Effects of Infrastructure Investment on Structural Change and Productivity Growth in China

Guo Kaiming (郭凯明)* and Wang Tengqiao (王藤桥)
Lingnan College, Sun Yat-sen University, Guanghzou, China

Abstract: *The rapid growth of infrastructure investment is a salient feature of China's economy since the reform and opening-up in 1978, contributing to not only the aggregate demand but also the structural change and productivity growth on the supply-side. This paper builds a multi-sector general equilibrium model to show how infrastructure investment influences structural change through price, investment and income effects, and influences productivity growth through the intensive and extensive marginal effects. By quantifying the model with China's economy for the period 1981-2017, the paper finds that the infrastructure investment restrained the rise of services, but boosted productivity growth over the period. The policy implication is that China should ramp up infrastructure investment to increase productivity as it pursues high-quality development, but give priority to new infrastructure and public-interest infrastructure to promote industrial structural upgrade.*

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1. Introduction

As a key aspect of China's macroeconomic policy, infrastructure investment has played an irreplaceable role in China's factor-driven economic growth over the past four decades. Yet as development quality takes priority over speed, there has been a rising concern about whether infrastructure investment will continue to drive structural change and productivity growth. This paper attempts to answer this question through theoretical analysis and empirical research.

This paper builds a multisector general equilibrium model that incorporates infrastructure investment. On the demand side, infrastructure investment increases investment demand, while investment and consumption comprise different shares across various sectors. On the supply side, infrastructure investment increases total factor productivity (TFP) and output levels in all sectors by varying degrees. Based on these characteristics, infrastructure investment influences structural change through the price, investment and income effects, respectively, and contributes to productivity growth through the intensive and extensive marginal effects. This paper employs China's macroeconomic data to quantify such effects, and puts forward relevant policy advice.

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* Corresponding author: Guo Kaiming, e-mail: guokm3@mail.sysu.edu.cn

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This paper's contribution are twofold:

(i) It contributes to theoretical research on structural transition from an infrastructure investment perspective. Mainstream theories on structural transition are primarily concerned with the effects of supply-side technology progress, capital deepening and demand preference (Kongsamut *et al*., 2001; Ngai and Pissarides, 2007; Acemoglu and Guerrieri, 2008), and recent studies focus on the effects of international trade and investment (Uy *et al*., 2013; Guo *et al*., 2017; Swicki, 2017), but none of these studies sheds light on the government role. Some studies examine how the market friction of production factors, which may stem from government policy or institutions, influences structural transition (Brandt and Zhu, 2010; Gai *et al*., 2013; Cheremukhin *et al*., 2017), and such studies may indirectly reveal the government role. Dekle and Vandenbrouke (2012) investigates how the government influences structural transition through the capital accumulation effects of taxation, but the model only assumes that the government transfers income to households without discussing the supply-side effects of government spending. This paper introduces government infrastructure investment into the structural transition model to unravel how infrastructure investment influences structural transition on the supply side and the demand side, which marks a marginal contribution to the literature on structural transition.

(ii) This paper builds upon quantitative research on the economic effects of infrastructure investment. The existing literature on this topic is predominantly empirical studies, most of which find that infrastructure exerts significantly positive effects on economic growth, employment and productivity (Zhang *et al*., 2010; Liu *et al*., 2010; Zhang, 2012; Zhou and Zheng, 2012; Wang *et al*. 2014; Tang, 2015; Ouyang and Zhang, 2016; Liao *et al*., 2018). However, these studies are not quantitative analyses at the national level. Jin (2016) and Hu *et al*. (2016) calculate China's infrastructure stock at the national level for growth accounting, but have yet to quantify the underlying theoretical mechanism. With a multi-sector general equilibrium model, this paper conducts a quantitative analysis of infrastructure investment's influence on structural change and productivity growth, which marks a marginal contribution to the literature on infrastructure.

2. Model Framework

Our model comprises two sectors differentiated by subscript $j\in\{0, 1\}$. Each sector contains a representative firm that rents private capital and hires labor for production in a fully competitive market, and the production function satisfies:

$$Y_j = A_j K_G^{\beta_j} K_j^{\alpha_j} L_j^{1-\alpha_j} \tag{1}$$

Where, Y_j is output; K_j and L_j respectively denote private capital and labor; parameter $0< \alpha_j <1$ is the output elasticity of private capital; $1-\alpha_j$ is the output elasticity of labor. $A_j K_G^{\beta_j}$ measures total factor productivity (TFP), where A_j is a technical parameter, and K_G is infrastructure stock. Parameter $\beta_j>0$ measures the extent to which infrastructure influences TFP, which may vary between the two sectors.

We use P_j, r and W_j denote product price, private capital rent, and wage, respectively. By solving the problem of the profit maximization, we obtain the following equations:

$$\alpha_j P_j Y_j = r K_j \tag{2}$$

$$\left(1-\alpha_j\right) P_j Y_j = W_j L_j \tag{3}$$

Where, labor wage may vary between the two sectors, which reflects the existence of labor market frictions.

We use $k_j = K_j / L_j$ denote capital-to-labor ratio. From equations (2) and (3), the relative prices of products from the two sectors can be expressed as:

$$\frac{P_1}{P_0}=\frac{\alpha_0 A_0 k_0^{\alpha_0-1}}{\alpha_1 A_1 k_1^{\alpha_1-1}}K_G^{\beta_0-\beta_1} \tag{4}$$

The demand side of the model comprises consumption demand and investment demand. Consumption demand structure is depicted by a representative consumer, whose utility function is Stone-Geary CES preference, and utility is $\left[\omega_0^{\frac{1}{\varepsilon}}(C_0+\bar{C})^{\frac{\varepsilon-1}{\varepsilon}}+\omega_1^{\frac{1}{\varepsilon}}C_1^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}$. Where, C_0 and C_1 respectively denote the output from the two sectors used for consumption. Parameter $0<\omega_j<1$ is a constant, and $\omega_0+\omega_1=1$; parameter $\varepsilon>0$ is a constant; parameter $\bar{C}\neq 0$ is a constant.

