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Servicification of investment and structural transformation: The case of China

Kaiming Guo [a], Jing Hang [a,*], Se Yan [b,*]

[a] Lingnan College, Sun Yat-sen University, China
[b] Guanghua School of Management, Peking University, China

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ABSTRACT

Structural transformation is a key feature of economic development. Traditional literature attributes it to changes in the sectoral composition of consumption. Different from it, we argue that "servicification" of investment goods, induced by investment-composition technological change, becomes an increasingly important reason for structural transformation, particularly for the rise of the services economy. Our study of the input output tables finds that the share of service inputs in investment goods has grown significantly in many countries since the 1980s, especially for investment-intensive economies such as China. To assess if the investment channel is quantitatively significant, we build a standard model with three broad sectors, but instead add an investment production function employing factors from all three sectors. Moreover, we incorporate investment-composition technological change by allowing the productivities of the three sectoral inputs to evolve over time. We calibrate the model to the Chinese economy from 1981 to 2014 and perform counter-factual experiments accordingly. We find that investment-composition technological change accounts for 33.1% decline in employment share of agriculture, 36.0% increase in employment share of manufacturing and 31.5% increase in employment share of services over the period. The magnitude of this effect on the share of services keeps growing, particularly after 2000. Our findings are not unique for China, but also apply to other economies experiencing the "servicification" of investment.

* Corresponding authors.
E-mail addresses: hangj5@mail.sysu.edu.cn (J. Hang), seyan@gsm.pku.edu.cn (S. Yan).

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1. Introduction

Structural transformation is one of the most salient features of economic development. As countries grow richer, we observe a shift of resources away from agriculture towards manufacturing and services, and then a decline in manufacturing further pushes a rise in services.[1] Traditional wisdom considers changes in the sectoral composition of consumption as the main driving force of such transformation, while assuming that investment is only composed of manufacturing goods (Herrendorf, Rogerson, & Valentinyi, 2014; Kongsamut, Rebelo, & Xie, 2001; Ngai & Pissarides, 2007).[2] If consumption is the only source, countries with high investment rates should witness a slow and prolonged process of structural transformation.

This was true for China before the early 2000s. Fig. 1 plots sectoral output shares across countries against GDP per capita.[3] While China was among the fastest growing countries and saw an investment rate higher than 35% for most years during the reform era, it had a long history with a relatively smaller service sector than the global average. However, the rise of services in China began to accelerate since the early 2000s. The output share of services rose by nearly 10 percentage points in the last decade. During the same period, the investment rate soared to almost 50% in 2010, which was even higher than the manufacturing share. The investment rate cannot be at such high level were all the manufacturing goods used for investment. Theories relying on the changes in the sectoral composition of consumption could hardly explain China's experience.

In fact, the acceleration of the rise of services occurred not only in China, but also in many other countries in the past decades, and the sectoral composition of consumption was unlikely to be able to fully account for such transformation. For example, the output share of services increases by 23.3 percentage points from 1970 to 2012 in Japan, 20.1 percentage points from 1985 to 2014 in Korea, and 25.2 percentage points from 1981 to 2014 in China. We later show that changes in the sectoral composition of consumption only push the share rising by 10.6 percentage points in Japan, 15.0 in Korea, and 20.0 in China.

To account for the process of structural transformation and particularly the accelerated rise of services, we highlight the role of the "servicification" of investment. The "servicification" of investment represents the tendency that the value-added of services accounts for a growing share of investment goods in many countries. It is to a large extent driven by the technological change that requires more service inputs to produce the investment goods. The major form of such investment-composition technological change is the development and deployment of information technology, which promotes investment in intangibles that are produced primarily in the service sector.[4] For example, software as an investment good makes up a growing source of value-added. The "servicification" of investment goods echoes the "servicification" of manufacturing proposed by a report from World Bank, as services are increasingly embodied and embedded in manufactured goods and constitute a larger source of value in the broader production process (World Bank, 2017). The report also emphasizes the contribution of the information and telecommunication technology. For example, it notes that data plays an increasingly important role in smart manufacturing.

To quantitatively investigate the role of the "servicification" of investment as a driving force behind the structural transformation, we adopt the standard framework of Herrendorf et al. (2014) with three broad sectors, but instead assume that investment is produced using outputs from the three sectors as inputs. This input-output structure allows us to easily disaggregate investment into sectors.[5] We calibrate the model to the Chinese economy. The model successfully mimics the process of structural transformation in China. We find that the changes in relative input prices are not enough to explain the changes in the sectoral composition of investment. Investment-composition technological change that requires more service inputs to produce investment goods is a major force. If held constant, the transformation out of agriculture and the rise of services will be much slower. We find that investment-composition technological change accounts for 33.1% decline in employment share of agriculture, 36.0% increase in employment share of manufacturing and 31.5% increase in employment share of services over the period.

The "servicification" of investment pushes the rise of services mainly after 2000. Before 2000, its effect on the share of services is

[1] According to Herrendorf et al. (2014), the share of manufacturing peaks when the log of GDP per capita by the 1990 international dollars reaches around 9. This was the case with the US in the 1950s, Japan in the 1970s and Korea in the 1990s.

[2] These include the classical income effect (Kongsamut et al., 2001) and the price effect (Ngai & Pissarides, 2007). Recent studies add international trade as another force affecting sectoral allocation (Matsuyama, 2009; Rodrik, 2016; Uy, Yi, & Zhang, 2013). These models break the link between production and consumption for a single country. But the forces affecting industrial structure at the global level still come from changing consumption structure. Despite a good approximation, Herrendorf et al. (2014) note that the assumption that investment sources only from manufacturing is becoming increasingly at odds with data, which motivates them to specify an independent investment sector. They however have not discussed how to match the independent investment sector to data except by simply assuming that the sectoral composition of investment is constant. They conjecture that it is less of a problem when the investment rate is low. This is not the case for the transitions of Asian growth miracles, which are characterized by increasing investment rate for a long period of time (Buera & Shin, 2013; Chang & Hornstein, 2015).

[3] Data on sectoral output share are from the UN Statistic Division. Data on GDP per capita are from the Penn World Table 9.0 (PWT 9.0). We drop countries with population less than 0.5 million and oil exporting countries in Middle East from the dataset.

[4] We use investment-composition technological change to distinguish from investment-specific technological change (Greenwood, Hercowitz, & Krusell, 1997). The former shifts the investment demand for sectoral output while the latter represents faster technological change in the investment sector relative to that in the consumption sector.

[5] The idea is similar with Basu, Fernald, Fisher, and Kimball (2013) in calibrating two-sector models of consumption and investment. In these models, TFP growth is usually inferred from relative price changes when the production functions are the same up to different TFP for consumption and investment, e.g., Greenwood et al. (1997). Similarly, Herrendorf et al. (2014) specify an independent investment sector which employ capital and labor. These procedures are infeasible without additional assumptions, because national accounts do not provide production data for consumption and investment.

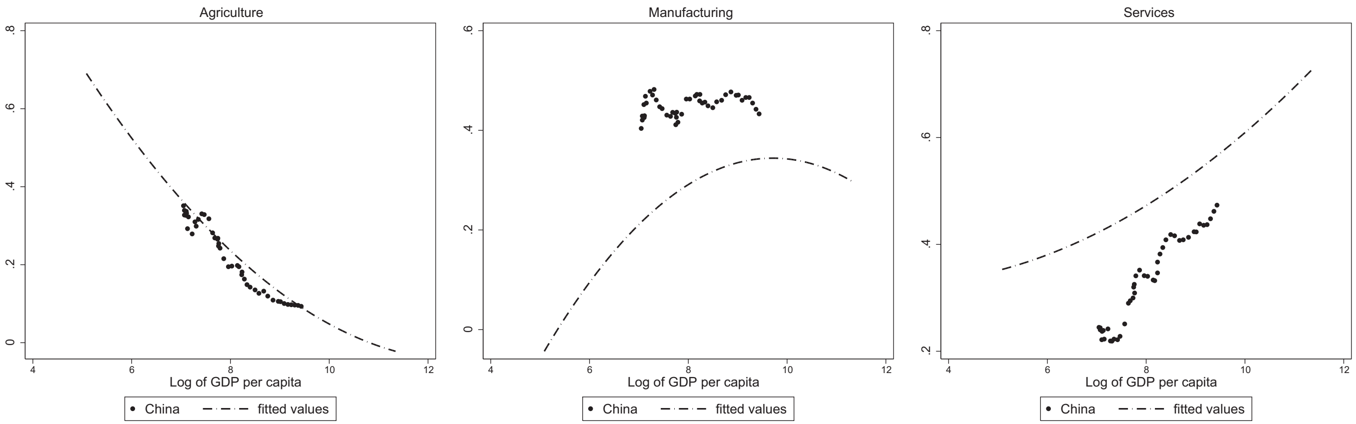

Fig. 1. Sectoral output shares against the level of development.

limited. But from 2000 to 2014, it increases the output share and the employment share of services by 4.2 percentage points and 6.2 percentage points respectively, close to 4.1 percentage points and 8.7 percentage points from 1981 to 2014. The investment channel is much more important than the consumption channel, because the changes of sectoral output shares caused by the changes in the sectoral composition of consumption are less than half a percentage point. Thus, we highlight the role of investment in understanding the catch-up of services in China.

We further assess the role of investment channel by assuming that the investment goods entirely source from the manufacturing sector. This alternative model performs much worse than our model. It fails to reconcile the moderate decline of manufacturing with the rising investment rate. In particular, the model predicts steeper curve of the manufacturing share, and accordingly, cannot mimic the rising trend of services in China. Without structural change in investment, the alternative model also predicts a steeper decline of the investment price, which reflects the role of the "servicification" of investment in keeping the investment price from falling. Traditionally, the literature argues that labor market wedges are an important driver behind underdeveloped services in China. We also find that wedges cannot fully account for that.

Our paper is connected to a large body of literature on structural transformation. Our model incorporates the standard mechanisms of structural change: the price effect driven by uneven sectoral productivity growth (Baumol, 1967; Ngai & Pissarides, 2007) or capital deepening under different sectoral technology (Acemoglu & Guerrieri, 2008; Ju, Lin, & Wang, 2015); and the income effect due to non-homothetic preferences (Boppart, 2014; Foellmi & Zweimuller, 2008; Kongsamut et al., 2001). These models focus on the sectoral composition of consumption, but we emphasize the role of investment. Garcia-Santana, Pijoan-Mas, and Villacorta (2019) and Herrendorf, Rogerson, & Valentinyi, 2020 also note that the investment channel is important. In their models, the sectoral composition of investment is affected solely by the relative price of inputs. In contrast, our investment production function incorporates technological change that shifts the relative productivities of sectoral inputs, which turns out to be the other important force behind the "servicification" of investment. Moreover, we present a full-fledged model with endogenous investment decision to conduct quantitative analysis on the role of such technological change in structural transformation.

Several papers also study China's structural transformation and pay particular attention to imperfect factor markets (Brandt & Zhu, 2010; Cao & Birchenall, 2013; Cheremukhin, Golosov, Guriev, & Tsyvinski, 2017; Dekle & Vandenbroucke, 2012). We embed in our model reduced form labor market wedges and intertemporal wedges. Some papers distinguish between state and non-state sectors, which is a key feature of China's economic transition (Brandt & Zhu, 2010; Song, Storesletten, & Zilibotti, 2011), but in this paper, we still focus on three broad sectors. Liao (2020) explains the rise of the service sector in China by focusing on the consumption side and examining disaggregated service industries. In contrast, we investigate the role of changes in investment composition.

The rest of the paper is organized as follows: Section 2 presents key facts about the sectoral composition of investment, Section 3 develops the baseline model, Section 4 calibrates the model to Chinese data, Section 5 presents numerical results, and Section 6 concludes.

