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The growth impact of infrastructure capital investment: the role of regional innovation capacity—evidence from China

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ABSTRACT

To verify the impact mechanism between infrastructure capital investment and regional economic growth in China, this study first estimates production capital stocks of the infrastructure by Perpetual Inventory Method (PIM) based on a balanced panel dataset for 31 Chinese provinces, autonomous regions and municipalities covering 1993–2017, then analyses the important mediating role of regional innovation capacity in the relationship between infrastructure capital investment and regional economic growth in China. The empirical results indicate that infrastructure capital investment can effectively promote economic growth in China. Furthermore, through analysing the mediating impact mechanism, the infrastructure capital investment can indirectly affect regional economic growth through the regional innovation capacity. When fully considering the potential heterogeneity, the mediating effect of developed regions is more significant than that of underdeveloped regions, and such a mediating effect is increasing with deepening industrialization. Therefore, a harmonious relationship between infrastructure capital investment and economic growth can be achieved if policymakers attempt to arouse the positive mediating role of regional innovation capacity when formulating relevant policies.

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1. Introduction

China's infrastructure capital investment in recent decades plays a significant role in its economic growth. From 1985 to 2017, the proportion of infrastructure investment to gross domestic product increased from 4.9% to 21.8% according to the related data

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from China Statistical Yearbook. Infrastructure investment, as an important part of the regional innovation system, makes the regional innovation capacity more dependent on it (Scaringella & Chanaron, 2016). The point infrastructures such as technology and education, and the network infrastructures such as transportation and communication not only help to increase the endowment of public capital but also enhance inter-regional accessibility by reducing transportation costs, thus promoting cross-regional spillover of innovative elements. Moreover, to date, innovation capacity has always been regarded as a key driving force of economic growth. Therefore, it is important and representative to investigate whether the infrastructure capital investment could indirectly affect regional economic growth through the regional innovation capacity.

Existing studies have investigated the relationship between infrastructure capital investment and economic growth (Aschauer, 1989; Horvat et al., 2021; Ouattara & Zhang, 2019; Yu et al., 2012; Zhang et al., 2021). However, most literature about the impact of China's infrastructure investment on economic growth only focuses on the impact of the capital investment of a certain type of infrastructure such as transportation, communication or water conservancy rather than the whole infrastructure due to the difficulty of data collection. Furthermore, scholars have started to focus on the mediating impact mechanism between infrastructure capital investment and economic growth. For instance, infrastructure capital investment can indirectly affect economic growth by reducing the cost of transportation (Donaldson, 2018; Li & Li, 2013) or promoting trade (Duranton et al., 2014; Faber, 2014).

However, the regional innovation capacity as an important mediating impact mechanism is often ignored in previous studies. In fact, on the one hand, the infrastructure investment not only enhances the independent innovation capacity in the place where the construction project is located but also speeds up the dynamic flows of products, knowledge, information and technology between different regions, ultimately promoting interregional innovation spillovers. particularly, some empirical studies have found that both information infrastructures (Aboal & Tacsir, 2018; Arvanitis & Loukis, 2020; Hwang & Shim, 2021) and transportation infrastructures (Donaldson & Hornbeck, 2016; Gao & Zheng, 2020; Zeng et al., 2021) can promote innovation capacity and innovation efficiency. On the other hand, innovation capacity has been regarded as the main driving force of a country's economic growth. Lucas (1988) and Romer (1990) theoretically explained the impact of innovation on economic growth. On this basis, some researchers verified the positive relationship between innovation capacity and regional economic growth through empirical study (Thompson, 2018; Tomizawa et al., 2020).

In summary, previous studies only study the improvement of infrastructure investment on innovation capacity, or the impact of innovation capacity on regional economic growth. However, to date, most of the studies have not considered infrastructure investment, regional innovation capacity, and regional economic growth in a uniform frame. To fill the above academic gaps, this study contributes to the existing literature in three aspects: First, this study analyses infrastructure capital investment, regional innovation capacity, and regional economic growth into a unified analysis framework, further identifies the regional innovation capacity as a crucial mediator and empirically analyses this mediating impact mechanism. Second, fully considering the spatial and temporal heterogeneity, we examine the mediating effect in the regions with different levels of economic development or at different stages of industrialization, by dividing 31 provincial-level regions into several groups based on the values of per capita GDP and industrialization rate (Jiang & Lin, 2013). Finally, compared with using physical volume or net capital stock to measure infrastructure capital investment, this study adopts the Perpetual Inventory Method (PIM) to estimate the productive capital stock of the whole infrastructure, which more accurately measures the actual production capacity and service efficiency of assets.

The rest of the study is structured as follows. Section 2 puts forward the hypotheses. Section 3 details the methodology and data. Section 4 presents the empirical results. Section 5 discusses the results. Section 6 draws the main conclusions and provides some policy implications.

2. Hypotheses

The new economic growth theory represented by Barro (1990) attempts to separate the infrastructure capital stock from the total capital stock and put it into the production function. It is found that infrastructure capital investment can produce positive externalities to other production factors, thereby promoting long-term economic growth. On this basis, Hulten et al. (2006) further relax the assumption of exogenous technology level and find out that the infrastructure capital investment not only produces positive externalities on private capital and labour, which improves marginal productivity of factors but also affects the technical level, which makes the production possibility curve move outward and causes the characteristic of increasing returns to scale. Meanwhile, the knowledge spillover based on innovation is conducive to promoting technological progress (Marsiglio & Tolotti, 2018; Jian et al., 2020). In other words, regional innovation capacity will directly affect the level of technological progress of one region, thereby affecting the level of economic growth.

Given this, the specific theoretical analysis is as follows:

First, the relationship between infrastructure capital investment and regional innovation capacity has been widely confirmed in current studies (Aboal & Tacsir, 2018; Arvanitis & Loukis, 2020; Hwang & Shim, 2021; Wang et al., 2018; Zeng et al., 2021). Regional innovation capacity refers to the capability of a region to transform new knowledge into new products, new technologies and new services, including knowledge innovation capacity, technological innovation capacity, institutional innovation capacity, management innovation capacity and so on (Fritsch & Slavtchev, 2011). As far as enterprises are concerned, the increase in infrastructure investment is a double-edged sword, which has both positive and negative effects on innovation capability. On the one hand, infrastructure improvement helps to deepen the degree of market integration, thus stimulating enterprises to expand the market scale (Jones & Salazar, 2021; Shively & Thapa, 2017). The expansion of the market scale then helps to share the R&D cost of enterprises and improve the R&D investment return rate, thus encouraging enterprises to increase R&D investment and improving the overall innovation capacity of enterprises (Ciftci & Cready, 2011; Jian et al., 2020).

On the other hand, the increase in infrastructure investment also aggravates the capital tension to a certain extent, pushes up the market interest rate, and increases the funding cost of enterprises, thus crowding out R&D investment projects with comparatively long return cycles, and restraining the improvement of enterprises' innovation capacity (Arza & Lopez, 2021).

Second, the relationship between regional innovation capacity and economic growth also has been generally confirmed in numerous studies (Hasan & Tucci, 2010; Jian et al., 2020; Thompson, 2018; Tomizawa et al., 2020). Regional innovation capacity is based on the knowledge innovation capacity of universities, with the technological innovation capacity of enterprises as the core, and with the institutional innovation capacity and management innovation capacity of governments as the guarantee. In the new economic growth theory, technological progress is regarded as the key factor of long-term economic growth, which can be obtained through knowledge spillover, improvement of existing technology and application of new products (Marsiglio & Tolotti, 2018). Additionally, the impact of the government's institutional innovation capacity and management innovation capacity on regional economic growth is that governments make technological innovation policies and create innovation circumstances, thereby improving the quality of production factors and optimizing the efficiency of resource allocation (Jia et al., 2019; Malen & Vaaler, 2017). Thus, we propose the following hypothesis:

Hypothesis 1: Infrastructure capital investment has a positive effect on regional economic growth by promoting regional innovation capacity.

In general, the role of regional innovation capacity in the relationship between infrastructure capital investment and economic growth is heterogeneous in regions with different levels of economic development. First, in the areas with high levels of economic development, the improvement of infrastructure capital is easier to stimulate regional innovation capacity. Economically developed areas have much more fiscal revenue and public expenditure, thus the density of infrastructure capital will be correspondingly higher, which promotes the regional innovation ability. For example, the increase in infrastructure capital density will inevitably lead to an increase in the number of scientific research institutes, traffic infrastructures, and information infrastructures. The increase in scientific research institutes is beneficial to breaking through the previous innovation achievements and forming interdisciplinary technological innovation (Jung et al., 2021). The increase in traffic infrastructures and information infrastructures makes the potential innovation subject break through the time and space constraints, greatly promoting the free flow of technical knowledge and speeding up the knowledge spillover (Aboal & Tacsir, 2018; Gao & Zheng, 2020).