By solving the problem of consumer utility, we may arrive at the sectoral composition of consumption:

$$\frac{P_0C_0}{P_0C_0+P_1C_1}=\frac{\omega_0P_0^{1-\varepsilon}}{\omega_0P_0^{1-\varepsilon}+\omega_1P_1^{1-\varepsilon}}\left(1+\frac{P_0\bar{C}}{P_0C_0+P_1C_1}\right)-\frac{P_0\bar{C}}{P_0C_0+P_1C_1} \tag{5}$$

$$\frac{P_1C_1}{P_0C_0+P_1C_1}=\frac{\omega_1P_1^{1-\varepsilon}}{\omega_0P_0^{1-\varepsilon}+\omega_1P_1^{1-\varepsilon}}\left(1+\frac{P_0\bar{C}}{P_0C_0+P_1C_1}\right) \tag{6}$$

Investment structure is depicted by the production sector of investment goods, in which a representative firm purchases products from the two sectors as intermediate inputs to produce investment goods. Assuming that the production function satisfies Stone-Geary CES technology:

$$I=\left[\theta_0^{\frac{1}{\rho}}(I_0+\bar{I})^{\frac{\rho-1}{\rho}}+\theta_1^{\frac{1}{\rho}}I_1^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} \tag{7}$$

Where, I is the quantity of investment goods. Parameter $0<\theta_j<1$ is a constant, and $\theta_0+\theta_1=1$; parameter $\rho>0$ is a constant; parameter $\bar{I}$ is a constant, and if $\bar{I}\neq 0$, there is a difference in the demand output elasticities of products from the two sectors.

By solving the problem of firm profit maximization, we obtain the sectoral composition of investment and the price of investment goods:

$$\frac{P_0I_0}{P_0I_0+P_1I_1}=\frac{\theta_0P_0^{1-\rho}}{\theta_0P_0^{1-\rho}+\theta_1P_1^{1-\rho}}\left(1+\frac{P_0\bar{I}}{P_0I_0+P_1I_1}\right)-\frac{P_0\bar{I}}{P_0I_0+P_1I_1} \tag{8}$$

$$\frac{P_1I_1}{P_0I_0+P_1I_1}=\frac{\theta_1P_1^{1-\rho}}{\theta_0P_0^{1-\rho}+\theta_1P_1^{1-\rho}}\left(1+\frac{P_0\bar{I}}{P_0I_0+P_1I_1}\right) \tag{9}$$

$$P_I=\left[\theta_0{P_0}^{1-\rho}+\theta_1{P_1}^{1-\rho}\right]^{\frac{1}{1-\rho}} \tag{10}$$

Where, P_I is the price of investment goods, which are used for infrastructure investment I_G and private investment I_P, respectively, i.e.:

$$I=I_G+I_P \tag{11}$$

The sums of private capital and labor employed in the two sectors are equal to private capital stock and total labor supply, respectively:

$$K_0+K_1=K_P \tag{12}$$

$$L_0+L_1=L \tag{13}$$

Where, K_P and L respectively denote private capital stock and total labor supply. The output from each sector from each sector are used for consumption and investment, respectively:

$$Y_j = C_j + I_j \tag{14}$$

Private investment and infrastructure investment are used for the accumulation of private capital and infrastructure stock, i.e.:

$$K_P' = (1 - \delta_P)K_P + I_P \tag{15}$$

$$K_G' = (1 - \delta_G)K_G + I_G \tag{16}$$

Where, δ_P and δ_G respectively denote the depreciation rates of private capital and infrastructure, respectively, and K_P' and K_G' respectively denote private capital stock and infrastructure stock in the next period.

3. Theoretical Analysis

3.1 Model Solution

This paper uses changes in the shares of output and employment in Sector 1 to measure the process of structural change. With equations (6), (9) and (14), it can be learned that the output share φ in Sector 1 is the weighted average between the share of Sector 1 in consumption and the share of Sector 1 in investment , and the weights are consumption rate and investment rate, respectively, i.e.:

$$\varphi = \frac{P_1Y_1}{P_0Y_0+P_1Y_1} = (1-s)\frac{(1+Z_C)\Phi_C}{(1+Z_C)\Phi_C+1} + s\frac{(1+Z_I)\Phi_I}{(1+Z_I)\Phi_I+1} \tag{17}$$

Where, s denotes investment rate, i.e.:

$$s = \frac{P_0I_0+P_1I_1}{P_0Y_0+P_1Y_1} \tag{18}$$

Z_C and Z_I respectively denote the relative size of non-homothetic terms in the utility function of consumption and the production function of investment, and satisfy:

$$Z_C = \bar{C}/C_0 \tag{19}$$

$$Z_I = \bar{I}/I_0 \tag{20}$$

Φ_C and Φ_I respectively capture the effects of relative price factor on the composition of consumption and investment, and satisfy:

$$\Phi_C = \frac{\omega_1}{\omega_0}\left(\frac{P_1}{P_0}\right)^{1-\varepsilon} = \frac{\omega_1}{\omega_0}\left(\frac{\alpha_0}{\alpha_1}\right)^{1-\varepsilon}\left(\frac{A_0}{A_1}\right)^{1-\varepsilon}K_G^{(\beta_0-\beta_1)(1-\varepsilon)}\left(\frac{k_1^{1-\alpha_1}}{k_0^{1-\alpha_0}}\right)^{1-\varepsilon} \tag{21}$$

$$\Phi_I = \frac{\theta_1}{\theta_0}\left(\frac{P_1}{P_0}\right)^{1-\rho} = \frac{\theta_1}{\theta_0}\left(\frac{\alpha_0}{\alpha_1}\right)^{1-\rho}\left(\frac{A_0}{A_1}\right)^{1-\rho}K_G^{(\beta_0-\beta_1)(1-\rho)}\left(\frac{k_1^{1-\alpha_1}}{k_0^{1-\alpha_0}}\right)^{1-\rho} \tag{22}$$

With equations (3) and (17), it can be learned that the employment share of Sector 1 ϕ satisfies:

$$\phi = \frac{L_1}{L_0+L_1} = \frac{(1-\alpha_1)\xi\varphi}{(1-\alpha_0)(1-\varphi)+(1-\alpha_1)\xi\varphi} \tag{23}$$

Where, $\xi = W_0/W_1$ is the labor wage ratio between the two sectors.

Aggregate labor productivity γ is the weighted average of labor productivity in both sectors with the employment share as the weight, i.e.:

$$\gamma = y_0(1-\phi) + y_1\phi \tag{24}$$

Where, $y_j = A_j K_G^{\beta_j} k_j^{\alpha_j}$ is the labor productivity of sector j.

3.2 Infrastructure Investment's Effects on Structural change

Based on equation (17), infrastructure investment may influence structural change through price, investment and income effects. First, infrastructure investment influences structural change by improving the level of infrastructure. Yet since infrastructure's productivity effects vary across sectors, improving the level of infrastructure will change the relative prices of sectoral output, thus affecting the sectoral composition of consumption and investment. In equation (17), the price effect influences Φ_C and Φ_I.

Specifically, if infrastructure's productivity effect for Sector 1 outweighs the effect for Sector 0, productivity will increase faster in Sector 1, causing Sector 1's relative prices to fall. In this case, both consumers and producers of investment goods will use cheaper products from Sector 1 to substitute products from Sector 0. If the substitution elasticity of products from the two sectors is low, i.e. it is hard to substitute products from Sector 0 with those from Sector 1, there will still be an increasing demand for products from Sector 1, but the increase will be limited. Hence, the falling relative price will play a dominant role, causing a decrease in the share of total spending in Sector 1. If the elasticity of substitution between the output from the two sectors is high, i.e. the output from Sector 1 may largely substitute those from Sector 0, there will be a substantial increase in the demand for the output from Sector 1, thus driving up the share of spending in Sector 1. Otherwise, if infrastructure's productivity effect is greater for Sector 0, the direction of the above-mentioned effects will be reversed.

The mechanism is revealed by equations (21) and (22). If infrastructure increases TFP more proportionately in Sector 1, i.e. $\beta_0 < \beta_1$, then $\partial\Phi_C/\partial K_G < 0 \Leftrightarrow \varepsilon < 1$, and $\partial\Phi_I/\partial K_G < 0 \Leftrightarrow \rho < 1$. When the elasticity of substitution between sectoral output for consumption ε is smaller than 1, a rise in the level of infrastructure will reduce the share of Sector 1 in consumption , and vice versa. When the elasticity of substitution ρ from the sectors in investment is smaller than 1, an increase in the level of infrastructure will reduce the share of Sector 1 in investment, and vice versa. If $\beta_0 > \beta_1$, the direction of this effect will be reversed. Notably, if one of the elasticities of substitution between sectoral output for consumption or investment is greater than 1 while the other is smaller than 1, infrastructure investment will exert an opposite influence on the sectoral composition of consumption and investment through its price effect. At this moment, the direction of the overall effect is uncertain. Only when the elasticities of substitution between sectorl output for consumption and investment are both greater or smaller than 1 will infrastructure investment exert a clear direction of price effect.

Second, infrastructure investment influences structural change through the investment effect. By raising the investment rate, infrastructure investment induces an expansion in the sector that accounts for a higher share in investment than its share in consumption. In equation (17), the investment effect influences s.

Specifically, the output share of Sector 1 is the weighted average between the share of Sector 1 in consumption and the share of Sector 1 in investment, and the weights are consumption rate and investment rate, respectively. If the share of Sector 1 in investment is greater than the share of Sector 1 in consumption, after infrastructure investment increases the investment rate, the output share of Sector 1 will rise due to the rising investment rate. On the contrary, if the share of Sector 1 in investment is smaller than its share in consumption, the direction of this effect will be reversed.

The mechanism is revealed in equation (17). The share of Sector 1 in consumption and its share in investment are $(1+Z_C)\Phi_C/[(1+Z_C)\Phi_C+1]$ and $(1+Z_I)\Phi_I/[(1+Z_I)\Phi_I+1]$, respectively, and $\partial\varphi/\partial s < 0 \Leftrightarrow (1+Z_C)\Phi_C > (1+Z_I)\Phi_I$. When $(1+Z_C)\Phi_C > (1+Z_I)\Phi_I$, i.e. the share of Sector

1 in investment is smaller than its share in consumption, an increase in investment rate driven by infrastructure investment will reduce the output share of Sector 1, and vice versa. Notably, the infrastructure investment effect depends on the difference between the sectoral compositions of investment and consumption since if there is no difference between the two, the investment effect will not exist.

Lastly, infrastructure investment influences structural change through income effects. By raising the level of infrastructure, infrastructure investment will promote productivity growth and increases in aggregate consumption and investment. Because the income elasticities in consumption or the output elasticities in investment are different between sector ouput, the sectoral compositions of consumption and investment will change with the increase of aggregate consumption and investment, respectively, thus driving structural change. In equation (17), the price effect influences Z_C and Z_I.

Specifically, if the income elasticity of consumption is greater in Sector 1 than in Sector 0, there will be a more significant increase in the relative demand for the Sector 1's output to Sector 0's output, and vice versa. Similarly, if the output elasticity of investment demand is greater in Sector 1 than in Sector 0, there will be a rise in the share of Sector 1 in investment as infrastructure investment drives up aggregate investment level, and vice versa.

The mechanism is revealed by in equations (19) and (20). As can be seen from the equations, $\partial Z_C/\partial C_0 > 0 \Leftrightarrow \bar{C} < 0$ and $\partial Z_I/\partial I_0 > 0 \Leftrightarrow \bar{I} < 0$. When $\bar{C} < 0$, the income elasticity of Sector 1's outpu in consumption is larger than Sector 0, Z_C will rise with the increase of C_0, causing the share of Sector 1 in consumption to rise. On the contrary, when $\bar{C} > 0$, the share of Sector 1 in consumption will decrease with the rise of C_0. When $\bar{I} < 0$, the output elasticity of investment demand is higher in Sector 1 than in Sector 0, Z_I will increase with the rise of I_0, resulting in an increase in the share of Sector 1 in investment. On the contrary, when $\bar{I} > 0$, the share of Sector 1 in investment will decrease with the rise of I_0.

3.3 Productivity Effects of Infrastructure Investment

According to equation (24), infrastructure investment influences aggregate labor productivity through its effects on labor productivity and employment share in each sector. By raising the level of infrastructure, infrastructure investment increases labor productivity in each sector, we call it intensive marginal effect; on the other hand, infrastructure investment changes the employment share in each sector, i.e. the weight of a sector's labor productivity in aggregate labor productivity. We call it extensive marginal effect. The direction of infrastructure investment's extensive marginal effect depends on the process of structural change. If infrastructure investment induces an increase in the employment share in the more productive sector, aggregate labor productivity will rise, and vice versa.

The mechanism is revealed by equation (24). As can be learned from equation (24), $\partial \gamma/\partial y_j > 0$, and $\partial \gamma/\partial \phi > 0 \Leftrightarrow y_1 > y_0$. It can be learned that since $\partial y_j/\partial K_G > 0$, infrastructure investment's intensive marginal effect increases aggregate labor productivity. Moreover, infrastructure investment's extensive marginal effect may be further decomposed into effect on labor productivity y_0 in Sector 0 and effect on labor productivity y_1 in Sector 1. The direction of infrastructure investment's extensive marginal effect depends on the process of structural change. If $y_1 > y_0$, i.e. Sector 1 is more productive than Sector 0, the employment share of Sector 1 ϕ will increase, thus driving aggregate labor productivity, and vice versa.

4. Quantitative Analysis

4.1 Parameter Calibration and Estimation

This section corresponds Sector 1 and Sector 0 in the theoretical model to the service sector and the industrial and agricultural sector for a quantitative analysis, respectively, and the industrial and agricultural sector is the sum of primary and secondary industries. The dataset convers the period 1981-2017.

The National Bureau of Statistics (NBS) has released the nominal value-added and value-added index for the primary, secondary and tertiary industries. By dividing the ratio between each industry's nominal value-added and nominal value-added in 1981 by the ratio between the value-added index of each industry and the value-added index of 1981, we obtain the price level of each industry. Then, the nominal value-added of each industry is divided by price to obtain the real value-added of each industry. The sum of nominal value-added in primary and secondary industries and the sum of real value-added are identified as the nominal and real output of the industrial and agricultural sector, respectively, and the nominal and real value-added of tertiary industry are identified as the nominal and real output of the service sector, respectively. Dividing the nominal output of both sectors by the real output gives us the price level.

The NBS has published employment data for the primary, secondary and tertiary industries, but due to several adjustments for the employment data, there is a significant increase in China's total employment in 1990 over 1989. Therefore, the employment data for 1981-1989 is from Holz (2006), and employment data since 1990 is from the NBS. By aggregating employment data in the primary and secondary industries, we obtain aggregate employment for the industrial and agricultural sector, and define employment in tertiary industry's total employment in the service sector.

The NBS-released total capital formation is total investment, which includes infrastructure and private investments. Capital formation needs to be further decomposed into these two types of investment, which requires data about total investment in fixed assets. We define infrastructure investment rate as the ratio of the fixed asset investment in the three sectors - "electric power, heat, fuel gas and water production and supply," "transportation, warehousing and postal service" and "water conservancy, environmental and public facilities management" - to the total fixed assets investment. This percentage is multiplied by total capital formation to arrive at infrastructure investment. Total capital formation minus infrastructure investment is private investment. Nominal investment divided by investment price is actual investment. Among them, investment price is calculated with equation (10). Based on infrastructure investment and private investment data, we set the annual depreciation rate to be 10%, and calculate infrastructure stock and private capital stock with the perpetual inventory method, respectively.

We assign the value of 0.5 to the parameters α_0 and α_1 in the production function of both sectors, i.e. both private capital and labor incomes account for 50% in each sector. Based on equation (2), we allocate total private capital to the two sectors to obtain private capital in each sector. By substituting the actual output, private capital and labor data of the two sectors into the production function equation (1), we may calculate each sector's TFP in each year.

According to Wu *et al*. (2019), the output elasticity of China's productive infrastructure is roughly in the range between 0.05 and 0.15. Jin (2016) finds that the output elasticity of China's infrastructure is around 0.1. Therefore, we set the output elasticity of the industrial and agricultural sector to be 0.05. Then, we conduct a linear least square regression of the logarithm of the TFP ratio between the service sector and the industrial and agricultural sector with respect to the logarithm of infrastructure stock. The estimation coefficient of the logarithm of infrastructure stock is the estimated difference between β_1 and β_0. This estimation result is 0.094, which means that infrastructure's effects on service sector TFP are greater than its effects on the industrial and agricultural sector.

To estimate parameters in the consumption utility function and investment production function, we also need to create the sectoral composition data of total consumption and total investment, the sectoral composition of consumption, and the sectoral composition of investment. We multiply the NBS-released consumption rate data by GDP to obtain total consumption, and subtract total consumption from total

Table 1: Model Parameter Values

Sector Production function	Parameter	β_0	β_1	α_0	α_1
	Value	0.050	0.144	0.500	0.500
Consumption Utility function	Parameter	ω_0	ω_1	ε	$\bar{C}$
	Value	0.618	0.382	0.027	-1143
Investment Production function	Parameter	θ_0	θ_1	ρ	$\bar{I}$
	Value	0.722	0.278	0.760	-927

GDP to obtain total investment. Both total consumption and total investment are nominal values.

There is no data directly related to the sectoral composition of consumption and investment measured from the value-added perspective. With Yan *et al.*'s (2018) method, this paper decomposes consumption and investment into the two sectors based on China's input-output tables from China's Industrial Productivity Database (CIP) and the World Input-Output Database (WIOD). Since the WIOD's calculation results are more accurate, we adopt the results calculated with the latest WIOD for each pair of two years with overlapped data sources. Our calculation results suggest that services account for a significantly higher share in consumption than in investment.

With the share of services in consumption and investment, the price levels of the service sector and the industrial and agricultural sector, total nominal consumption and total nominal investment data, we conduct a feasible generalized least square non-linear estimation of equations (6) and (9). Estimation results suggest that the model's predicted values are very close to actual data - their difference is smaller than three percentage points for most years.

In the consumption utility function, the elasticity of substitution between products from the two sectors is 0.027, which is close to 0, i.e. the outputs from the two sectors are highly complementary with each other. In the investment production function, the elasticity of substitution between products from the two sectors is 0.760, which is significantly greater than 0. This estimate is higher than the elasticity of substitution in the utility function, but still relatively low. The non-homothetic terms of consumption utility function and investment production function and are both significantly lower than zero, indicating that the income elasticity of consumption demand and the output elasticity of investment demand are both smaller than those of the service sector. Parameters that determine the weights of products from the two sectors in the consumption utility function and the investment production function are also both significant, and this result is consistent with expectations. Table 1 presents the values of all model parameters.

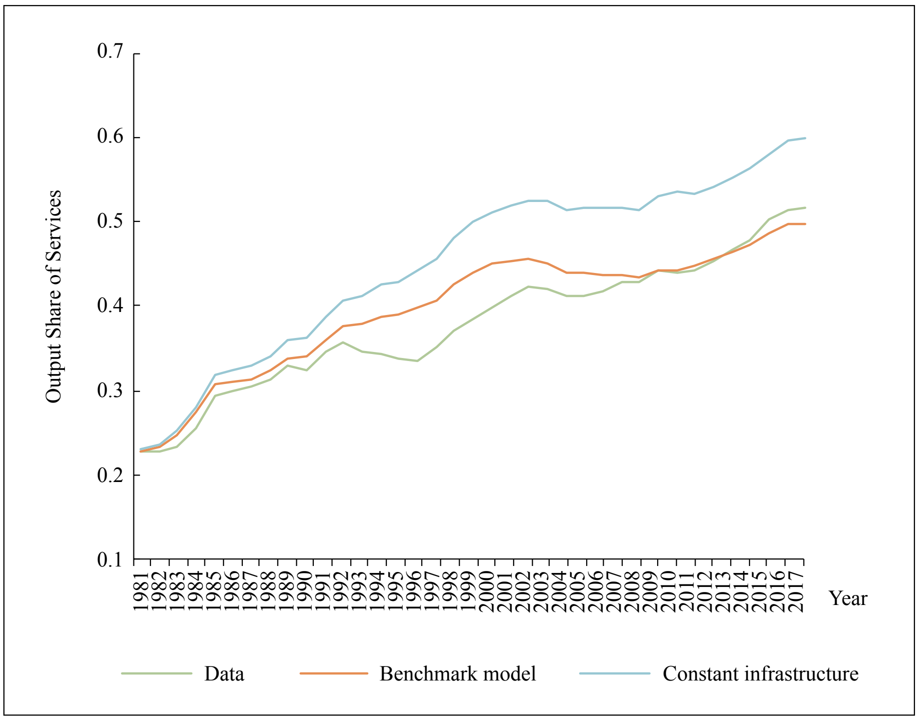
4.2 Results of the Benchmark Model

Based on the parametric values in Table 1, we conduct a numerical simulation of the model. First, we generate an exogenous variable sequence. Specifically, we calculate Z_C and Z_I with equations (19) and (20) based on the estimated $\bar{C}$ and $\bar{I}$ and the actual data of industrial and agricultural consumption and investment. We divide private capital in both sectors by employment to arrive at k_j. With equation (1), we calculate A_j directly, and then the growth rate of A_0/A_1 from actual data. The value of A_0/A_1 for 1981 in the model is calibrated to make the predicted share of the service sector in 1981 identical with data. Afterwards, we generate the A_0/A_1 sequence with the growth rate of in each year's data and the calibrated value of A_0/A_1 for 1981. With the nominal value-added and employment data of the two sectors, we directly calculate the nominal wage through equation (3) before generating the labor wage ratio ξ.

With the exogenous variable sequence, we calculate the shares of output and employment in the service sector with equations (17) and (23), and calculate labor productivity with equation (24). The results are referred to as benchmark model results. Figure 1 compares the benchmark model results with the service sector ratio and labor productivity in data, and Table 2 reports relevant quantitative analysis results.

As can be seen from Figure 1 and Table 2, the model well fits the rising trends of the shares of output and employment of the service sector. Except for an error of around five percentage points between the benchmark model and data for the mid- and late 1990s, errors for other periods are all smaller than four percentage points. In the benchmark results, the shares of service sector output and employment increase by 26.9 and 29.4 percentage points over the period 1981-2017, respectively, and the actual increases are 28.9 and 31.3 percentage points, respectively. That is to say, the model accounts for 93.1% (i.e. 26.9/28.9) of the output share of services and 93.9% of the employment share of services (29.4/31.3). As can be seen from the share of services in consumption and investment, the model also well fits the structural change of consumption and investment. In the benchmark model, the share of services in consumption and investment increases by 36.2 and 20.3 percentage points, respectively, and the actual increases are 33.6 and 20.0 percentage points, respectively. That is to say, the benchmark results are very close to data.

With respect to labor productivity, the model well fits the process of productivity growth. According to the benchmark results, China's aggregate labor productivity increases by 20.05 times over the period 1981-2017, and the actual increase is 19.79 times. Obviously, the two figures are very close to each other. In all the years, the errors between the benchmark results and data of aggregate labor productivity are all smaller than the absolute level of labor productivity in 1981.



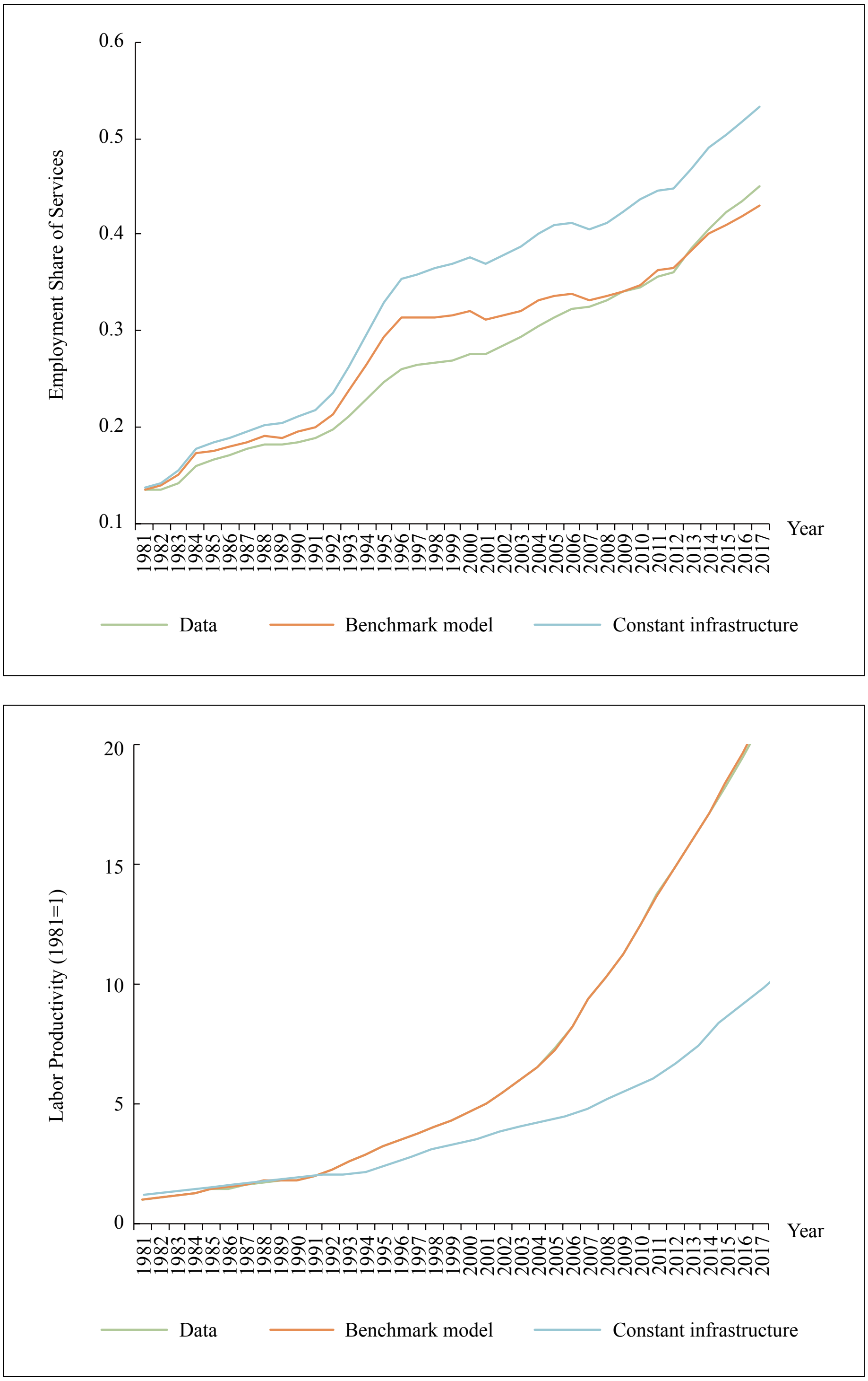


Figure 1: Numerical Simulation Results of Structural Change and Productivity Growth

Table 2: Model Estimates vs. Actual Data of Structural Change and Productivity Growth

	Changes in output share of services	Changes in employment share of services	Changes in the share of services in consumption	Changes in the share of services in investment	Changes in labor productivity
Data	28.9%	31.3%	33.6%	20.0%	19.79
Benchmark model	26.9%	29.4%	36.2%	20.3%	20.05
Constant infrastructure	36.9%	39.5%	44.8%	22.4%	12.94

Notes: Change in the share of services is the difference between the share in 2017 and the share in 1981; productivity change is the times of productivity growth by 2017 over 1981.

4.3 Counterfactual Simulation

This section evaluates the effects of infrastructure investments through a counterfactual simulation. By fixing the infrastructure stock of various years at the level of 1981, i.e. infrastructure investment is only used to compensate for depreciation, we calculate the infrastructure investment and investment rate of various years. Then, we calculate the actual output of the industrial and agricultural sector with equation (1), and decompose the actual output into the sector's actual consumption and actual investment, which gives us the relative size of the non-homothetic terms in the consumption utility function and the investment production function for various years. Following the benchmark model's calculation process, we obtain the service sector's share and labor productivity at this moment with relevant results shown in Figure 1 and Table 2. The difference between the counterfactual simulation result and the benchmark model result reflects infrastructure investment's effects.

First, let us look at the structural change effects of infrastructure investment. As can be learned from Figure 1 and Table 2, the shares of employment and output of the service sector have both increased substantially under counterfactual simulation, reaching 59.9% and 53.3% by 2017, respectively, or 10.3 and 10.3 percentage points higher than the benchmark results. That is to say, China's infrastructure investment has restrained the increase of the shares of employment and output of the service sector for the period 1981-2017. Given the actual increases of the shares of employment and output of the service sector by 26.9 and 29.4 percentage points, respectively, infrastructure investment has restrained the increase in the output share of the service sector by 27.7% (10.3/(10.3+ 26.9) and the increase in the employment share of the service sector by 25.9% (i.e., 10.3/(10.3+29.4), so the influences are highly significant. The shares of services in consumption and investment have increased by 44.8 and 22.4 percentage points under counterfactual simulation, respectively. Compared with the benchmark results, it can be learned that infrastructure investment has reduced the shares of services in consumption and investment by 8.6 and 2.2 percentage points, respectively. Obviously, the impact on the sectoral composition of consumption is higher than the impact on the sectoral composition of investment.

This paper further decomposes the total effects into the price, investment and income effects. Figure 2 shows the trend of the three effects over the years. The income, investment and price effects of infrastructure investment share similar trends no matter measured by the output share or the employment share of services. The income effect has increased the share of services, and the increase is in an inverted U-shaped trend. While the investment and price effects have both reduced the share of services, the magnitude of the price effect is slightly larger than that of the investment effect. Despite the short-term economic shock during 2008-2009, which led to volatility in the investment effect, the impacts of investment and price effects have been increasing.

Table 3 identifies infrastructure investment's effects on the share of the service sector over different

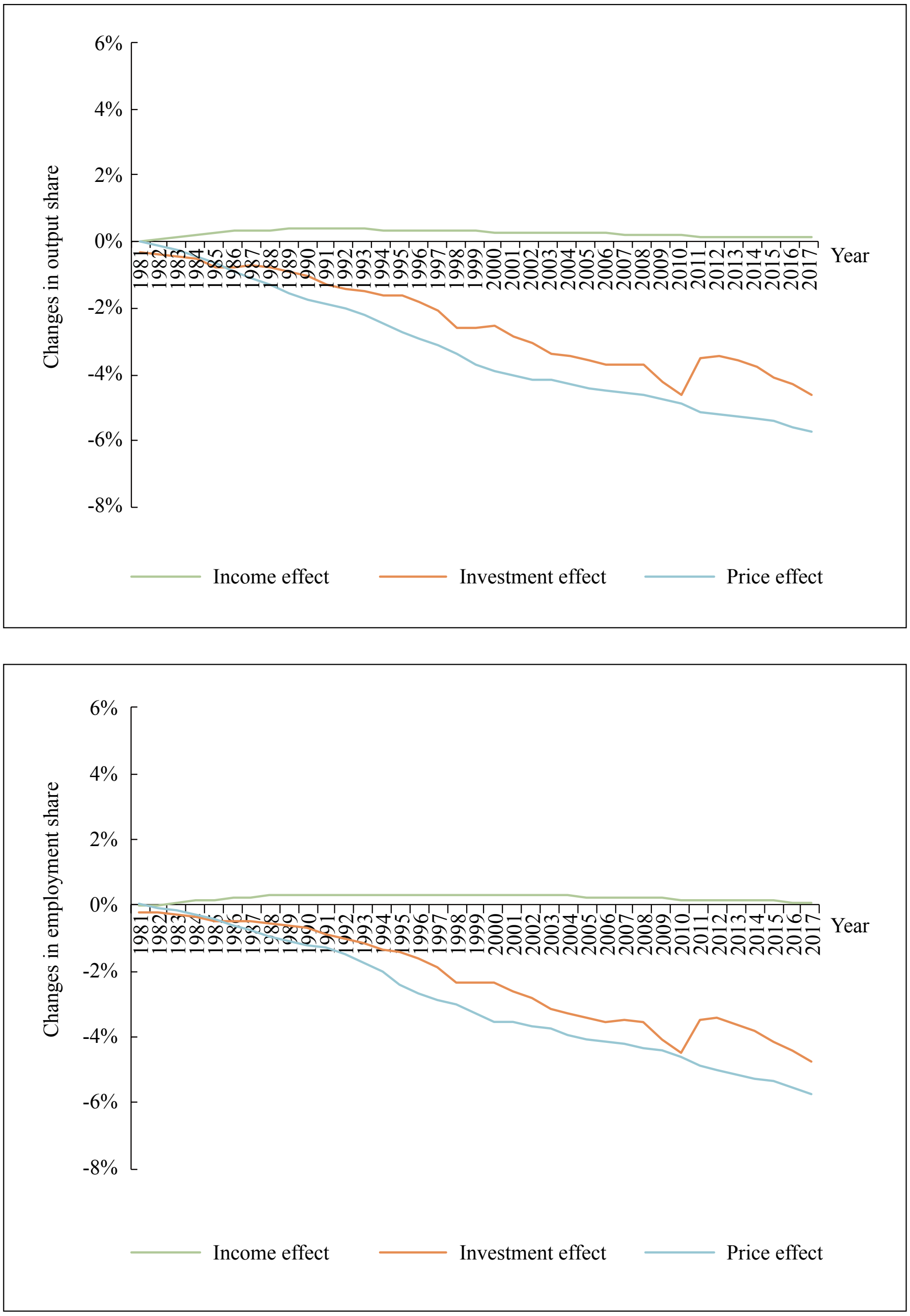


Figure 2: The Effects of Infrastructure Invesment on the Share of Services

periods. For the entire period 1981-2017, the price effect of infrastructure investment played a dominant role, reducing the shares of output and employment of services by 5.7 percentage points. The investment effect played a less significant role, reducing the share of services by nearly 5.0 percentage points. The income effect was positive but exerted a small impact, and only increased the share of services by about 0.1 percentage point.

Infrastructure investment's effects on the share of the service sector arose after 1990, which can

Table 3: The Effects of Infrastructure Invesment on the Share of Services

Period	1981-2017		1981-1990		1981-2000		1981-2010	
Share	Output share	Employment share	Output share	Employment share	Output share	Employment share	Output share	Employment share
Aggregate effect	-10.3%	-10.3%	-2.3%	-1.6%	-6.2%	-5.6%	-9.3%	-8.9%
Price effect	-5.7%	-5.7%	-1.7%	-1.2%	-3.9%	-3.5%	-4.9%	-4.6%
Investment effect	-4.6%	-4.7%	-1.0%	-0.7%	-2.6%	-2.4%	-4.6%	-4.5%
Income effect	0.1%	0.1%	0.4%	0.3%	0.3%	0.3%	0.2%	0.2%

be seen more clearly from Figure 1. From 1981 to 1990, infrastructure investment's negative effect on the share of the service sector was smaller than 2.5 percentage points. This negative effect gradually increased as the price and investment effects intensified. By 2000, infrastructure investment's negative effect on the share of the service sector increased to about six percentage points. By 2010, the price and investment effects were roughly equal to each other, but after 2010, the investment effect diminished, and the price effect became a dominant factor.

This section examines the productivity effects of infrastructure investment. As can be learned from Figure 1 and Table 2, when infrastructure is constant, labor productivity growth significantly slowed. In 2017, labor productivity only increased by 12.94 times over the 1981 level. Given that labor productivity in the benchmark model is 21.05 times the level of 1981, China's infrastructure investment contributed 33.8% to labor productivity growth over the period 1981-2017 (i.e. (21.05-13.94)/21.05), raising the annual average labor productivity growth by 1.2 percentage points.

We further decompose the total effect into the intensive marginal effect and the extensive marginal effect[1]. Figure 3 depicts the decomposed results of the intensive marginal effect and extensive marginal effect, and Table 4 offers relevant quantitative analysis results. As can be seen from the table, the marginal effects for the industrial and agricultural sector and the service sector account for 11.5% and 15.9%, respectively, of infrastructure investment's contribution to labor productivity growth - both are significant. The result reveals that infrastructure has a smaller effect on the industrial and agricultural sector's productivity than on the service sector's. Although the industrial and agricultural sector accounts for a greater share of employment than does the service sector, the intensive marginal effect of infrastructure investment in the industrial and agricultural sector will still be greater than the intensive marginal effect on the service sector. In comparison, 6.4% of labor productivity growth stems from the extensive marginal effect, which implies that infrastructure investment reduces the employment share of the service sector with lower productivity, thus raising labor productivity by 6.4% and contributing 18.9% to the aggregate effect of 33.8% (6.4%/33.8%).

Infrastructure investment always exerts a smaller intensive marginal effect on the industrial and agricultural sector than on the service sector. As the industrial and agricultural sector accounts for a falling employment share, the service sector accounts for a rising employment share . Meanwhile, infrastructure investment accounts for a lower share of productivity growth in the industrial and

[1] The process of decomposition is as follows: $\tilde{x}$ denotes the value of variable in counterfactual simulation. According to equation (24), infrastructure investment's productivity effect can be decomposed into $Y - \tilde{Y} = (y_0 - \tilde{y}_0)(1 - \tilde{\phi}) + (y_1 - \tilde{y}_1)\tilde{\phi} + (y_1 - y_0)(\phi - \tilde{\phi})$. The left side of the equation is the aggregate effects, and the first and second terms on the right side correspond to the intensive marginal effect of the industrial and agricultural sector and the intensive marginal effect of the service sector, respectively. The third term is the extensive marginal effect.

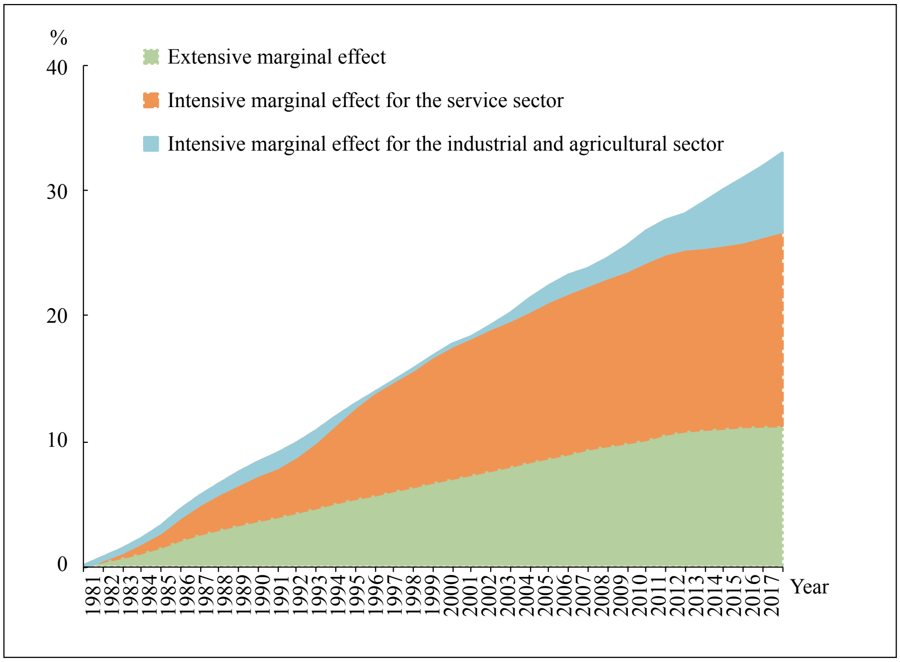


Figure 3: Cumulative Productivity Effect of Infrastructure Investment

Table 4: Infrastructure Investment's Productivity Effects

Period	Aggregate effect	Intensive marginal effect for the industrial and agricultural sector	Intensive marginal effect for the service sector	Extensive marginal effect
1981-2017	33.8%	11.5%	15.9%	6.4%
1981-1990	7.4%	3.7%	4.8%	-1.1%
1981-2000	18.2%	7.2%	10.8%	0.2%
1981-2010	27.4%	10.3%	14.5%	2.5%

agricultural sector and a greater weight of productivity growth in the service sector. Without any further changes, therefore, there is an increase in the difference of intensive marginal effect between the two sectors. Although the impact of the extensive marginal effect started to turn from positive to negative in the mid-1990s, its impact is smaller compared with the intensive marginal effect.

4.4 Sensitivity Analysis

This section conducts a sensitivity analysis of some parameters. Parameter β_j determines the extent through which infrastructure influences productivity in various sectors, and its estimation result varies a lot in the literature. First, we focus on the difference in infrastructure's productivity effects for various sectors. To do so, we keep β_0's value to be 0.05, and reduce β_1's value to 0.1, i.e. the difference between β_1 and β_0 is reduced to 0.05. In the mechanism through which infrastructure investment influences the share of the service sector, the price effect is dependent on the difference in the extent to which infrastructure influences productivities in the two sectors. The smaller such difference, the lower the impact of price effect will be. Consistent with the theoretical model, the price effect at this moment is smaller than the price effect in the benchmark model as shown in Table 3, causing infrastructure investment's aggregate effect on the share of the service sector to be smaller than in the benchmark model. With infrastructure's diminishing effect on the productivity of the service sector , the intensive marginal effect on the service sector will decrease as well.

Moreover, it is also necessary to analyze infrastructure's synchronous effects on productivities in various sectors. To do so, we increase the values of β_0 and β_1 by 0.1 simultaneously, and the difference between β_1 and β_0 remains constant. In the mechanism through which infrastructure investment influences the share of the service sector, the income effect is dependent on the extent to which infrastructure influences productivities in both sectors. Greater influence means that the income effect will exert a more significant influence. Consistent with the theoretical model, the income effect at this moment is higher than in the benchmark model as shown in Table 3, so that infrastructure investment's aggregate effect on the share of the service sector is smaller than in the benchmark model. However, since the impact of the income effect is negligible among the three effects, change in the income effect and aggregate effect is also very limited. Due to infrastructure's increased productivity effect for the two sectors, the intensive marginal effect has increased for both the industrial and agricultural sector and the service sector, which in turn deeepens the aggregate effect.

Parameter α_j determines the output elasticity of private capital in different sectors. In the input-output tables, the output elasticity of industrial and agricultural private capital is relatively high, but some studies remind an over-estimation in the labor income share in the agriculture sector's data. As the first step, we focus on how private capital influences output elasticity in the industrial and agricultural sector. While keeping α_1's value to be 0.5, we increase α_0's value to 0.75. Then, we examine how private capital influences output elasticity in the service sector. While keeping α_0's value to be 0.5, we increase α_1's value to 0.75. In both contexts, there is no significant change in infrastructure investment's effects on the size and productivity of the service sector.

5. Conclusions and Policy Discussions

Rapid growth in infrastructure investment has been a key aspect of China's economy over the years. From theoretical and quantitative perspectives, this paper conducts a detailed analysis of how infrastructure investment influences structural change and productivity growth. This study finds that infrastructure investment may also generate positive supply-side effects with the following policy implications:

First, China should ramp up infrastructure investment to raise productivity and promote high-quality economic development. As China's current per capita infrastructure stock is only 20%-30% the level of developed countries, China needs to keep the investment rate high to sustain rapid economic growth. As shown in this study, China's infrastructure investment accounts for a hefty share of aggregate investment; with its strong spillover effects, infrastructure has substantially raised productivity in all economic sectors. Hence, putting a brake on infrastructure investment will cause downward growth pressures to productivity.

Second, China should restructure infrastructure investment to drive structural change. This study finds that China's structural change can be driven by a shift towards new infrastructure and public-interest infrastructure. Unlike traditional infrastructures such as transportation, power supply and water conservancy, new infrastructure led by 5G, artificial intelligence, industrial Internet, and the Internet of Things generates new technologies, industries, and business modes. As new modes of production take hold, the intra-industry structural upgrade can be achieved. While traditional infrastructure is more dependent on industry and agriculture, public-interest infrastructure such as the environment, culture, education, healthcare, and elderly care involves more service sector inputs, especially modern services. Therefore, the more service-based public-interest infrastructure investment will increase demand for producer services, and thus promote industrial upgrade. CE

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