2. Servicification of investment

2.1. International evidence

This section describes the key facts regarding the evolution of sectoral source of value in investment goods. Data on sectoral compositions of consumption and investment are not readily available. We use information on world input output tables from World Input Output Database (WIOD). WIOD only provides data from 1995. For years prior to 1995 in the US, we obtain data from Herrendorf, Rogerson, and Valentinyi (2013). They constructed data using national input output tables from Bureau of Economic Analysis (BEA). For years prior to 1995 in Japan, Korea and China, we use national input output tables from the Japan Industrial Productivity Database (JIP), Bank of Korea (BOK) and the China Industrial Productivity Database (CIP) respectively. In contrast to national input output tables, world input output tables are preferred because they allow us to trace the source of consumption and investment to different countries. We aggregate industries into the three broad sectors: agriculture, manufacturing, and services.[6]

Sectoral composition of investment in many countries is vastly different from sectoral composition of consumption. The services account for a growing share of investment. We call the rise of services in investment the "servicification" of investment. Fig. 2 presents the sectoral compositions of investment and consumption in the US. The share of services in investment is much lower than that in consumption, while the share of manufacturing in investment is much higher. The trends are, however, similar. Between 1947 and 2010, the shares of agriculture, manufacturing and services in investment changed by −2.1, −14.7 and 16.8 percentage points, respectively. Very moderate changes in the sectoral composition of investment prior to 1980 are followed by rapid subsequence changes. Between 1980 and 1998, the share of manufacturing in investment decreased by 12.4 percentage points, while the share of services increased by 12.6 percentage points. However, sectoral composition of investment has been very stable since 1998. The share of services in WIOD was higher than that in BEA for most overlapping years, but it did not change the whole picture of the trend of sectoral composition of investment.

Fig. 3 presents sectoral compositions of investment and consumption in Japan. The shares from 1970 to 2012 are close to those in the US from 1947 to 2010. The share of services in investment increased from around 30% to over 40% with the falling share of agriculture and manufacturing, and was more than 35 percentage points lower than the share of services in consumption on average.

[6] We discuss the decomposition method and the sector classification in details in the appendix.

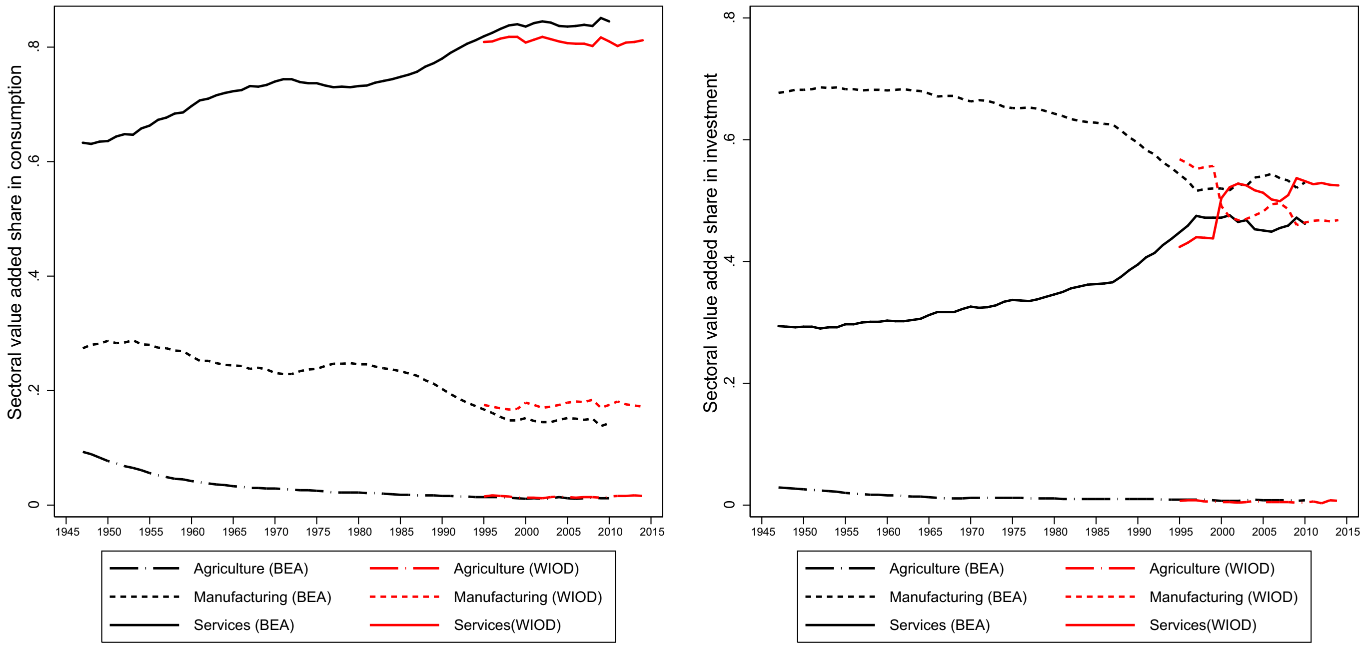

Fig. 2. Sectoral compositions of consumption and investment in the United States.

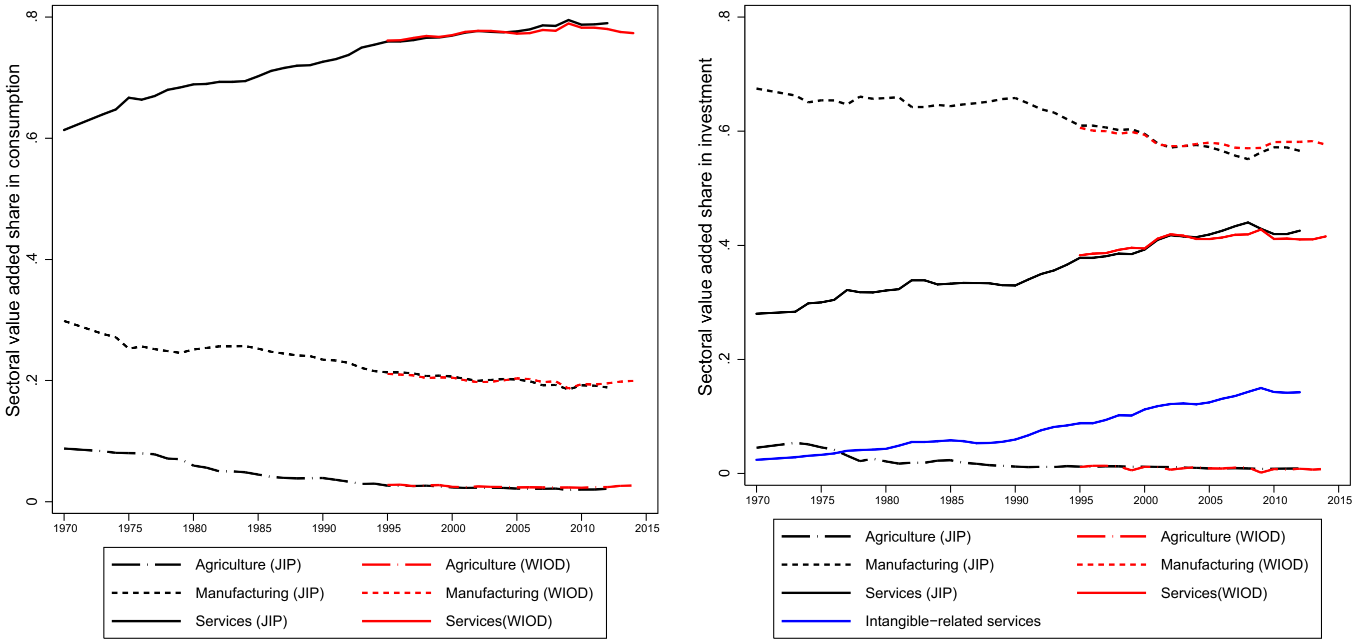

Fig. 3. Sectoral compositions of consumption and investment in Japan.

The difference between the WIOD and JIP database was negligible.

Fig. 4 presents sectoral compositions of investment and consumption in Korea. The share of services in consumption and in investment are a bit lower than those in the US and Japan, but the upward trend is the same. The share of agriculture, manufacturing and services in investment changed by −3.8, −12.7 and 16.5 percentage age points from 1985 to 2014. Though the share of services in consumption and in investment were higher and the share of manufacturing was lower in WIOD prior to 2010, the difference between the two data sources was within 5 percentage points for most overlapping years.

Fig. 5 presents sectoral compositions of investment and consumption in China. Not surprisingly, sectoral composition of investment was also dramatically different from that of consumption. Services in investment was becoming more important while the role of agriculture was declining. Between 1981 and 2010, the shares of agriculture, manufacturing and services in investment changed by −11.9, −11.2 and 23.1 percentage points. Although there were some discrepancies between the WIOD and CIP database from 2007 to 2010, when China's trade surplus to GDP ratio reached its peak, the gap between the two sources was also moderate for most overlapping years.

For other economies, we again use the world input output tables from WIOD. The 2013 WIOD dataset covers 40 economies from 1995 to 2010. Of the 40 economies, 21 economies experienced a decline in the share of manufacturing in investment by less than 5 percentage points, and 9 economies by more than 5 percentage points; 24 economies experienced a rise in the share of services by less than 5 percent points, and 12 economies by more than 5 percentage points. The 2016 WIOD dataset covers 43 economies from 2000 to 2014. Of the 43 economies, 21 economies experienced a decline of the share in manufacturing in investment by less than 5 percentage points, and 13 economies by more than 5 percentage points; 20 economies experienced a rise in the share of services by less than 5 percentage points, and 15 economies by more than 5 percentage points. Fig. 6 plots sectoral composition of consumption and investment of the 43 economies against GDP per capita in 1990 international dollars from Maddison Historical Statistics. The share of services in investment rose along with the level of development. The share of manufacturing in investment was negatively correlated with the level of development, which was different from the inverted-U shaped trend of the share of manufacturing in consumption. For most economies, though lower than that in consumption, the share of services in investment was more than 1/3.

2.2. Technological change

The "servicification" of investment in many countries can be largely attributed to the investment-composition technological change that increases the productivity of services in producing investment goods. The development and deployment of information technology may cause such a change. The reason is that it promotes investment in intangibles, and the production of intangible capital takes place primarily in the service sector. Intangibles can be classified into three major types of assets: computerized information, innovative property, and economic competencies (Corrado, Hulten, & Sichel, 2009).[7] Corrado et al. (2009) find that investment on intangibles has increased substantially and promoted economic growth in the recent decades in the United States. A large body of empirical work report similar findings for Canada, Japan, Korea, the United Kingdom and a number of EU countries (Belhocine, 2009; Fukao, Miyagawa, Mukai, Shinoda, & Tonogi, 2009; Marrano, Haskel, and Wallis, 2009; Corrado, Haskel, Jona-Lasinio, & Iommi, 2012; Roth & Thum, 2013; Chun & Nadiri, 2016}. In some emerging markets, such as India and China, investment in intangibles is also found to be important for productivity and growth (De & Dutta, 2007; Hulten & Hao, 2012; Tian, Ni, & Li, 2016).

Based on the definition of intangible capital, we attribute specific industries to intangible-related services in Japan, Korea, and China.[8]Figs. 3–5 also respectively present the share of intangible-related services in investment in each country. They all confirm that the reason for the "servicification" of investment goods is that more activities in services are producing intangibles. The share of intangible-related services rose by 11.8 percentage points in Japan from 1970 to 2012, implying that without the growth of intangible-related services, the share of services would only rise by 2.8 percentage points. The share of intangible-related services rose by 16.2 percentage points in Korea from 1985 to 2014, close to 16.5 percentage points rise of the share of services. The share of intangible-related services in investment rose by 14.0 percentage points in China from 1981 to 2010, more than half the rise of the share of services. Intangible-related services were becoming primary industries that boost the "servicification" of investment. From 1992 to 2010, the share of intangible-related services in investment rose by 8.4 percentage points, together with 1.8 percentage points decline for other services, making the share of services rising by 6.6 percentage points.

Several studies support these findings. A report from World Bank documents the "servicification" of manufacturing, as services are increasingly embodied, either as inputs or as enablers for trade to take place, and embedded, either bundled with or added to manufactured goods, in the manufacturing production (World Bank, 2017). It echoes the "servicification" of investment because a large

[7] Computerized information includes software and database. Innovative property includes R&D, mineral exploitation, copyright and license costs, other product development, design and research expenses. Economic competencies include brand equity, firm-specific human capital, and organizational structure.

[8] For Japan, intangible-related services include advertising, other services for businesses, entertainment, broadcasting, information services and internet-based services, publishing, video picture, sound information, character information production and distribution, education, research. For Korea, Bank of Korea changed the industrial classification in 2005 and in 2010, so our classification of intangible-related services changes accordingly for Korea. But intangible-related services over the whole period largely include communication, information services, software, finance, insurance, business services, education, publishing, and R&D. For China, we attribute five industries out of eleven industries in services in CIP to intangible-related services, which are Information & computer services, Financial intermediations, Leasing, technical, science & business services, Education, Cultural, sports, entertainment services, residential & other services.

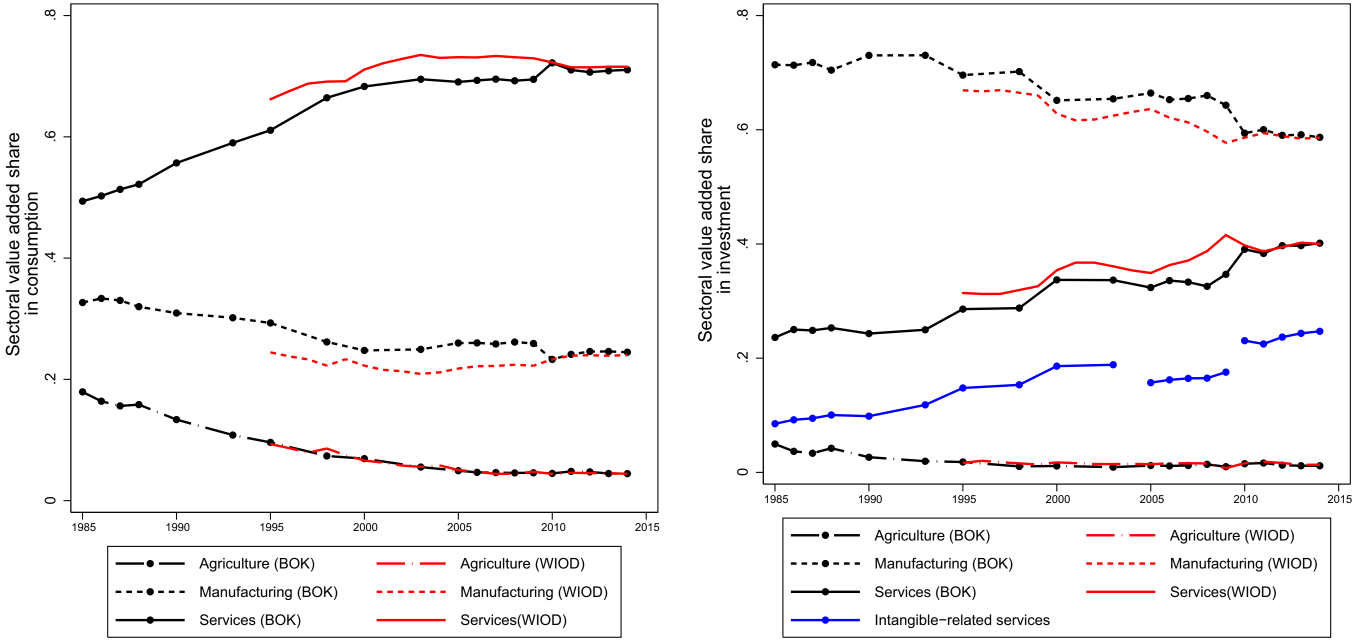

Fig. 4. Sectoral compositions of consumption and investment in Korea.

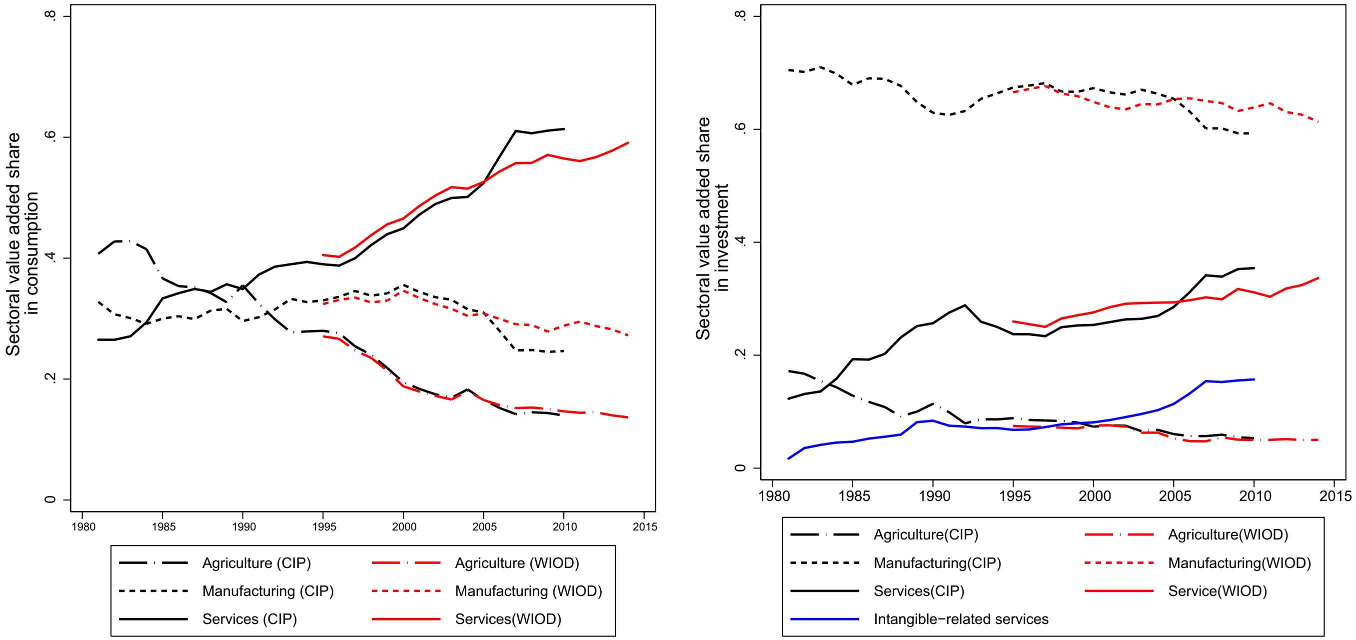

Fig. 5. Sectoral compositions of consumption and investment in China.

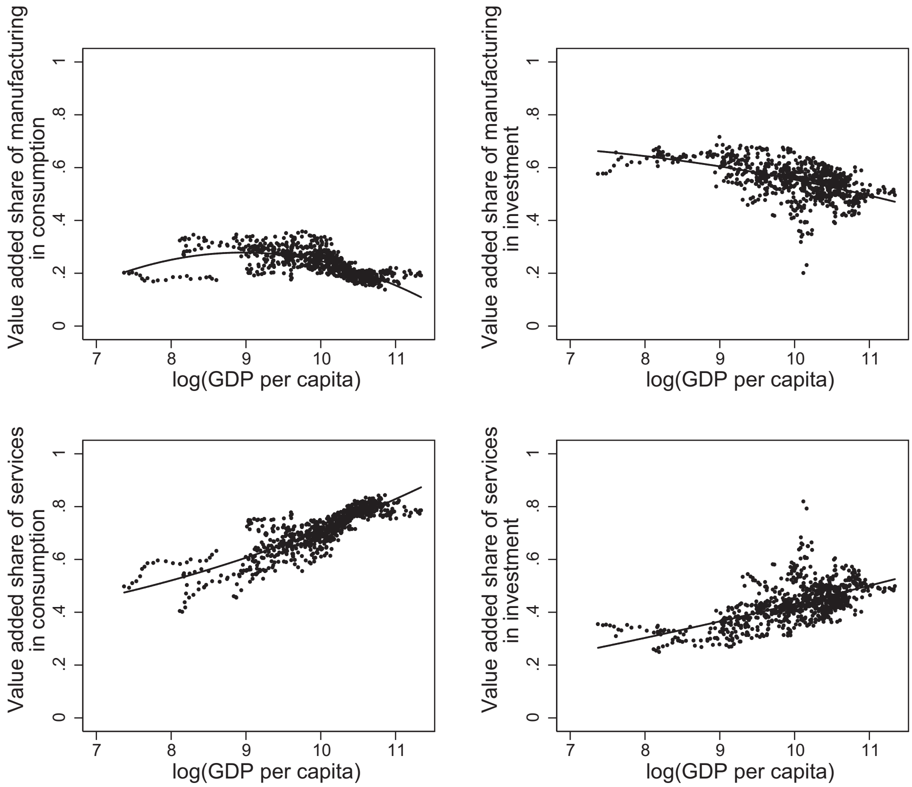

Fig. 6. Sectoral compositions of consumption and investment against the level of development.

part of investment goods are manufactured goods. The report also highlights the information and telecommunication technology as data plays an increasingly important role in smart manufacturing. It notes: "Dramatic changes in ICT have given rise to a category of 'modern' services - financial, telecommunication, and business services - that can be digitally stored, codified, and more easily traded... ICT development also means that scale economies have become important in ICT-enabled service sectors as the marginal cost of providing an additional unit approaches zero."

A report from World Intellectual Property Organization looks at how much income accrues to labor, tangible capital, and intangible capital in global value chain production across all manufacturing activities (World Intellectual Property Organization, 2017). It examines national accounts and international trade statistics from around the world and company data. It finds that intangible capital, such as branding, design and technology, accounted for nearly one third of the total value of manufactured goods sold throughout 2000–2014. The intangible capital share rose from 27.8% in 2000 to 31.9% in 2007, but remained stable since then.

A report from Asia-Pacific Economic Cooperation provides a series of firm-level case studies about a range of manufacturing value chains around the East Asia and Pacific region (Patrick & Pasadilla, 2016). It finds that in the value chain of computer servers, approximately 96 services categories were involved in production. Much of the services were intangible-related services, such as company registration and licensing services, financial services, accounting, auditing and bookkeeping services, information technology services, telecom services, patent, and trademark protection. In the value chains of mining and construction equipment (90 services categories involved), oil and gas industry equipment (94 services categories involved), thermal power generation equipment (74 services categories involved), intangible-related services also played an important role. While the contribution of intangible-related services was not easily quantified, it was surely considerable.

2.3. Accounting results

To further gauge the importance of the "servicification" of investment goods in structural transformation, we decompose changes in sectoral value-added share into changes in the sectoral composition of investment and consumption, and changes in investment rate. Note that if trade is balanced, then the output share of sector j is the weighted average of its share in consumption and investment,

$$s_{jt} = s_{jt}^{c}(1 - i_t) + s_{jt}^{i} i_t \tag{1}$$

where s_{jt} is the value-added share of sector j at time t, s_{jt}^{c} and s_{jt}^{i} are the sectoral shares in consumption and in investment respectively, and i_t is the investment rate. The value-added share of sector j changes over τ periods is given by

$$s_{jt+\tau} - s_{jt} = (1 - i_t)\left(s^c_{jt+\tau} - s^c_{jt}\right) + i_t\left(s^i_{jt+\tau} - s^i_{jt}\right) + \left(s^i_{jt+\tau} - s^c_{jt+\tau}\right)(i_{t+\tau} - i_t) \quad (2)$$

where the three terms on the right-hand side are the changes induced by changes in consumption composition, investment composition, and investment rate respectively.

Table 1 presents the decomposition results for the US, Japan, Korea and China. We subtract net exports from total value-added before decomposition. For the US, because the investment rate was less than 20% for most of the time, changes in sectoral composition of consumption played a major role in the changes in sectoral shares of total value-added. However, changes in sectoral composition of investment and the investment rate together still accounted for 23.8% ((2.5 + 0.9)/14.3) decline in the share of manufacturing in total value-added and 17.8% ((2.9 + 0.9)/21.3) increase in the share of services from 1947 to 2010.

For Japan, Korea and China with high investment rates, the mechanism of investment is much more important. For Japan, changes in the sectoral composition of investment accounted for 23.8% (4.3/18.1) decline in the share of manufacturing and 24.9% (5.8/23.3) increase in the share of services in total value-added from 1970 to 2012. During the same time, the investment rate fell by nearly 20 percentage points, accounting for 39.2% (7.1/18.1) decline in the share of manufacturing and 29.6% (6.9/23.3) increase in the share of services in total value-added. For Korea, though the investment rate in 1985 was almost the same as in 2014, changes in the sectoral composition of investment alone accounted for 40.6% (3.9/9.6) decline in the share of manufacturing and 24.8% (5/20.1) increase in the share of services in total value-added from 1985 to 2014. For China, changes in the sectoral composition of investment and in investment rate were even more important for changes in the share of agriculture in total value-added. They all reduced the share of agriculture by 6.6 percentage points, more than one-quarter (6.6/23.3) of total decline from 1981 to 2014. Because the investment rate was higher in 2014 than in 1981, changes in investment rate prevented manufacturing from declining, the opposite of the changes within consumption and investment. Without changes in investment rate, manufacturing share would decrease by 6.8 percentage points. However, the increase in the investment rate raised manufacturing share by 5.0 percentage points, making the total change of only a 1.9 percentage points decline. For the share of services, changes in sectoral composition of investment played an important role, accounting for nearly 1/3 (8.0/25.2) increase in the share of services.

We also apply the decomposition approach to economies in both the 2013 and 2016 WIOD datasets. We still consider the sum of consumption and investment as total value-added. We calculate the contributions of changes in consumption composition, investment composition and investment rate to the changes in value-added share of services from 1995 to 2014. Though changes in consumption composition were important for changes in services, the role of investment cannot be ignored. The contribution of consumption composition to the changes in services was between 80%–120% in 18 economies. Thus, the investment composition and the investment rate together accounted for more than 1/5 changes in services in the remaining 22 economies, and even more than a half in Austria, Canada, Cyprus, Japan, Korea, Mexico, Malta, Portugal, Slovak, Slovenia, and the United States.

In summary, in this section we find that the "servicification" of investment prevails in many countries. It can be attributed to investment-composition technological change, which promotes investment in intangibles. The accounting exercises show that the mechanism of investment is important for the process of structural transformation, particularly in economies with high investment rates.

3. Model

We now describe a closed economy model that can be used to explore the role of investment in structural transformation.[9] We modify a standard model of structural model as summarized in Herrendorf et al. (2014). Time is discrete, indexed by $t = 0, 1, 2, \ldots$. All markets are competitive. There are three sectors indexed by $j \in \{a, m, s\}$: agriculture, manufacturing, and services. Each sector has a representative firm with access to a Cobb-Douglas production technology,

$$Y_{jt} = A_{jt} K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j} \quad (3)$$

where Y_{jt} is the sectoral output, K_{jt} and L_{jt} are capital and labor input respectively, A_{jt} is the sector-specific productivity, and α_{jt} is sector-specific output elasticity of capital. Each sector's output is used for consumption or as intermediate inputs to produce investment goods. The good market clearing condition is

$$Y_{jt} = C_{jt} + I_{jt} \quad (4)$$

where C_{jt} and I_{jt} are sector-j goods that are respectively used in final consumption and in producing investment goods. Total capital and labor endowment is given by K_t and L_t. We normalize the labor endowment to one. The two resource constraints for capital and labor are given by

$$\sum_j K_{jt} = K_t, \sum_j L_{jt} = 1 \quad (5)$$

[9] A closed economy model is suitable to study China's structural transformation, because though China is a large exporter, the ratio of net export to GDP is less than 5% for most of time. Moreover, the procedure to disaggregate the consumption goods and the investment goods into three sectors has adjusted the data for the difference between the sectoral compositions of exports and imports. See appendix for more detailed information.

Table 1
Decomposition of changes in sectoral output shares.

Country (year)	Sector	Total change	Consumption composition	Investment composition	Investment rate
U.S. (1947–2010)	Agriculture	−7.0	−6.7	−0.4	0.0
	Manufacturing	−14.3	−10.9	−2.5	−0.9
	Services	21.3	17.5	2.9	0.9
Japan (1970–2012)	Agriculture	−5.2	−4.0	−1.4	0.2
	Manufacturing	−18.1	−6.6	−4.3	−7.1
	Services	23.3	10.6	5.8	6.9
Korea (1985–2014)	Agriculture	−10.5	−9.4	−1.2	0.0
	Manufacturing	−9.6	−5.7	−3.9	0.0
	Services	20.1	15.0	5.0	0.0
China (1981–2014)	Agriculture	−23.3	−16.7	−4.5	−2.1
	Manufacturing	−1.9	−3.3	−3.5	5.0
	Services	25.2	20.0	8.0	−2.9

Note: The numbers are in percentage points.

labor is not freely mobile between sectors. We introduce labor market frictions by simply adding wedges that lead to sector-specific wages. On the other hand, capital is assumed to be freely mobile between sectors. The profit maximization problem of a sector-j representative firm is then given by

$$max_{K_{jt},L_{jt}} \quad P_{jt}Y_{jt} - r_tK_{jt} - w_{jt}L_{jt}$$

where P_{jt} is the price of the sector j good, r_t is the rental rate of capital, and w_{jt} is the sector-specific wage rate. As discussed above, sectoral wages are linked to each other through reduced-form wedges

$$w_{at} = \xi_{at}w_{mt}, w_{st} = \xi_{st}w_{mt} \tag{6}$$

where the wedges ξ_{jt} are expressed relative to the manufacturing sector. Let $\xi_{mt} = 1$ for notational purpose. The profit maximization problem leads to the factor demand functions

$$\alpha_jP_{jt}Y_{jt} = r_tK_{jt} \tag{7}$$

$$(1-\alpha_j)P_{jt}Y_{jt} = w_{jt}L_{jt} \tag{8}$$

The investment goods are produced by a representative firm with the following CES technology

$$I_t = A_{It}\left[\theta_{at}^{1/\rho}I_{at}^{(\rho-1)/\rho} + \theta_{mt}^{1/\rho}I_{mt}^{(\rho-1)/\rho} + \theta_{st}^{1/\rho}I_{st}^{(\rho-1)/\rho}\right]^{\rho/(\rho-1)} \tag{9}$$

where ρ is the elasticity of substitution. A_{It} and θ_{jt} respectively represent the factor-neutral and factor-specific productivities, and θ_{jt} add up to one. Investment-composition technological change is reflected by the evolution of A_{It} and θ_{jt}. By assuming an investment goods production function, we deviate from the traditional model where investment is usually assumed to source only from manufacturing. The function is also different from the models in Garcia-Santana et al. (2019) and Herrendorf, Rogerson, & Valentinyi, 2020 by letting the productivities of sectoral inputs change over time.[10]

Profit maximization of the representative investment producer leads to

$$\frac{P_{jt}I_{jt}}{P_{It}I_t} = \frac{\theta_{jt}P_{jt}^{1-\rho}}{\sum_{j'}\theta_{j't}P_{j't}^{1-\rho}} \tag{10}$$

where P_{It} is the price of investment goods,

$$P_{It} = A_{It}^{-1}\left[\sum_j \theta_{jt}P_{jt}^{1-\rho}\right]^{1/(1-\rho)} \tag{11}$$

[10] Changes in θ_{jt} may shift the demand for sectoral output from investment. A main finding in this paper is that such demand shift is important for accounting for structural transformation in investment. We thus allow the sectoral weight to change in the investment production function, different from Garcia-Santana et al. (2019) and Herrendorf, Rogerson, & Valentinyi, 2020, who only consider the price effect. Changes in θ_{jt} also generate an "income effect" that could also be induced by a non-homothetic production function. We choose the current setting mainly for technical reasons: a non-homothetic production function does not have the constant returns to scale property. It is OK if the production function has decreasing returns to scale, but it is problematic if the production function has increasing returns to scale as firms producing the investment good will have negative profit. We avoid this problem by assuming the weights change exogenously. Moreover, we find it difficult to justify the economic meanings of the non-homotheticity in investment production.

There is a representative consumer maximizing discounted life-time utility,

$$\sum_t \beta^t \frac{C_t^{1-\sigma}}{1-\sigma}$$

where $0<\beta<1$ is the discount factor, $\sigma>0$ is the inverse of the intertemporal elasticity of substitution, and C_t is a consumption aggregator,

$$C_t = \left[\omega_a^{1/\epsilon}\left(C_{at}+\overline{C}_a\right)^{(\epsilon-1)/\epsilon} + \omega_m^{1/\epsilon}\left(C_{mt}+\overline{C}_m\right)^{(\epsilon-1)/\epsilon} + \omega_s^{1/\epsilon}\left(C_{st}+\overline{C}_s\right)^{(\epsilon-1)/\epsilon}\right]^{\epsilon/(\epsilon-1)} \tag{12}$$

where ω_j, ϵ and $\overline{C}_j$ are constant. The weight parameters ω_j add up to 1. The elasticity of substitution is determined by ϵ. Including $\overline{C}_j \neq 0$ in preference makes the aggregator non-homothetic, which is emphasized in the literature as a driving force behind structural transformation. The budget constraint for the representative agent is given by

$$\sum_j P_{jt}C_{jt} + P_{It}I_t = r_tK_t + \sum_j w_{jt}L_{jt}$$

Given investment, capital evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t \tag{13}$$

where δ is a constant depreciation rate.

As shown in Herrendorf et al. (2014), the utility maximization problem can be broken into two sub-problems. First, the household solves the intertemporal problem

$$max_{C_t,K_t} \quad \sum_t \beta^t \frac{C_t^{1-\sigma}}{1-\sigma}$$

subject to

$$P_{Ct}C_t + P_{It}K_{t+1} = (1-\delta)P_{It}K_t + r_tK_t + \sum_j w_{jt}L_{jt} + P_{at}\overline{C}_a + P_{mt}\overline{C}_m + P_{st}\overline{C}_s$$

where P_{Ct} is the price of aggregate consumption to be defined below. Solving the intertemporal problem leads to the familiar Euler equation,

$$C_t^{-\sigma} = \beta C_{t+1}^{-\sigma}\frac{P_{Ct}}{P_{Ct+1}}\frac{(1-\delta)P_{It+1}+r_{t+1}}{P_{It}} \tag{14}$$

where $[(1-\delta)P_{It+1}+r_{t+1}]/P_{It}$ is the gross return to investment in money unit, and multiplying it with P_{Ct}/P_{Ct+1} transforms the return into a unit of aggregate consumption. Following Chari, Kehow, & McGrattan (2007) and Cheremukhin et al. (2017), we impose intertemporal wedge ξ_{It} into the Euler equation,

$$\xi_{It} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\frac{P_{Ct}}{P_{Ct+1}}\frac{(1-\delta)P_{It+1}+r_{t+1}}{P_{It}} \tag{15}$$

The second sub-problem is the intratemporal problem allocating aggregate consumption expenditure to different goods,

$$max_{C_{jt}} \quad C_t$$

subject to

$$\sum_j P_{jt}C_{jt} = P_{Ct}C_t - P_{at}\overline{C}_a - P_{mt}\overline{C}_m - P_{st}\overline{C}_s$$

Solving the intratemporal problem, we have

$$\frac{P_{jt}\left(C_{jt}+\overline{C}_j\right)}{P_{Ct}C_t} = \omega_j\left(\frac{P_{jt}}{P_{Ct}}\right)^{1-\epsilon} \tag{16}$$

From these conditions, the price of aggregate consumption is defined as

$$P_{Ct} = \left[\sum_j \omega_j P_{jt}^{1-\epsilon}\right]^{1/(1-\epsilon)} \tag{17}$$

We further use the aggregate consumption as the numeraire in each period, such that $P_{Ct}=1$.

The equilibrium of this economy is defined as a sequence of prices $\{P_{It}, P_{jt}, w_{jt}, r_t\}_{j=a,\ m,\ s}$ and allocation $\{C_{jt}, I_{jt}, K_{jt}, L_{jt}\}_{j=a,\ m,\ s}$ such that (1) Given prices, the household maximizes utility (Eq. (15), (16)); (2) Given prices, the firms maximize profits (Eq. (7), (8), (10); (3) All markets clear (Eq. (3), (4) and (5)); (4)Intersectoral wage differences are determined by exogenous labor market wedges (Eq. (6)); (5) Capital evolves over time according to Eq. (13).

4. Calibration

We now calibrate the model to the Chinese economy from 1981 to 2014. We calibrate the production parameters α_a, α_m, α_s with China's national input-output tables from the National Bureau of Statistics (NBS) in China.[11] $1 - \alpha_j$ corresponds to the labor income share by sector, which does not change much over time. We attribute the average value to the parameters. The calibrated values are 0.114, 0.622, 0.549 for α_a, α_m, α_s respectively.[12] The labor income share was large for agriculture, probably because the NBS distributed the mixed income in agriculture to the labor income, which overestimated the labor income share in agriculture. As a robustness check, we also let $\alpha_a = 0.5$ later.

With the output elasticities, we derive Solow residuals for each sector as our productivity measures. This procedure requires data on real value-added, capital stock, and labor input by sector. The NBS reports sectoral value-added in current price and sectoral value-added index. We normalize the price in 1981 for each sector to one, and compute the price in year t by dividing the growth factor of nominal value-added with the growth factor of the index from year 1981 to year t.[13] The real value-added by sector is the ratio of nominal value-added to the price. For the labor input, we use the employment data from the NBS. The employment series was revised by the NBS at various points of time. These revisions do not go all the way back, so certain inconsistencies exist. We resort to Holz (2006) to form a consistent employment series.[14] We construct data on total capital stock following the perpetual inventory method and then allocate total capital stock to each sector using sectoral capital demand Eq. (7). The procedure also generates nominal rent. We assume that capital depreciates at the rate $\delta = 0.05$. The initial capital stock in 1981 is calculated as the steady state value given the investment in 1981 and the average growth rate of real investment from 1981 to 2000. Sectoral productivities are plotted in the top-left panel of Fig. 7. Consistent with existing results, agricultural TFP experienced a fast growth over the period. The average annual growth rates over the period were larger for agriculture (4.83%) and manufacturing (2.97%), while productivity of services grew slower (0.91%).

Next, we estimate the preference parameters $\left\{\omega_j, \overline{C}_j, \epsilon\right\}$ and investment-composition productivities $\{\theta_{jt}, \rho, A_{It}\}$. For consumption and investment in nominal values, we obtain data on final consumption expenditure and gross capital formation from the NBS, and then divide them by total employment. As explained by Herrendorf et al. (2013), because we define sector-specific production function in the value-added form, it is important to interpret sectoral consumption and sectoral investment as the value-added component of consumption and investment. We have decomposed consumption and investment into their value-added components using the input output tables from WIOD and CIP. As the two data sources mostly trace each other, we merge the data from the two sources. For the overlapping years, the WIOD data is used.

With nominal consumption and investment, sectoral shares and sectoral deflators, we respectively estimate $\left\{\omega_j, \overline{C}_j, \epsilon\right\}$ and $\{\theta_{jt}, \rho\}$ by minimizing the sum of squared deviations between the actual sectoral shares and their counterparts in the model, using eqs. (16) and (10). The estimate of ϵ is 0.884, and the estimates of ω_a, ω_m, ω_s are 0.086, 0.323 and 0.591, respectively. The nonhomothetic parts $\overline{C}_a$ is negative and $\overline{C}_s$ is positive, implying low income elasticity of demand for agricultural goods and high income elasticity of demand for services.[15]

To estimate $\{\theta_{jt}, \rho\}$ in practice, we assume that factor-specific productivities grow at constant rates, or more specifically, we write

$$log\theta_{at} - log\theta_{mt} = \gamma_1 + \gamma_2 t \tag{1.18}$$

$$log\theta_{st} - log\theta_{mt} = \gamma_3 + \gamma_4 t \tag{1.19}$$

where γ_1, γ_2, γ_3, γ_4 are constant.[16] Fig. 8 plots the predicted values of investment compositions. The model can generate changes in sectoral shares of investment in data, with the gap between the predicted values and the data less than 4 percentage points in most

[11] For the period 1981 to 2014, we have input-output information for 1987, 1990, 1992, 1995, 1997, 2000, 2002, 2005, 2007, 2010 and 2012.

[12] We also calculate labor income shares by sector with the input output tables from CIP. The results are similar.

[13] We subtract net exports from total value-added. Specifically, we treat the sum of consumption and investment as total value-added, and then allocate it between sectors by sectoral shares.

[14] The NBS adjusted the employment series with data from 2000 and 2010 population census, but the revisions did not cover years prior to 1990. As a result, the total employment in 1990 is much larger than it is in 1989. Holz (2006) adjusted the pre-1990 total employment series using the 1982 and 1990 population census as anchors, and applied the sectoral employment shares reported by NBS to the revised total employment series. We merge the adjusted pre-1990 sectoral employment data from Holz (2006) with the post-1989 sectoral employment data from the NBS.

[15] We also test the importance of nonhomothetic parts by setting $\overline{C}_j = 0$. As expected, the model then fails to generate the trend of sectoral shares, with the values for agriculture, manufacture and services hovering around 0.25, 0.30 and 0.45. Therefore, the nonhomothetic parts are crucial for the model to capture trend of sectoral composition of consumption.

[16] To guarantee the sum of θ_a, θ_m, θ_s equals one, factor-neutral productivity A_{It} would change accordingly.

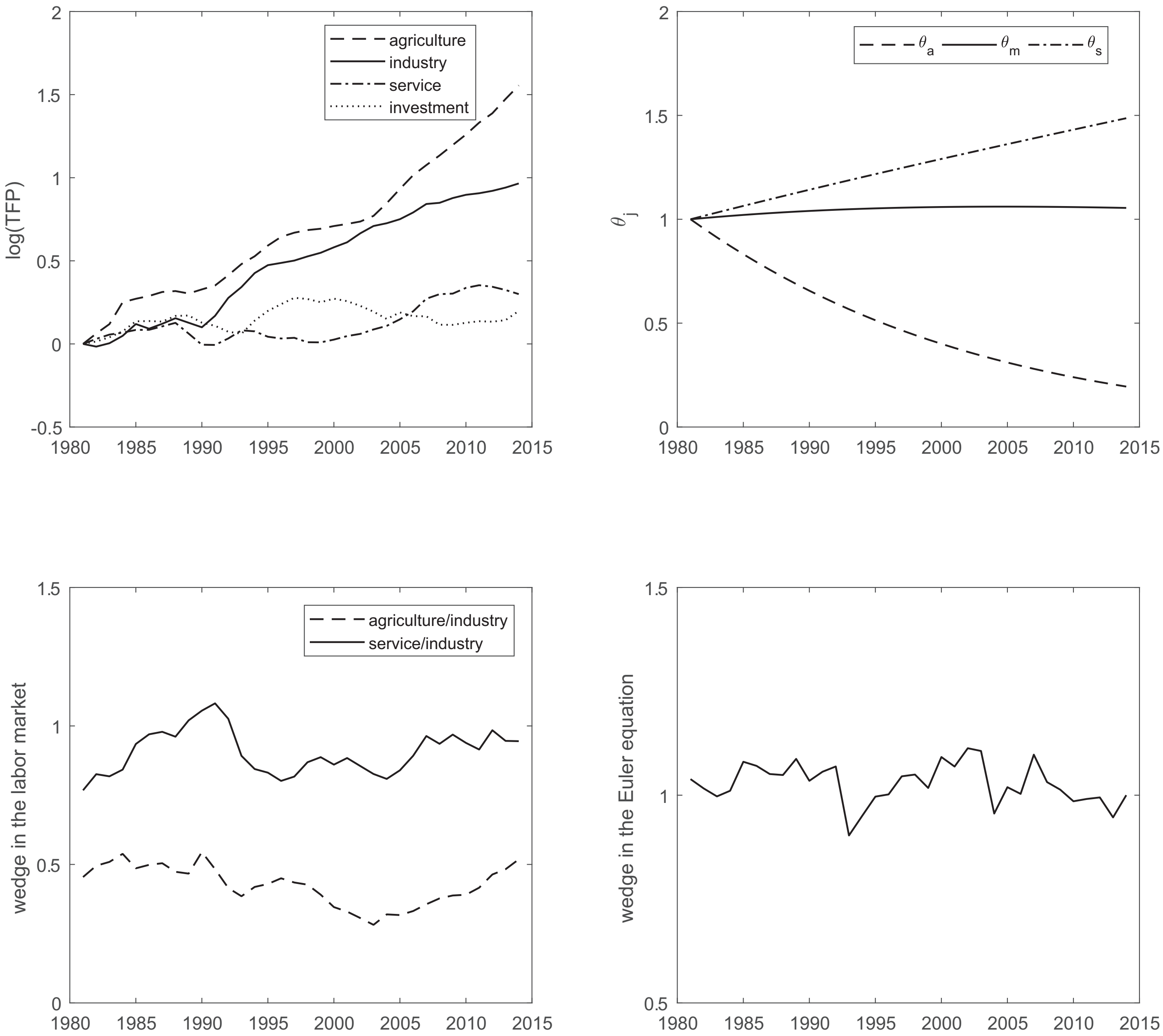

Fig. 7. The evolution of technologies and wedges.

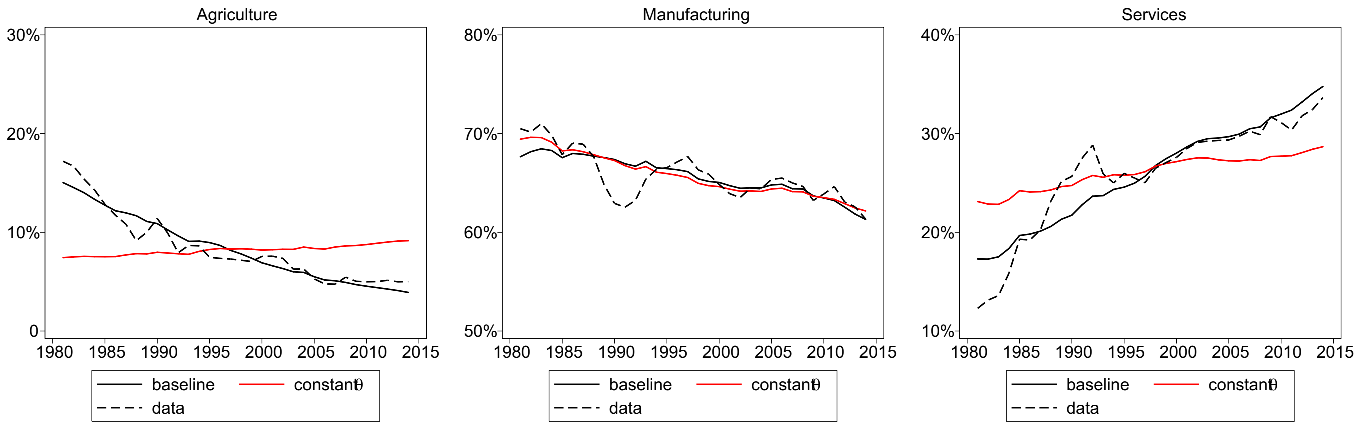

Fig. 8. Sectoral composition of investment: model vs data.

years. The estimate of ρ is 0.528. The estimates of $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ are −1.504, −0.0512, −1.364, and 0.0104 respectively, implying that the annual growth rate of productivity of services is 1.04 percentage points higher than that of manufacturing output and 6.16 higher than that of agricultural output.

Combining Eqs. (1.18), (1.19) and $\sum_j \theta_{jt} = 1$, we calculate θ_j for each year from 1981 to 2014. The top-right panel in Fig. 7 plots the series of θ_j. In the plot we normalize the values in 1981 to one. The diversified growth path of θ_j implies that the relative price of sectoral output cannot explain changes in sectoral composition of investment alone. To test it, we estimate the parameters under the constraint that θ_{jt} is constant, or $\gamma_2 = \gamma_4 = 0$. The predicted values of investment composition are also presented in Fig. 8. It is confirmed that uneven productivity growth of sectoral outputs in producing investment goods is crucial. The fit of the specification without the technological change is much worse. It predicts a 1.7 percentage points increase in the share of agriculture and a 5.6 percentage points increase in the share of services, in contrast to a 12.2 percentage points decrease in the share of agriculture and a 21.4 percentage points increase in the share of services in data. The intuition is straightforward. The relative prices of agriculture and services rise, but the share of agriculture decreases while the share of services increases. The price effect alone cannot explain both.

We calibrate factor-neutral productivityA_{It} in the investment production function to the relative price of investment to consumption. We first obtain the gross fixed capital formation and household final consumption expenditure, both in current price and in constant price, from the World Bank's World Development Indicators (WDI). The deflator of each variables is the ratio of the values in current price to the values in constant price. Following Karabarbounis and Neiman (2014), we compute the relative price of investment to consumption as the ratio of the deflator of fixed capital formation to the deflator of final consumption expenditure. Real consumption is defined as the summation of real sectoral consumption, which is the ratio of the nominal value to the deflator. We divide the nominal consumption by the real consumption to obtain the consumption price. The investment price is then constructed by multiplying the relative price of investment to consumption with the consumption price. We divide the nominal value by the investment price to obtain the real investment, which is used to construct data on real capital, as discussed before. With the real investment, we compute A_{It} using Eq. (9), where I_{jt} is obtained by dividing nominal sectoral value added in investment by the deflator. The logged values are depicted in the top-left panel of Fig. 7. Though experiencing fluctuations in the 1990s, the productivity grew slowly. In 2014, it was merely 10.8% higher than it was in 1981.

With nominal output and labor input by sector, we construct wedges using sectoral labor demand eq. (8) and the definition of wedges (6). The bottom-left panel of Fig. 7 plots the derived labor wedges. The wedge for services hovered around 1, despite big swing in the early years. It became relatively stable in later years. The wedge for agriculture, however, was substantially lower than 1, with a downward trend since the mid-1980s. This was consistent with widening rural-urban income gap, by and large due to the Hukou system that impeded rural-urban migration.

For the intertemporal wedge, we need to construct the consumption aggregator and its price first. The price of the consumption aggregator can be computed by Eq. (17). The consumption aggregator can be derived either by Eq. (12) or by Eq. (16). The results from the two equations are broadly consistent. We use the result from Eq. (16). With the consumption aggregator and its price, the price of investment and the nominal rent, we then compute intertemporal wedge ξ_{It} using Eq. (15). We assume that $\beta = 0.96$ and $\sigma = 1$. The intertemporal wedge is depicted in the bottom-right panel of Fig. 7. The wedge dived in the early 1990s, and then gradually increased before showing a downward trend, implying that there were other forces outside the model that drive the decline of the investment rate in the late 1990s and the rise in the 2000s. The forces may include the soft landing policies in the late 1990s, and the reform in the financial sector in 2000s, as discussed in Song et al. (2011). We summarize the parameter values in the baseline model in Table 2.

5. Quantitative result

We now employ the model to quantitatively assess the role of investment behind China's structural transformation during the reform era.

Table 2
Calibrated parameter values.

Parameters						Calibration target
	α_a 0.114	α_m 0.622	α_s 0.549			Capital income shares by sector
ω_a 0.086	ω_m 0.323	ω_s 0.591	ϵ 0.884	$\overline{C}_a$ −242.1	$\overline{C}_s$ 223.8	Sectoral composition of consumption
γ_1 −1.504	γ_2 −0.0512	γ_3 −1.364	γ_4 0.0104	ρ 0.528		Sectoral composition of investment
		β 0.96				Long-run interest rate per year = 4.2%
		σ 1				Intertemporal elasticity of substitution = 1
		δ 0.05				Holz (2006)

5.1. Baseline

We simulate the model for 300 years. Fig. 9 reports the model dynamics of sectoral shares of employment and output between 1981 and 2014. Although it tends to slightly over-predict the rise of services in late 1990s, the baseline model indeed well captures the trend of China's structural transformation. The differences in employment shares and in output shares between the baseline and data are within three percentage points most of the time. As in Table 3, the baseline predicts a 42.6 percentage points decline of employment share in agriculture, a 15.0 percentage points increase in manufacturing and a 27.6 percentage points increase in services. In data, the changes are −38.6, 11.6 and 27.0 percentage points. For output shares, it predicts a 27.4 percentage points decline in agriculture, a 3.1 percentage points increase in manufacturing and a 24.2 percentage points increase in services. In data, the changes are −23.3, −1.9 and 25.2 percentage points.

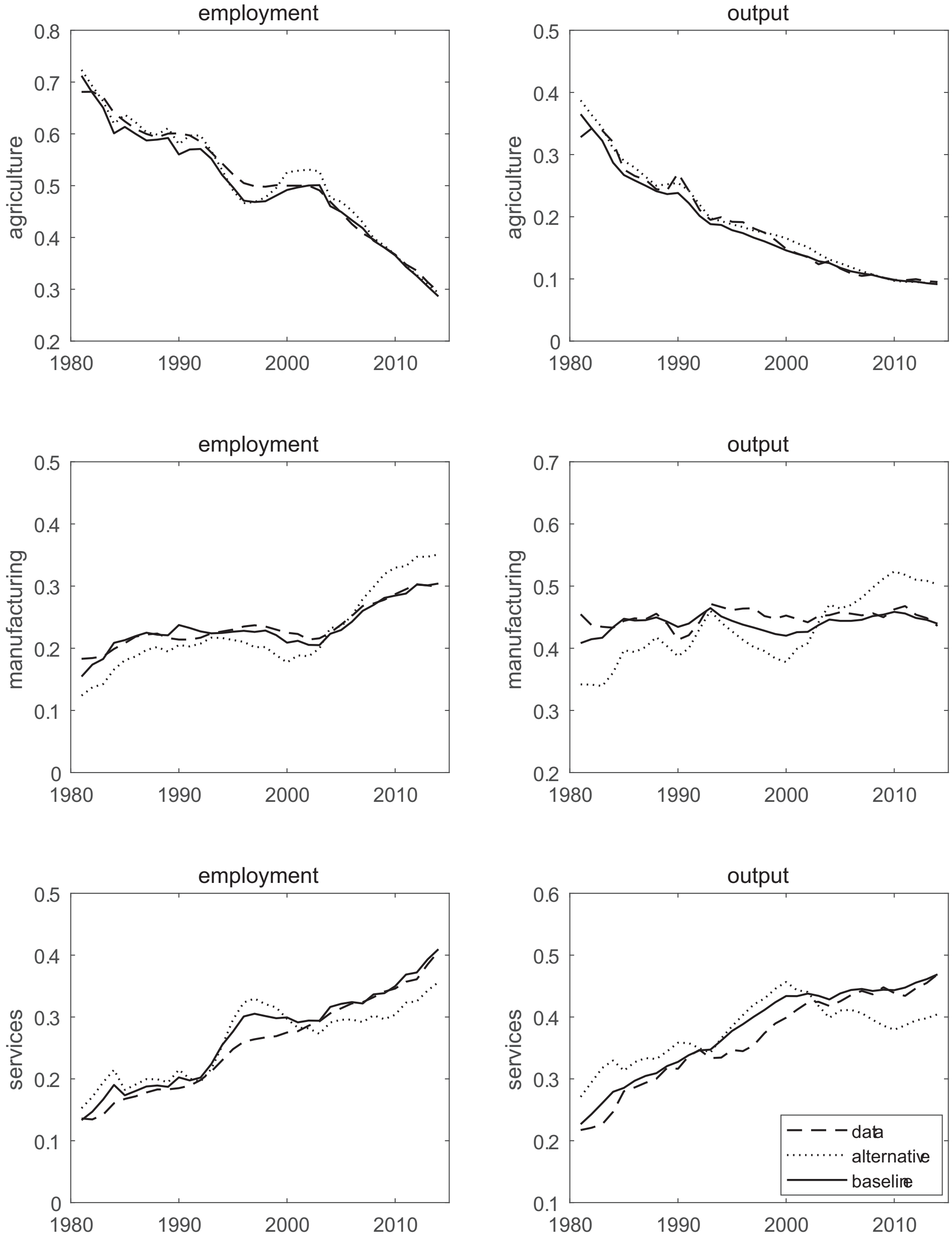

Fig. 9. Sectoral shares of employment and output: baseline.

Table 3
Changes in sectoral shares from 1981 to 2014.

Sector	Employment			Output		
	Data	Baseline	Alternative	Data	Baseline	Alternative
Agriculture	−38.6	−42.6	−43.1	−23.3	−27.4	−29.4
Manufacturing	11.6	15.0	22.7	−1.9	3.1	16.1
Services	27.0	27.6	20.4	25.2	24.2	13.3

Note: The numbers are in percentage points.

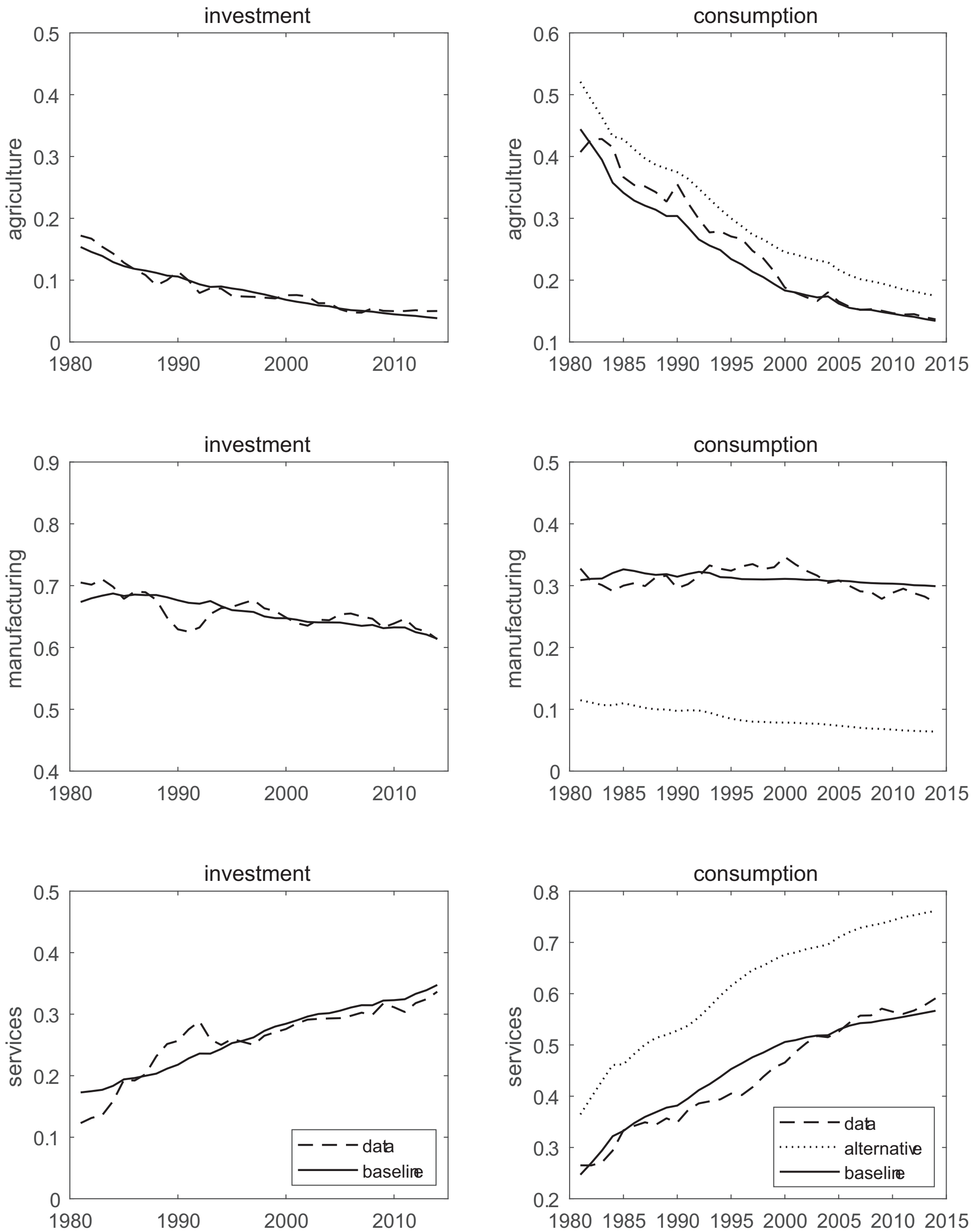

Fig. 10. Sectoral compositions of investment and consumption: baseline.

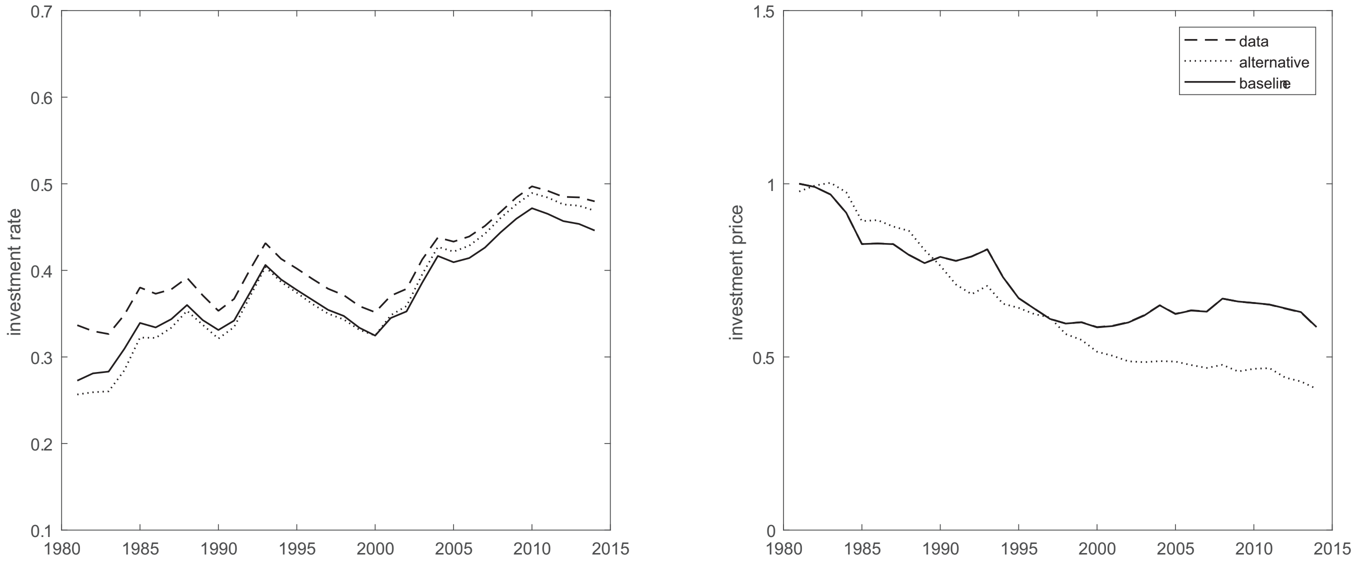

Fig. 11. Investment rate and investment price: baseline.

The fit of the baseline with respect to sectoral compositions of investment and consumption to data is good too, as depicted in Fig. 10. It succeeds in generating the steady decline of agriculture and manufacturing and the rise of services in investment. For sectoral composition of consumption, though the share of agriculture is smaller and the share of services is larger than those in data in most years prior to 2000, the gaps between the model and data are moderate. Fig. 11 plots the investment rate and the investment price. The baseline successfully predicts the fluctuation of investment rate, including the downward trend in the late 1990s and the rise in the 2000s. It also precisely mimics the investment price in data.

To further assess the role of sectoral composition of investment, we remove the investment production function from the model, and instead assume that the investment goods entirely source from the manufacturing sector, as commonly adopted in the literature. Then the real investment is computed as the ratio of the nominal investment to the manufacturing deflator. We again calibrate the preference parameters to sectoral output shares. The sectoral TFPs, the wedges, and the remaining parameters are calibrated by the

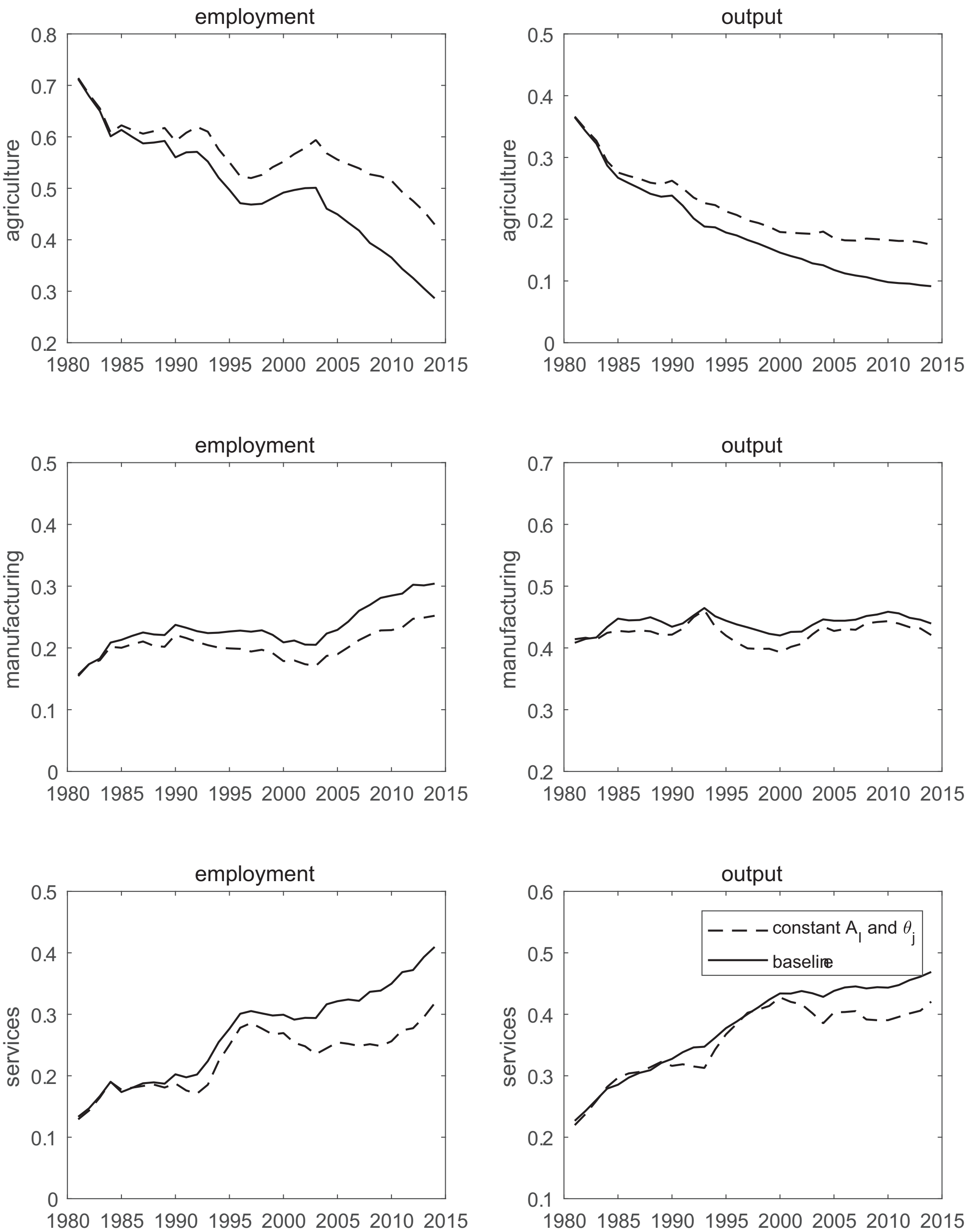

Fig. 12. Sectoral shares of employment and output: investment-composition technology.

same procedure as before.

The results of the alternative model are also presented in Figs. 9–11. Unsurprisingly, by targeting sectoral output shares, the alternative model predicts the composition of consumption far away from data, even when the model still captures the fluctuation of the investment rate well. More importantly, because the manufacturing share in investment is 100% and in consumption is less than 10% in most years, the rise of the investment rate now implies steeper curves of manufacturing share, in terms of either employment or output. As in Table 3, the alternative model predicts a 22.7 percentage points rise of employment share and a 16.1 percentage points rise of output share for the manufacturing sector, more than 10 percentage points away from those in data. Accordingly, it fails to mimic the rise of services, with the predicted rise of the employment share of services to be 6.6 percentage points lower than it is in data, and for the output share, it is 11.9 percentage points lower. The literature traditionally relies on exogenous labor market wedges to explain under-developed services in China. Our results show that the effect of wedges may be bigger than we thought as the model

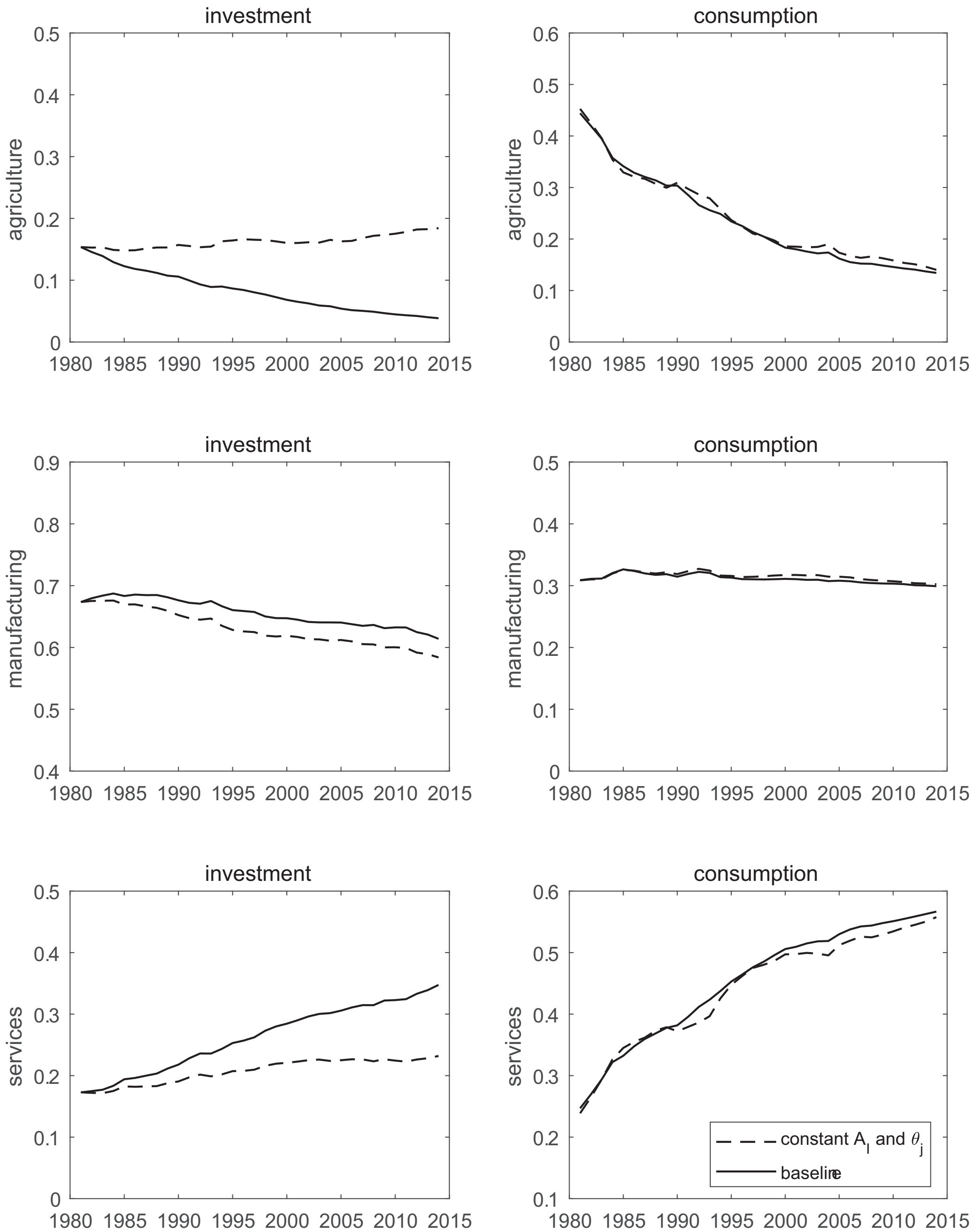

Fig. 13. Sectoral compositions of investment and consumption: investment-composition technology.

without structural transformation in investment over-predicts the rise of manufacturing. Structural transformation in investment undoes part of the rise in manufacturing caused by higher investment rate.

The alternative model also predicts a steeper decline of the investment price because the price of manufacturing good rises slower than the prices of agricultural and services goods. The relative price of investment is stable from 2000 to 2014 in data rather than declining persistently in the alternative model, as the rise of services in investment keeps the relative price of investment from falling.

In summary, the baseline with varying sectoral composition of investment does a better job than the model without it in capturing the process of China's structural transformation and the declining trend of the investment price. Moreover, performing counter-factual experiments on the baseline can quantify the effects of the investment-composition technological change, which is potentially a new force driving structural transformation.

5.2. The effects of investment-composition technology

To investigate the effects of investment-composition technology, we simulate the model under alternative evolution of investment-composition technology. We set investment-composition technology at initial values for all the years, while other technology parameters and wedges remain the same as in the baseline. The differences between the results under the counter-factual experiment and the baseline model reflect the effects of investment-composition technology. We also decompose the effect of investment-composition technology on sectoral output shares by Eq. (2). Figs. 12–13 plot the results. Table 4 reports the decomposition result.

Fig. 12 shows that when the investment-composition technology remains at the initial levels, the shares of manufacturing and services are much smaller and the share of agriculture is much larger in 2014 than those in the baseline. We find that changes in the employment shares in agriculture, manufacturing and services are −28.4, 9.6 and 18.9 percentage points from 1981 to 2014, compared to −42.6, 15.0 and 27.6 percentage points in the baseline. In terms of the output share, the changes are −20.8, 0.7 and 20.1 percentage points, compared to −27.4, 3.1 and 24.2 percentage points in the baseline. Thus, investment-composition technological change accounts for 33.1% (14.1/42.6) decline in employment share and 24.1% (6.6/27.4) decline in output share for the agricultural sector, 36.0% (5.4/15) increase in output share for the manufacturing sector, and 31.5% (8.7/27.6) increase in employment share and 16.9% (4.1/24.2) increase in output share for the service sector.

The effects of investment-composition technology on sectoral shares are substantial because it is a major factor behind the changes in the sectoral composition of investment, as depicted in Fig. 13. When the investment-composition technology is fixed at the initial level, the agricultural share in investment increases by 3.1 percentage points from 1981 to 2014, compared to 11.5 percentage points decline in the baseline. In 2014, the share of manufacturing is 3.0 percentage points lower than it is in the baseline, and the share of services is 11.6 percentage points lower. In contrast, the effects of investment-composition technology on sectoral composition of consumption are limited. Because the productivities of outputs from agriculture and services change at faster rates than the productivity of output from manufacturing in producing investment goods, as depicted in the top-right panel of Fig. 7, the magnitude of the effects of investment-composition technology on the shares of agriculture and services in investment is larger than on the share of manufacturing. It in turn explains why the shares of agriculture and services are more sensitive to investment-composition technology than the share of manufacturing. It is also confirmed in Table 4. Among the mechanisms through which investment-composition technological change affects sectoral output shares, the contributions of the sectoral composition of investment are 60.6% (4.0/6.6) for agriculture, 40.0% (1.0/2.5) for manufacturing and 73.2% (3.0/4.1) for services. In contrast, the effects of the sectoral composition of consumption are negligible.

We also find that as the efficiency in investment production is fixed, the relative price of investment is higher than it is in baseline, which causes a negative effect on the investment rate in most years. However, despite the plunge of the investment rate in the late 1990s, the effects of such mechanism are limited. In 2014, the investment rate is only 2.5 percent lower than that in the baseline. As in Table 4, changes in the investment rate induced by investment-composition technological change play a limited role in changes in sectoral output shares.

Investment-composition technological change pushes the rise of services primarily since 2000. For years prior to 2000, its effect on the share of services is limited. As the two bottom panels in Fig. 12 show, in 2000, the output share of services is only 0.6 percentage points lower than it is in baseline, and the employment share of services is only 3.0 percentage points lower. In contrast, in 2014, the output share of services is 4.8 percentage points lower and the employment share of services is 9.2 percentage points lower than their counterparts in the baseline. Table 4 reports the effects of the technological change in investment from 2000 to 2014, calculated as the differences of changes in sectoral shares between the baseline and the counter-factual results over the period. The technological change in investment increases the output share and the employment share of services by 4.2 percentage points and 6.2 percentage points respectively from 2000 to 2014, close to 4.1 percentage points and 8.7 percentage points from 1981 to 2014. The investment channel is much more important than the consumption channel, because the changes of sectoral output shares due to the changes in the sectoral composition of consumption are less than half a percentage point. Thus, the investment-composition technological change, which raises the relative efficiency of services in producing investment goods, is the key factor behind the catch-up of services in China.

5.3. Robustness check

We examine the robustness of our results to alternative value of output elasticity of labor in agriculture, to different ways of measuring the relative price of investment, and to the incorporation of international trade at sectoral level in this section.

In the first set of robustness check, we let the output elasticity of capital in agriculture $\alpha_a = 0.5$, which is chosen by Brandt and Zhu (2010) and Cheremukhin et al. (2017). We again estimate sectoral capital, sectoral TFP, and wedges that are related to α_a. The model

Table 4
The effects of investment-composition technology on sectoral shares.

Year	Sector	Employment	Output			
		Total	Total	Consumption composition	Investment composition	Investment rate
1981–2014	Agriculture	−14.1	−6.6	−0.3	−4.0	−2.2
	Manufacturing	5.4	2.5	−0.3	1.0	1.7
	Services	8.7	4.1	0.6	3.0	0.5
2000–2014	Agriculture	−8.3	−3.4	0.0	−1.6	−1.9
	Manufacturing	2.2	−0.8	0.3	−0.2	−0.9
	Services	6.2	4.2	−0.4	1.8	2.8

Note: The numbers are in percentage points.

still captures the trends of sectoral shares of employment and output. We repeat the counter-factual experiments. The result shows that investment-composition technological change is still an influential contributor to structural transformation as it changes the sectoral composition of investment, and it increases the share of services mainly after 2000.

In the second set of robustness check, we measure the relative price of investment from the PWT 9.0 and BEA following Restuccia and Urrutia (2001) and Karabarbounis and Neiman (2014). We divide the PWT relative price of investment in China, which is the ratio of the price level of capital formation to the price level of household consumption, by the PWT relative price investment in the U.S. We then multiply this ratio by the ratio of the deflator of gross private domestic investment to the deflator of personal consumption expenditure for the U.S from the BEA. The relative price of investment now exhibits a steeper decline from 1981 to 2014. In 2014, it drops to 24.2% what it is in 1981, compared to 58.9% constructed in the WDI data. We estimate real investment, sectoral capital, sectoral TFP, factor-neutral technology in investment production function, and inter-temporal wedge that are related to the price of investment. The model recovers the process of structural transformation. The results regarding the effects of investment-composition technology barely change. The rising share of services in investment caused by technological change since 2000 is still a major factor pushing the rise of services in total output.

In the third set of robustness check, we incorporate international trade at sectoral level by allowing net export in the good market clearing condition. We take the ratios of domestic absorption to total output by sector to be exogenous, which we construct from CIP and WIOD. We perform the same quantitative exercises as in the baseline model. As the ratios of net export to total output in manufacturing and services are less than 5% for most years, the modified model still fit the data well, with the changes in sectoral shares less than one percentage point from the baseline. Regarding the effects of technological change, the quantitative results also barely change. Thus, the results in the baseline hold when international trade is taken into consideration.

6. Conclusion

The "servicification" of investment induced by investment-composition technological change prevails in many countries. It can be an important reason for the structural transformation and particularly for the rise of services. To assess whether the investment channel is quantitatively significant, we develop a standard model by incorporating an investment production function employing factors from the three broad sectors. We calibrate the model to China's economy.

Sectoral composition of investment in China moved towards services and away from agriculture and manufacturing from 1981 to 2014, with the investment rate at a high level of around 40%. We find that the "servicification" of investment cannot be explained by changes in input prices alone. Investment-composition technological change that requires more services to produce investment goods is a major force, which in turn contributes a lot to the structural transformation out of agriculture during the reform era and the acceleration of services since 2000.

The "servicification" of investment goods occurs not only in China, but also in many other countries in the past decades. Our accounting exercise has revealed that the mechanism of investment is important for the rise of services in some countries. Thus, we conjecture that investment-composition technological change may also be an important force behind structural transformation in countries with high investment rates. Our quantitative exercises should be extended to them further.

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Appendix A. Supplementary data

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