Second, it is more conducive to playing the role of regional innovation capacity in promoting regional economic growth in the regions with high levels of economic development. On the one hand, it is easier to gather high-quality talents and absorb external technologies in these regions. Only on the premise of having a high level of technology absorption capacity, can the governments more completely apply the knowledge to innovation activities, to enhance the overall regional innovation capacity(Yi et al., 2019). On the other hand, more funds that mainly come from fiscal revenue can be invested in scientific research institutions in these regions.

Meanwhile, the innovation atmosphere of these regions is relatively strong, and people are more willing to accept new ideas and new products (Jian et al., 2020). It not only enhances the regional independent innovation capacity but also continuously transforms the regional innovation capacity into the driving force of regional economic growth. Thus, we propose the following hypothesis:

> ***Hypothesis 2*****:** In the regions with a higher level of economic development, the mediating effect of regional innovation capacity is greater.

When a country is at different stages of industrialization, the role of regional innovation capacity in the relationship between infrastructure capital investment and economic growth is also heterogeneous. First, the effect of infrastructure capital investment on regional innovation capacity is more obvious at the highly industrialized stage (Sawada, 2019). Specifically, in the early stage of industrialization, agriculture and labour-intensive manufacturing industry that do not have high requirements for innovation are the dominant (Frankema, 2015). Meanwhile, the infrastructure construction is still immature and there is not a convenient transportation network, which is not conducive to the flow of innovative elements. Therefore, the impact of infrastructure capital investment on regional innovation capacity in the early stage of industrialization is relatively limited. When a country enters the middle or later stage of industrialization that must rely more on innovation-driven economic development, the industry starts a major shift from labour-intensive industry to capital/technology-intensive industry (Franck & Galor, 2021; Qi et al., 2019). Meanwhile, industrial development requires a better innovation environment for the free flow of innovation elements (Ritala et al., 2015). At this stage, the infrastructure construction has been improved, which can not only provide a better transportation environment for the development of leading industries but also greatly promote the free flow of innovation elements.

Second, in terms of the impact of regional innovation capacity on economic growth, the effect is also more obvious at the stage of high industrialization. Economic growth was mainly driven by export and investment, rather than innovation in the early stage of industrialization (Haraguchi et al., 2019). Meanwhile, due to the low economic strength and weak market competitiveness, it is difficult for governments to invest more funds in R&D sectors and reduce the cost of enterprise technology innovation by financial support or allowance. Endogenous growth theory indicates that sustained economic growth relies on technological progress and innovation (Romer, 1990). Hence, in the middle and late stages of industrialization, with the enhancement of national economic strength and the internal demand of technology-intensive industries for innovation, governments will spend more fiscal revenue on enterprise technology innovation and high-level talent training (Mu et al., 2010). The rational allocation of innovation elements such as technology, talent, and capital through the synergy of system and market will have an important impact on sustained economic growth. Thus, we propose the following hypothesis:

> ***Hypothesis 3*****:** If a country is at the highly industrialized stage, the mediating effect of regional innovation capacity is greater.

3. Model setting, index selection and data sources

3.1. Model setting

The mediating effect model is employed to test the three hypotheses. We use the causal step approach proposed by Baron and Kenny (1986) to estimate the mediating effect model. Such an approach requires the researcher to estimate the coefficient on each path in the model and then ascertain whether a variable function as a mediator by judging whether the related statistical criteria are met. Based on the above analysis, the construction of the mediating effect model is divided into the following steps.

Firstly, without considering the influence of regional innovation capacity, this article constructs the following model to explore the total effect of infrastructure capital investment on regional economic growth. The specific model is as follows:

$$\ln y_{it} = \alpha_0 + \alpha_I \ln k_{it}^I + \alpha_F \ln k_{it}^F + \sum\nolimits_{j=1}^{7} \alpha_J C_{itj} + \mu_i + \kappa_t + \varepsilon_{it} \tag{1}$$

where i represents a provincial administrative unit, t represents time; y denotes the actual per capita GDP of each region, which is used to measure the economic growth level of the region; k^I and k^F respectively stand for infrastructure capital stock per capita and non-infrastructure capital stock per capita; C is a vector composed of various other factors affecting regional economic growth; μ_i, κ_t, ε_{it} are random disturbance terms, considering both the individual effect μ_i and the time effect κ_t.

Secondly, the effect of infrastructure capital stock on regional innovation capacity is tested. The specific model is as follows:

$$ic = \alpha_1 + \beta_I \ln k_{it}^I + \beta_F \ln k_{it}^F + \sum\nolimits_{j=1}^{7} \beta_j C_{itj} + \mu_i + \kappa_t + \varepsilon_{it} \tag{2}$$

where ic denotes regional innovation capacity as a mediator.

Finally, the influence of both infrastructure capital stock and regional innovation capacity on regional economic growth is considered. The specific model is as follows:

$$\ln y_{it} = \alpha_0 + \alpha_I' \ln k_{it}^I + \varphi \ln ic + \alpha_F' \ln k_{it}^F + \sum\nolimits_{j=1}^{7} \alpha_j' C_{itj} + \mu_i + \kappa_t + \varepsilon_{it} \tag{3}$$

In the above models, α_I is the total effect of infrastructure capital stock on regional economic growth; α_I' is the direct effect of infrastructure capital stock on regional economic growth when the influence of regional innovation capacity and other control variables are controlled; $\beta_I \times \varphi$ is the mediating effect that is identical to the indirect effect. The relationship between total effect (α_I), direct effect (α_I') and indirect effect ($\beta_I \times \varphi$) is as follows (Mackinnon et al., 1995):

$$\alpha_I = \alpha_I' + \beta_I \times \varphi \tag{4}$$

If both β_I and φ in the model are statistically significant, and α_I' is closer to zero than α_I, then regional innovation capacity can be regarded as a mediator of the relationship between infrastructure capital stock and regional economic growth.

3.2. Index selection

3.2.1. Dependent variable and core explanatory variables

We take per capita real GDP (y) as the dependent variable to measure the economic growth level of each region. It is measured by the ratio of the GDP of each region to the number of employees. Per capita infrastructure production capital stock (k^I) and per capita non-infrastructure production capital stock (k^F) are used as core explanatory variables. The calculation formula is derived from the *Measuring Capital-OECD Manual* (2009), as follows:

$$KP_{i,t} = \sum\nolimits_{\tau=0}^{T-1} d_\tau K_{i,t} \quad (5)$$

where KP represents infrastructure and non-infrastructure production capital stock, and K indicates their gross capital stock; T and τ denote the service life and the service age of assets, respectively; d_τ described by the age-efficiency function is the relative efficiency of the asset, which represents the marginal production efficiency of old capital goods relative to new capital goods. The age-efficiency function used in this article is the hyperbolic age-efficiency profile. Hyperbolic decline takes the form:

$$d_\tau = (T - \tau)/(T - \theta\tau) \quad (6)$$

where θ[1] ≤ 1 is a parameter that shapes the form of the function.

The calculation formula of $K_{i,t}$ that represents the gross capital stock of infrastructure and non-infrastructure is as follows:

$$K_{i,t} = K_{i,t-1} + I_{i,t} - R_{i,t} = \sum\nolimits_{\tau=0}^{T-1} S_{i,\tau} I_{i,t-\tau} \quad (7)$$

where $I_{i,t}$ represents the new investment in fixed assets of infrastructure and non-infrastructure; $R_{i,t}$ and $S_{i,t}$ respectively describe their replacement needs and their residual value rate of fixed assets, both of which are determined by retirement functions. This article chooses the bell-shaped retirement function that is more commonly used in international accounting. The form of the lognormal frequency distribution in this model is:

$$f_\tau = \frac{1}{\sqrt{2\pi} \times \sigma} \times \frac{1}{\tau} \times \exp\left(-\frac{(\ln \tau - \mu)^2}{2\sigma^2}\right), \ \sigma = \sqrt{\ln\left(1 + (m/s)^{-2}\right)}, \ \mu = \ln m - 0.5\sigma^2 \quad (8)$$

where τ is the age of the asset; σ and μ are the standard deviation and mean of the lognormal function; m and s are the mean and the standard deviation of the underlying normal distribution. With m as the estimated average service life, the standard deviation s is set to between $2/m$ and $4/m$. Considering the actual situation, s in this article is set to $4/m$. Based on this, the corresponding survival function can be obtained by $S_\tau = 1 - \int_0^t f_\tau$.

Table 1. Statistical description of variables (before logarithm).

Variable	Variable name	Unit	Mean	Std. dev.	Min	Max
y	Per capita economic growth	Yuan/person	23384.9	20292.65	2374.561	123369.2
k^I	Infrastructure capital stock per capita	Yuan/person	21422.75	19936.19	949.921	150543.3
k^F	Non-infrastructure capital stock per capita	Yuan/person	36446.15	43307.68	1406.757	277689.8
ic	Regional innovation capacity	Pieces/10,000 people	11.05	21.058	0.08	157.2
hca	Human capital accumulation	Ten thousand yuan	19.274	15.072	4.450	101.230
gs	Government size	—	0.195	0.162	0.048	1.379
soe	state-owned economy proportion	—	0.428	0.186	0.101	0.975
is	Industrial structure proportion	—	0.410	0.083	0.276	0.806
ul	Urbanization level	—	0.341	0.168	0.130	0.910
dtd	Degree of trade dependence	—	0.342	0.521	0.017	3.350
rd	R&D investment	100 million yuan	163.639	320.154	0.020	2343.630

Source: Authors.

3.2.2. Mediating variable

Concerning international standards, the mediating variable in this article is the logarithm of regional innovation capacity (*lnic*), which is measured by the logarithm of the number of patent applications per 10,000 people in each region. Compared with other indicators such as sales revenue of new products or the comprehensive index of regional innovation capacity, patent data is not only easier to obtain, but also reflects the commercial use of innovation capacity. Most studies argue that patent data is objective and slowly changing, so it is still a relatively reliable alternative indicator to measure regional innovation capacity (Acs et al., 2002). In addition, compared with the number of patent authorizations, the number of patent applications can objectively reflect the true level of a region's innovation capacity without being affected by man-made evaluation such as the ability of patent examination and patent judgment.

3.2.3. Control variables

This article mainly selects the following control variables: 1) Human capital accumulation (*hca*) is measured by human capital stock per head of each province in the *China Human Capital Report* (2019). 2) Government size (*gs*) is measured by the proportion of local government fiscal expenditures in the region's GDP. 3) Proportion of state-owned economy (*soe*) is measured by the proportion of state-owned investment in total fixed-asset investment. 4) Industrial structure (*is*) is measured by the proportion of the added value of the tertiary industry in the region's GDP. 5) Urbanization level (*ul*) is measured by the proportion of the non-agricultural population in the total population. 6) Degree of trade dependence (*dtd*) is measured by the proportion of total import and export trade volume in GDP. 7) R&D investment (*rd*) is measured by the research and development expenditure of each region.

3.3. Data collection

The panel data used in this study are constituted of China's 31 provincial-level regions during 1993–2017. Taiwan, Hong Kong, and Macao are excluded because of data unavailability. The descriptive statistics of variables are reported in Table 1. It should be noted that the raw data are deflated by the 1993 constant price index to

Table 2. Results of mediation analysis.

	ln*y* (1)	ln*ic* (2)	ln*y* (3)
$\ln k^I$	0.2171*** (0.0160)	0.1666*** (0.0604)	0.2100*** (0.0159)
ln*ic*			0.0426*** (0.0097)
$\ln k^F$	0.0860*** (0.0131)	0.6816*** (0.0495)	0.0570*** (0.0145)
Hac	0.0021*** (0.0007)	0.0174*** (0.0026)	0.0013* (0.0007)
gs	−0.1146** (0.0543)	1.7154*** (0.2046)	−0.1878*** (0.0561)
soe	−0.1637*** (0.0478)	0.6345*** (0.1804)	−0.1908*** (0.0476)
is	−0.5803*** (0.0911)	0.1263 (0.3436)	−0.5857*** (0.0900)
ul	0.3229*** (0.0735)	1.5645*** (0.2769)	0.2562*** (0.0741)
dtd	0.0002 (0.0124)	0.1841*** (0.0468)	−0.0076 (0.0124)
rd	−0.00002 (0.00002)	0.0003*** (0.0001)	−0.0001 (0.0001)
Constant	6.3664*** (0.1088)	−8.5812*** (0.4147)	6.7165*** (0.1367)
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Adj. R^2	0.9873	0.9423	0.9876
Observations	775	775	775
Sobel test		0.0071** (0.0030)	
Bootstrap test		0.0071* (0.0036)	
Proportion of mediating effect		3.27%	

Note: Standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively; the same below.
Source: Authors.

eliminate the influence of price fluctuation. The raw data are taken from the *China Statistical Yearbook* (1994-2018), *China Trade and External Economic Statistical Yearbook* (1994-2018), *China Compendium of Statistics*, and statistical yearbooks during 1994-2018 in different regions.

4. Results

4.1. Baseline results of mediation analysis

After the Hausman test, this article adopts time and entity fixed effects (FE) to estimate model (1) ∼ model (3), and the baseline results are reported in columns (1) ∼ (3) of Table 2. Specifically, As shown in columns (1) and (3) of Table 2, the coefficient of total effect (α_I) is 0.2171 with a 1% significance level, while the coefficient of direct effect (α_I') is 0.2100 with a 1% significance level, indicating that infrastructure capital stock has a significant positive impact on regional economic growth and the direct effect is slightly smaller than the total effect. Thus, it is evident that infrastructure capital stock has a mediating effect on regional economic growth. As shown in columns (2) and (3) of Table 2, the coefficient of infrastructure capital stock on regional innovation capacity (β_I) is 0.1666 and the coefficient of regional innovation capacity on regional economic growth (φ) is 0.0426 with a 1% significance level. It means that infrastructure capital stock has a significant positive impact on regional innovation capacity and the continuous enhancement of regional innovation capacity can further promote regional economic growth.

In addition, the mediating effect ($\beta_I \times \varphi$) is 0.0071, indicating that each 1% increase in infrastructure capital stock can result in a 0.0071% rise in regional economic growth because of infrastructure capital stock's effect on regional innovation capacity when other conditions remain unchanged. Finally, as shown in Table 2, both the Sobel test and Bootstrap test support that regional innovation capacity has a significant mediating effect, and the mediating effect accounts for 3.27% of the total effect of infrastructure capital stock on regional economic growth. Therefore, hypothesis 1 proposed in this article is confirmed.

4.2. Mechanism test analysis of sub-samples

According to section 2, the mediating effect of regional innovation capacity may be more obvious in economically developed regions. China is divided into provinces, autonomous regions, and municipalities directly under the central government. Although their administrative ranks are the same, the levels of economic development are different. In general, the economic development level of municipalities is higher than that of provinces, and that of provinces is higher than that of autonomous regions. In the sample period from 1993 to 2017, the average real GDP per capita of municipalities is around 45,100 yuan, about 24,500 yuan higher than that of provinces and about 27,100 yuan higher than that of autonomous regions. Given this, this article draws on the sub-sample mechanism test method of Li and Li (2013) and divides the samples into three types: municipalities, provinces, and autonomous regions to judge the heterogeneous impact of regional innovation capacity. The regression results are reported in columns (1) to (9) of Table 3.

First, as shown in columns (1) to (3) of Table 3, it is easy to find that coefficients of per capita infrastructure capital stock on regional innovation capacity and regional innovation capacity on per capita GDP are still significantly positive, which once again confirms hypothesis 1. However, we found that the coefficient of direct effect is not significant, indicating that in the samples of municipalities, regional innovation capacity plays a completely mediating role in the relationship between infrastructure capital stock and economic growth. Meanwhile, the Sobel test and Bootstrap test both show that the proportion of mediating effect accounts for 45.79%. Second, as shown in columns (4) to (6) of Table 3, the estimated result of provinces resembles that of municipalities. The only difference is that the coefficient of direct effect becomes smaller and more significant, showing that in the samples of provinces, regional innovation capacity plays a partial mediating role in the relationship between infrastructure capital stock and economic growth. And the mediating effect accounts for 14.75%. Finally, columns (7) to (9) of Table 3 show that in the samples of autonomous regions, the coefficient of regional innovation capacity on per capita GDP is insignificant and the results of Sobel and Bootstrap tests are also insignificant, implying that regional innovation capacity does not play mediating effect between infrastructure capital stock and economic growth. In summary, the effect of infrastructure capital stock on economic growth is totally mediated by regional innovation capacity in the most economically developed municipalities and is partly mediated by regional innovation capacity in relatively developed provinces, while the effect of infrastructure capital stock on economic growth is not mediated by regional innovation capacity in the most backward autonomous regions. