, I do not explicitly differentiate firm from establishment. Generally, a firm could have multiple establishments. Each establishment produces in a single physical location. Each establishment is assigned a single industry. Therefore, a firm that has multiple establishments may de facto produce in more than one sector. Note that the distinction helps us understand how the sector-level input-output linkages are formed, it does not impact the model result and the quantitative analysis in the next section.

Firm Production

For the production of an intermediate-inputs variety $X_{ijt}(\omega)$, a firm in sector i can either produce in house by directly employing labor and capital or source the variety from sector j . The market structure of producing intermediate-inputs variety is monopolistic competitive.⁸ Suppose a firm chooses to produce in house, the output and price are given by

$$X_{ijt}^H(\omega) = a_{ijt}^H(\omega) k_{ijt}^\alpha(\omega) l_{ijt}^{1-\alpha}(\omega), \quad (3.7)$$

$$P_{ijt}^H(\omega) = \frac{\nu}{\nu-1} \frac{\tilde{w}_{it}}{a_{ijt}^H(\omega)}. \quad (3.8)$$

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

On the other hand, the production of the intermediate-inputs variety $X_{ijt}(\omega)$ can be sourced from sector j . Suppose there is always a firm in sector j which can directly use the sectoral gross output as input to produce the sourced variety. Assume there is a sector-to-sector sourcing cost τ_{ijt} if a firm in sector i sources the I-I variety from sector j at t .⁹ Specifically, the production function and the price equation are given by

$$X_{ijt}^X(\omega) = a_{ijt}^X(\omega) Q_{ijt}(\omega), \quad (3.9)$$

$$P_{ijt}^X(\omega) = \frac{\nu}{\nu-1} \frac{\tau_{ijt} P_{jt}}{a_{ijt}^X(\omega)}. \quad (3.10)$$

Here $X_{ijt}^X(\omega)$ and $P_{ijt}^X(\omega)$ are the output and the price of the sourced I-I variety, and $a_{ijt}^X(\omega)$ is the productivity of the sourcing firm. The $Q_{ijt}(\omega)$ is the gross output used by a firm in sector j as input to produce the sourced I-I variety to a firm in sector i . In the spirit of discussion of capital formation in [Romer \(1990\)](#), the formal description specifies that a firm produces the sourced I-I variety as a black box that takes the sectoral gross output in on one side and gives the I-I variety out of the other side. The correct interpretation of this description is that the

⁸I follow a large number of studies assuming monopolistic competition at firm production. The model result and the quantitative analysis in the next section do not depend on the assumption of monopolistic competition, so long as firms have constant markup. The result holds in a competitive market.

⁹In the model, I assume an equivalent sourcing cost τ_{ijt} between within-firm insourcing and cross-firm outsourcing. Within-firm insourcing means that an establishment adopts inputs from another establishment and both establishments are owned by the same firm. Establishments have different locations, implies that sourcing costs are incurred even for insourcing activities ([Fort 2017](#)).

forgone final output is never produced. The resource that would have been used to produce final output are used instead to produce I-I varieties.

Following [Eaton and Kortum \(2002\)](#), I assume that firms draw their productivities from a Fréchet distribution:

$$\Pr[a_{ijt}^H \leq a] \equiv F_{it}(a) = e^{-T_{it}a^{-\zeta}}, \quad (3.11)$$

$$\Pr[a_{ijt}^X \leq a] \equiv F_{jt}(a) = e^{-T_{jt}a^{-\zeta}}. \quad (3.12)$$

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

$$P_{ijt}^*(\omega) = \min(P_{ijt}^H(\omega), P_{ijt}^X(\omega)). \quad (3.13)$$

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

3.2.3 Equilibrium

In each period, all markets are clear in equilibrium. We have three parts of market clearing conditions. First, the market clearing conditions of the production of gross output, intermediate inputs and intermediate-inputs varieties are given by the following equations:

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

$$P_{ijt}^H X_{ijt}^H = \int_0^1 P_{ijt}^H(\omega_H) X_{ijt}^H(\omega_H) d\omega_H,$$

$$P_{ijt} X_{ijt} = P_{ijt}^X X_{ijt}^X + P_{ijt}^H X_{ijt}^H = \int_0^1 P_{ijt}^*(\omega) X_{ijt}(\omega) d\omega, \quad (3.14)$$

$$P_{it} Q_{it} = \sum_{j=1}^J P_{ijt} X_{ijt}, \quad (3.15)$$

$$P_t Q_t = \sum_{i=1}^J P_{it} Q_{it}. \quad (3.16)$$

Here ω_X and ω_H are those of varieties that are produced by sourcing and in-house production, respectively. Second, the supply of the sectoral gross output equals the demand of the sectoral gross output. The demand contains the final consumption (final demand) and the inputs sourcing (intermediate demand) from all the sectors. Specifically, we have the following resource constraint:

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

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

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

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

At each period t , the equilibrium is characterized by the representative consumer's optimal allocations of the sectoral consumption and the producers' optimal allocations of sectoral production, intermediate inputs, and intermediate-inputs varieties. To be specific, the representative consumer maximizes C_t subject to the aggregate consumption in equation (3.2) and the budget constraint in equation (3.3). The aggregate producer maximizes the aggregate gross output Q_t by optimally allocating the sectoral gross output Q_{it} subject to the aggregate production in equation (3.4) and the aggregate budget constraint in equation (3.16).

The producers' problem can be further divided into two levels: sector level and firm level. Sectoral producer maximizes the sectoral gross output as in equation (3.5) by optimally allocating the intermediate inputs subject to the sectoral gross output budget constraint in equation (3.15). Likewise, sectoral producer also maximizes the sectoral intermediate input according to equation (3.6) subject to the intermediate-inputs budget constraint in equation (3.14). At the firm level, for both in-house production and inputs sourcing, I assume that the monopolistically competitive producers draw their productivities from the Frechet distribution following equation (3.11) and equation (3.12). Then they learn their in-house price and sourcing price following equation (3.8) and equation (3.10). Producers always choose the lower price in each period.

After solving the model (all proofs of this and other propositions of this chapter are given in Appendix B.1), the following proposition summarizes the sectoral structure terms, the sectoral production, the sectoral consumption and the aggregate prices:

Proposition 1 (Equilibrium Solution of The Key Variables). *In the competitive equilibrium, the sectoral value added share η_{it} , the vector of Domar weights $\gamma_t = [\gamma_{it}]$ and the consumption share λ_{it} are given by the following equations:*

$$\eta_{it} = (1 - \sigma_{it})\gamma_{it}, \quad (3.17)$$

$$\gamma_t = (I - B_t)^{-1} \lambda_t, \quad (3.18)$$

$$\lambda_{it} = \Omega_i \left(\frac{P_{it}}{P_t} \right)^{1-\varepsilon} C_t^{\varepsilon_i-1}. \quad (3.19)$$

Here B_t is the input-output matrix, with B_{ijt} indicating the intermediate input share of sector i in producing sector j gross output at time t . The term σ_{it} denotes the demand intensity of intermediate inputs of sector i : $\sigma_{it} \equiv \sum_{j=1}^J B_{jit}$. In addition, the sectoral consumption, the sectoral gross output, the aggregate value added price P_{Yt} and the aggregate gross output price P_t are given by the following equations:

$$C_{it} = \Omega_i \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon} C_t^{\varepsilon_i}, \quad (3.20)$$

$$Q_{it} = \Psi_{it}^\kappa \left(\frac{P_{it}}{P_t} \right)^{-\rho} Q_t^{\xi_i}, \quad (3.21)$$

$$P_{Yt} = \left(\sum_{i=1}^J \Omega_i P_{it}^{1-\varepsilon} C_t^{\varepsilon_i-1} \right)^{\frac{1}{1-\varepsilon}}, \quad (3.22)$$

$$P_t = \left(\sum_{i=1}^J \Psi_{it}^\kappa P_{it}^{1-\rho} Q_t^{\xi_i-1} \right)^{\frac{1}{1-\rho}}. \quad (3.23)$$

In contrast to the exogenous consumption in Chapter 2, the sectoral consumption depends on the sectoral price and the aggregate income. The sectoral gross output has as similar function form as the sectoral consumption. However, the price elasticity and the income elasticity are allowed to be different between the consumption equation (3.20) and the production equation (3.21). More importantly, the equation of value added share (3.17) and Domar weight (3.18) are the same with their counterparts in equation (2.1) of Chapter 2.

Based on Proposition 1, I further derive the structural change equations in the following proposition:

Proposition 2 (Structural Change). *The relative consumption share and the relative value added share are given by the following two equations:*

$$\log \frac{\lambda_{it}}{\lambda_{jt}} = \log \frac{\Omega_i}{\Omega_j} + (1 - \varepsilon) \log \frac{P_{it}}{P_{jt}} + (\epsilon_i - \epsilon_j) \log C_t, \quad (3.24)$$

$$\log \frac{\eta_{it}}{\eta_{jt}} = \log \frac{1 - \sigma_{it}}{1 - \sigma_{jt}} + \kappa \log \frac{\Psi_{it}}{\Psi_{jt}} + (1 - \rho) \log \frac{P_{it}}{P_{jt}} + (\xi_i - \xi_j) \log Q_t. \quad (3.25)$$

Notice that since σ_{it} corresponds to the sectoral demand intensity of intermediate inputs, the first term on the right-hand side of equation (3.25) is called the I-I demand effects. Recall that the primitive and the network heterogeneity jointly contribute to the variation of the Domar weight following Chapter 2. In this case, the primitive (consumption share) heterogeneity depends on the price effects and the income effects according to equation (3.24). These two effects are absorbed by the last two terms on the right-hand side of equation (3.25). Therefore, the second term on the right-hand side of equation (3.25) must represent the network heterogeneity which is positively determined by the intermediate-inputs supply multiplier.¹⁰ Consequently, the second term $\log \frac{\Psi_{it}}{\Psi_{jt}}$ represents the I-I supply effects.

In aggregate, the four terms on the right-hand side of equation (3.25) correspond to the I-I demand effects, the I-I supply effects, the price effects, and the income effects, respectively. Holding other effects constant, for the I-I supply effects, economic resource moves to the sectors with a greater expansion of I-I supply multiplier if $\kappa > 0$; economic resource moves to the sectors with a greater contraction of I-I supply multiplier if $\kappa < 0$. Holding other effects constant, for the I-I demand effects, economic resource moves to the sectors with a greater contraction of I-I demand multiplier. For the price effects, ceteris paribus, economic resource moves to the sectors with a relatively increasing price if $\varepsilon \in (0, 1)$ and $\rho \in (0, 1)$; economic resource moves to the sectors with a relatively decreasing price if $\varepsilon \in (1, \infty)$ and $\rho \in (1, \infty)$. For the income effects, ceteris paribus, economic resource moves to the sectors with a larger income elasticity. The qualitative price effects and income effects are in line with Ngai and Pissarides (2007) and Kongsamut et al. (2001).

The structural change mechanisms in this chapter nest the literature. If I assume no input-output linkage such that $B = 0$, time-invariant sector weight $\Psi_{it} = \Psi_i$ and same elasticities between the production equation (3.4) and the consumption equation (3.2), the right-hand side of equation (3.25) is equivalent to that of equation (3.24) which is the core equation of structural change in Comin et al. (2019). Therefore, equation (3.25) is a generalized structural change equation that admits heterogeneous input-output linkages.

¹⁰See the discussion of I-I supply channel in Subsection 2.3.2 of Chapter 2.

While the price effects and the income effects are well studied in the structural change literature, the I-I supply and the I-I demand effects are overlooked by the literature. Almost none of them can independently identify the I-I supply and the I-I demand effects as in equation (3.25), due to the ignorance of input-output linkages, firm heterogeneity, and nonhomothetic CES technology. If I only explore the consumption share based structural change, input-output linkages probably are irrelevant following equation (3.24). Since I am interested in value added share based structural change, this ignorance omits two prominent channels: the I-I demand and the I-I supply.

In addition to the implication for structural change, the equilibrium result of this model reveals endogenous input-output linkages and sectoral prices. The following proposition summarizes these results:

Proposition 3 (Endogenous Input-Output Linkages and Sectoral Prices). *The input-output linkages intensity depends on the sector-to-sector sourcing costs τ_{ijt} , TFP scale parameters T_{it} , trade elasticity ζ and CES parameter θ . Specifically, the input-output linkage intensity is given by the following equation:*

$$B_{jit} \equiv \frac{P_{ijt}X_{ijt}}{P_{it}Q_{it}} \frac{P_{ijt}^X X_{ijt}^X}{P_{ijt}X_{ijt}} = \left(\frac{P_{ijt}}{P_{it}} \right)^{-\theta} \frac{T_{jt}(P_{jt}\tau_{ijt})^{-\zeta}}{T_{jt}(P_{jt}\tau_{ijt})^{-\zeta} + T_{it}(\tilde{w}_{it}\tau_{iit})^{-\zeta}}. \quad (3.26)$$

Moreover, the sectoral gross output price P_{it} and the intermediate-inputs price P_{ijt} are given by the following two equations respectively:

$$P_{it} = \left[\sum_{j=1}^J (P_{ijt})^{-\theta} \right]^{-\frac{1}{\theta}}, \quad (3.27)$$

$$P_{ijt} = \frac{\nu}{\nu-1} \left[\Gamma \left(\frac{1-\nu+\zeta}{\zeta} \right) \right]^{\frac{1}{1-\nu}} \left[T_{jt}(P_{jt}\tau_{ijt})^{-\zeta} + T_{it}(\tilde{w}_{it}\tau_{iit})^{-\zeta} \right]^{-\frac{1}{\zeta}}. \quad (3.28)$$

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

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

The input-output linkages intensity equation resembles the gravity equation in [Eaton and Kortum \(2002\)](#). Equation (3.26) suggests that the intensity of input-output linkages depends on the intermediate-inputs share of gross output and the sourcing share of intermediate inputs. In particular, the intermediate-inputs share adjusts at the intensive margin due to the standard CES set up, and the sourcing share changes at the extensive margin à la [Eaton and Kortum \(2002\)](#). According to equation (3.26), the sector with a higher TFP scale supplies more intermediate inputs, which corresponds to the absolute advantage in [Eaton and Kortum \(2002\)](#). It further implies that firms have comparative advantage for supplying a broader range of intermediate inputs.

The comparative advantage of a higher TFP scale is offset by a higher marginal cost and sourcing cost. Following equation (3.26), the dispersion parameter ζ determines the sensitivity of inputs sourcing to the relative sourcing cost, which is analogous to the elasticity of the trade share to the relative trade cost in [Eaton and Kortum \(2002\)](#). A lower value of ζ implies a higher intensity of sourcing. A lower value of ζ suggests a higher degree of dispersion among firm-level productivities, which indicates a greater trade scope of intermediate-inputs varieties. Essentially, firm-level producers always seek the cheaper intermediate-inputs varieties. Furthermore, following Proposition 3, the relative sectoral price inversely depends on the relative sectoral efficiency. Here I define the sectoral efficiency as follows: $\Phi_{it}^{\frac{\theta}{\zeta}} = \sum_{j=1}^n \Phi_{ijt}^{\frac{\theta}{\zeta}}$. It is easy to derive $\frac{P_{it}}{P_{jt}} = \left(\frac{\Phi_{it}}{\Phi_{jt}} \right)^{-\frac{1}{\zeta}}$.

3.3 Quantitative Results

This section presents the calibration results and quantifies the importance of the four effects on structural change. For the convenience of illustration, I focus on the most evident trend of structural change: from manufacturing to market services. The results consistently hold to the other two sectors. I leave the results for the other sectors in Appendix B.2.4. I first show the benchmark calibration results in the next subsection. I study which channel is crucial driving the value added share based structural change in the second subsection. I leave a similar case study for employment share based structural change in Appendix B.2.6.

The primary database of this chapter is the World Input-Output Database. There are two relevant datasets under the WIOD: the Socio Economic Accounts (SEA) and the world input-output tables (WIOT) 2013. I obtain the input-output tables from the WIOT. Other nominal data and local price deflators are available in the SEA. As [Fort \(2017\)](#) points out, the domestic sourcing of intermediate inputs is disproportionately more significant than foreign

sourcing. Without loss of generality, this chapter ignores the import and export data.¹¹ This chapter also ignores the data on government consumption, tax/subsidy, and transport margin. For most major economies, these values are tiny in determining the economic structure. The sectoral nominal gross output equals the sum of the value added and all the sectoral use of intermediate inputs.

The final panel data are available for 4 sectors and 35 countries throughout the interval 1995-2007.¹² Given the data, I construct the following useful variables for this chapter: nominal input-output linkages intensities, sectoral gross output prices, aggregate real consumption and output, nominal sector shares in value added and consumption.

3.3.1 Benchmark Estimation and Calibration

The parameter identification is inclusive of two parts. First, I use a regression to estimate the structural change parameters for both the production side as in equation (3.25) and the consumption side as in equation (3.24). Second, for the TFP scale and trade costs and the remaining parameters, I calibrate their values to the observed sectoral prices, input-output tables and wage growth. Note that the two parts are estimated or calibrated independently.

Production-Side Elasticities

I estimate the production-side elasticities of structural change following equation (3.25). Specifically, for each sector pair ij , the regression equation is given by

$$\log \frac{\eta_{mi,t}}{\eta_{mj,t}} = \beta \log \frac{1 - \sigma_{mi,t}}{1 - \sigma_{mj,t}} + \kappa \log \frac{\mu_{mi,t}^s}{\mu_{mj,t}^s} + (1 - \rho) \log \frac{P_{mi,t}}{P_{mj,t}} + (\xi_i - \xi_j) \log Q_{m,t} + f_m + f_t + e_{mt}. \quad (3.29)$$

¹¹There are two reasons for ignoring the international trade in this chapter. First, regarding the intermediate input, the domestic trade is far more prominent than the international trade. The ratio of the domestic trade of intermediate inputs to GDP is about 1 in both rich economies like the US and emerging economy like China (Jones 2011b). In contrast, the ratio of the foreign trade of intermediate inputs to GDP is much smaller. Even for the 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 the sourcing, the domestic sourcing still remarkably dominates particularly for the services sourcing, though we do see a rise in the services offshoring. The international trade of final goods is much less comparable than the domestic trade of intermediate inputs as well. According to Jacks and Tang (2018), the world exports of the 52 major economies to GDP is around 12 percent on average through 1995-2007. Second, Chapter 2 suggests that the main empirical correlations hold even with the consideration of the international trade of intermediate inputs and final output.

¹²See Appendix A.3 for the list of the 35 countries and the sector classification.

Dependent Variable : $\log \frac{\eta_{it}}{\eta_{jt}}$							
Coefficient	(1)	(2)	(3)	(4)	(5)	(6)	(7)
β		1.486*** (0.065)	0.896*** (0.045)	0.887*** (0.042)	1.737*** (0.083)	0.970*** (0.053)	0.845*** (0.056)
κ		1.406*** (0.046)	0.803*** (0.037)	0.686*** (0.037)	0.689*** (0.036)	0.646*** (0.044)	0.802*** (0.055)
$1 - \rho$	0.408*** (0.028)	0.272*** (0.026)	0.472*** (0.030)	0.503*** (0.029)	0.478*** (0.029)	0.547*** (0.043)	0.336*** (0.037)
$\xi_{OG} - \xi_{Manu}$	-0.024** (0.011)	0.020** (0.008)	-0.073*** (0.028)	-0.059 (0.052)	-0.004 (0.051)	0.682*** (0.070)	0.012 (0.068)
$\xi_{MS} - \xi_{Manu}$	-0.049*** (0.009)	-0.050*** (0.008)	0.190*** (0.022)	-0.029 (0.041)	0.044 (0.040)	0.452*** (0.059)	0.124** (0.054)
$\xi_{NMS} - \xi_{Manu}$	-0.050*** (0.009)	-0.008 (0.007)	0.073** (0.030)	-0.097* (0.064)	-0.011 (0.055)	0.022 (0.068)	0.291*** (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

This table reports the results of OLS estimation of the relative value added share on the four effects. The benchmark sector is manufacturing. The β estimates the I-I demand effects, κ estimates the I-I supply effects, $1 - \rho$ estimates the price effects, and the remaining three terms estimate the income effects of the other three sectors relative to manufacturing. The terms *DC* and *LDC* stand for developed countries group and developing countries group respectively. The "DE approx." means the approximation of the I-I demand effects: $\log(1 - \sigma_{ict}) \approx -\sigma_{ict}$. See the main text for detail. Here ***, **, * denote significance at 1 percent, 5 percent and 10 percent critical values respectively.

Table 3.1 Estimation of production-side structural change

Here f_m and f_t are country fixed effect and year fixed effect, respectively.¹³ The error term is $e_{mt} = \kappa \left(\frac{\Psi_{mi,t}}{\Psi_{mj,t}} - \frac{\mu_{mi,t}^s}{\mu_{mj,t}^s} \right)$, conditional on the sector pair ij . I choose manufacturing as the benchmark sector following Comin et al. (2019). The structural change terms are relative value added share of the other three sectors to manufacturing. I present the estimation results in Table 3.1.¹⁴

The first four columns of Table 3.1 report the estimation results with all sampling countries. Column 1 replicates the conventional price effect and income effects on structural change. The result suggests a significantly positive price effect and negative income effects. The positive price effect is consistent with the prediction in Ngai and Pissarides (2007). When sectoral goods are complementary ($\rho < 1$), structural change arises from the sectors with

¹³I control year fixed effect since structural change tends to be a cross-country phenomenon as well (Herrendorf et al. 2014). In Comin et al. (2019), they do not control year fixed effect. They concentrate on within-country structural change. Based on the column 3 and column 4 of Table 3.1, except for the magnitudes of the income effects, the estimation results do not change too much without the year fixed effect.

¹⁴Following Comin et al. (2019), I use a linear seemingly unrelated regressions to estimate the above regression equation. This is to ensure the equivalent elasticities of price, I-I supply and I-I demand across sectors, while allowing sector-specific income elasticity.

a lower price growth to the sectors with a higher price growth. The price effect is still significant when I add the intermediate-inputs demand and supply effects in column 2. The magnitude is smaller than that in column 1, which suggests that part of the price effect in column 1 is absorbed by the intermediate-inputs 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 the price effects. It suggests that the structural change has larger correlations with the intermediate-inputs supply and demand channels than with the price channel.

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

The last three columns display the results of the other three estimation strategies with the country and year fixed effects. The intermediate-inputs demand effects on the right-hand side of the regression equation (3.29) contain the relative value added term which also enters the left-hand side of the regression equation. This may introduce bias. To account for this potential bias, I apply the first-order Taylor rule approximation: $\log(1 - \sigma_{ict}) \approx -\sigma_{ict}$. The estimation result is given in column 5. Now the estimation of the I-I demand elasticity is different, but the I-I supply and the price elasticities are roughly the same as in column 4. I further display the estimation results for developed countries and developing countries in column 6 and column 7 respectively. Again, I find that the intermediate-inputs demand and supply elasticities are always significant and greater than the price elasticity. Column 6 and column 7 suggest that the income elasticities are different between the developed countries and developing countries.

Notice that the benchmark estimation of the producer-side elasticities are likely to suffer endogeneity bias, such as the reverse causality bias. For instance, the positive correlation between the relative value added share and the relative I-I supply multiplier may reflect causality from either side. Rather than interpreting that the sector with a larger growth of supply connections grows faster, one may argue that the sector growing faster may be able to increasingly supply intermediate inputs to the downstream sectors. The best approach to

solve the endogeneity bias probably is the instrumental variable (IV) method. Boppart (2014) instruments the expenditure levels by household income when he estimates the benchmark income effect on structural change. I leave the IV estimation for future study.

Consumption-Side Elasticities

Similar to the production-side elasticities, I use a regression to estimate the consumption-side elasticities. The regression equation is given by

$$\log \frac{C_{mi,t}}{C_{mj,t}} = -\varepsilon \log \frac{P_{mi,t}}{P_{mj,t}} + (\epsilon_i - \epsilon_j) \log C_{mt} + f_m + f_t + u_{mt}.$$

Notice that here I use the relative real consumption rather than the relative nominal consumption as the dependent variable, because the relative price also enters the right-hand side of the regression equation. The time-invariant sector weight is absorbed by the country fixed effect. All the coefficients are estimated with both a country fixed effect and a year fixed effect. Here the error term is taken as a measurement error. I assume a fully exogenous error term in the consumption-side regression.¹⁵

Sourcing Cost, TFP Scale, and Marginal Cost Composite

For the remaining parameters, I calibrate their values in two steps. First, suppose the trade elasticity ζ , CES parameters θ and ν are known, I calibrate the sourcing 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 wages.

In the first step, I use a non-linear fixed effect method, given the input-output linkages intensity equation (3.26) and price equations (3.27) and (3.28) in Proposition 3. I normalize a zero distortion in within-sector sourcing, such that $\tau_{iit} = 1$. For each country in each year, I have 20 primitives to calibrate.¹⁶ Given the data on B_{jit} and P_{it} , these 20 values are exactly identified. They are identified by the following iterative fixed effect method:

1. Given $\tilde{w}_{it}$, T_{it} are computed by using B_{iit} equation (3.26) and I-I price equation (3.28).
2. Given $\tilde{w}_{it}$ and T_{it} , τ_{ijt} are computed by using B_{jit} equation (3.26) and I-I price equation (3.28).

¹⁵In the model, price is dependent on the primitives, which is given in Proposition 3. The aggregate consumption is taken as exogenous.

¹⁶Since 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} .

Parameter	Benchmark	First Experiment	Second Experiment
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}	$\hat{T}_{it}$	$\hat{T}_{it}$	$\hat{T}_{i,1995}$

The first column reports the parameter values under the benchmark estimation and calibration. The last two columns display the estimated parameters with the model simulated data, under the first counterfactual experiment and under the second counterfactual experiment, respectively. $\hat{\tau}_{ijt}$ and $\hat{T}_{it}$ are the calibrated sourcing cost and TFP scale under the benchmark case. $\hat{\tau}_{ij,1995}$ and $\hat{T}_{i,1995}$ are the sourcing cost and TFP scale under the counterfactual experiments in which they stay at their initial year values over time for all countries and for all sectors or sector-pairs.

Table 3.2 Parameter estimation and calibration

3. Given T_{it} and τ_{ijt} , $\tilde{w}_{it}$ are computed by using P_{it} equation (3.27) and I-I price equation (3.28).
4. Repeat the first three steps until T_{it} converges.

This approach is applied to each country in each year.¹⁷ This chapter offers a different calibration method than the literature, thereby contributing to the calibration method of the Eaton-Kortum model (Caliendo and Parro 2015; Caliendo et al. 2017; Dekle et al. 2008).

Trade Elasticity and Other CES Parameters

Finally, I jointly calibrate ζ , θ and ν . The first two are calibrated to matching the model-generated moment with the data-generated moment based on the marginal cost composite

¹⁷To solve a model, we have at least two methods: quantitative method and analytical method. While the quantitative method could be highly productive in computation, it may lose some degrees of freedom; and vice versa for the analytic method. In this chapter, I use a quantitative method to calibrating the model primitives to the observable variables in line with Caliendo et al. (2017). For the analytical method in this context, Dekle et al. (2008) provide a good discussion.

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 an assumption of a common capital share and a constant rental rate: $\alpha = \frac{1}{3}$ and $r_{it} = r$. For the second assumption, I ignore the time-variant rental rate and assuming a globally constant rental rate for each country in each sector. Hence, an implicit assumption is the perfect capital mobility across countries and across sectors. In addition, I normalize $\tilde{w}_{it} = 1$ for the US manufacturing sector in the year 2005. Therefore, the variation of the marginal cost composite parameter now is only determined by the sectoral wage. I estimate the sectoral wage based on the data on annual labor compensation and the data on annual working hours from the SEA dataset: $w_{it} = \frac{w_{it}L_{it}}{L_{it}}$. The model-generated average growth rate of sectoral wage is $\Delta_M(\tilde{w}_i)$, which is given in the last calibration component. Let the corresponding data-generated moment be $\Delta_D(\tilde{w}_i)$. Jointly find ζ and θ to minimize the moment gap, which is formally given by

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

Here m stands for country. Since ν only enters the constant term, it does not affect the relative values in the key structural change equation (3.25). I calibrate $\nu = 3.5$ to allow a 40 percent markup following [Boehm \(2018\)](#). The benchmark calibration results are summarized in column 2 of Table 3.2.

3.3.2 Accounting for Structural Change

In this subsection, I study to what extent the intermediate-inputs supply and demand effects account for the structural change from manufacturing to market services. I quantitatively compare the I-I supply effects and I-I demand effects versus the price effects and income effects. I leave the similar results for the other two sectors relative to manufacturing in Appendix B.2.4.

This subsection utilises the calibrated TFP scale T_{it} , sourcing costs τ_{ijt} and other parameters to simulate the model, and then uses the simulated data to run the regression (3.29) which is used to decompose the individual effects on structural change. I use the originally calibrated T_{it} and τ_{ijt} in the baseline decomposition exercise, and use the counterfactual T_{it} and τ_{ijt} in the two experimental exercises.

In the first experiment, I fix the sourcing costs and let the TFP scale change as in the original calibration results. Specifically, I assume that the sourcing costs τ_{ijt} stay the initial year values $\hat{\tau}_{ij,1995}$ for all sectors and for all countries. In the second experiment, I fix the TFP scale and let the sourcing costs change as in the original calibration results. Specifically,

I assume that the TFP scale parameters T_{it} stay the initial year values $\hat{T}_{i,1995}$ for all sectors and for all countries.

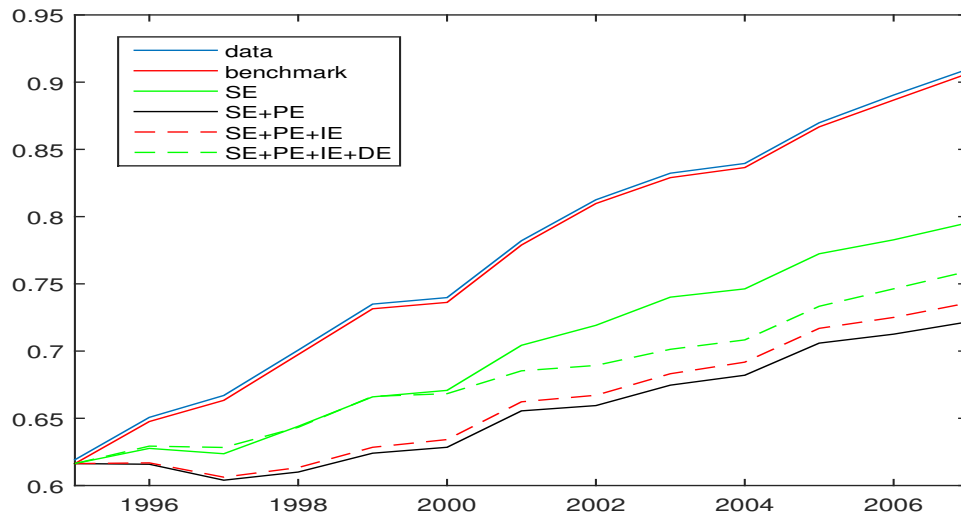
The specific steps are outlined as follows. First, I obtain the calibrated T_{it} and τ_{ijt} for the baseline exercise, and the counterfactual $\hat{\tau}_{ij,1995}$ and $\hat{T}_{i,1995}$ for the two experimental exercises. Second, I use the model to simulate the sectoral prices, consumption shares, input-output linkages intensities, then the I-I supply multipliers, the I-I demand intensities, and finally the value added shares. Note that the simulation exercise in the second step does not require the parameter values of the production-side elasticities. Third, I use the regression equation (3.29) to estimate the four effects given the simulated data. Lastly, given the new estimated production-side elasticities, I do the decomposition exercises which are demonstrated in the following subsections.

The estimated parameters are reported in Table 3.2. The baseline producer-side elasticities are the same with the regression estimation results that use the raw data as illustrated in column 2 of Table 3.2. This is not surprising since the original primitives T_{it} and τ_{ijt} are exactly calibrated to the raw data of the sectoral price and the input-output linkages intensities. The simulated data would be identical to the raw data. The producer-side elasticities under the two experiments are given in column 3 and column 4 of Table 3.2. In column 3, suppose $\tau_{ijt} = \hat{\tau}_{ij,1995}$, and I assume that other parameters do not change except for the production-side elasticities. In column 4, suppose $T_{it} = \hat{T}_{i,1995}$ and the rest of the study follows the first experiment. I find similar estimation results for the four production-side elasticities between the two counterfactual experiments.

Baseline Decomposition

With the structural change equation (3.29) and the parameter values in hand, I decompose the attribution of structural change from manufacturing to market services into the four effects. Figure 3.1 shows the decomposition of structural change based on the baseline calibration results in column 2 of Table 3.2. The horizontal axis indicates the year, and the vertical axis shows the values of the relative value added shares of market services to manufacturing in logarithm. In Figure 3.1, the blue solid curve represents the relative value added shares in the data. This is the time series pattern of the relative value added shares of market services to manufacturing for the 35 major economies on average.¹⁸ From 1995 to 2007, the monotonic rise in the relative value added shares implies the structural change from manufacturing to market services. The red solid curve plots the relative value added shares under the regression prediction with the country and year fixed effects. Figure 3.1 suggests that the OLS prediction

¹⁸I take a simple arithmetic average unless otherwise specified in this and other exercises of this chapter.



The horizontal axis denotes year, and the vertical axis shows the relative value added share of market services to manufacturing in log level. The blue solid curve and the red solid curve plot the actual data and the OLS predicted values respectively. The remaining four curves are simulated values when I shut down the I-I supply effect (SE), price effect (PE), income effect (IE) and I-I demand effect (DE) sequentially. The corresponding results follow the legend. See the main text for detail.

Fig. 3.1 Decomposition under the benchmark estimation

is very close to the data. It implies that the model does a good job matching the structural change facts, under the baseline estimation.

Figure 3.1 suggests that the intermediate-inputs supply effect is comparable to the price effect on structural change. To account for the quantitative consequence of each effect, I perform counterfactual exercises. First, suppose the relative intermediate-inputs supply multipliers stay the initial year values for all countries, I simulate the relative value added shares. The green solid curve shows the simulated relative value added shares without the intermediate-inputs supply effect. The wedge between the red solid curve and the green solid curve, therefore, indicates the magnitude of the I-I supply effect on structural change. Likewise, I continue to switch off the price effect, the income effect and the intermediate-inputs demand effect sequentially by fixing these effects at their initial year values.¹⁹ The black solid curve, the red dash curve, and the green dash curve show the simulated relative value added shares under the three counterfactual scenarios, respectively. As a result, the wedge between the green solid curve and the black solid curve shows the price effect; the wedge between the black solid curve and the red dash curve indicates the income effect; and eventually, the

¹⁹Since the structural change equation (3.25) is a log-linear equation, the sequence of the counterfactual exercises is irrelevant to the quantitative implication of the four effects.

wedge between the red dash curve and the green dash curve denotes the intermediate-inputs demand effect. According to Figure 3.1, the I-I supply effect is the largest. Then it is followed by the price effect. The income effect and the I-I demand effect are trivial, compared with the I-I supply effect and the price effect.

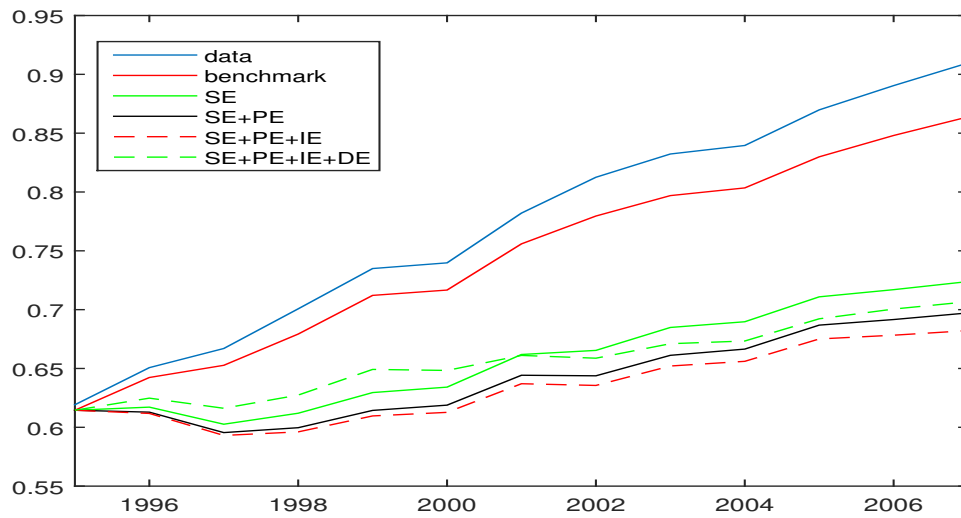
Decomposition under The Two Experiments

Following the estimation results in column 3 and column 4 of Table 3.2, I decompose the four effects in the same way as in the baseline decomposition. I show the decomposition result in Figure 3.2 based on the parameter values in column 3 of Table 3.2, and present the decomposition result in Figure 3.3 based on the parameter values in column 4 of Table 3.2. Both Figure 3.2 and Figure 3.3 suggest that the intermediate-inputs supply effects—the wedge between the red solid curve and the green solid curve—are the dominant effects on structural change. While the price effects are significant, they are now much smaller than the intermediate-inputs supply effects. Based on the results in Figure 3.2 and Figure 3.3, the intermediate-inputs supply effects are more than twice as large as the price effects. Besides, the intermediate-inputs demand effects and the income effects are still modest.

In aggregate, the intermediate-inputs supply effects dominate the structural change from manufacturing to market services, under both the baseline and the two experimental decomposition. The price effects are always significant, have a smaller magnitude than the I-I supply effects. The intermediate-inputs demand effects are statistically significant, but economically modest in driving structural change. The income effects, however, are not always significant and they are modest. The structural results are line with the descriptive evidence as in Goodman and Steadman (2002) who shows that the growth of business-oriented services inputs is stronger than the growth of consumer-oriented services output in driving the rise of services.

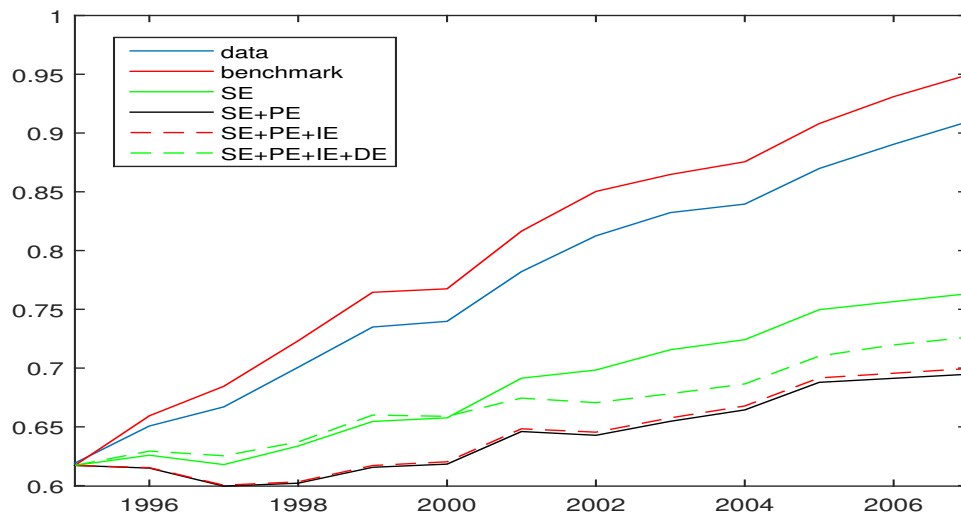
3.4 Intermediate-Inputs Supply Channel

Given the crucial intermediate-inputs supply effect on structural change, this section examines the intermediate-inputs supply channel in more depth. I explore two kinds of fundamental forces: sourcing cost and TFP scale. I show how divergent the sourcing costs and the TFP scales are among the four sectors in the first subsection. Given these divergences, I show their quantitative implications for structural change through the intermediate-inputs supply channel in the second subsection.



The horizontal axis denotes year, and the vertical axis shows the relative value added share of market services to manufacturing in log level. The blue solid curve and the red solid curve plot the actual data and the OLS predicted values respectively. The remaining four curves are simulated values when I shut down the I-I supply effect (SE), price effect (PE), income effect (IE) and I-I demand effect (DE) sequentially. The corresponding results follow the legend. See the main text for detail.

Fig. 3.2 Decomposition under the first counterfactual experiment



The horizontal axis denotes year, and the vertical axis shows the relative value added share of market services to manufacturing in log level. The blue solid curve and the red solid curve plot the actual data and the OLS predicted values respectively. The remaining four curves are simulated values when I shut down the I-I supply effect (SE), price effect (PE), income effect (IE) and I-I demand effect (DE) sequentially. The corresponding results follow the legend. See the main text for detail.

Fig. 3.3 Decomposition under the second counterfactual experiment

3.4.1 Origins of Structural Change

I examine the fundamental factors in this subsection. Given the structural change from manufacturing to market services, it is important to know why this occurs in the model. First, I attempt to check how divergent the calibrated primitives are among the four sectors, particularly between manufacturing and market services. Then in the next subsection, I further study whether these disparities give rise to structural change from manufacturing to market services.

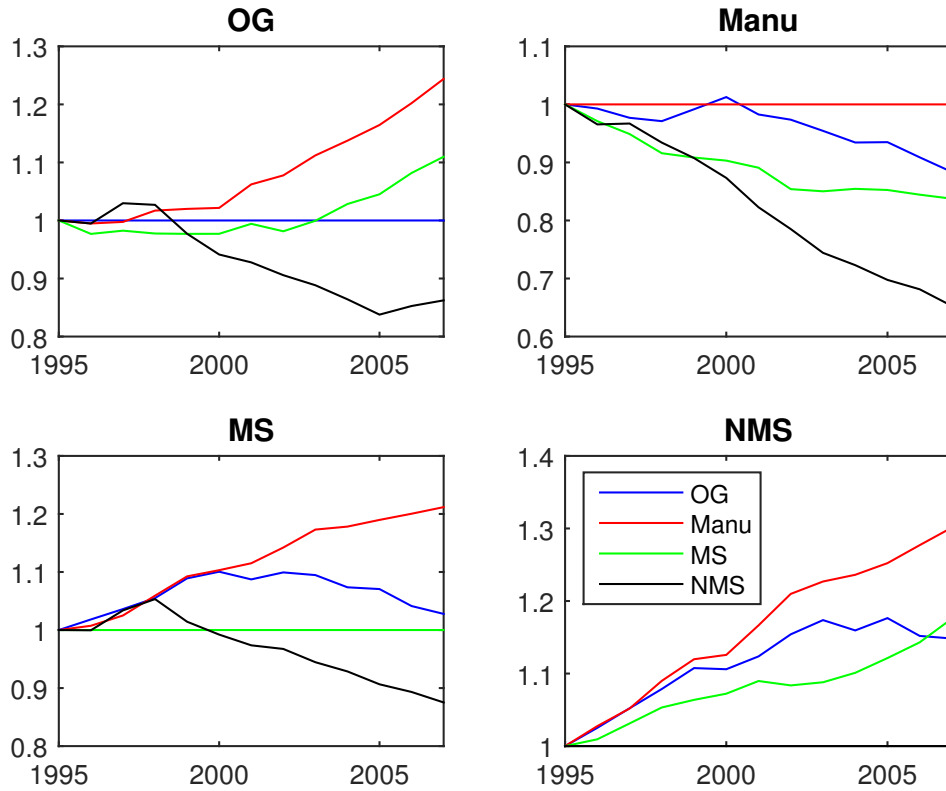
I focus on the trade and the productivity primitives: sourcing cost τ_{jit} and TFP scale T_{it} . A relatively decreasing sourcing cost τ_{jit} or a higher growth rate of TFP scale T_{it} implies a growing comparative advantage for supplying intermediate inputs from sector i to sector j , which raises the intermediate input share of sector i in sector j . Therefore, a sector with relatively decreasing sourcing cost or relatively increasing TFP scale over time would increasingly supply intermediate inputs, resulting in rising value added share through the I-I supply channel.

Sourcing cost

Figure 3.4 shows the pattern of the sourcing costs. The four panels display the sourcing costs to the four sectors respectively. In each panel, the four curves plot the average sourcing cost of the 35 economies from the four sectors that are labeled by the legend. All the sourcing costs are normalized to 1 in the beginning year 1995. If I compare manufacturing with market services, the sourcing cost from market services grows much more slowly than from manufacturing, which is consistent with the recent evidence by Eckert (2019) who shows a much higher reduction of trade cost from business services than from goods. Both paper impute the trade cost based on the input-output and other data. Based on Figure 3.4, in most of the period, the sourcing cost from manufacturing grows faster than from the other three sectors. It implies that compared to manufacturing, the other three sectors, particularly the services sectors, have increasing comparative advantage for supplying intermediate inputs.

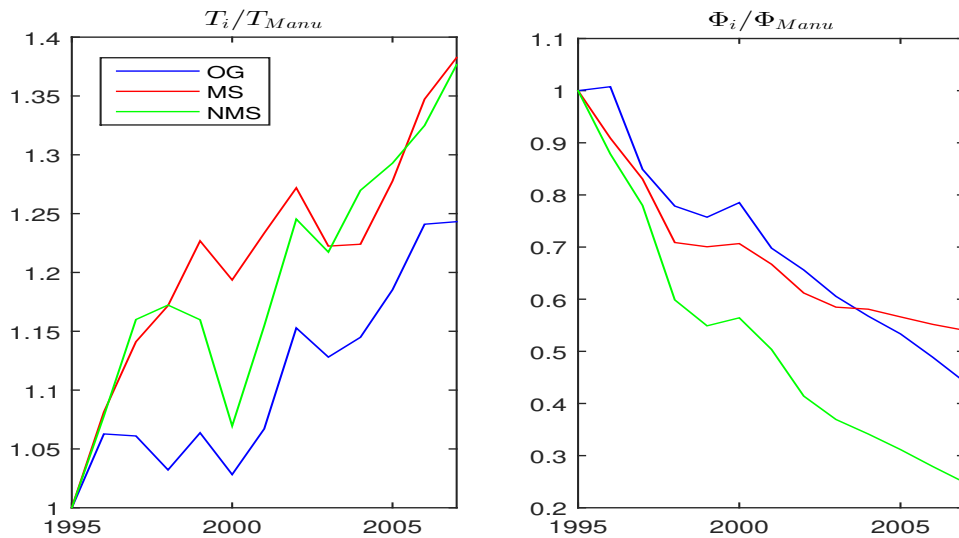
TFP Scale

Figure 3.5 demonstrates the pattern of TFP scale. The left-hand panel displays the trends of the relative TFP scale T_{it} of the other three sectors to manufacturing through 1995-2007, and the right-hand panel displays the trends of the relative efficiency Φ_{it} . By definition, the relative efficiency in logarithm is inversely proportional to the relative price in logarithm: $\frac{\Phi_{it}}{\Phi_{jt}} = \left(\frac{P_{it}}{P_{jt}} \right)^{-\zeta}$. In each year, the relative values are averaged over the 35 economies. The



The horizontal axis denotes year, and the vertical axis shows the values of sourcing cost. The values are normalized to 1 in the initial year. The four panels represent the sourcing cost to the four sectors (in the header) respectively. At each panel, the four curves show the sourcing cost from the four sectors (in the legend). The four sectors are other goods (OG), manufacturing (Manu), market-services (MS) and non-market services (NMS).

Fig. 3.4 Sector-to-sector sourcing cost



The horizontal axis denotes year, and the vertical axis shows the values of the relative TFP scale (left panel) and the relative sectoral efficiency (right panel) over time. The values are normalized to 1 in the initial year. In both panels, the three curves show the relative values of the other three sectors (in the legend) to manufacturing. The other three sectors are other goods (OG), market services (MS) and non-market services (NMS). The benchmark sector is manufacturing (Manu).

Fig. 3.5 Relative TFP scale and efficiency

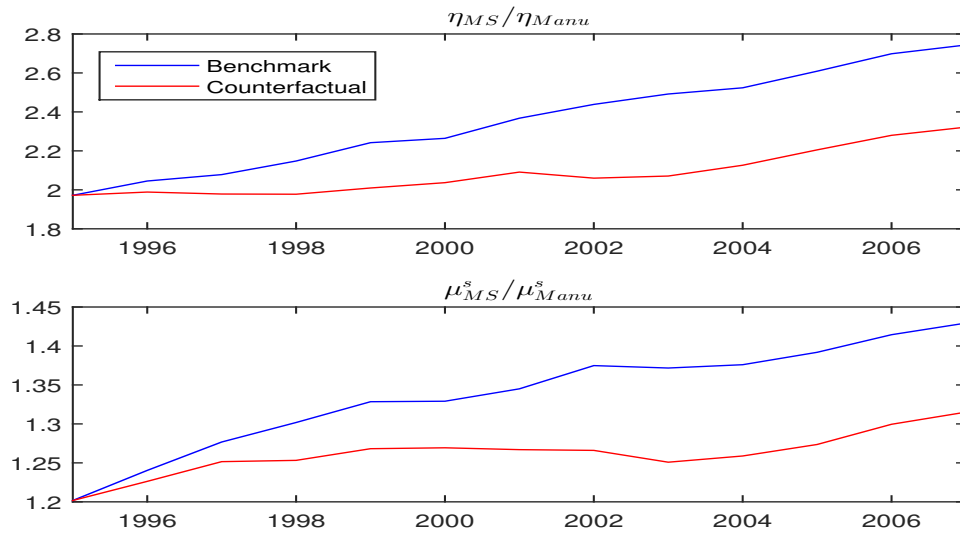
right-hand panel suggests that the efficiency growth of manufacturing is larger than the other three sectors. This is consistent with many studies which find a larger sectoral productivity growth in manufacturing than in services.²⁰ Surprisingly, the left-hand panel shows a very different picture for TFP scale growth. It suggests that the growth of manufacturing TFP scale is the slowest. Figure 3.5 implies that the higher growth rate of manufacturing efficiency is probably due to the access to the higher TFP scale growth in the other three sectors. Because manufacturers increasingly source their inputs from other sectors, particularly services. Those sourced inputs may confer higher productivity growth to manufacturing.

3.4.2 Why Structural Change Arises?

In this subsection, I illustrate how the intermediate-inputs supply effects are generated by the two comparative advantage forces that are identified by the last subsection. In particular, given the rising comparative advantage for supplying intermediate inputs, the model implies that market services have a larger growth of I-I supply multiplier than manufacturing. Hence, the relative sector shares of market services to manufacturing rise. I evaluate the I-I supply channel through the following two counterfactual studies.

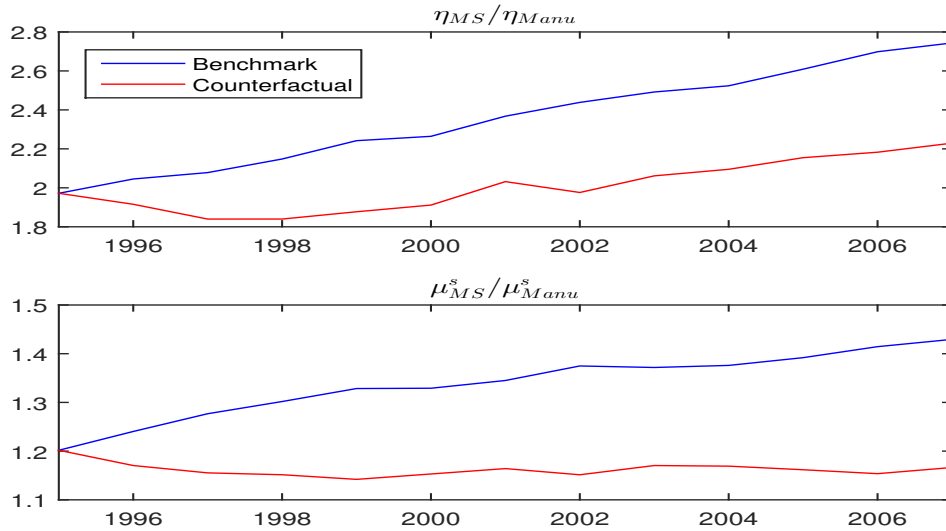
The first counterfactual study aims to quantify the role of sourcing cost in generating the I-I supply channel and structural change. Suppose market services have as same growth path of sourcing costs as manufacturing, I identify the change on the relative I-I supply multipliers and the relative value added shares of market services to manufacturing. The second counterfactual study aims to quantify the role of TFP scale in generating the I-I supply channel and structural change. In this case, suppose market services have as same growth path of TFP scale as manufacturing, I identify the change on the relative I-I supply multipliers and the relative value added shares of market services to manufacturing. Given the disparities of the two fundamental forces between manufacturing and market services in the last subsection, I examine how important of these disparities in generating the growth pattern of the relative I-I supply multipliers and the relative value added shares. In the two counterfactual studies, if market services have the same growth path of comparative advantage forces with manufacturing, the relative I-I supply multipliers and the relative value added shares of market services to manufacturing are expected to increase by a smaller proportion, compared to the benchmark case.

²⁰See evidence in [Bernard and Jones \(1996\)](#), [Duarte and Restuccia \(2010\)](#) and [Uy et al. \(2013\)](#).



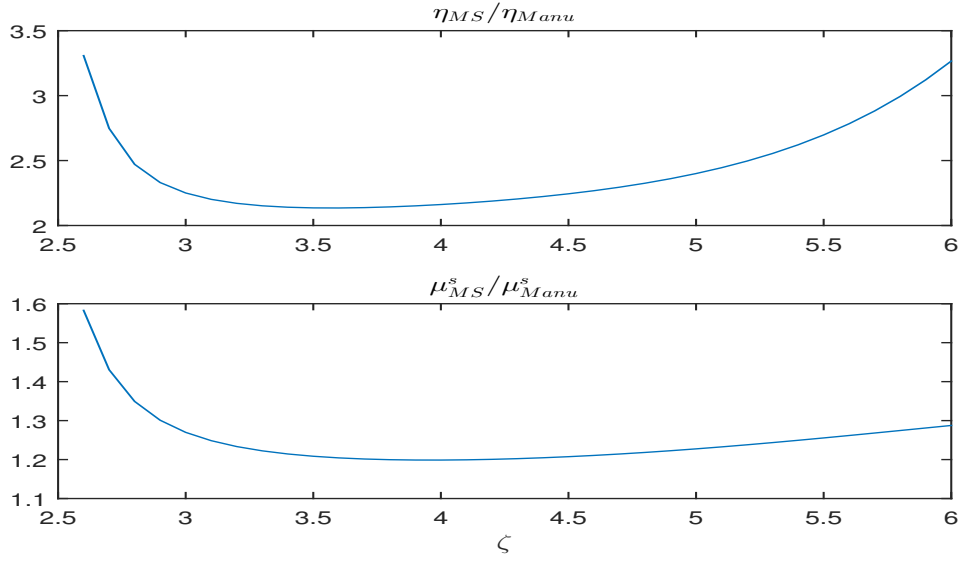
The horizontal axis denotes year, and the vertical axis shows the values of the relative value added share in the upper panel and the relative I-I supply multiplier in the lower panel. The relative is in the sense of market services to manufacturing. The blue curve plots the actual data, and the red curve plots the counterfactual values when manufacturing has the same growth path of sourcing cost with market services. In each year, the values are averaged over 35 economies.

Fig. 3.6 Role of sourcing cost: market services to manufacturing



The horizontal axis denotes year, and the vertical axis shows the values of relative value added share in the upper panel and relative I-I supply multiplier in the lower panel. The relative is in the sense of market services to manufacturing. The blue curve plots the actual data, and the red curve plots the counterfactual values when manufacturing has the same growth path of TFP scale with market services. In each year, the values are averaged over 35 economies.

Fig. 3.7 Role of TFP scale: market services to manufacturing



The horizontal axis shows the values of trade elasticity ζ , and the vertical axis shows the values of relative value added share in the upper panel, and the values of relative I-I supply multiplier in the lower panel. The relative is in the sense of market services to manufacturing. The values are averaged over 35 economies in year 2007.

Fig. 3.8 Role of trade elasticity: market services to manufacturing

Role of sourcing cost and Role of TFP Scale

Figure 3.6 and Figure 3.7 present the results of these two counterfactual studies, respectively. The results are consistent with my expectation. Without the increasing comparative advantage, the relative I-I supply multipliers and the relative value added shares of market services to manufacturing increase by a much smaller proportion than 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 services is due to a larger growth of TFP scale in market services than manufacturing and a smaller growth of sourcing costs from market services than from manufacturing. As far as I know, this implication has not been explored by the literature. Second, these results are consistent with the model predictions. The model suggests that one of the critical channels driving structural change is the I-I supply. Figure 3.6 and Figure 3.7 suggest that the relative I-I supply multipliers move coherently with the relative value added shares.

Role of Trade Elasticity

Finally, I study the role of trade elasticity in affecting the relative I-I supply multiplier and the relative value added share. Holding other parameters constant, I study how the relative I-I supply multipliers and the relative value added shares response to the trade elasticity

ζ . I present this result in Figure 3.8. When trade elasticity is less than around 4.5, Figure 3.8 suggests that the smaller the trade elasticity, the larger values of the relative I-I supply multipliers and the relative value added shares of market services to manufacturing. Recall that a lower ζ implies a higher dispersion of firm productivities, which further suggests a larger degree of trade incentives among firms. Since market services have growing comparative advantage relative to manufacturing for supplying intermediate inputs, a smaller trade elasticity magnifies the comparative advantage of market services. When trade elasticity is larger than 4.5, the relative I-I supply multipliers are almost stable while the relative value added shares increase with the trade elasticity. The relative prices increase with the trade elasticity. The price effect supports the rising relative value added shares at a higher value of trade elasticity.

3.5 Conclusion

While 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 the externalities of technological interaction as in Romer (1986) and Romer (1990). This chapter recasts the great insight of Marshall by following the discussion of Hirschman (1958) and Leontief (1974). I show that input-output linkages play a critical role in one of the most salient growth facts: structural change.

This chapter underscores the role of input-output linkages in driving structural change. In particular, the primary reason value added share falls in manufacturing and rises in market services in this chapter is due to the growing comparative advantage in market services relative to manufacturing. Since both the growth of sourcing cost and TFP scale favor market services, this sector can supply increasingly more intermediate inputs than manufacturing sector. To satisfy the rising demand for inputs sourcing, economic resource transfers from manufacturing to market services. The recent evidence of rising services sourcing from services sector to manufacturing sector supports this mechanism, as documented by Goodman and Steadman (2002) and Goldschmidt and Schmieder (2017).

The mechanism of input-output linkages in this chapter complements the structural change literature which mostly focuses on final demand factors: price and income effects. In this chapter, I do not ignore the price effects and the income effects. In particular, this chapter reveals an essential role of the price effects in structural change. On top of the final demand factors, this chapter highlight the crucial role of the intermediate-inputs supply and demand in driving structural change. In contrast, these interdependent relationships between producers are overlooked by most structural change studies. Hence, I view this chapter making an

important contribution by extending the structural change literature with a new credible mechanism: input-output linkages between producers.

Given structural change reflecting intersectoral inputs sourcing, this chapter offers a different implication for TFP growth. The TFP growth slow-down as many people worry about through the structural change may be overstated. According to the price effects in the existing literature, structural change implies that our economy transfers from the higher TFP growth sector (manufacturing) to the lower TFP growth sector (services). However, if structural change partially reflects the rising sourced economic activities from services to manufacturing, 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 sector or services sector. As highlighted in Section 3.4, the growth rate of TFP scale is higher in services than in manufacturing, though the growth of sectoral efficiency is most significant in manufacturing. The detail of the productivity implication is obviously beyond the scope of this chapter. It opens an interesting question to the future study.

Chapter 4

Input-Output Linkages and Productivity Measurement

This chapter studies the role of input-output (IO) linkages in sectoral and aggregate productivity measurement in 39 major economies through 1995-2007. The main finding is that while IO linkages appear neutral in aggregate productivity, they are crucial in sectoral productivity measurement. Without taking the IO linkages into account, the measures of sectoral productivities under the conventional development accounting method are biased for all sampling sectors and countries. This chapter also re-examines previous productivity studies based on the World Input-Output Database. The quantitative analysis suggests that their results are likely to be biased due to the ignorance of IO linkages.

4.1 Introduction

Are input-output linkages neutral in productivity measurement? The answer may appear yes to many macroeconomists. Input-output linkages are largely ignored in existing literature on productivity measurement ([Bernard and Jones 1996](#); [Herrendorf and Valentinyi 2012](#)). Abstracting from gross output and intermediate inputs, these studies directly use value added as production and primary inputs to measure productivity. An implicit assumption is the neutrality of input-output linkages in productivity measurement. In this chapter, I test the validity of this implicit assumption. This chapter studies the role of input-output linkages in productivity measurement. I introduce the same multi-sector model with input-output

linkages as in Chapter 2. The results suggest that input-output linkages are neutral in aggregate productivity, but are non-neutral in sectoral productivity measurement.

I start with a multi-sector model with input-output linkages following Jones (2011b). In each sector, a representative producer produces gross output by optimally allocating primary inputs and intermediate inputs. Assume both the aggregate and sectoral production function are constant return to scale Cobb-Douglas. I solve the equilibrium aggregate TFP under this simple *input-output economy*. On the other hand, I consider a *value added economy* that is analogous to the input-output economy. In the value added economy, sectoral production is value added, and only primary inputs (capital and labor) are required. In the value added economy, all sectors are independent without the input-output linkages. I solve the equilibrium aggregate TFP in this value added economy as well. I compare the aggregate productivity and sectoral productivity between the two economies.

This chapter has three findings. First, the aggregate TFP is theoretically equal between the input-output economy and the value added economy. This result depends on a few assumptions and a definition. The production technology is constant return to scale Cobb-Douglas, which implies exogenous input shares and sectoral production shares. Sectoral capital shares of value added are assumed to be equal between the two economies. In addition, sectoral value added is defined as the difference between the corresponding gross output and the total use of intermediate inputs. These assumptions and definition together imply that the allocation of real primary inputs are equal between the two economies at the sector level. Hence, it further implies an equivalent use of aggregate capital and labor between the two economies, which unsurprisingly leads to the aggregate TFP equivalence.

Second, relative to the development accounting (DA) method with IO linkages, the conventional DA method without IO linkages yields measurement bias in sectoral productivity. Based on the model result of aggregate TFP equivalence, I construct a sectoral value added based productivity which takes into account the input-output linkages. I label this measurement as the sectoral productivity under the IO method. On the other hand, I assume that an econometrician measures the value added based productivity directly using the conventional development accounting method. The econometrician neglects all the input-output linkages. I label this measurement as the sectoral productivity under the DA method. These two methods measure the same productivity: value added based TFP. However, the measurement methods are different, which could yield divergent measurement results. Indeed, the quantitative analysis suggests that the measures of sectoral TFP under the DA method differ from those under the IO method in all the 39 sampling countries. Moreover, the results suggest that the conventional DA method generates a different decomposition of aggregate TFP growth rate, compared with the IO method.

Third, the results of previous productivity studies which ignore the input-output linkages are likely to be biased. I re-examine three representative papers ([Bernard and Jones 1996](#); [Herrendorf and Valentinyi 2012](#); [McMillan et al. 2014](#)) under both the DA method and the IO method based on the World Input-Output Database (WIOD). The exercise aims to check whether the results of previous productivity studies under the DA method are biased relative to the corresponding results under the IO method. The quantitative analyses suggest that the results of previous productivity studies could be misleading. That is, without taking the input-output linkages into account, we may misinterpret the contribution of structural change in aggregate productivity growth; we may misunderstand the growth convergence of sectoral productivities across the OECD countries; we may estimate a biased degree of relative disparity of sectoral TFP to income.

This chapter is closely related to a recent literature which discusses the role of input-output linkages in productivity. [Duarte and Restuccia \(2017\)](#) show that incorporating input-output linkages reduces the cross-country productivity differences in traditional services (housing, health and government), while raises the cross-country productivity differences in non-traditional services (transportation, communication and finance). This chapter focuses on the role of input-output linkages in aggregate and sectoral productivity measurement, whereas [Duarte and Restuccia \(2017\)](#) emphasizes the importance of heterogeneous services sectors in accounting for the cross-country productivity differences. In addition, input-output linkages arguably amplify the low productivity growth ([Jones 2011a](#)) and misallocation ([Jones 2011b](#)) in poor countries, given the multiplier effect of input-output linkages. This chapter assumes Cobb-Douglas technology, which is in line with [Jones \(2011b\)](#) and [Duarte and Restuccia \(2017\)](#).

This chapter contributes to a literature which compares the input-output economy with the value added economy. [Domar \(1961\)](#) compares the two economies with a Cobb-Douglas production function and an arbitrarily defined value added share. [Balk \(2009\)](#) compares the two economies with a general production function. Both [Domar \(1961\)](#) and [Balk \(2009\)](#) argue that the aggregate productivity could be different between the two economies. In this chapter, I demonstrate the theoretically equivalent aggregate TFP between the two economies, given Cobb-Douglas technology and endogenous value added share. In this sense, this chapter is consistent with [Leal \(2017\)](#) who shows an equivalent de facto sector weights in aggregate productivity (named as the degree of influence in [Leal \(2017\)](#)) between the input-output economy and the value added economy. Indeed, the model result of this chapter also generates the same degree of influence between the two economies. While this chapter studies the implication of the aggregate TFP equivalence for sectoral TFP measurement, [Leal \(2017\)](#) does not discuss any implication for sectoral productivity measurement.

This chapter proceeds as follows. Section 4.2 presents the framework for the input-output economy and value added economy. Section 4.2 also shows the aggregate TFP equivalence result and the construction of sectoral TFP measurement based on the equivalence result. I show the quantitative comparison of sectoral TFP and the decomposition of aggregate TFP growth in Section 4.3. Then Section 4.4 presents a re-examination of previous productivity studies, and Section 4.5 concludes.

4.2 Model

This section presents the model. I first consider an input-output economy. Suppose there is an economy with many sectors. These sectors are interconnected by input-output linkages. I introduce the same multi-sector model with input-output linkages as in Chapter 2. I solve the aggregate value added and the aggregate TFP in equilibrium. The model of the input-output economy and the equilibrium results are given in the next subsection. Then I consider an analogous value added economy. I neglect all the input-output linkages. In each sector, a representative producer directly produces value added by employing labor and capital. For this value added economy, I also derive the aggregate value added and the aggregate TFP in equilibrium. The model of the value added economy and the equilibrium results are given in the second subsection.

Following the first two subsections, I compare the aggregate TFP between the two economies. I show the theoretical equivalence of aggregate TFP in the third subsection. Based on the result of theoretical equivalence, I obtain a sectoral value added based TFP in the last subsection. I label this TFP as the sectoral TFP measurement under the IO method. In contrast, I develop another sectoral value added based TFP measurement by directly using the conventional development accounting method without considering the input-output linkages. I label it as the sectoral TFP measurement under the DA method.

4.2.1 The Input-Output Economy

The model follows Jones (2011b) without international trade and distortion. Suppose there are J sectors in an economy. The production function of the sectoral gross output is constant return to scale Cobb-Douglas:

$$Q_i = A_{GOi} K_i^{(1-\sigma_i)\alpha_i} L_i^{(1-\sigma_i)(1-\alpha_i)} \prod_{j=1}^J X_{ij}^{\sigma_{ij}}. \quad (4.1)$$

Here $\sigma_i = \sum_{j=1}^J \sigma_{ij}$, K_i and L_i stand for capital and labour demand of sector i respectively, and α_i is capital share of value added in sector i . The X_{ij} represents the intermediate input produced by sector j and used by sector i , and A_{GOi} is gross output based TFP of sector i . The gross output is either consumed as final goods or supplied to other (including itself) sectors as intermediate inputs:

$$C_j + \sum_{i=1}^J X_{ij} = Q_j. \quad (4.2)$$

The aggregate final output (real GDP) Y is assumed to be a Cobb-Douglas aggregation of sectoral consumption C_i , such that

$$Y = \prod_{i=1}^J C_i^{\lambda_i}. \quad (4.3)$$

Here λ_i is consumption share of sector i and $\sum_{i=1}^J \lambda_i = 1$.

In the static competitive equilibrium, a representative consumer maximizes the aggregate final consumption by optimally choosing consumption from each sector:

$$\max_{C_i} \prod_{i=1}^J C_i^{\lambda_i} - \sum_{i=1}^J P_i C_i.$$

The first order condition is given by

$$\lambda_i \frac{Y}{C_i} = P_i. \quad (4.4)$$

In each sector, a representative producer maximizes the sectoral profit by optimally choosing capital, labor and intermediate inputs:

$$\max_{K_i, L_i, X_{ij}} P_i A_{GOi} K_i^{(1-\sigma_i)\alpha_i} L_i^{(1-\sigma_i)(1-\alpha_i)} \prod_{j=1}^J X_{ij}^{\sigma_{ij}} - rK_i - wL_i - \sum_{j=1}^J P_j X_{ij}.$$

The first order conditions of choosing capital, labour and intermediate inputs are given by the following equations respectively:

$$(1 - \sigma_i)\alpha_i \frac{P_i Q_i}{K_i} = r, \quad (4.5)$$

$$(1 - \sigma_i)(1 - \alpha_i) \frac{P_i Q_i}{L_i} = w, \quad (4.6)$$

$$\sigma_{ij} \frac{P_i Q_i}{X_{ij}} = P_j. \quad (4.7)$$

Assume capital and labour are inelastically supplied. The market clearing conditions are given by

$$\sum_{i=1}^J K_i = K, \quad (4.8)$$

$$\sum_{i=1}^J L_i = L. \quad (4.9)$$

There are 9 equations to solve 9 variables in equilibrium: $Y, Q_i, K_i, L_i, X_{ij}, C_i, P_j, w, r$.

After solving the model (all proofs of this and other propositions of this chapter are given in Appendix C.1), the following proposition summarizes the key results of the input-output economy:

Proposition 4 (Equilibrium Solution of The IO Economy). *In the competitive equilibrium, the aggregate value added and the aggregate TFP are solved by the following equations:*

$$Y = TFP_{GO} K^{\hat{\alpha}_{GO}} L^{1-\hat{\alpha}_{GO}}, \quad (4.10)$$

$$\log TFP_{GO} = \gamma' \log A_{GO} + \lambda' W_c + \gamma' W_{GOq}. \quad (4.11)$$

Here TFP_{GO} is the aggregate TFP in the input-output economy. The term A_{GO} is a column vector ($J \times 1$) of sectoral gross output based TFP. Domar weight $\gamma = (I - B)^{-1} \lambda$, where B is the input-output matrix with $B_{ji} = \sigma_{ij}$, $\gamma_i = \frac{P_i Q_i}{Y}$ and λ is a column vector ($J \times 1$) of consumption shares. Aggregate Capital share $\hat{\alpha}_{GO} = \gamma' [(1 - \sigma) \circ \alpha]$, where $\circ$ denotes the Hadamard (piecewise) product, and σ and α are column vectors ($J \times 1$) of demand intensities of intermediate inputs and capital shares. Allocation terms $W_c = \log \lambda - \log \gamma$, and $W_{GOq} = (1 - \sigma_i) \alpha_i \log \theta_{GOKi} + (1 - \sigma_i)(1 - \alpha_i) \log \theta_{GOLi} + \sum_{j=1}^J \sigma_{ij} \log \theta_{ij}$, with allocation parameters $\theta_{GOKi} = \frac{(1 - \sigma_i) \alpha_i \gamma_i}{\sum_{i=1}^J (1 - \sigma_i) \alpha_i \gamma_i}$, $\theta_{GOLi} = \frac{(1 - \sigma_i)(1 - \alpha_i) \gamma_i}{\sum_{i=1}^J (1 - \sigma_i)(1 - \alpha_i) \gamma_i}$, and $\theta_{ij} = \sigma_{ij} \frac{\gamma_i}{\gamma_j}$.

The aggregate TFP contains a weighted sum of sectoral TFP. The sector weight is Domar weight, a result that is consistent with the input-output literature (Acemoglu et al. 2012; Carvalho and Gabaix 2013; Domar 1961; Hulten 1978).

4.2.2 The Corresponding Value Added Economy

Suppose now I ignore the input-output linkages. The sectoral output is value added which is produced by using only primary inputs:

$$Y_i = A_{VAi} K_i^{\beta_i} L_i^{(1-\beta_i)}. \quad (4.12)$$

Here A_{VAi} is the value added based TFP of sector i , β_i is the capital share of sector i . The aggregate final output is assumed to be a Cobb-Douglas composite of sectoral value added, given by

$$Y = \prod_{i=1}^J Y_i^{\eta_i}. \quad (4.13)$$

Here η_i is the value added share of sector i and $\sum_{i=1}^J \eta_i = 1$. Similar to the input-output economy, the first order conditions of consumer's optimization problem and producers' optimization problem are given by the following equations:

$$\eta_i \frac{Y}{Y_i} = P_{Yi}, \quad (4.14)$$

$$\beta_i \frac{P_{Yi} Y_i}{K_i} = r, \quad (4.15)$$

$$(1 - \beta_i) \frac{P_{Yi} Y_i}{L_i} = w. \quad (4.16)$$

Likewise, assume capital and labor are inelastically supplied. The market clearing conditions are given by equation (4.8) and equation (4.9). In equilibrium, the following proposition summarizes the key results of the value added economy:

Proposition 5 (Equilibrium Solution of The Value Added Economy). *In the competitive equilibrium, the aggregate value added and the aggregate TFP are given by*

$$Y = TFP_{VA} K^{\hat{\alpha}_{VA}} L^{1-\hat{\alpha}_{VA}}, \quad (4.17)$$

$$\log TFP_{VA} = \eta' \log A_{VA} + \eta' W_{VAq}. \quad (4.18)$$

Here TFP_{VA} is the aggregate TFP in the value added economy. The term A_{VA} is a column vector ($J \times 1$) of sectoral value added based TFP. Aggregate Capital share $\hat{\alpha}_{VA} = \eta' \beta$, where η and β are column vectors ($J \times 1$) of value added shares and capital shares. Allocation term $W_{VAq} = \beta_i \log \theta_{VAKi} + (1 - \beta_i) \log \theta_{VALi}$, with allocation parameters $\theta_{VAKi} = \frac{\beta_i \eta_i}{\sum_{i=1}^J \beta_i \eta_i}$ and $\theta_{VALi} = \frac{(1-\beta_i)\eta_i}{\sum_{i=1}^J (1-\beta_i)\eta_i}$.

Compared to the aggregate TFP equation (4.11) in the input-output economy, the sector weight now is value added share in equation (4.18).

4.2.3 Aggregate TFP Equivalence

Regardless of which economy I model, the sectoral capital share of value added should be the same. Thus, we should have $\alpha_i = \beta_i$. Let's define the sectoral value added as $rK_i + wL_i$. I assume that the sectoral value added is equal between the two economies. In the IO economy, the sectoral value added is $(1 - \sigma_i)P_iQ_i$ following equation (4.5) and equation (4.6). In the value added economy, the sectoral value added is $P_{Yi}Y_i$ following equation (4.15) and equation (4.16). Hence, we have $P_{Yi}Y_i = (1 - \sigma_i)P_iQ_i$. Given $P_{Yi}Y_i = (1 - \sigma_i)P_iQ_i$, the sectoral capital allocations K_i are equal between the two economies following equation (4.5) and equation (4.15). These conditions together with Proposition 4 and Proposition 5 imply the following proposition:

Proposition 6 (Aggregate TFP equivalence). *Given $\alpha_i = \beta_i$ and $P_{Yi}Y_i = (1 - \sigma_i)P_iQ_i$, we have*

$$\eta_i = (1 - \sigma_i)\gamma_i, \quad (4.19)$$

$$TFP_{VA} = TFP_{GO}. \quad (4.20)$$

Put it differently, the aggregate TFP equivalence depends on two conditions: (i) an equivalent capital share of sectoral value added between the two economies; (ii) the sectoral value added ($P_{Yi}Y_i$) in the value added economy equals the difference between the sectoral gross output (P_iQ_i) and the sectoral use of intermediate inputs ($\sigma_i P_iQ_i$) in the input-output economy.

Now I return to the equations of aggregate value added (4.10) and (4.17) to briefly prove the equivalence. The formal proof is given in Appendix C.1. Note that if the aggregate capital shares equal between the two economies: $\hat{\alpha}_{GO} = \hat{\alpha}_{VA}$, the aggregate TFP must be equal as well. The aggregate capital share is a weighted average of the sectoral capital shares. Given the equal sectoral weights $\eta_i = (1 - \sigma_i)\gamma_i$, I can show the equivalent product of the sector weight and the capital share between the two economies:

$$\eta_i \beta_i = \gamma_i (1 - \sigma_i) \alpha_i.$$

Consequently, the aggregate capital share equals: $\hat{\alpha}_{GO} \equiv \sum_{i=1}^J \gamma_i (1 - \sigma_i) \alpha_i = \hat{\alpha}_{VA} \equiv \sum_{i=1}^J \eta_i \beta_i$, which implies the equivalent aggregate TFP between the input-output economy and the value added economy.

Proposition 6 is in line with Leal (2017) who shows that under the Cobb-Douglas production function and the competitive equilibrium, the IO economy is equivalent to the value added economy. In particular, Leal (2017) points out an equivalent degree of influence that is a variation on sector weight. Based on Leal (2017), the degree of influence in the input-output economy is $(1 - \sigma_i)\gamma_i$, and the degree of influence in the value added economy

is η_i . They are equal following equation (4.19). While Leal (2017) focuses on the degree of influence, this chapter focuses on productivity. Notice that the result of aggregate TFP equivalence may be not generalized to other frameworks. The aggregate TFP equivalence breaks down under a general production function (Balk 2009), or under a Cobb-Douglas production function but with an arbitrarily defined valued added share (Domar 1961).

4.2.4 Sectoral TFP Measures

Based on the result of aggregate TFP equivalence, I construct a mapping equation between the value added based TFP and the gross output based TFP at the sector level. Specifically, following equation (4.11) and equation (4.18), I have

$$(1 - \sigma_i) \log A_{VAi} = \log A_{GOi} + ((I - B')W_c)_i + \sum_{j=1}^J \sigma_{ij} \log \theta_{ij}. \quad (4.21)$$

Here $((I - B')W_c)_i$ refers to the value of entry i of the column vector $(I - B')W_c$. For each gross output based TFP A_{GOi} , I can calculate a corresponding value added based TFP A_{VAi} such that the aggregate TFP is equivalent between the IO economy and the value added economy. I label the value added based TFP A_{VAi} which is computed by equation (4.21) as the sectoral TFP measurement under the IO method: A_{VAi}^{IO} . In particular, the gross output based TFP $\log A_{GOi}$ in equation (4.21) could be calculated by a conventional development accounting method following equation (4.1). On the other hand, assume that an econometrician directly uses a conventional development accounting method to calculate the value added based TFP A_{VAi} following equation (4.12). I label this TFP as the sectoral TFP measurement under the DA method: A_{VAi}^{DA} . Note that both A_{VAi}^{IO} and A_{VAi}^{DA} are value added based TFP, but they are measured by very different methods: development accounting with IO linkages and development accounting without IO linkages, respectively. I study whether these two measures of productivity are divergent in the next section.

4.3 Quantitative Analysis

4.3.1 Data

Similar to the previous two chapters, the major database I use in this chapter is the World Input-Output Database (WIOD). For the input-output tables, I use the World Input-Output Table (WIOT) dataset. For the national account data on capital, labor, and local price deflators, I use the Socio Economic Accounts (SEA) dataset.

The Sector and Industry Relative Price (SIRP) database from [Inklaar and Timmer \(2014\)](#) is necessary to transfer the local real values into the global real values. Specifically, I first use the time series data of price deflators in the SEA to calculate the real values of value added, intermediate inputs and gross outputs at the 2005 local prices. The SEA dataset provides all the useful value added price deflators and gross output price deflators. I use the gross output price deflators to deflate the nominal values of intermediate inputs. Then I aggregate the 35 sectors into 4 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 compute the real gross outputs, real value added and real intermediate inputs at the 2005 global reference prices.

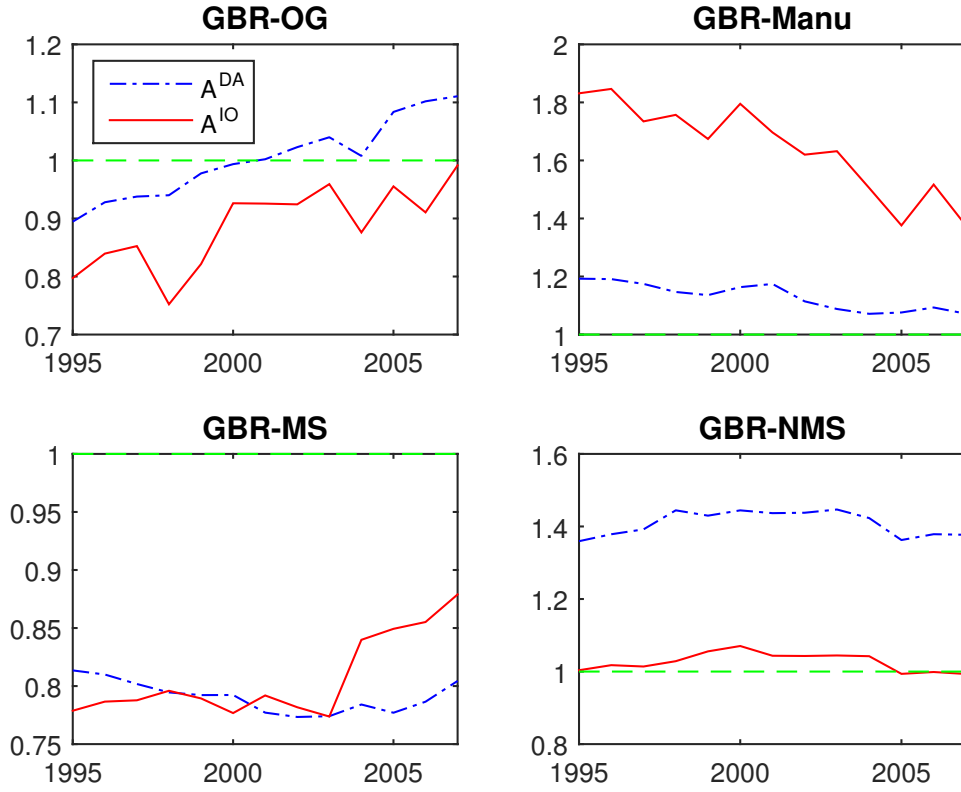
The real primary inputs are computed in a similar way. The SEA dataset provides sectoral values of real capital stock at the 1995 local prices. I compute the real capital stock at the 2005 local prices by using the capital price deflators in SEA. Then I use the capital PPP deflators from the Penn World Table (PWT) 8.1 to compute the real capital stock at the 2005 global prices. For the labor input, I use the total employment hours. An alternative choice is the number of employees. Many papers including [Fadinger et al. \(2017\)](#) argue for the choice of total employment hours. Because the data on working hours admit the accounting for different working patterns, for instance, full-time and part-time.

The final panel data are available for 4 sectors and 39 countries through 1995-2007.¹ The capital data are not available for the year 2008 and 2009 for a few European countries in the WIOD 2013. Besides, since the SIRP database does not provide data on PPP price deflators for Taiwan, I remove Taiwan out of the sample. Given the data, I construct the following useful variables: real gross outputs, real value added, real intermediate inputs, real capital stock, and number of working hours.

4.3.2 Measurement Bias in Sectoral TFP

In this subsection, I show evidence of measurement bias in sectoral productivity when ignoring the input-output linkages. The productivity is measured by two different methods: development accounting with IO linkages (IO method) and development accounting without IO linkages (DA method). Specifically, I compare A_{VAi}^{IO} and A_{VAi}^{DA} for 39 countries and 4 sectors through 1995-2007.

¹See Appendix [A.3](#) for the list of 35 countries and the sector classification. Another four countries are Bulgaria, Indonesia, India and Russia.



The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The solid curve plots the sectoral TFP measures under the IO method, and the dash curve plots the sectoral TFP measures under the DA method.

Fig. 4.1 The sectoral TFP of the UK relative to the US

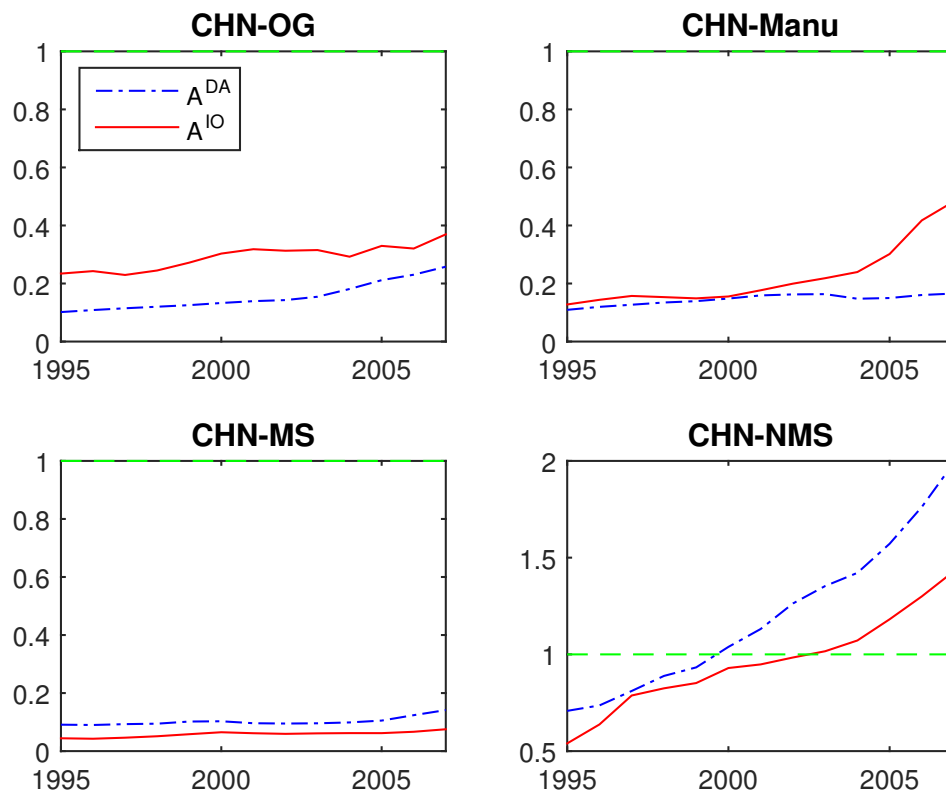
To show the productivity measurement in a meaningful way, all the productivity measures are normalized to their US counterparts:

$$\frac{A_{GOi,c}}{A_{GOi,US}} = \frac{Q_{i,c}}{Q_{i,US}} \times \frac{K_{i,US}^{(1-\sigma_{i,US})\alpha_{i,US}}}{K_{i,c}^{(1-\sigma_{i,c})\alpha_{i,c}}} \times \frac{L_{i,US}^{(1-\sigma_{i,US})(1-\alpha_{i,US})}}{L_{i,c}^{(1-\sigma_{i,c})(1-\alpha_{i,c})}} \times \prod_{j=1}^J \frac{X_{ij,US}^{\sigma_{ij,US}}}{X_{ij,c}^{\sigma_{ij,c}}}. \quad (4.22)$$

Here c stands for country. Then given the gross output based TFP in equation (4.22), I compute the value added based TFP under the IO method A_{VAi}^{IO} following equation (4.21).

Assume the econometrician uses the DA method to compute the productivity following equation (4.12). The normalized productivity is calculated by

$$\frac{A_{VAi,c}^{DA}}{A_{VAi,US}^{DA}} = \frac{Y_{i,c}}{Y_{i,US}} \times \frac{K_{i,US}^{\alpha_{i,US}}}{K_{i,c}^{\alpha_{i,c}}} \times \frac{L_{i,US}^{1-\alpha_{i,US}}}{L_{i,c}^{1-\alpha_{i,c}}}. \quad (4.23)$$



The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The solid curve plots the sectoral TFP measures under the IO method, and the dash curve plots the sectoral TFP measures under the DA method.

Fig. 4.2 The sectoral TFP of China relative to the US

To simplify the computation, I assume a constant capital share $\alpha_{ic} = 1/3$ for all sectors and countries and for all years.

Figure 4.1 and Figure 4.2 exemplify the measurement divergence for two countries: the UK and China, respectively. The four panels show the results for the four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG). The measurement divergence between the two methods are visible in all sectors. For the case of the UK, the DA method tends to overestimate the TFP of the non-market service sector and the other goods sector but underestimate the manufacturing TFP. Based on the IO measurement, we can observe a strong convergence in the UK market services since 2003. However, we cannot see the convergence based on the DA measurement. For the case of China, while the DA method overestimates the market services and the non-market services TFP, it underestimates the TFP of manufacturing and other goods sector. Under the IO measurement, we can observe a productivity catch-up in the Chinese manufacturing sector

particularly since 2003. We cannot observe the catch-up based on the DA measurement. Overall, Figure 4.1 and Figure 4.2 point out the measurement biases in sectoral productivity by the DA method relative to by the IO method.

4.3.3 Decomposition Bias in Aggregate TFP Growth

It is a common practice in the literature to decompose aggregate TFP growth into a few contributing factors (McMillan et al. 2014). Given the biased measurement of sectoral TFP in the last subsection, the decomposition of aggregate TFP growth is likely to be biased.

This subsection examines whether the decomposition of aggregate TFP growth is biased. Similar to the last subsection, I first assume that the econometrician measures the sectoral TFP by the DA method. The input-output linkages are overlooked by the econometrician. Based on the sectoral TFP, the econometrician computes the aggregate TFP following equation (4.18). In the second exercise, I replace the sectoral TFP under the DA method with the sectoral TFP under the IO method. I compare the decomposition of aggregate TFP growth between the two exercises.

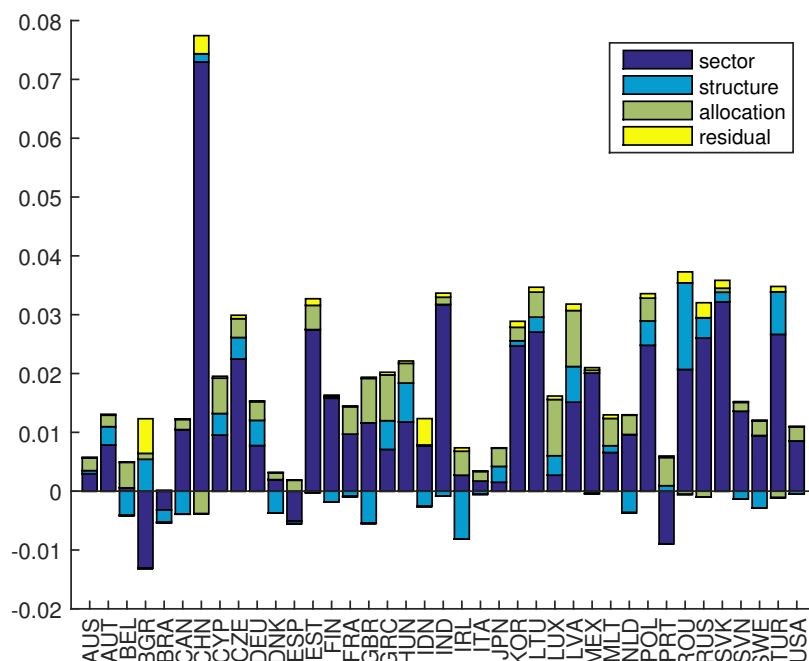
Following equation (4.18), I decompose the aggregate TFP growth by the following equation:

$$\begin{aligned} \frac{\Delta TFP_{VA,t+1}}{TFP_{VA,t}} &= \sum_i^J \eta_{i,t} \Delta \log A_{VAi,t+1} + \sum_i^J \log A_{VAi,t+1} \Delta \eta_{i,t+1} \\ &\quad + \sum_i^J \{ \eta_{i,t} \Delta W_{VAqi,t+1} + W_{VAqi,t+1} \Delta \eta_{i,t+1} \} + \text{residual}_{t+1}. \end{aligned} \quad (4.24)$$

Equation (4.24) suggests that the aggregate TFP growth rate is decomposed into four terms. The first term is a weighted average of the sectoral TFP growth rate. By construction, the sector weight is the value added share. The second term is a sum of the product of value added share change and the sectoral TFP in logarithm. This term summarizes the change in value added share across sectors. A negative value indicates structural change from the sectors with higher TFP to the sectors with lower TFP, and vice versa. The third term captures the contribution of the allocation. I leave everything else in the residual term. Following McMillan et al. (2014), I label the first term as the within-sector TFP growth and the second term as the cross-sector structural change.²

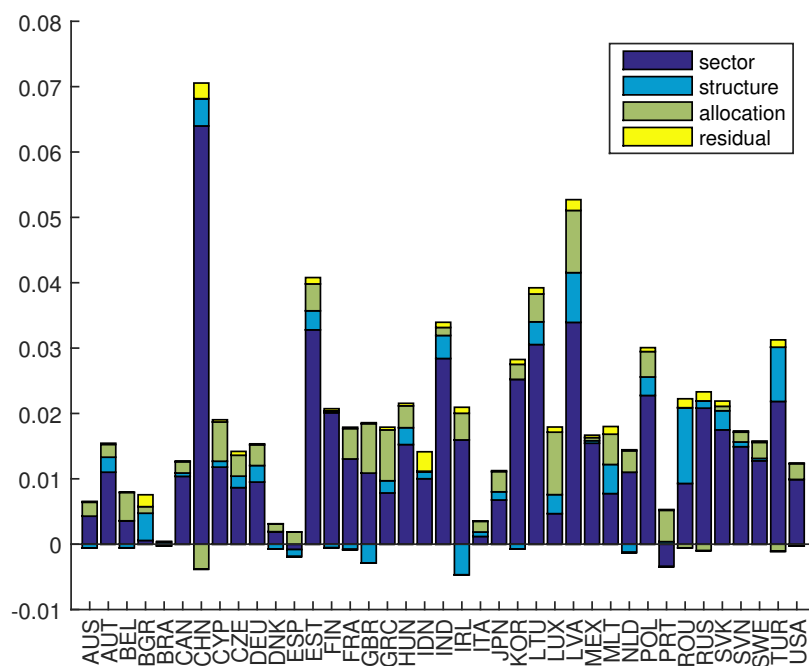
Figure 4.3 demonstrates the decomposition result of the average annual growth rate of aggregate TFP under the IO method, namely the unbiased decomposition for the 39 major

²The third term is always the same between the two exercises. Therefore, this subsection only pays attention to the first two terms.



The dark blue bar indicates the within-sector TFP growth rate, the light blue bar corresponds to the structural change, the green bar stands for the allocation term, and the yellow bar denotes the residual error. The sectoral TFP are estimated by the IO method. The connection between the country codes and country names are given in Appendix A.3.

Fig. 4.3 Decomposition of aggregate TFP growth under the IO method



The dark blue bar indicates the within-sector TFP growth rate, the light blue bar corresponds to the structural change, the green bar stands for the allocation term, and the yellow bar denotes the residual error. The sectoral TFP are estimated by the DA method. The connection between the country codes and country names are given in Appendix A.3.

Fig. 4.4 Decomposition of aggregate TFP growth under the DA method

(1) Country	(2) Sec(IO)	(3) Sec(DA)	(4) Stu(IO)	(5) Stu(DA)	(6) Agg(IO)	(7) Agg(DA)
Latvia	1.513	3.393	0.605	0.761	3.198	5.277
Ireland	0.271	1.595	-0.814	-0.468	-0.047	1.592
Bulgaria	-1.313	0.057	0.542	0.417	-0.002	0.818
Slovak	3.218	1.748	0.164	0.292	3.616	2.197
Czech	2.248	0.865	0.364	0.176	3.025	1.426
Romania	2.069	0.929	1.472	1.159	3.698	2.211
Australia	0.297	0.429	0.052	-0.058	0.581	0.596
Canada	1.047	1.037	-0.391	0.052	0.841	1.277
Indonesia	0.773	1.001	-0.260	0.103	0.954	1.459
Korea	2.472	2.522	0.084	-0.074	2.893	2.750
United States	0.854	0.991	-0.049	-0.029	1.054	1.214
China	7.296	6.399	0.139	0.417	7.345	6.665

Column (1) lists the country codes for a few countries. Column (2) and column (3) display the within-sector TFP growth rate under the IO method and the DA method respectively. Column (4) and column (5) display the structural change under the IO method and the DA method respectively. Column (6) and column (7) display the aggregate TFP growth rate under the IO method and the DA method respectively. All numbers are in percentage points.

Table 4.1 Summary of the primary decomposition bias (%)

economies through 1995-2007. The average refers to the geometric mean over the 13 years. For the within-sector TFP growth, the average growth rate is around 2.5 percent per annum in the 19 developing countries, and it is about 1 percent in the 20 developed countries. While the within-sector TFP growth rate reached about 7 percent in China, it was less than 1 percent in Brazil and Indonesia. In contrast to the more than 1 percent of within-sector TFP growth rate in Finland and the UK, the growth rate was below 0.2 percent in Japan and Italy. The structural change experience are heterogeneous among the sampling countries, even though they may share similar development features. For example, while China had a growth-enhancing (positive) structural change, emerging economies such as Brazil, Indonesia and India experienced a growth-reducing (negative) structural change. The structural change was growth-enhancing in Australia and Germany, whereas it was growth-reducing in Canada and the UK.

Figure 4.4 shows the decomposition result under the DA method, namely the biased decomposition for the same countries. Table 4.1 summarizes the main differences between the two decomposition exercises. Table 4.1 reports the results for 12 countries which include rich economies such as the US, Australia and Canada and the emerging economies such as China, Indonesia and Romania. Column (2) and column (3) display the within-sector TFP growth rate under the IO method and the DA method respectively. Then the analogous results

for the structural change are given in column (4) and column (5), and results for the aggregate TFP growth rate are given in column (6) and column (7).

Three findings are noteworthy. First, the DA method measures a different sign of structural change than the IO method for 11 out of 39 countries. For instance, column (4) and column (5) of Table 4.1 suggest opposite signs of structural change for Australia, Canada, Indonesia and Korea. Second, for the within-sector TFP growth, the measurement could be very divergent between the DA method and the IO method. According to column (2) and column (3) of Table 4.1, while the DA method overestimates the growth rate by more than one percentage point in Latvia, Ireland and Bulgaria, it underestimates the growth rate by more than one percentage point in Slovak, Czech and Romania. Third, for the aggregate TFP growth rate, the difference between the two methods could be significant as well. The last two columns of Table 4.1 reveals that while the DA method overestimates the US aggregate TFP growth rate by about 15 percent, it underestimates the Chinese aggregate TFP growth rate by about 9 percent. The measurement bias of aggregate TFP growth rate is even more startling in countries like Ireland and Canada.

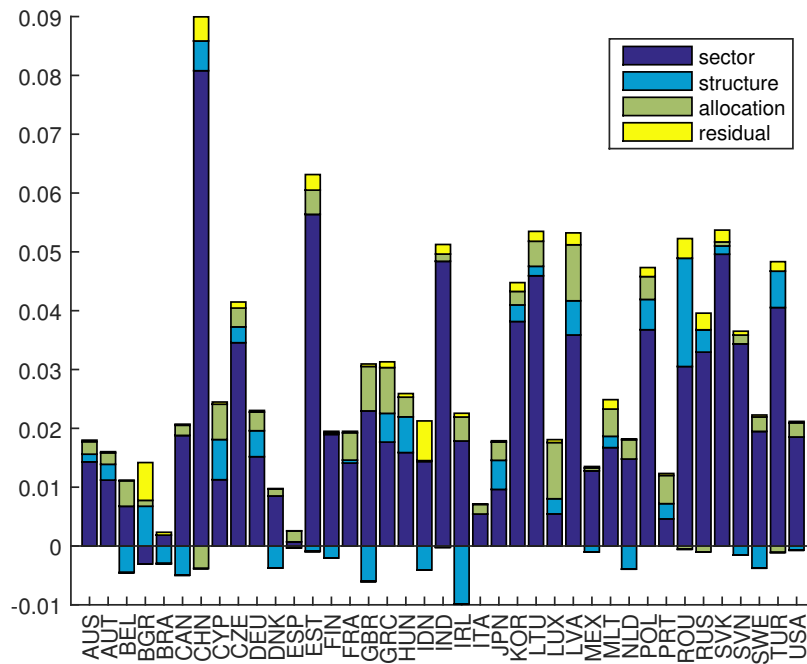
Note that the measurement difference in the aggregate TFP growth rate does not contradict the result of aggregate TFP equivalence in Section 4.2. The aggregate TFP equivalence suggests that if we measure the sectoral value added based TFP under the IO method, we should end up with the same aggregate TFP following equation (4.18) with the one that is calculated by aggregating the sectoral gross output based TFP following equation (4.11). Put it differently, if we measure the sectoral TFP under the DA method, the aggregate TFP could be divergent between the input-output economy and the value added economy.

4.4 Re-examination of Previous Productivity Studies

The quantitative analysis thus far has focused on the role of input-output linkages in the measurement of sectoral productivity and aggregate productivity growth. In this section, I study the implication of input-output linkages for various results which have been established in the literature. All of these results have been established without the consideration of input-output linkages. I re-examine these results based on the data of WIOD. I review and compare these results under the DA method versus under the IO method.

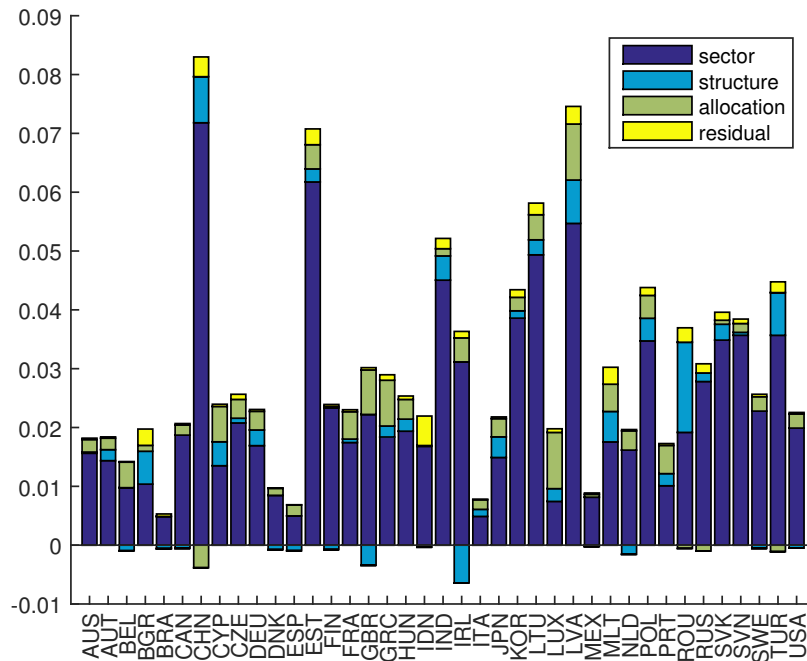
4.4.1 Effect of Structural Change on Aggregate Productivity Growth

The first paper I re-examine is [McMillan et al. \(2014\)](#). They decompose the annual growth rate of aggregate labor productivity into the within-sector productivity growth rate and



The dark blue bar indicates the within-sector labor productivity growth rate, the light blue bar corresponds to the structural change, the green bar stands for the allocation term, and the yellow bar denotes the residual error. The sectoral labor productivities are estimated by the IO method. The connection between the country codes and country names are given in Appendix A.3.

Fig. 4.5 Decomposition of aggregate labour productivity growth under the IO method



The dark blue bar indicates the within-sector labor productivity growth rate, the light blue bar corresponds to the structural change, the green bar stands for the allocation term, and the yellow bar denotes the residual error. The sectoral labor productivities are estimated by the DA method. The connection between the country codes and country names are given in Appendix A.3.

Fig. 4.6 Decomposition of aggregate labour productivity growth under the DA method

(1) Country	(2) Stu(IO)	(3) Rank(IO)	(4) Stu(DA)	(5) Rank(DA)
Hungary	0.607	5	0.205	17
Greece	0.488	10	0.187	18
Malta	0.192	18	0.517	6
India	-0.022	24	0.412	7
Spain	-0.030	25	-0.094	35

(1) Ctry Code	(2) Sec(IO)	(3) Rank(IO)	(4) Sec(DA)	(5) Rank(DA)
Slovak	4.960	3	3.485	9
Latvia	3.587	9	5.470	3
Czech	3.456	10	2.077	16
Romania	3.051	13	1.917	19
Ireland	1.785	19	3.115	11

The upper panel displays the rankings of structural change, and the lower panel displays the rankings of within-sector labor productivity growth for the five countries. For both panels, column (2) and column (3) show the original values (%) and rankings under the IO method respectively, column (4) and column (5) show the original values (%) and rankings under the DA method respectively.

Table 4.2 Rankings of structural change and within-sector labor productivity growth

structural change as in equation (4.24). They find heterogeneous paths of structural change across countries. Their results suggest that while many Asian developing countries, such as India and Thailand, achieved a growth-enhancing structural change, many Latin American developing countries like Argentina and Brazil experienced a growth-reducing structural change.

I re-examine [McMillan et al. \(2014\)](#) by a decomposition of the growth rate of aggregate labor productivity, following equation (4.24). Figure 4.5 displays the decomposition result under the IO method, and Figure 4.6 displays the decomposition result under the DA method. To highlight the differences, I show the rankings of the contribution of structural change and within-sector productivity growth for a few countries in Table 4.2. The upper panel shows the rankings of structural change among the 39 countries for the following countries: Hungary, Greece, Malta, India and Spain. The lower panel of Table 4.2 reports the rankings of the within-sector productivity growth rate for the following five countries: Slovak, Latvia, Czech, Romania and Ireland. These countries are chosen since the biased results are most evident in these countries. For both panels, column (2) and column (3) demonstrate the original values (%) and rankings (among 39 countries) under the IO method respectively, and column (4) and (5) show the values and rankings under the DA method respectively.

Relative to the rankings under the IO method, the rankings under the DA method could be significantly biased. The upper panel of Table 4.2 suggests that while the DA method underestimates the contribution of structural change for Hungary and Greece, the contribution of structural change is overestimated for Malta and India. In particular, India achieved a growth-enhancing structural change based on the DA method following Figure 4.6. In contrast, the structural change in India was slightly growth-reducing based on the IO method following Figure 4.5. Besides, for the within-sector productivity growth rate, the lower panel of Table 4.2 suggests a downward measurement bias for Slovak, Czech and Romania and an upward measurement bias for Latvia and Ireland.

4.4.2 Sectoral Productivity Convergence

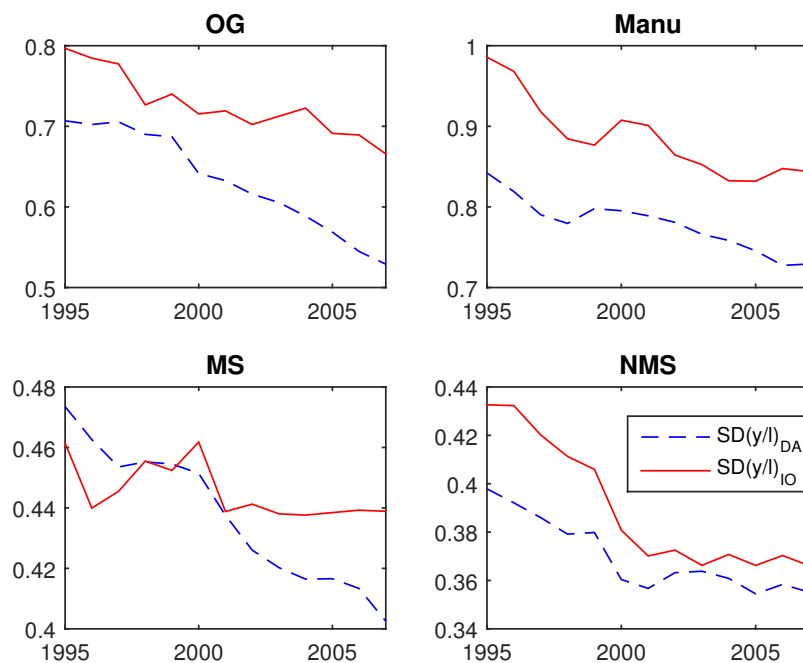
Bernard and Jones (1996) study the sectoral productivity convergence across 14 OECD countries. Both labor productivity and TFP are examined in Bernard and Jones (1996). They consider two types of convergence: σ -convergence and β -convergence. The σ -convergence explores whether the standard deviation of cross-country sectoral productivities shrinks over time. If the volatility falls over time, there is evidence of σ -convergence. On the other hand, the β -convergence investigates whether countries with initially higher productivity have lower productivity growth over time. If the initially less productive countries grow faster than the initially more productive countries, there is evidence of β -convergence. The β -convergence can be tested by the following regression equation:

$$\Delta \log A_c = \alpha + \beta \log A_{c,0} + \varepsilon_c.$$

Here $\Delta \log A_c$ denotes the average growth rate of sectoral TFP in country c , and $\log A_{c,0}$ indicates the sectoral TFP in logarithm at the initial year in country c .

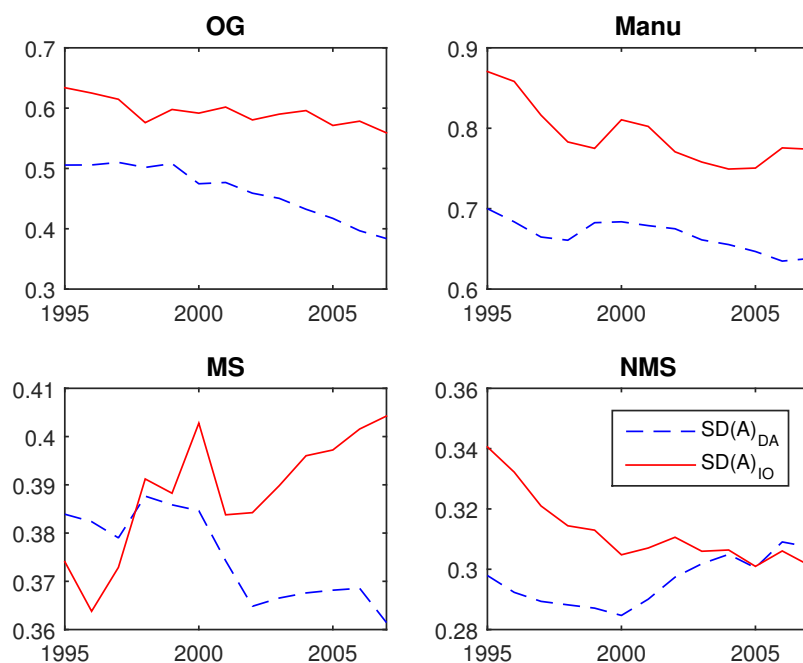
I re-examine the σ -convergence result based on the WIOD with 29 OECD countries and 4 sectors through 1995-2007. Again, I use both the DA measures of sectoral productivity and the IO measures of sectoral productivity. Figure 4.7 displays the volatility of sectoral labor productivity across the 29 OECD countries from 1995 to 2007. Figure 4.8 displays the analogous volatility for sectoral TFP. In both figures, the four panels indicate the four sectors. The solid curve plots the volatility under the IO method, and the dash curve plots the volatility under the DA method.

Both Figure 4.7 and Figure 4.8 suggest inconsistent paths of convergence between the two measurement methods. The most evident inconsistency occurs in the market services sector. While the DA method suggests a strong σ -convergence in the market services, the IO method suggests little evidence of σ -convergence. In particular, the TFP volatility under



The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The solid curve plots the standard deviation given the sectoral productivities that are measured by the IO method, and the dash curve plots the counterparts under the DA method.

Fig. 4.7 The standard deviation of sectoral labor productivities across 29 OECD countries



The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The solid curve plots the standard deviation given the sectoral TFP that are measured by the IO method, and the dash curve plots the counterparts under the DA method.

Fig. 4.8 The standard deviation of sectoral TFP across 29 OECD countries

the IO method increases over time in the market services sector, which implies divergence instead of convergence across the 29 OECD countries through 1995-2007. Moreover, while the DA method overestimates the σ -convergence in the other goods sector, it underestimates the σ -convergence in the non-market services sector.³

For the β -convergence, Table 4.3 and Table 4.4 report the regression estimation, based on the sectoral labor productivity and the sectoral TFP, respectively. In both tables, the upper panel shows the estimation results under the IO method, and the lower panel shows the estimation results under the DA method. In each panel, the last four rows report the estimation results for the four sectors.

In line with the results of σ -convergence, Table 4.3 and Table 4.4 suggest an inconsistent β -convergence between the IO based estimation in the upper panel and the corresponding DA based estimation in the lower panel. For both the sectoral labor productivity and the sectoral TFP, while the IO method suggests little evidence of β -convergence in the market services, the DA method suggests a strong β -convergence. While the DA method overestimates the β -convergence in the other goods sector, it underestimates the β -convergence in the non-market services sector.

4.4.3 “Problem Sectors”

Given the large income difference between the rich countries like the US and the poor countries like India, Herrendorf and Valentinyi (2012) study which sectors account for the large income gap. Specifically, they study the sectoral productivity disparity relative to the income disparity across countries. They use the following regression equation:

$$\log A_i^c = \alpha_i + \beta_i \log(Y/L)^c + \varepsilon_i^c.$$

Here i stands for either an aggregate level or a sector level, c stands for a country, $(Y/L)^c$ is the average GDP per capita over years in country c , and A_i^c is the average aggregate or sectoral TFP in country c . As Herrendorf and Valentinyi (2012) show, the regression equation implies the following relationship between the relative TFP and the relative GDP per capita to their US counterparts:

$$\frac{A_i^c}{A_i^{US}} = \left[\frac{(Y/L)^c}{(Y/L)^{US}} \right]^{\beta_i} \frac{\exp \varepsilon_i^c}{\exp \varepsilon_i^{US}}.$$

³In both Figure 4.7 and Figure 4.8, the DA method suggests a smaller decline of volatility than the IO method in the non-market services sector. On the other hand, the DA method suggests a larger decline of volatility than the IO method in the other goods sector.

<i>(i) Dependent Variable : $\Delta\log(Y/L)_{i,IO}$</i>				
Sector	β	SE	t	R^2
OG	-0.013**	0.006	-2.14	0.145
Manu	-0.026***	0.009	-2.85	0.231
MS	-0.010	0.007	-1.40	0.068
NMS	-0.018***	0.005	-3.34	0.293

<i>(ii) Dependent Variable : $\Delta\log(Y/L)_{i,DA}$</i>				
Sector	β	SE	t	R^2
OG	-0.023***	0.003	-6.53	0.612
Manu	-0.015***	0.005	-3.20	0.275
MS	-0.018***	0.005	-3.25	0.281
NMS	-0.016**	0.006	-2.56	0.195

The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The upper panel shows the estimation results of β -convergence under the IO method, and the lower panel shows the estimation results of β -convergence under the DA method.

Table 4.3 Regression test of β -convergence: sectoral labour productivity

<i>(i) Dependent Variable : $\Delta\log(A)_{i,IO}$</i>				
Sector	β	SE	t	R^2
OG	-0.013	0.008	-1.55	0.082
Manu	-0.026**	0.010	-2.65	0.206
MS	0.001	0.008	0.15	0.001
NMS	-0.022***	0.008	-2.79	0.224

<i>(ii) Dependent Variable : $\Delta\log(A)_{i,DA}$</i>				
Sector	β	SE	t	R^2
OG	-0.022***	0.004	-5.61	0.539
Manu	-0.011**	0.005	-2.29	0.163
MS	-0.010*	0.005	-1.76	0.103
NMS	-0.011	0.009	-1.24	0.054

The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The upper panel shows the estimation results of β -convergence under the IO method, and the lower panel shows the estimation results of β -convergence under the DA method.

Table 4.4 Regression test of β -convergence: sectoral TFP

Method	Agg	OG	Manu	MS	NMS
DA	0.777	0.552	1.029	0.814	0.347
IO	0.747	0.661	1.059	0.748	0.264

The four sectors are manufacturing (Manu), market-services (MS), non-market services (NMS) and other goods (OG). The second column shows the estimation results for the aggregate economy (Agg), and the last four columns display the estimation results for the four sectors respectively.

Table 4.5 Estimation of relative disparity of TFP to income

Therefore, the larger value of β , the larger degree of the TFP disparity relative to the income disparity on average.

I re-examine the regression study in [Herrendorf and Valentinyi \(2012\)](#) based on the World Input-Output Database. The OLS regression is performed over the 39 major economies and 4 sectors through 1995-2007. I use both the TFP measurement under the DA method and the TFP measurement under the IO method. Table 4.5 reports the estimation results. The estimation results under the two methods are given in the last two rows of Table 4.5. The second column shows the estimation of the relative disparity of the aggregate TFP to income, and column 3 to column 6 show the estimation results of the relative disparity of the four sectoral TFP to income.

Two findings are generated from Table 4.5. First, the DA method and the IO method suggest a very close estimation of the relative disparity for the aggregate TFP. This result is broadly in line with the aggregate TFP equivalence in Proposition 6. Second, the estimation results are inconsistent in the sectoral TFP between the DA method and the IO method. In particular, the IO method suggests that the relative disparity for the market services (0.748) is close to that for the aggregate TFP (0.747), while the DA method implies a greater degree of relative disparity for the market services (0.814) than that for the aggregate TFP (0.777). Moreover, compared to the IO method, the DA method overestimates the relative disparity for the non-market services sector and underestimates the relative disparity for the other goods sector.

4.5 Conclusion

This chapter points out the importance of input-output linkages in productivity measurement. On the one hand, I use a multi-sector framework with input-output linkages to model the input-output economy. On the other hand, I construct an analogous value added economy in which input-output linkages are absent. After solving the two economies in competitive equilibrium, I find an equivalent aggregate productivity between the two economies. The

aggregate equivalence result suggests that input-output linkages are neutral in affecting aggregate productivity.

While input-output linkages may be not so relevant in aggregate productivity measurement, they are crucial in sectoral productivity measurement. Without incorporating the input-output linkages, the conventional development accounting method yields biased measurement in sectoral productivity. In particular, the quantitative results suggest that the conventional development accounting method delivers biased measurement for all sectors and for all countries. The biased sectoral productivity further implies biased decomposition of aggregate productivity growth. Moreover, without taking the input-output linkages into account, previous sector-level productivity studies are likely to suffer measurement bias. For instance, we may misunderstand the sectoral productivity convergence across the OECD countries based on the result in [Bernard and Jones \(1996\)](#).

Chapter 5

Conclusion

This dissertation studies the implications of input-output linkages for structural change and productivity measurement in the three main chapters. Chapter 2 presents the novel evidence and mechanism of input-output linkages in structural change. Based on the evidence and mechanism, Chapter 3 develops a multi-sector general equilibrium model to quantify the new mechanism versus the existing mechanisms in the literature. In Chapter 4, I discuss how input-output linkages impact productivity measurement at both sector and aggregate level. These three chapters together contribute to the recent mounting literature on the role of input-output linkages in growth and development ([Baqae and Farhi, 2017](#); [Fadinger et al., 2017](#); [Jones, 2011a,b](#)).

Following the recent input-output literature ([Acemoglu et al., 2017](#)), Chapter 2 and Chapter 3 take the input-output linkages as the producer networks rather than the standard Leontief input-output matrix. Chapter 2 shows a positive correlation between the sector share in value added and the supply (forward) linkages of intermediate inputs, and a negative correlation between the sector share in value added and the demand (backward) linkages of intermediate inputs. These correlations are strong and robust at the sector level, particularly the supply-side correlation. It will be worthwhile to test these correlations with firm-level data in the future. For example, can we see the growing value added share of services firms on the one hand and the rise of supply linkages on the other hand? Can we see the opposite phenomenon in manufacturing firms?

Chapter 3 studies the fundamental forces behind the rise of services and the decline of manufacturing. Relative to manufacturing, services have growing comparative advantage for supplying intermediate inputs. As a result, services adopt more labor and capital than manufacturing to satisfy the rising demand for inputs sourcing. The growing comparative advantage comes from the lower growth rate of sourcing cost and higher growth rate of TFP scale of services than manufacturing. While this mechanism is supported by the US

descriptive evidence in [Goodman and Steadman \(2002\)](#) and the Germany sector-level evidence in [Dustmann et al. \(2014\)](#) and [Goldschmidt and Schmieder \(2017\)](#), it would be better to examine the mechanism in firm-level case studies. For example, as carefully illustrated by [Goldschmidt and Schmieder \(2017\)](#), can we observe the rising external outsourcing activities from manufacturing firms to service firms and the structural change between the two types of firms? Is the rise of external outsourcing activities caused by the relative change of outsourcing cost? Chapter 2 and Chapter 3 call for careful empirical microfoundation study in the future.

Both the results of the model and the empirical study of Chapter 4 confirm the non-neutrality of input-output linkages in productivity measurement. A natural question following Chapter 4 is that whether input-output linkages matter for other growth and development issues. For example, do input-output linkages have a spillover effect on economic growth? As far as I know, the growth literature mainly discusses the technological spillover effect on economic growth, following the line of [Romer \(1986\)](#) and [Romer \(1990\)](#). The input-output linkages spillover dates back to Alfred Marshall. This spillover effect has been argued by [Hirschman \(1958\)](#) and many subsequent papers. However, we still lack a model to rationalize the mechanism of input-output linkages spillover.

Though the main objectives of this dissertation are studying how input-output linkages impact structural change and productivity measurement, the main findings generate important policy implications. If structural change partially reflects the within- and cross- firm sourcing activities, the productivity slowdown through structural change is probably overstated. Because the same cleaner should have similar productivity regardless which firm or which industry she works for. Given the important role of input-output linkages in sectoral productivity measurement, both academics and policy makers should be careful when they evaluate sector-oriented productivity policies. The specific policy implications are beyond the scope of this dissertation, and they are interesting questions to study in the future.

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Appendix A

Appendix of Chapter 2

A.1 Equilibrium Solution of The Closed Economy Model

The optimization problem of the aggregate producer is given by

$$\max_{C_i} P_Y \prod_{i=1}^J C_i^{\lambda_i} - \sum_{i=1}^J P_i C_i.$$

The allocation of sectoral consumption is given by

$$\lambda_i \frac{P_Y Y}{C_i} = P_i. \quad (\text{A.1})$$

Equation (A.1) implies $P_i C_i = \lambda_i P_Y Y$.

The optimization problem of the sectoral representative producer is given by

$$\max_{K_i, L_i, X_{ij}} P_i A_i K_i^{(1-\sigma_i)\alpha_i} L_i^{(1-\sigma_i)(1-\alpha_i)} \prod_{j=1}^J X_{ij}^{\sigma_{ij}} - r K_i - w L_i - \sum_{j=1}^J P_j X_{ij}.$$

The allocation of intermediate inputs, capital and labor are given by the following equations:

$$\sigma_{ij} \frac{P_i Q_i}{X_{ij}} = P_j, \quad (\text{A.2})$$

$$(1 - \sigma_i) \alpha_i \frac{P_i Q_i}{K_i} = r, \quad (\text{A.3})$$

$$(1 - \sigma_i)(1 - \alpha_i) \frac{P_i Q_i}{L_i} = w. \quad (\text{A.4})$$

The budget constraint equation can be rewritten as

$$P_j Q_j = P_j C_j + \sum_{i=1}^J P_j X_{ij}.$$

Equation (A.2) implies $P_j X_{ij} = \sigma_{ij} P_i Q_i$, substitute this condition to the budget constraint, we have

$$\begin{aligned} P_j Q_j &= P_j C_j + \sum_{i=1}^J \sigma_{ij} P_i Q_i, \\ \frac{P_j Q_j}{P_Y Y} &= \frac{P_j C_j}{P_Y Y} + \sum_{i=1}^J \sigma_{ij} \frac{P_i Q_i}{P_Y Y}, \\ \gamma_j &= \lambda_j + \sum_{i=1}^J \sigma_{ij} \gamma_i, \\ \gamma &= \lambda + B\gamma, \\ \gamma &= (I - B)^{-1} \lambda. \end{aligned}$$

Equation (A.3) and equation (A.4) together imply that

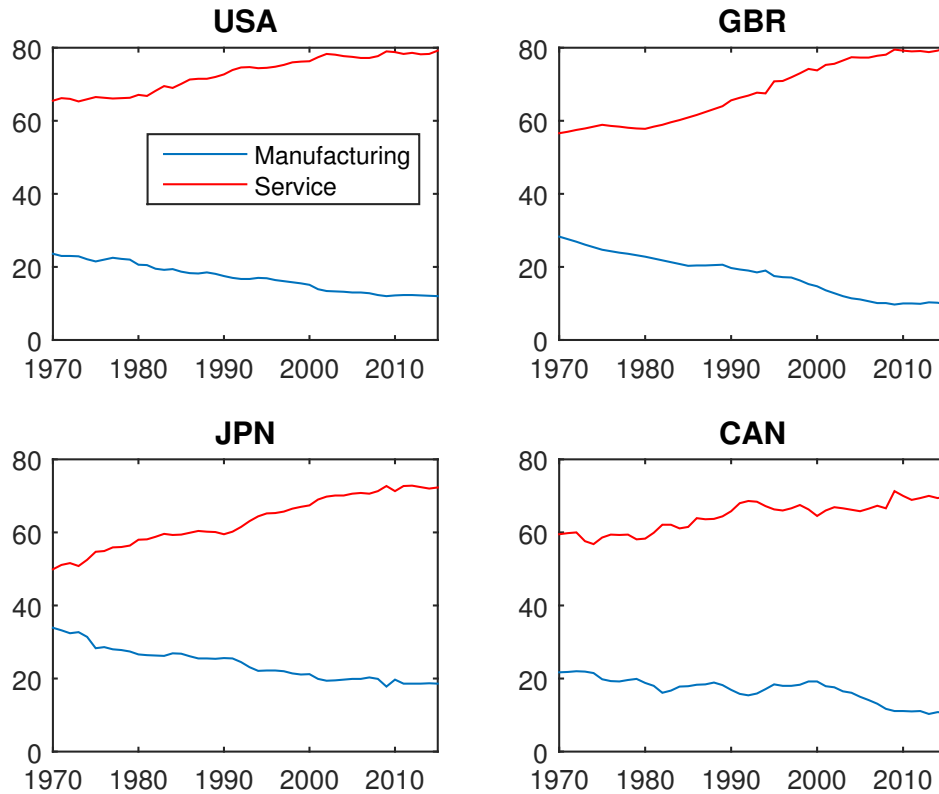
$$\begin{aligned} rK_i + wL_i &= (1 - \sigma_i) P_i Q_i, \\ P_{Yi} Y_i &= (1 - \sigma_i) P_i Q_i, \\ \frac{P_{Yi} Y_i}{P_Y Y} &= (1 - \sigma_i) \frac{P_i Q_i}{P_Y Y}, \\ \eta_i &= (1 - \sigma_i) \gamma_i. \end{aligned}$$

Equation (A.4) and the definition of Domar weight jointly imply that

$$\begin{aligned} \frac{wL_i}{P_Y Y} &= (1 - \sigma_i)(1 - \alpha_i) \gamma_i, \\ \frac{L_i}{L} &= \frac{(1 - \sigma_i)(1 - \alpha_i) \gamma_i}{\sum_{i=1}^J (1 - \sigma_i)(1 - \alpha_i) \gamma_i}. \end{aligned}$$

A.2 Additional Evidence

In this section, I present more evidence. First, for major economies, Value added share fell in manufacturing and rose in services since 1970. This trend was more obvious in the last two decades. Second, value added share increased with intermediate-inputs supply multiplier



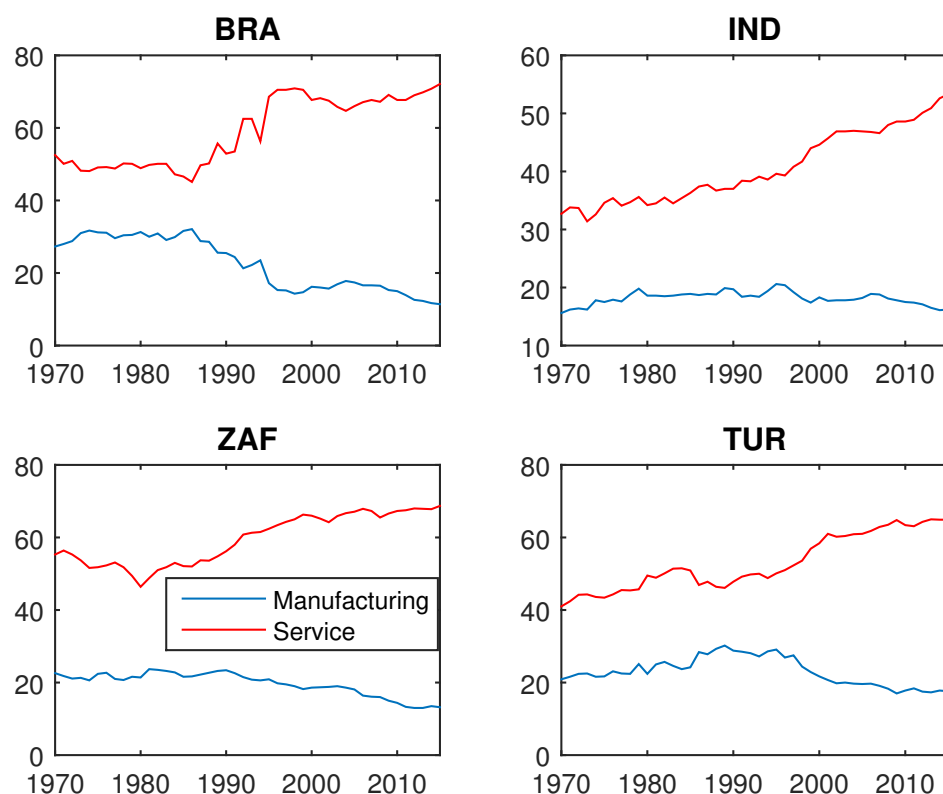
The horizontal axis denotes year, and the vertical axis shows the value of value added share at percentage point. The four countries are the US, the UK, Japan and Canada. Computation is based on National Accounts Main Aggregate Database from the UN.

Fig. A.1 Long run value added share for four developed economies

for the US two-digit industries through 1963-2015. Third, relative price of manufacturing to services matched well with relative nominal value added share in both developed and developing countries.

A.2.1 Structural Change: Value Added Based

The evidence of structural change has been documented by many structural change studies. I show this evidence for 4 developed economies in figure A.1: the US, the UK, Japan and Canada; and for 4 developing economies in figure A.2: Brazil, India, South Africa and Turkey. These two figures present the time series pattern of value added share for manufacturing sector and services sector since 1970. The horizontal axis denotes year, and the vertical axis shows the value added share at percentage point.

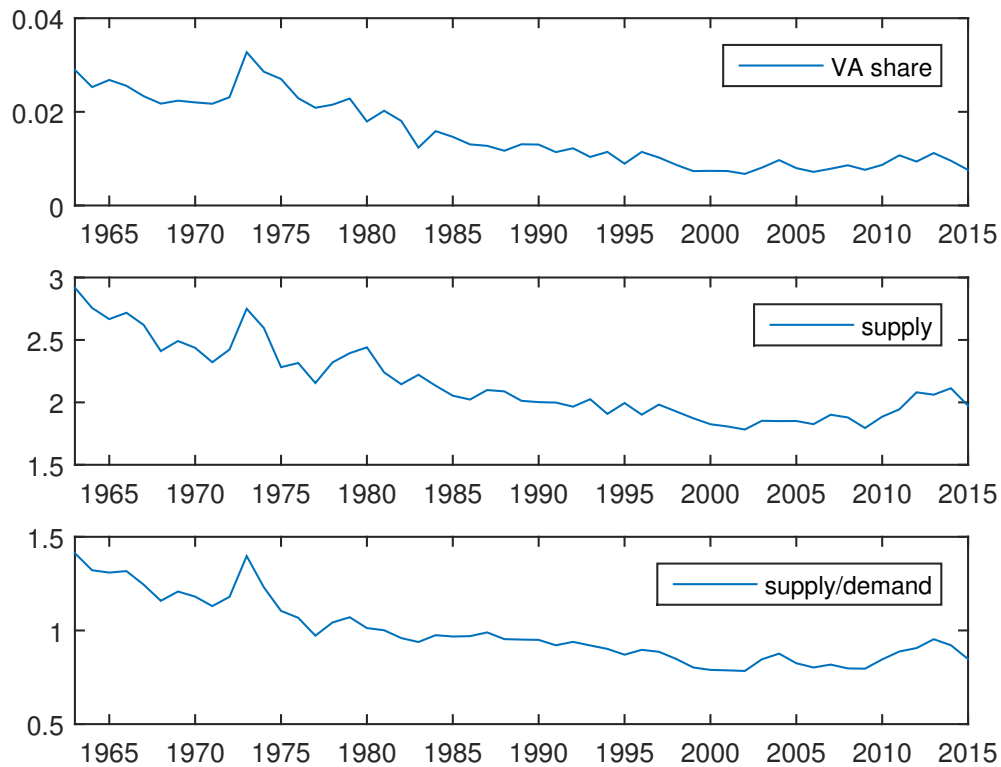


The horizontal axis denotes year, and the vertical axis shows the value of value added share at percentage point. The four countries are the US, the UK, Japan and Canada. Computation is based on National Accounts Main Aggregate Database from the UN.

Fig. A.2 Long run value added share for four developing economies

Figure A.1 and figure A.2 suggest that value added share dropped in manufacturing sector and surged in services sector since 1970. This fact is evident in both developed economies and developing economies. These economies not only have very different development process, but also have 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 experienced significant structural change from manufacturing to services.

Besides, structural change was more visible after 1990, in particular for developing economies. We can observe that structural change tended to accelerate in UK and Canada after 1990. The value added share of manufacturing fell more significantly since 1990 on the one hand; the share of services rose more remarkably after 1990 on the other hand. For developing economies, structural change was not obvious before 1990. Since 1990, we can



The horizontal axis denotes year, and the vertical axis shows the value of value added (VA) share (upper panel); intermediate-inputs supply multiplier (middle panel); and intermediate-inputs demand multiplier (lower panel). Computation is based on the Industry Input-Output Accounts Data from the BEA.

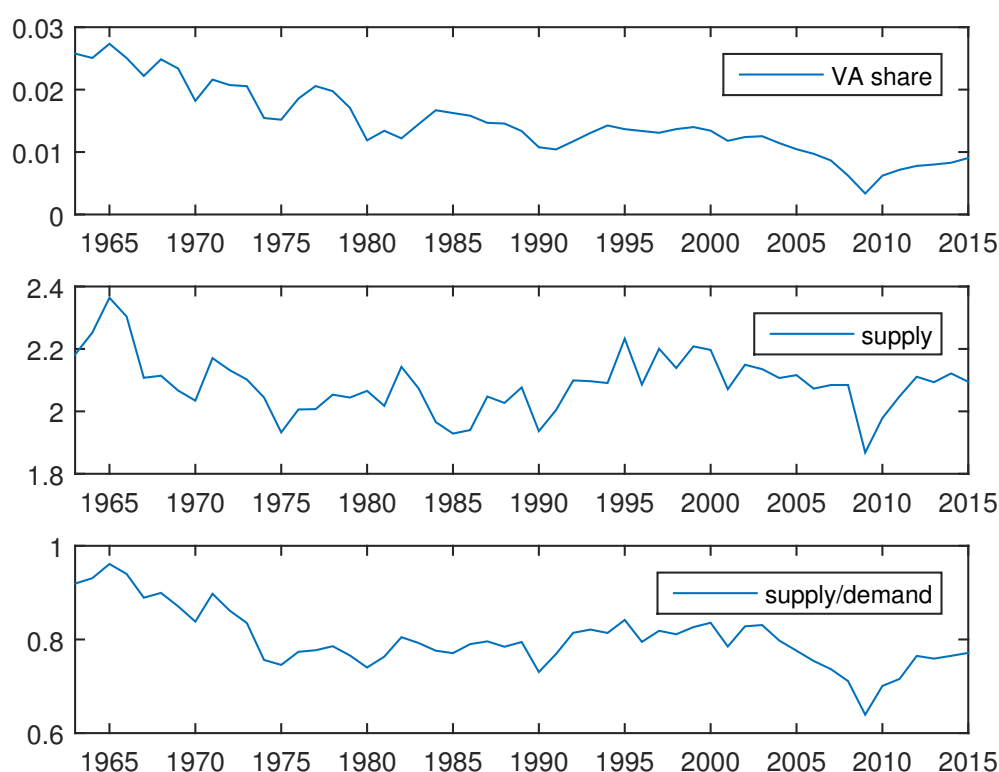
Fig. A.3 Structural change and multipliers: farms

observe rapid structural change in all the developing economies in figure A.2. This fact has two implications. First, Value added share is one of the critical economic structure terms which depicts the structural change fact in the major economies.¹ Second, I do not omit the structural change fact by using the World Input-Output Database (WIOD) which contains data between 1995 and 2007.

A.2.2 Value Added Share and I-I Supply Multiplier

The evidence complements the main evidence in section 2.2. I show a positive correlation between value added share and intermediate-inputs supply multiplier for the US two-digit sectors. I show the evidence for the farm sector in figure A.3; the sector of motor vehicles,

¹For description and discussion of value added share based structural change, see Herrendorf et al. (2014) and Rodrik (2016).

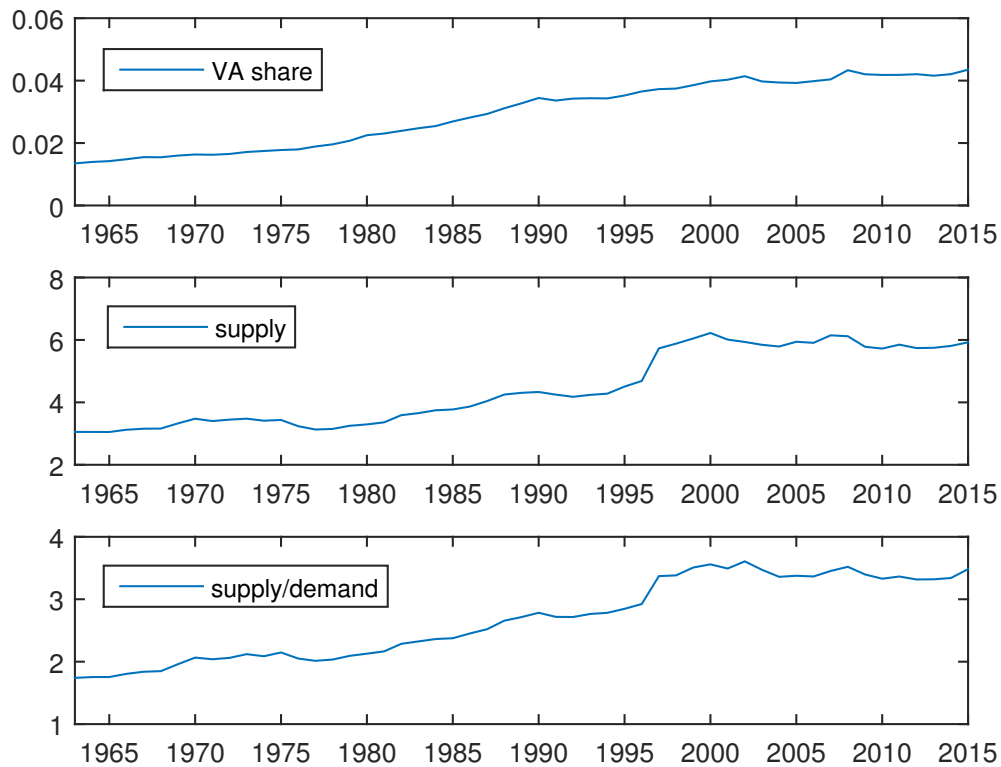


The horizontal axis denotes year, and the vertical axis shows the value of value added (VA) share (upper panel); intermediate-inputs supply multiplier (middle panel); and intermediate-inputs demand multiplier (lower panel). Computation is based on the Industry Input-Output Accounts Data from the BEA.

Fig. A.4 Structural change and multipliers: motor vehicles, bodies and trailers, and parts

bodies and trailers, and parts in figure A.4; the sector of miscellaneous professional, scientific and technical services in figure A.5. Each figure shows one example of the positive association in the agriculture sector, manufacturing sector and services sector respectively. In each figure, the top panel displays the long-run pattern of value added share, the middle panel displays the long-run pattern of intermediate-inputs supply multiplier, and the bottom panel displays the long-run pattern of the relative intermediate-inputs supply multiplier to demand multiplier.

Figure A.3 to figure A.5 suggest a strong positive correlation between the US sectoral value added share and the intermediate-inputs supply multiplier through 1963-2015. For the agriculture and manufacturing sectors, the declining value added share largely matched with the decreasing intermediate-inputs supply multiplier. For the service sector, the rising value added share was also largely consistent with the increasing intermediate-inputs supply multiplier. Moreover, these figures suggest that the pattern of the I-I supply multiplier was



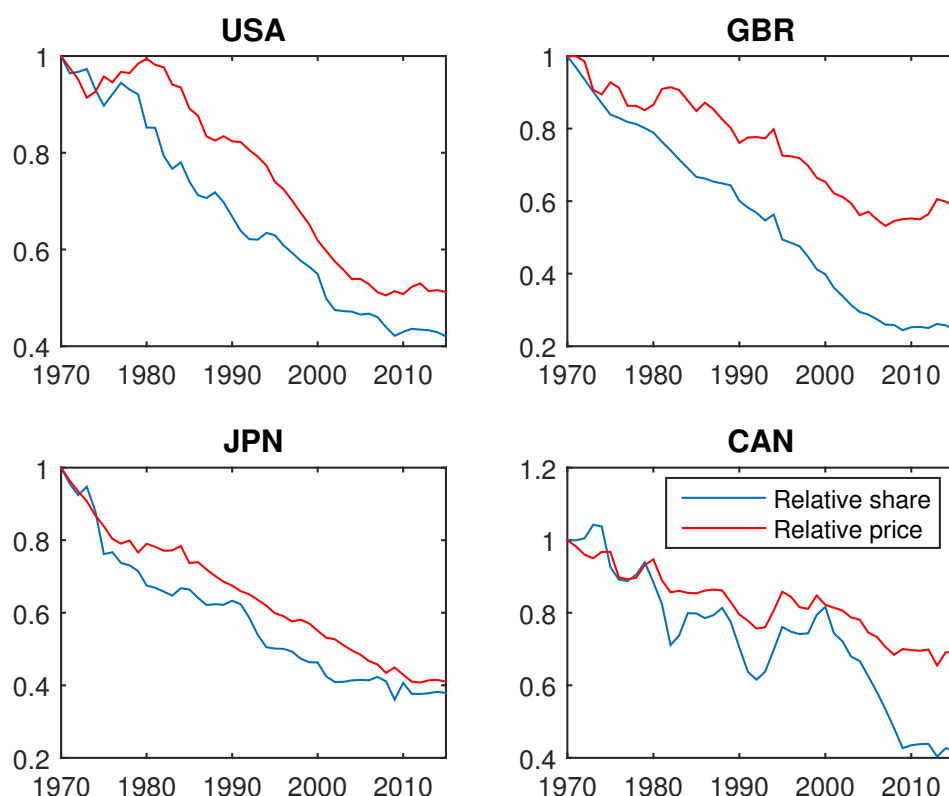
The horizontal axis denotes year, and the vertical axis shows the value of value added (VA) share (upper panel); intermediate-inputs supply multiplier (middle panel); and intermediate-inputs demand multiplier (lower panel). Computation is based on the Industry Input-Output Accounts Data from the BEA.

Fig. A.5 Structural change and multipliers: food and beverage and tobacco products

very consistent with the pattern of relative I-I supply to I-I demand multiplier. This finding implies that the intermediate-inputs demand multiplier was relatively stable, compared with the I-I supply multiplier. The stable intermediate-inputs demand multiplier was consistent with [Jones \(2011b\)](#) and [Duarte and Restuccia \(2017\)](#), in which they find that US sectoral intermediate-inputs demand intensity was stable over time. Furthermore, figure [A.4](#) suggests that the relative I-I supply to I-I demand multiplier matched with the value added share better than the I-I supply multiplier. It implies that the I-I demand multiplier also matters to determine the value added share.

A.2.3 Price Effect

This subsection documents the correlation between the relative sectoral price and the relative sector share in value added. It aims to show the descriptive evidence of the price effect

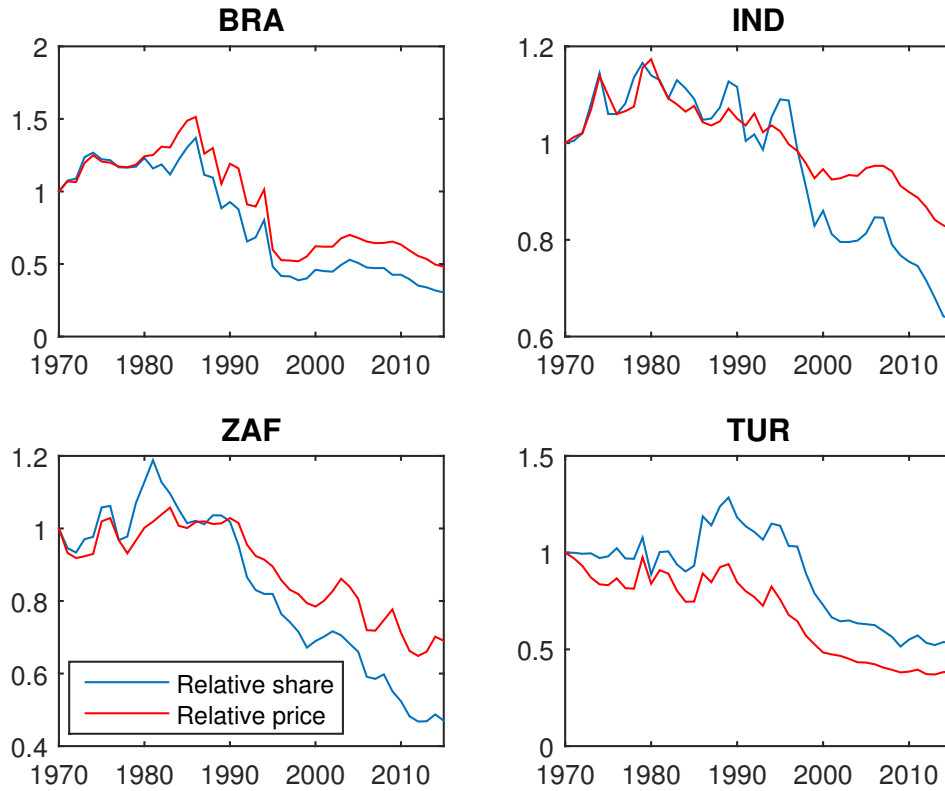


The horizontal axis denotes year, and the vertical axis shows the index of relative value added share and relative price of manufacturing to services. Computation is based on National Accounts Main Aggregate Database from the UN.

Fig. A.6 Value added share and price for four developed economies

on structural change. According to [Ngai and Pissarides \(2007\)](#), when manufacturing and services are complementary to the consumer, structural change arises from the sectors with lower price growth rate to the sectors with higher price growth rate. It implies that we should see a positive correlation between the relative price and the relative value added share of manufacturing to service. I present the evidence for four developed economies and four developing economies in figure [A.6](#) and figure [A.7](#) respectively. The sampling countries and year interval are exactly the same as in subsection [A.2.1](#). In both figures [A.6](#) and [A.7](#), the horizontal axis denotes year, and the vertical axis shows the index of the relative value added share and the relative price of manufacturing to service. The index is normalized to 1 in the year 1970.

Figure [A.6](#) and figure [A.7](#) suggest that the relative price tracked with the relative value added share well. In this period, the relative value added share of manufacturing to service



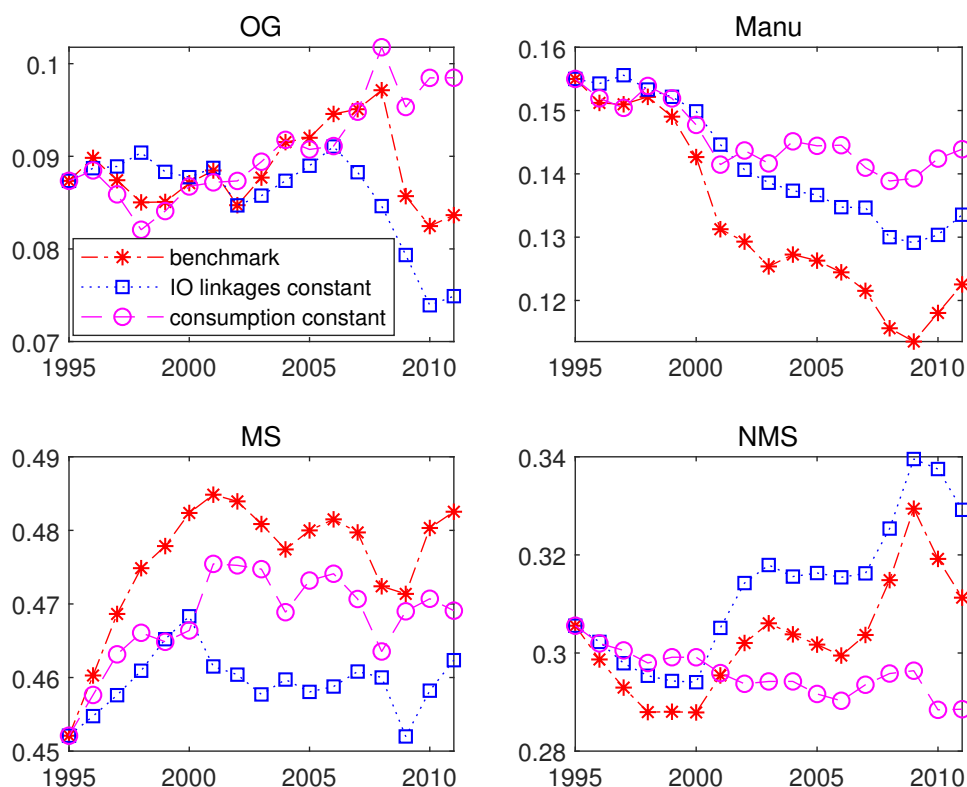
The horizontal axis denotes year, and the vertical axis shows the index of relative value added share and relative price of manufacturing to services. Computation is based on National Accounts Main Aggregate Database from the UN.

Fig. A.7 Value added share and price for four developing economies

fell particularly in the sampling developed countries. At the same time, the relative price of manufacturing to service also drops. There is a strong positive correlation between the relative price and the relative value added share, which is consistent with the prediction in [Ngai and Pissarides \(2007\)](#).

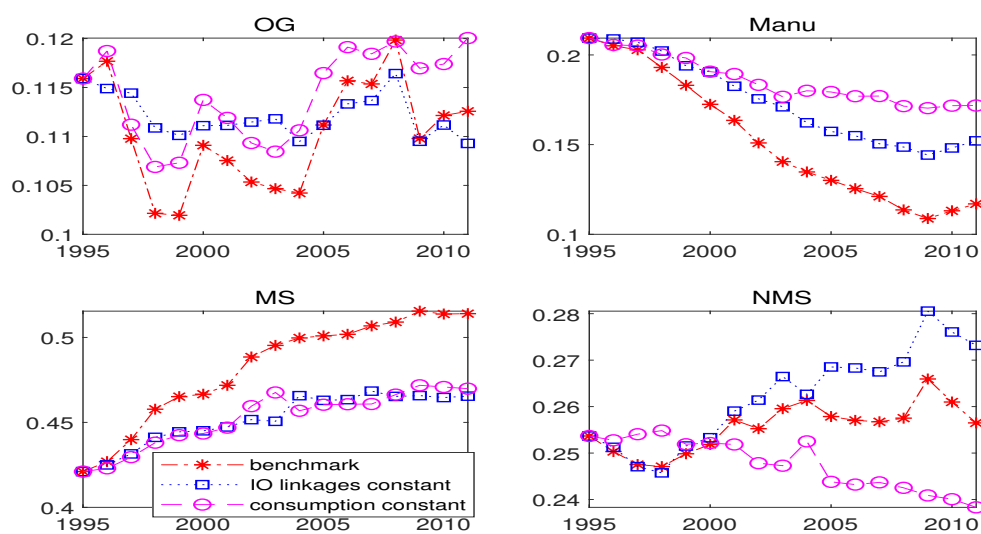
A.2.4 Intermediate Demand Versus Final Demand: Domestic Sourcing

This subsection conducts empirical study to compare the intermediate demand mechanism with the final demand mechanism. I perform two counterfactual studies based on equation (2.1). In the first counterfactual study, the input-output linkages are taken as constant over time. In the second one, the consumption shares hold constant over time. Under both studies, I compare the counterfactual value added shares with the original value added shares that we



The horizontal axis denotes year, and the vertical axis shows the values of value added shares. The four panels stand for the four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG). Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.8 The US sector shares in value added



The horizontal axis denotes year, and the vertical axis shows the values of value added shares. The four panels stand for the four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG). Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.9 The UK sector shares in value added

observe in the data. If the two mechanisms are relevant, we should observe a deviation of the counterfactual value added share from the data.

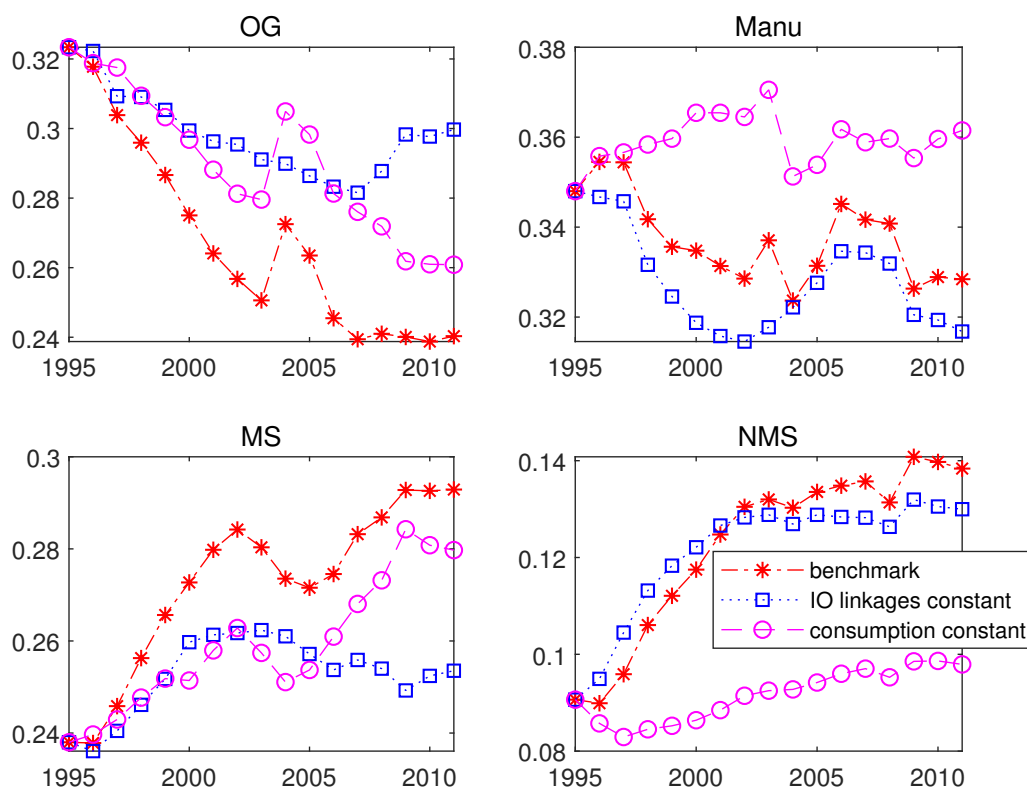
Figure A.8 and Figure A.9 show the sectoral value added shares for the US and for the UK, respectively. The value added shares are plotted for the four sectors in the four panels: manufacturing, market services, non-market services and other goods. In each panel, the red and star curve describes the value added shares under the benchmark case (data); the blue and square curve plots the value added shares under the first counterfactual case in which the domestic input-output linkages are taken as constant over 1995-2011; the magenta and circle curve demonstrates the value added shares under the second counterfactual case in which the domestic consumption shares are assumed to be constant over 1995-2011.

Figure A.8 and Figure A.9 suggest that the intermediate demand mechanism is comparable to the final demand mechanism. For the market services sector, without the contribution of intermediate demand, the value added shares increase by a much smaller proportion than the benchmark case. The US market services shares hardly rise without the intermediate demand; the intermediate demand mechanism is close to the final demand mechanism in the UK services sector. We can also observe the significant effect of intermediate demand in the US and the UK manufacturing sector, though the final demand effect is stronger than the intermediate demand effect. For the non-market services and other goods sector, intermediate demand still play a crucial role in the trends of value added shares.

Figure A.10 and Figure A.11 present the result of the counterfactual study for two emerging economies: China and India, respectively. If we turn off the mechanism of intermediate demand, the market services shares in value added (blue and square curve) go up much less than the service shares that are observed in the data (red and star curve) in both China and India. Moreover, the intermediate demand mechanism is stronger than the final demand mechanism affecting the market services shares. For the other goods sector, without considering the variation of input-output linkages over time, the sector shares reduce by a smaller proportion than the benchmark counterpart. The intermediate demand effect seems to be larger than the final demand effect on the value added shares of other goods. By contrast, for manufacturing and non-market services, final demand plays a more important role than intermediate demand in the trend of value added shares. In summary, intermediate demand is as crucial as final demand determining structural change in China and India.

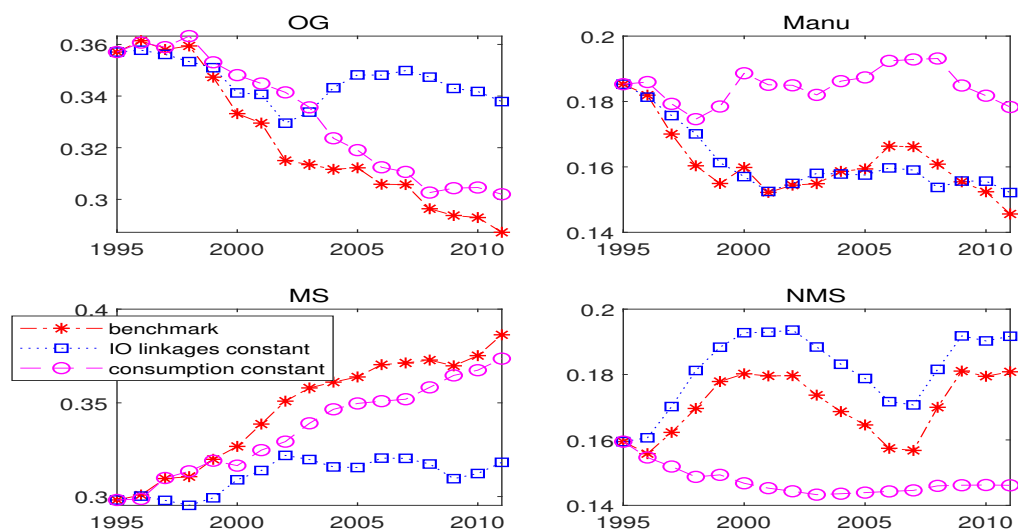
A.2.5 Intermediate Demand Versus Final Demand: Global Sourcing

Now I proceed to perform counterfactual study which aims to compare the intermediate demand mechanism versus the final demand mechanism in terms of impacting the sector share in value added in the context of global value chains. The counterfactual study is performed



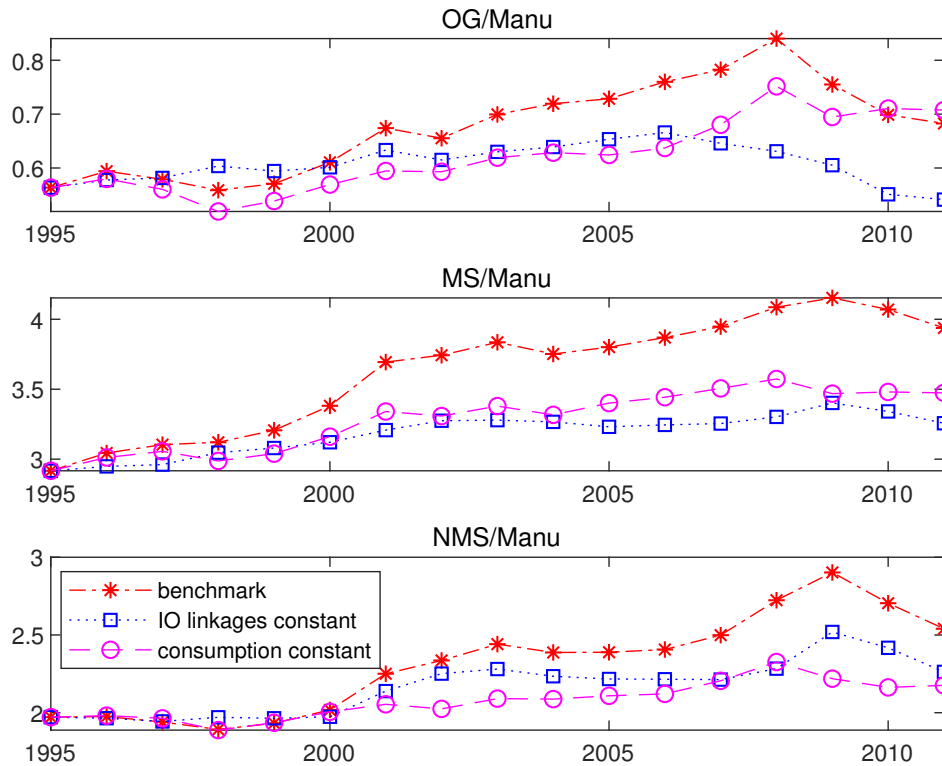
The horizontal axis denotes year, and the vertical axis shows the values of value added shares. The four panels stand for the four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG). Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.10 Sector shares in value added in China



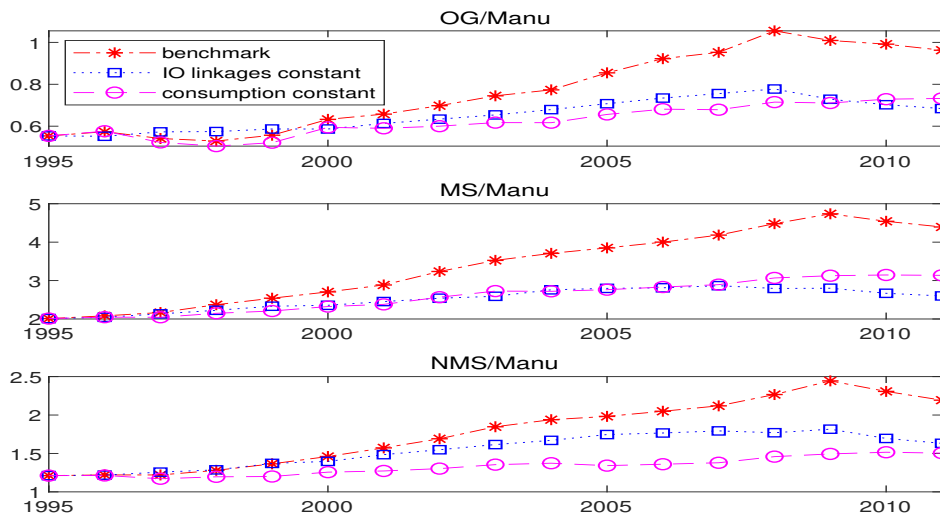
The horizontal axis denotes year, and the vertical axis shows the values of value added shares. The four panels stand for the four sectors: manufacturing (Manu), market services (MS), non-market services (NMS) and other goods (OG). Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.11 Sector shares in value added in India



The horizontal axis denotes year, and the vertical axis shows the values of relative value added shares of the three sectors to manufacturing (Manu): other goods (OG), market services and non-market services, respectively. Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.12 The US sectoral value added shares relative to manufacturing



The horizontal axis denotes year, and the vertical axis shows the values of relative value added shares of the three sectors to manufacturing (Manu): other goods (OG), market services and non-market services, respectively. Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.13 The UK sectoral value added share relative to manufacturing

the same way as that of the domestic sourcing in the last section, but based on equation (2.2). I turn off the two mechanisms individually and then check how much the counterfactual value added shares deviate from the data. If the deviation is significant, it implies an important mechanism for structural change.

Figure A.12 and Figure A.13 illustrate the relative value added shares for the US and the UK, respectively. The three panels plot the relative sector shares of the three sectors to manufacturing: other goods, market services and non-market services. In each panel, the benchmark relative sector share, the relative sector shares under the first counterfactual study (constant IO linkage) and the relative sector shares under the second counterfactual study (constant consumption shares) are represented by the red and star curve, the blue and square curve and the magenta and circle curve, respectively.

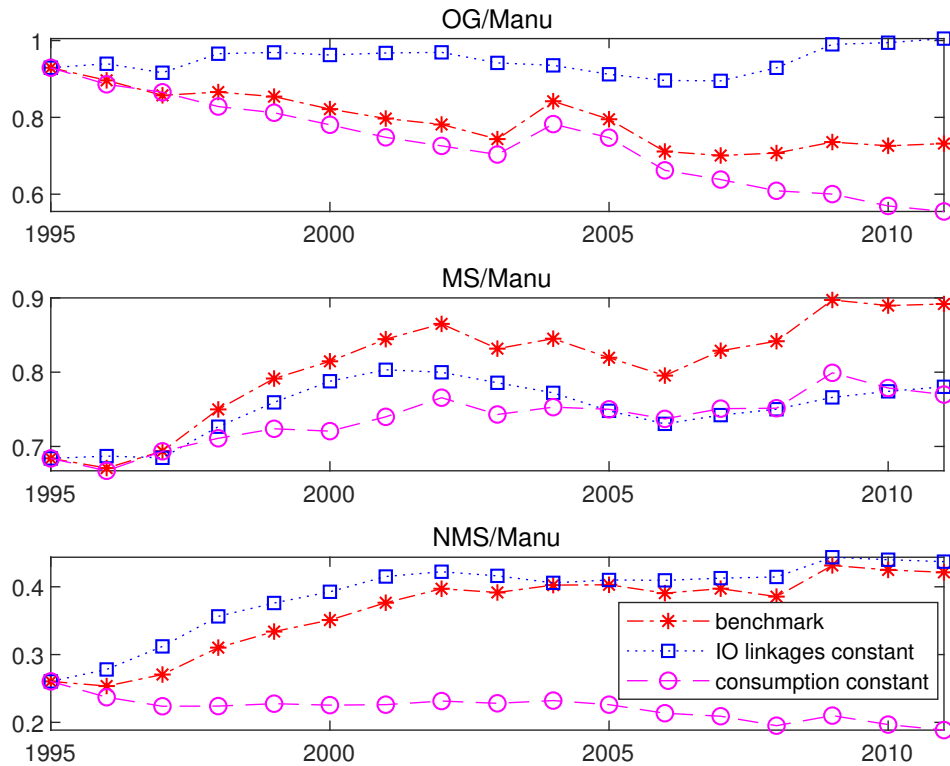
Figure A.12 and Figure A.13 suggest a comparable role of the intermediate demand with the final demand in structural change in the US and the UK. If we assume constant input-output linkages over time, the counterfactual relative shares of the three sectors to manufacturing (blue and square curve) rise by a much smaller magnitude than the benchmark relative sector shares (red and star curve). Without the contribution of intermediate demand, the structural change from manufacturing to the other three sectors is attenuated. Moreover, Figure A.12 and Figure A.13 suggest that the intermediate demand mechanism is close to the final demand mechanism for the US and UK structural change.

The result of the counterfactual study for China and India are shown in Figure A.14 and Figure A.15, respectively. Figure A.14 and Figure A.15 suggest that while intermediate demand effect is stronger than final demand effect on structural change from other goods to manufacturing, it is weaker on structural change from manufacturing to non-market services. For the structural change from manufacturing to market services, the intermediate demand mechanism is close to the final demand mechanism in both China and India.

Overall, both the result of the counterfactual study in the domestic sourcing and the counterfactual study in the global value chains suggest that the intermediate demand effect is comparable to the final demand effect on structural change.

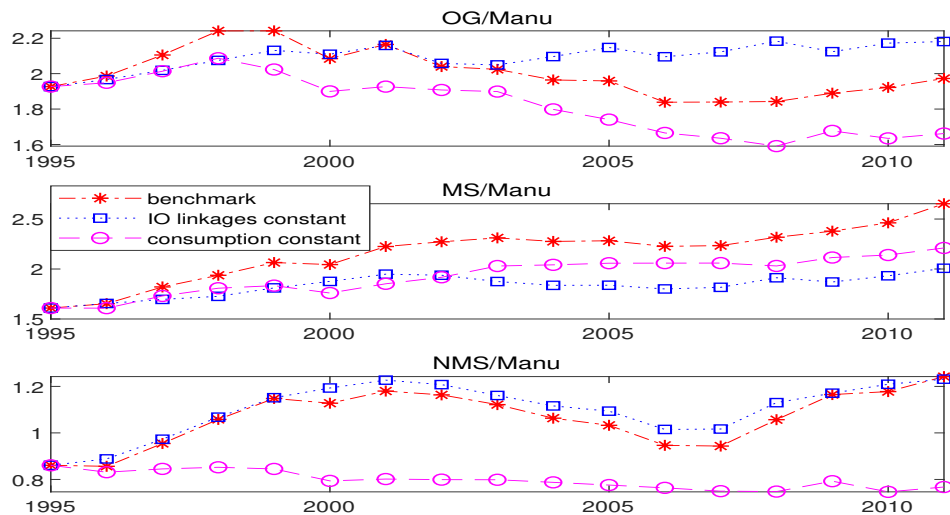
A.3 Main Data Description

In this thesis, 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 \(2014\)](#).



The horizontal axis denotes year, and the vertical axis shows the values of relative value added shares of the three sectors to manufacturing (Manu): other goods (OG), market services and non-market services, respectively. Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.14 Relative sectoral value added share to manufacturing in China



The horizontal axis denotes year, and the vertical axis shows the values of relative value added shares of the three sectors to manufacturing (Manu): other goods (OG), market services and non-market services, respectively. Each panel shows the value added shares under the benchmark case and the two counterfactual cases.

Fig. A.15 Relative sectoral value added share to manufacturing in India

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.

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 (AUS); Austria (AUT); Belgium (BEL); Canada (CAN); Germany (DEU); Denmark (DNK); Spain (ESP); Finland (FIN); France (FRA); UK (GBR); Greece (GRC); Ireland (IRL); Italy (ITA); Japan (JPN); Malta (MLT); Netherlands (NLD); Portugal (PRT); Sweden (SWE); US (USA); Luxembourg (LUX). The developing countries include the following countries: Brazil (BRA); China (CHN); Cyprus (CYP); Czech (CZE); Estonia (EST); Hungary (HUN); Korea (KOR); Latvia (LVA); Lithuania (LTU); Mexico (MEX); Poland (POL); Romania (ROU); Slovak (SVK); Slovenia (SVN); Turkey (TUR).

Appendix B

Appendix of Chapter 3

B.1 Proofs of the Propositions

B.1.1 Proposition 1: Equilibrium Solution of the Key Variables

I start with the consumer's optimization problem. The two constraint equations (3.2) and (3.3) are transformed to become the following two equations:

$$\sum_{i=1}^J \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\varepsilon-1}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}} = 1, \quad (\text{B.1})$$

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

The Lagrangian equation is given by

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

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

$$P_{it} C_{it} = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon} \Omega_i^{\frac{1}{\varepsilon}} \left(\frac{C_{it}}{C_t^{\frac{\varepsilon-1}{1-\varepsilon}}} \right)^{\frac{\varepsilon-1}{\varepsilon}}. \quad (\text{B.3})$$

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

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

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

$$P_t C_t = \frac{\rho_t}{\omega_t} \frac{1-\varepsilon}{\varepsilon}. \quad (\text{B.4})$$

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

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

Therefore, the optimal intratemporal sectoral consumption allocation C_{it} is solved as in equation (3.20).

Based on equation (3.20), I derive the consumption share as in equation (3.19). Then given equation (3.19), I have the following condition:

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

Accordingly, the aggregate price index is derived as in equation (3.22).

Next I turn to the producer's optimization problem at sector level. The derivation of sectoral gross output equation (3.21) and the corresponding aggregate price index equation (3.23) follow exactly the same way as solving the optimal sectoral consumption and aggregate price above. We could think of a social planner who maximizes aggregate gross output at every period t .

Given the input-output linkages B with $B_{jit} \equiv \frac{P_{ijt}^X X_{ijt}^X}{P_{it} Q_{it}}$, the sectoral gross production budget constraint equation in section 3.2.3 becomes to

$$P_{jt} C_{jt} + \sum_{i=1}^J B_{jit} P_{it} Q_{it} = P_{jt} Q_{jt}. \quad (\text{B.5})$$

Divide both sides of the equation (B.5) by aggregate value added $P_{Yt}Y_t$, the budget constraint is transformed by the following equation:

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

Following the above equation, I further derive the budget constraint as follows:

$$\gamma_t = \lambda_t + B_t \gamma_t. \quad (\text{B.6})$$

Then I can easily solve equation (B.6), and derive the vector of Domar weight as in equation (3.18). 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 $\sigma_{it} \equiv \sum_{j=1}^J \frac{P_{ijt}^X X_{ijt}^X}{P_{it}Q_{it}}$. QED.

B.1.2 Proposition 2: Structural Change

Equation (3.24) follows the logarithm transformation of equation (3.20) with respect to sector i and sector j. Make a logarithm transformation of equation (3.20) and (3.21), I have the following two equations:

$$\log \frac{C_{it}}{C_{jt}} = \log \frac{\Omega_i}{\Omega_j} - \varepsilon \log \frac{P_{it}}{P_{jt}} + \log \frac{C_t^{\varepsilon_i}}{C_t^{\varepsilon_j}}, \quad (\text{B.7})$$

$$\log \frac{Q_{it}}{Q_{jt}} = \kappa \log \frac{\Psi_{it}}{\Psi_{jt}} - \rho \log \frac{P_{it}}{P_{jt}} + \log \frac{Q_t^{\xi_i}}{Q_t^{\xi_j}}. \quad (\text{B.8})$$

Based on equation (B.7) and equation (B.8), I have the following equations:

$$\begin{aligned} \log \frac{\lambda_{it}}{\lambda_{jt}} &= \log \frac{\Omega_i}{\Omega_j} + (1 - \varepsilon) \log \frac{P_{it}}{P_{jt}} + (\varepsilon_i - \varepsilon_j) \log C_t, \\ \log \frac{\gamma_{it}}{\gamma_{jt}} &= \kappa \log \frac{\Psi_{it}}{\Psi_{jt}} + (1 - \rho) \log \frac{P_{it}}{P_{jt}} + (\xi_i - \xi_j) \log Q_t. \end{aligned}$$

Based on equation (3.17), I transform the relative value added share in logarithm as the following way

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

This is the equation (3.25).

QED.

B.1.3 Proposition 3: Endogenous Input-Output Linkages and Sectoral Prices

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

$$\begin{aligned}\Pr(P_{ijt}^H(\omega) \geq p) &= \Pr\left(\frac{\nu}{\nu-1} \frac{\tilde{r}}{a_{ijt}^H(\omega)} \geq p\right) \\ &= \Pr\left(a_{ijt}^H(\omega) \leq \frac{\nu}{\nu-1} \frac{\tilde{r}}{p}\right).\end{aligned}$$

The above probability together with equation (3.11) implies that the CDF of the in-house price is given by

$$G_{ijt}^H(p) \equiv \Pr(P_{ijt}^H(\omega) \leq p) = 1 - \exp\left[-A_{it}\left(\frac{\nu}{\nu-1} \frac{\tilde{r}}{p}\right)^{-\zeta}\right]. \quad (\text{B.9})$$

Similar, the CDF of outsourcing price from sector j at time period t is given by

$$G_{ijt}^X(p) \equiv \Pr(P_{ijt}^X(\omega) \leq p) = 1 - \exp\left[-A_{jt}\left(\frac{\nu}{\nu-1} \frac{\tau_{ijt} P_{jt}}{p}\right)^{-\zeta}\right]. \quad (\text{B.10})$$

According to equation (3.13), the probability of intermediate-inputs variety price which is not larger than p the producer of sector i actually pays is given by

$$\begin{aligned}\Pr(P_{ijt}^*(\omega) \leq p) &= 1 - \Pr(P_{ijt}^*(\omega) \geq p) \\ &= 1 - \Pr(P_{ijt}^H(\omega) \geq p, P_{ijt}^X(\omega) \geq p) \\ &= 1 - (1 - \Pr(P_{ijt}^H(\omega) \leq p))(1 - \Pr(P_{ijt}^X(\omega) \leq p)).\end{aligned}$$

Substitute equation (B.9) and equation (B.10) to the above probability, I derive the CDF of the intermediate-inputs variety price producer of sector i actually pay, which is given by

$$G_{ijt}(p) \equiv \Pr(P_{ijt}^*(\omega) \leq p) = 1 - \exp(-\Phi_{ijt} p^\zeta). \quad (\text{B.11})$$

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 in the following:

$$\begin{aligned}
 \pi_{ijt}(\omega) &= \Pr(P_{ijt}^X(\omega) \leq P_{ijt}^H(\omega)) \\
 &= \int_0^\infty \exp\left[-A_{it}\left(\frac{\tilde{r}}{p}\right)^{-\zeta}\left(\frac{\nu}{\nu-1}\right)^{-\zeta}\right] dG_{ijt}^X(p) \\
 &= \int_0^\infty \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta} \zeta p^{\zeta-1} \exp(-\Phi_{ijt}p^\zeta) dp \\
 &= \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta} \frac{1}{\Phi_{ijt}} \int_0^\infty \zeta p^{\zeta-1} \Phi_{ijt} \exp(-\Phi_{ijt}p^\zeta) dp \\
 &= \frac{A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}}{A_{it}\tilde{r}^{-\zeta} + A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}}. \tag{B.12}
 \end{aligned}$$

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. Moreover equation (B.11) also implies that the probability does not depend on intermediate input variety, that is, equation (B.11) 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

$$\begin{aligned}
 G_{ijt|X}(p) &= \Pr(P_{ijt}^X(\omega) \leq p | P_{ijt}^X(\omega) \leq P_{ijt}^H(\omega)) \\
 &= \frac{1}{\pi_{ijt}} \int_0^p \Pr(z \leq P_{ijt}^H(\omega)) dG_{ijt}^X(z) \\
 &= \frac{1}{\pi_{ijt}} \int_0^p \exp\left[-A_{it}\left(\frac{\tilde{r}}{z}\right)^{-\zeta}\left(\frac{\nu}{\nu-1}\right)^{-\zeta}\right] dG_{ijt}^X(z) \\
 &= \frac{1}{\pi_{ijt}} \int_0^p \left(\frac{\nu}{\nu-1}\right)^{-\zeta} A_{jt}(\tau_{ijt}P_{jt})^{-\zeta} \zeta z^{\zeta-1} \exp(-\Phi_{ijt}z^\zeta) dz \\
 &= \left(\frac{\nu}{\nu-1}\right)^{-\zeta} \frac{A_{jt}(\tau_{ijt}P_{jt})^{-\zeta}}{\pi_{ijt}} \frac{1}{\Phi_{ijt}} \int_0^p \zeta z^{\zeta-1} \Phi_{ijt} \exp(-\Phi_{ijt}z^\zeta) dz \\
 &= \int_0^p \zeta z^{\zeta-1} \Phi_{ijt} \exp(-\Phi_{ijt}z^\zeta) dz \\
 &= \Pr(P_{ijt}^*(\omega) \leq p) \\
 &= G_{ijt}(p). \tag{B.13}
 \end{aligned}$$

Therefore, the distribution of intermediate-inputs outsourcing price of sector i from sector j is exactly the same as the general price distribution of sector i.

Assume the representative producer minimizes the total intermediate input cost at every sector pair ij, subject to the intermediate input equation (3.6). Given equation (3.6), the equilibrium quantity and price of intermediate-inputs variety are given by the following two equations:

$$X_{ijt}(\omega) = \left(\frac{P_{ijt}(\omega)}{P_{ijt}} \right)^{-\nu} X_{ijt} \quad (\text{B.14})$$

$$P_{ijt} = \left(\int_0^1 P_{ijt}(\omega)^{1-\nu} d\omega \right)^{\frac{1}{1-\nu}} \quad (\text{B.15})$$

Based on equation (B.13) to equation (B.15), the total spending of outsourcing of sector i from sector j at time t is given by

$$\begin{aligned} P_{ijt}^X X_{ijt}^X &= \int_0^1 P_{ijt}^X(\omega) X_{ijt}^X(\omega) d\omega \\ &= \int_{1\{P_{ijt}^X(\omega)=P_{ijt}^*(\omega)\}} P_{ijt}^*(\omega) X_{ijt}(\omega) d\omega \\ &= \int_{1\{P_{ijt}^X(\omega)=P_{ijt}^*(\omega)\}} \left(\frac{P_{ijt}^*(\omega)}{P_{ijt}} \right)^{1-\nu} P_{ijt} X_{ijt}(\omega) d\omega \\ &= P_{ijt}^{\nu-1} P_{ijt} X_{ijt} \int_{1\{P_{ijt}^X(\omega)=P_{ijt}^*(\omega)\}} P_{ijt}^{*(1-\nu)}(\omega) d\omega \\ &= P_{ijt}^{\nu-1} P_{ijt} X_{ijt} E \left[P_{ijt}^{*(1-\nu)}(\omega) | \omega \in 1\{P_{ijt}^X(\omega) = P_{ijt}^*(\omega)\} \right] \Pr(\omega \in 1\{P_{ijt}^X(\omega) = P_{ijt}^*(\omega)\}) \\ &= P_{ijt}^{\nu-1} P_{ijt} X_{ijt} E \left[P_{ijt}^{*(1-\nu)}(\omega) \right] \pi_{ijt} \\ &= P_{ijt}^{\nu-1} P_{ijt} X_{ijt} P_{ijt}^{1-\nu} \pi_{ijt} \\ &= P_{ijt} X_{ijt} \pi_{ijt}. \end{aligned} \quad (\text{B.16})$$

Equation (B.16) 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,

$$\frac{P_{ijt}^X X_{ijt}^X}{P_{ijt} X_{ijt}} = \pi_{ijt} = \frac{A_{jt}(\tau_{ijt} P_{jt})^{-\zeta}}{A_{it} \tilde{r}^{-\zeta} + A_{jt}(\tau_{ijt} P_{jt})^{-\zeta}}. \quad (\text{B.17})$$

Assume the representative producer of each sector minimizes the total material cost or total intermediate input cost from all other sectors, subject to the sectoral gross output production function (3.5). Given the CES aggregation of sectoral gross output, the equilibrium quantity

of intermediate input is given by

$$X_{ijt} = \left(\frac{P_{ijt}}{P_{it}} \right)^{-(1+\theta)} Q_{it}. \quad (\text{B.18})$$

The equilibrium price of sector i is given by equation (3.27). Equation (B.18) implies that the equilibrium share of intermediate input of sectoral pair ij to sector i is given by

$$\frac{P_{ijt}X_{ijt}}{P_{it}Q_{it}} = \left(\frac{P_{ijt}}{P_{it}} \right)^{-\theta} \quad (\text{B.19})$$

Therefore, equation (B.17) and equation (B.19) together imply that equation (3.26) holds in equilibrium.

We can derive the intermediate-inputs price P_{ijt} by following equation (B.15) and the CDF formula of P_{ijt} from equation (B.11). Specifically, we have the following derivation:

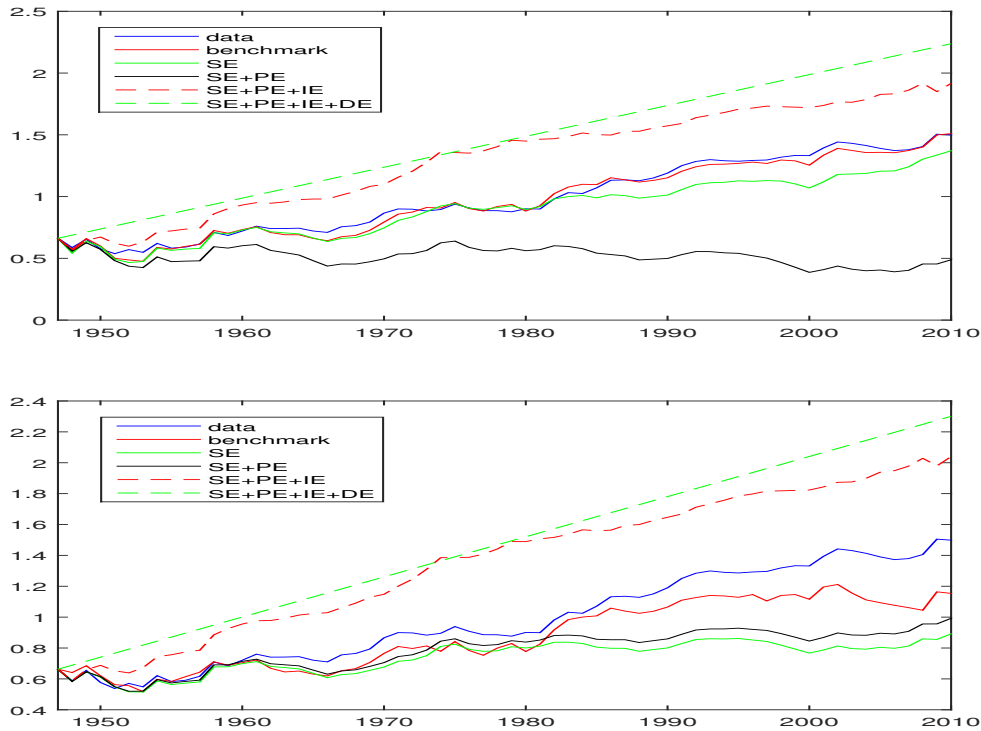
$$\begin{aligned} P_{ijt}^{1-\nu} &= \int_0^1 P_{ijt}(\omega)^{1-\nu} d\omega \\ &= \int_0^\infty p^{1-\nu} dG_{ijt}(p) \\ &= \int_0^\infty p^{1-\nu} \Phi_{ijt} \zeta p^{\zeta-1} \exp(-\Phi_{ijt} p^\zeta) dp. \end{aligned}$$

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.

$$\begin{aligned} P_{ijt}^{1-\nu} &= \int_0^\infty p^{1-\nu} \exp(-\Phi_{ijt} p^\zeta) dz \\ &= \int_0^\infty \left(\frac{z}{\Phi_{ijt}} \right)^{\frac{1-\nu}{\zeta}} \exp(-z) dz \\ &= \Phi_{ijt}^{-\frac{1-\nu}{\zeta}} \int_0^\infty z^{\frac{1-\nu}{\zeta}+1-1} \exp(-z) dz \\ &= \Phi_{ijt}^{-\frac{1-\nu}{\zeta}} \Gamma\left(\frac{1-\nu}{\zeta} + 1\right). \end{aligned} \quad (\text{B.20})$$

Equation (B.20) together with the definition of Φ_{ijt} from equation (B.11) imply that equation (3.28) holds in equilibrium.

QED.



The horizontal axis denotes year, and the vertical axis shows the value of the relative value added share of services to manufacturing in log level. The Upper panel displays the benchmark decomposition, and the Lower panel shows the decomposition under the simulation case 1.

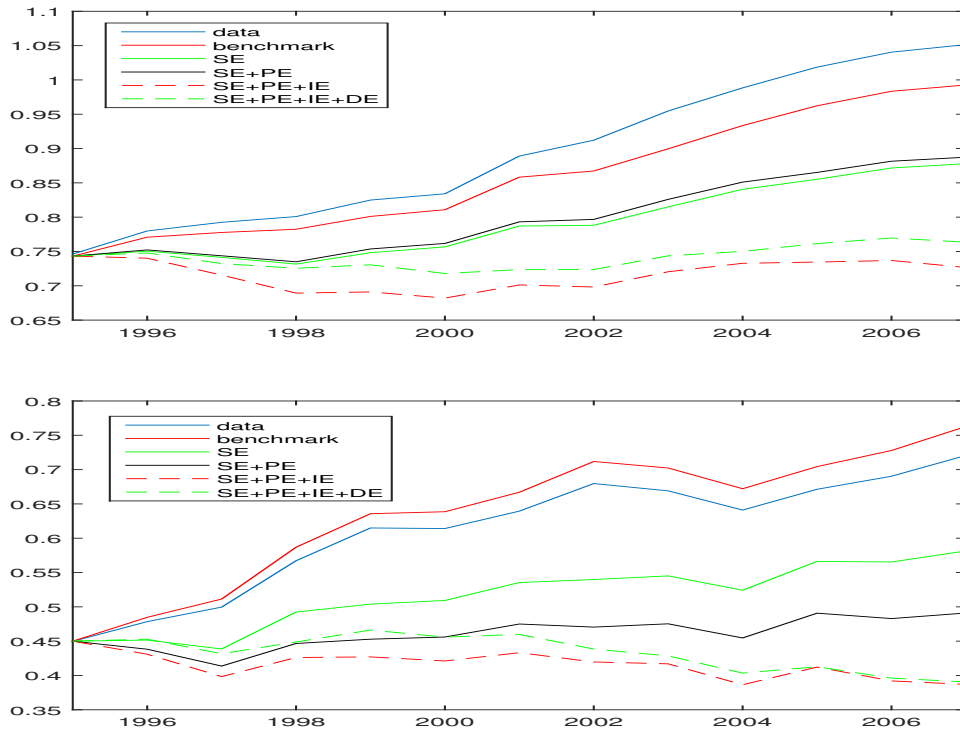
Fig. B.1 Decomposition of the US long run structural change

B.2 Additional Results

This section presents a few validation exercises. I show the decomposition result using the US long-term data in subsection B.2.1. The decomposition result of developed countries and developing countries are given in subsection B.2.2. I report the decomposition result with other parameter values in subsection B.2.3. Then subsection B.2.4 demonstrates the result of decomposition for other two sectors. The model implies a unitary elasticity on the intermediate-inputs demand effect. Subsection B.2.5 presents the decomposition result with an imposition of $\beta = 1$. Finally, subsection B.2.6 illustrates the quantitative result for employment share based structural change.

B.2.1 The US Long Run Data: 1947-2010

The quantitative result in section 3.3 is based on the panel data of 35 major economies through 1995-2007. A natural question would be whether the headline result holds in long run time series data. I answer this question based on the US long run data.



The horizontal axis denotes year, and the vertical axis shows the value of the relative value added share of market service to manufacturing in log level. The upper panel displays the decomposition result for developed countries; lower panel for developing countries.

Fig. B.2 Decomposition for developed countries and developing countries

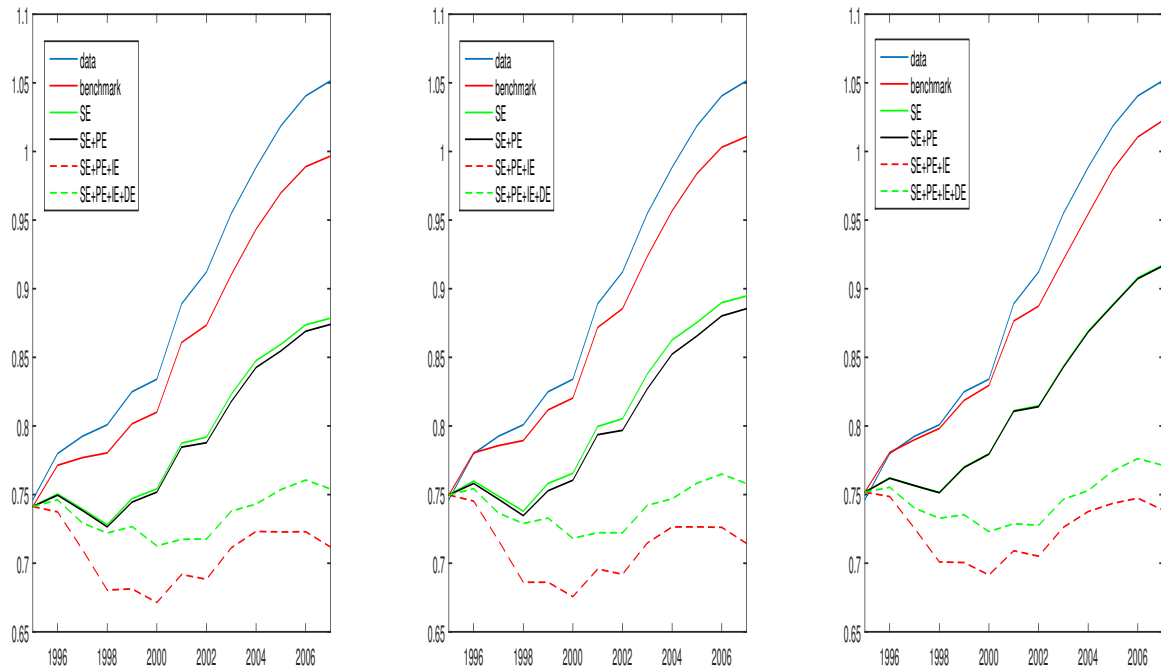
The input-output linkages data come from Input-Output Accounts Data in Bureau of Economic Analysis (BEA). I can find the long run linkages data since 1947 in the BEA. Following [Herrendorf et al. \(2013\)](#), the individual industries are aggregated into three broad sectors: Agriculture, manufacturing and service. The sectoral price data come from [Herrendorf et al. \(2013\)](#) who compute the three sectoral prices mainly based on data from National Income and Product Accounts (NIPA) and the BEA.¹

Given the US data, I replicate the benchmark decomposition exercise in the upper panel of figure B.1, and replicate the decomposition exercise under the model simulation case 1 in the lower panel of figure B.1.² I make a first-difference transformation to the relative value added share and the four effects. Because the unit root test³ suggests that these variables, particularly aggregate income, are non-stationary. In both cases, the I-I supply effect is significant at 1 percent level. The result of the benchmark decomposition in the upper panel suggests that the

¹See [Herrendorf et al. \(2013\)](#) for the price data and the exact data sources.

²I keep the parameter values of ζ , θ and ν as same as in section 3.3.

³Here I use Dickey-Fuller test.



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

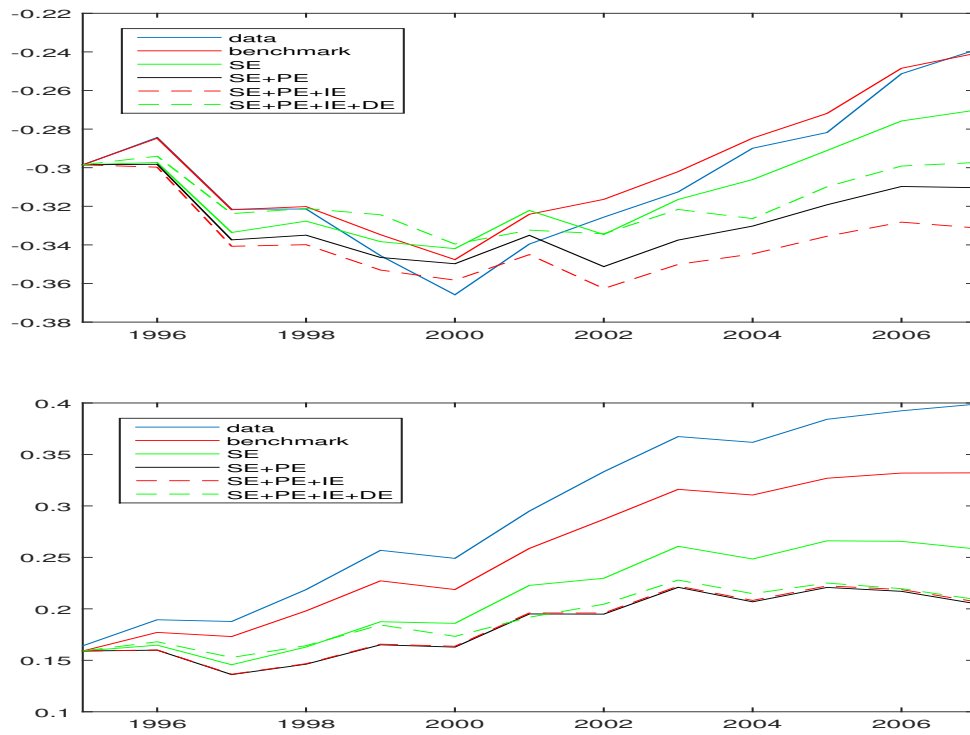
Fig. B.3 Decomposition results with various parameter values of ζ and θ .

I-I supply effect is not as large as the price effect. However, the decomposition result under the model simulated data in the lower panel suggests a strong I-I supply effect on structural change from manufacturing to services.

The income effects are negative and sizable in both cases. In contrast, [Herrendorf et al. \(2013\)](#) find positive and small income effects. The main difference between [Herrendorf et al. \(2013\)](#) and this chapter is that the consumption expenditure is aggregate expenditure in final demand in this chapter whereas consumption expenditure is per capita consumption expenditure in [Herrendorf et al. \(2013\)](#). If I use per capita consumption expenditure, I got a similar result as in [Herrendorf et al. \(2013\)](#).

B.2.2 Developed Countries and Developing Countries

The decomposition result in subsection 3.3.2 may mask the heterogeneous attribution of structural change between developed countries and developing countries. Rather than pooling all nations together, I show the decomposition result for developed countries in the upper



The horizontal axis denotes year, and the vertical axis shows the value of the relative value added share in log level. The upper and the lower panel show the decomposition result of the relative other goods and non-market service to manufacturing respectively.

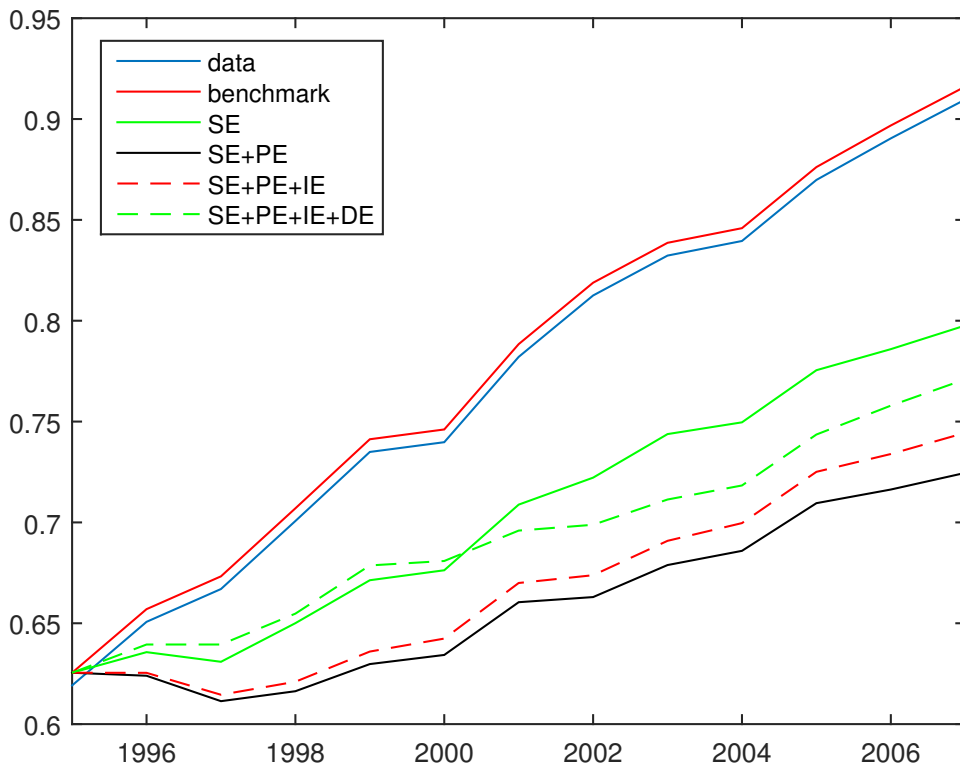
Fig. B.4 Decomposition of other goods and non-market service to manufacturing

panel of figure B.2 and for developing countries in the lower panel of figure B.2. The list of developed country and developing country follows The World Factbook.⁴ For both groups, figure B.2 suggests that the I-I supply effects are significant and comparable to the price and income effects; the I-I demand effects are significant but economically small. For both groups of countries, income effects are positive and significantly large. It implies that the overall trivial income effects are probably due to mixed income effects between the developed countries and the developing countries.

B.2.3 Various Parameter Values of ζ and θ

The calibration of TFP scale and trade cost are conditional on the parameter values of ζ and θ . In this subsection, I study how the decomposition result responses to the various parameter values of ζ and θ . It turns out that the decomposition result is robust to ζ and θ . Given the smooth calibration result with data on developed countries, I do this exercise based on the

⁴Finally, there are 20 developed countries and 15 developing countries in the panel data.



The horizontal axis denotes year, and the vertical axis shows the value of the relative value added share of market service to manufacturing in log level. The result is based on the benchmark decomposition with $\beta = 1$.

Fig. B.5 Decomposition with $\beta = 1$

data on developed countries. I show the decomposition result in figure B.3. In the three panels of figure B.3 from the left to the right, I show the decomposition result under three combinations of parameter values: $\zeta = 4, \theta = 3$; $\zeta = 4, \theta = 4$; and $\zeta = 1.2, \theta = 1.2$ respectively. The decomposition result varies only marginally among the three cases.

B.2.4 Other Two Sectors

In section 3.3, I mainly focus on the relative value added share of market service to manufacturing. In this subsection, I show the decomposition results for the other two sectors: non-market service and other goods. I report the decomposition result of the relative value added share of other goods to manufacturing in the upper panel of figure B.4; and the result of non-market service to manufacturing in the lower panel of figure B.4. For both panels, the decomposition result is based on the parameter values in column 3 of table 3.2. Both panels of figure B.4 suggest strong I-I supply effects on structural change, which is again

Dependent Variable : $\log \frac{l_{it}}{l_{jt}}$							
0 Coefficient	(1)	(2)	(3)	(4)	(5)	(6)	(7)
β		0.568*** (0.079)	0.112** (0.050)	0.116*** (0.043)	0.264*** (0.087)	0.234*** (0.050)	0.029 (0.067)
κ		0.861*** (0.053)	0.356*** (0.042)	0.160*** (0.038)	0.165*** (0.037)	0.319*** (0.040)	-0.065 (0.063)
$1 - \rho$	0.281*** (0.034)	0.198*** (0.033)	0.031 (0.033)	0.071** (0.028)	0.066** (0.028)	0.245*** (0.039)	0.034 (0.040)
$\epsilon_{OG} - \epsilon_{Manu}$	0.004 (0.013)	0.049*** (0.012)	-0.080** (0.033)	-0.349*** (0.061)	-0.341*** (0.061)	0.484*** (0.064)	-0.331*** (0.083)
$\epsilon_{MS} - \epsilon_{Manu}$	0.031*** (0.009)	0.048*** (0.009)	0.417*** (0.023)	-0.080** (0.034)	-0.071** (0.034)	0.174*** (0.047)	-0.129** (0.061)
$\epsilon_{NMS} - \epsilon_{Manu}$	-0.023** (0.010)	0.017* (0.009)	0.340*** (0.032)	-0.274*** (0.048)	-0.263*** (0.047)	0.083 (0.061)	-0.320*** (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 B.1 Estimation of employment share based structural change

comparable to the price effects. The income effect is significant in other goods sector but trivial in non-market service. The I-I demand effect is negative and significant in the other good sector but trivial in non-market service.

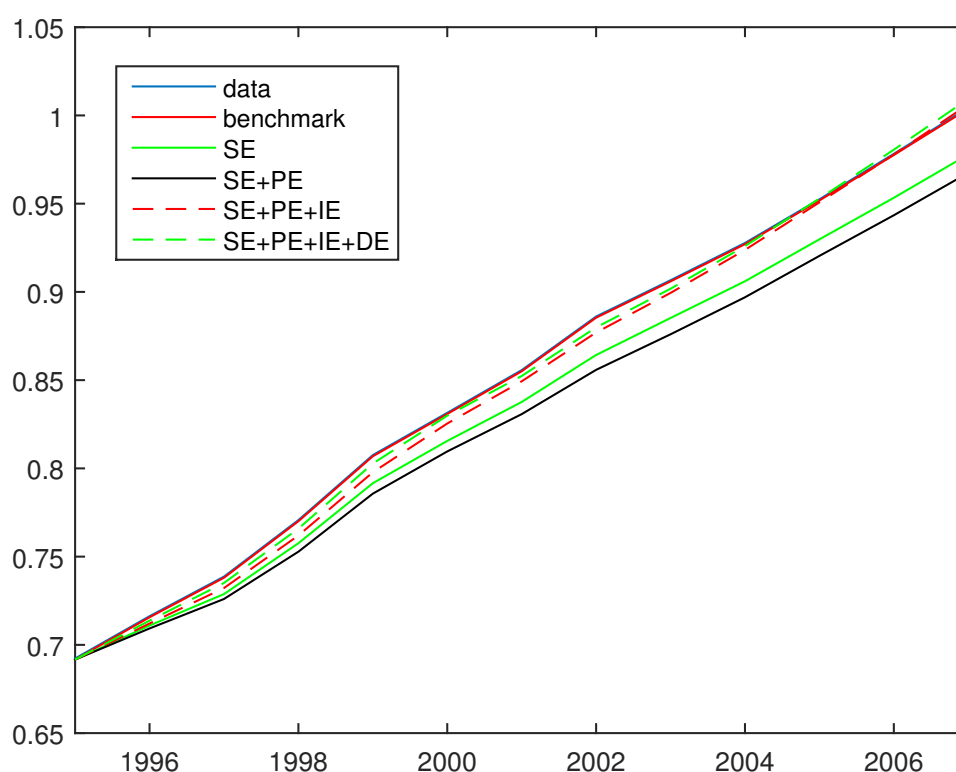
B.2.5 Imposing $\beta = 1$

The model implies a unitary elasticity of relative value added share to the I-I demand effect. When I use regression to estimate the elasticity in section 3.3, I do not impose this constraint. Though the estimated elasticity is close to 1 in section 3.3, it is valuable to check how the decomposition result responses to this constraint. I show the result of decomposition with this constraint in figure B.5. This decomposition result is based upon the benchmark calibration with the constraint of $\beta = 1$. Comparing figure B.5 with figure 3.1 in which I do not impose this constraint, they are almost the same. The only gentle difference is that the I-I demand effect is modestly larger in figure B.5 than that in figure 3.1.

B.2.6 Employment Share Based Structural Change

In the main body of this chapter, I discuss the structural change in terms of value added share and consumption share. Another common structure term is employment share.⁵ As

⁵See Comin et al. (2019), Rodrik (2016), and Kehoe et al. (2018) for the discussion about employment share based structural change.



The horizontal axis denotes year, and the vertical axis shows the value of the relative value added share of market service to manufacturing in log level.

Fig. B.6 Decomposition of employment share based structural change

illustrated in section 2.3.2, sectoral employment share equals value added share when I assume equivalent capital share and wages across sectors. This equivalence is given in equation (2.1). In this subsection, I estimate the elasticities of the four effects on employment share based structural change.

I show the estimation result in table B.1. Compare with the estimation result in table 3.1, the elasticity of the I-I demand effects, I-I supply effects and price effects are smaller in employment share based structural change than in value added share based structural change. Except for column (7), the estimated coefficients are significant in these three effects. In particular, for the I-I supply effects, they are always significant at 1 percent level. In column 3, when I only control the country fixed effect, the income effect and the I-I supply effect are larger than the price effect and the I-I demand effect. It implies that Income effect and I-I supply effect are two essential effects on within-country structural change from manufacturing to market service. In column 4, when I further control the year fixed effect, both the I-I supply effect and the income effect 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 critical to affect cross-country structural change.

I do a similar benchmark decomposition exercise, based on the employment share based structural change. The estimation of the four effects are based on column 4 of table B.1. Figure B.6 displays the decomposition result of the relative employment share of market service to manufacturing. Consistent with the above argument, all four effects are small. But we can still observe the significant I-I supply effect and income effect. Overall the result of table B.1 and figure B.6 suggest that the I-I supply effect and income effect are essential in within-country employment share based structural change. They tend to be less critical in cross-country employment share based structural change.

Appendix C

Appendix of Chapter 4

C.1 Proofs of the Propositions

C.1.1 Proposition 4: Equilibrium Solution of The IO Economy

Based on equation (A.1) and equation (4.7), I have

$$P_j C_j + \sum_{i=1}^n \sigma_{ij} P_i Q_i = P_j Q_j. \quad (\text{C.1})$$

Substitute equation (4.4) to equation (C.1), I have the following equation:

$$\lambda_j + \sum_{i=1}^n \sigma_{ij} \frac{\lambda_i Q_i}{C_i} = \frac{\lambda_j Q_j}{C_j}.$$

Let $v_j = \frac{\lambda_j Q_j}{C_j}$, then I have

$$\lambda + Bv = v.$$

Here λ is a $J \times 1$ vector of sectoral consumption expenditure share, B is the input-output matrix ($J \times J$) with $B_{ji} = \sigma_{ij}$. I solve the vector v in the above equation by

$$v = (I - B)^{-1} \lambda \equiv \gamma, \quad (\text{C.2})$$

where

$$\gamma_i = \frac{\lambda_i Q_i}{C_i} = \frac{P_i Q_i}{Y}.$$

According to equation (C.2), γ is a vector of Domar weights (Domar 1961). The Domar weight is defined as a ratio of sectoral gross output value to aggregate value added, which shows the importance of a sector in the input-output economy.

Substitute equation (C.2) to equation (4.7). The intermediate input is given by

$$X_{ij} = \sigma_{ij} \frac{\gamma_i}{\gamma_j} Q_j = \theta_{ij} Q_j. \quad (\text{C.3})$$

Here $\theta_{ij} = \sigma_{ij} \frac{\gamma_i}{\gamma_j}$. Similar, I solve the optimal capital allocation K_i and labor allocation L_i by substituting equation (C.2) to equation (4.5) and equation (4.6). I have the following result:

$$K_i = \frac{(1 - \sigma_i) \alpha_i \gamma_i}{\sum_{i=1}^n (1 - \sigma_i) \alpha_i \gamma_i} K = \theta_{GOKi} K, \quad (\text{C.4})$$

$$L_i = \frac{(1 - \sigma_i)(1 - \alpha_i) \gamma_i}{\sum_{i=1}^n (1 - \sigma_i)(1 - \alpha_i) \gamma_i} L = \theta_{GOLi} L. \quad (\text{C.5})$$

Here $\theta_{GOKi} = \frac{(1 - \sigma_i) \alpha_i \gamma_i}{\sum_{i=1}^n (1 - \sigma_i) \alpha_i \gamma_i}$, and $\theta_{GOLi} = \frac{(1 - \sigma_i)(1 - \alpha_i) \gamma_i}{\sum_{i=1}^n (1 - \sigma_i)(1 - \alpha_i) \gamma_i}$. On top of the factor share, equations (C.3) to equation (C.5) suggest that the optimal input allocation depends on the Domar weight. The sector which has a higher Domar weight has a higher revenue share, therefore, requiring more inputs to produce.

Then I substitute the optimal intermediate inputs, capital and labour from equations (C.3), (C.4) and (C.5) to equation (4.1). The sectoral gross output is represented by

$$Q_i = A_{GOi} (\theta_{GOKi} K)^{(1 - \sigma_i) \alpha_i} (\theta_{GOLi} L)^{(1 - \sigma_i)(1 - \alpha_i)} \prod_{j=1}^n (\theta_{ij} Q_j)^{\sigma_{ij}}.$$

I transform the above equation in logarithm form, which is given by

$$q = \log A_{GO} + \delta_{GOK} \log K + \delta_{GOL} \log L + B' q + W_{q1}.$$

Here q is a $J \times 1$ vector with $q_i = \log Q_i$, A_{GO} is a $J \times 1$ vector of gross output based TFP, $\delta_{GOK} = (1 - \sigma) \circ \alpha$ which is a Hadamard product of the column vector $1 - \sigma$ and column vector α . Similar, we have $\delta_{GOL} = (1 - \sigma) \circ (1 - \alpha)$; $W_{GOqi} = (1 - \sigma_i) \alpha_i \log \theta_{GOKi} + (1 - \sigma_i)(1 - \alpha_i) \log \theta_{GOLi} + \sum_{j=1}^n \sigma_{ij} \log \theta_{ij}$. The sectoral gross output in logarithm form q is given by the following equation:

$$q = (I - B')^{-1} (\log A_{GO} + W_{GOq} q + \delta_{GOK} \log K + \delta_{GOL} \log L). \quad (\text{C.6})$$

According to the equation (C.2), $C_i = \frac{\lambda_i Q_i}{\gamma_i}$. The consumption vector in logarithm form is represented by

$$c = q + W_c.$$

Here $c_i = \log(C_i)$ and $W_c = \log \lambda - \log \gamma$. According to equation (4.3), I solve the aggregate final output by

$$\log Y = \lambda' c = \lambda' W_c + \lambda' q = \lambda' W_c + \lambda' (I - B')^{-1} (\log A_{GO} + W_{GOq} + \delta_{GOK} \log K + \delta_{GOL} \log L).$$

The aggregate TFP therefore, is given by the following equation:

$$\log TFP_{GO} = \lambda' W_c + \lambda' (I - B')^{-1} W_{GOq} + \lambda' (I - B')^{-1} \log A_{GO} = \lambda' W_c + \gamma' W_{GOq} + \gamma' \log A_{GO}. \quad (C.7)$$

QED.

C.1.2 Proposition 5: Equilibrium Solution of The Value Added Economy

According to equation (4.14), $P_{Yi} Y_i = \eta_i Y$. Substitute this condition to equation (4.15) and equation (4.16), I solve the equilibrium K_i and L_i in the value added economy as

$$K_i = \frac{\beta_i \eta_i}{\sum_{i=1}^n \beta_i \eta_i} K = \theta_{\text{VAK}i} K, \quad (C.8)$$

$$L_i = \frac{(1 - \beta_i) \eta_i}{\sum_{i=1}^n (1 - \beta_i) \eta_i} L = \theta_{\text{VAL}i} L. \quad (C.9)$$

Here $\theta_{\text{VAK}i} = \frac{\beta_i \eta_i}{\sum_{i=1}^n \beta_i \eta_i}$ and $\theta_{\text{VAL}i} = \frac{(1 - \beta_i) \eta_i}{\sum_{i=1}^n (1 - \beta_i) \eta_i}$. Then substitute equation (C.8) and equation (C.9) to equation (4.12), I express the sectoral value added by

$$Y_i = A_{\text{VA}i} (\theta_{\text{VAK}i} K)^{\beta_i} (\theta_{\text{VAL}i} L)^{(1 - \beta_i)}.$$

Then I transform the sectoral value added into a logarithm form, which is given by

$$y = \log A_{\text{VA}} + \delta_{\text{VAK}} \log K + \delta_{\text{VAL}} \log L + W_{\text{VA}q}.$$

Here y is a $J \times 1$ vector with $y_i = \log Y_i$, and A_{VA} is a $J \times 1$ vector of sectoral value added based TFP. The term δ_{VAK} is a $J \times 1$ vector of capital share β_i , and δ_{VAL} is a $J \times 1$ vector of labour share $1 - \beta_i$, and $W_{\text{VA}qi} = \beta_i \log \theta_{\text{VAK}i} + (1 - \beta_i) \log \theta_{\text{VAL}i}$. Based on equation (4.13), the

aggregate value added is solved by

$$\log Y = \eta' y = \eta' (\log A_{VA} + \delta_{VAK} \log K + \delta_{VAL} \log L + W_{VAq}). \quad (C.10)$$

Here η is a $J \times 1$ vector of sectoral value added shares. The aggregate TFP in the value added economy therefore, is given by

$$\log TFP_{VA} = \eta' W_{VAq} + \eta' \log A_{VA}.$$

QED.

C.1.3 Proposition 6: Aggregate TFP Equivalence

Given $\alpha_i = \beta_i$ and $P_{Yi} Y_i = (1 - \sigma_i) P_i Q_i$, we have $\theta_{GOKi} = \theta_{VAKi}$. Based on the definition of θ_{GOKi} and θ_{VAKi} from equation (C.4) and equation (C.8), we have

$$\eta_i = (1 - \sigma_i) \gamma_i.$$

Based on equation (C.2), the relationship between consumption and gross output is given by

$$c = q + \log \lambda - \log \gamma. = q + W_c$$

According to equation (4.3), the IO based aggregate final output in logarithm form is

$$\log Y = \lambda' c = \lambda' q + \lambda' W_c.$$

Then, based on equation (C.10), I have the following equation:

$$\eta' \log A_{VA} = \lambda' q + \lambda' W_c - \eta' (\delta_{VAK} \log K + \delta_{VAL} \log L + W_{VAq}). \quad (C.11)$$

Substitute equation (C.11) to equation (4.18), the TFP_{VA} in logarithm form is given by

$$\log TFP_{VA} = \lambda' q + \lambda' W_c - \eta' (\delta_{VAK} \log K + \delta_{VAL} \log L). \quad (C.12)$$

Based on equation (C.6) and equation (C.7), the TFP_{GO} in logarithm form is given by

$$\log TFP_{GO} = \lambda' W_c + \lambda' q - \lambda' (I - B')^{-1} (\delta_{GOK} \log K + \delta_{GOL} \log L). \quad (C.13)$$

Combine equation (C.12) and equation (C.13), the difference of aggregate TFP between the two economies is given by

$$\log TFP_{VA} - \log TFP_{GO} = (\hat{\alpha}_{GO} - \hat{\alpha}_{VA})(\log K - \log L). \quad (\text{C.14})$$

Here $\hat{\alpha}_{GO} = \lambda'(I - B')^{-1} \delta_{GOK}$ and $\hat{\alpha}_{VA} = \eta' \delta_{VAK}$. Given equation (4.19), the aggregate capital shares are equivalent since we have the following condition:

$$\hat{\alpha}_{VA} = \eta' \delta_{VAK} = \gamma'[(1 - \sigma) \circ \alpha] = \lambda'(I - B')^{-1} \delta_{GOK} = \hat{\alpha}_{GO}$$

Therefore, $\log TFP_{VA} = \log TFP_{GO}$, according to equation (C.14).

QED.

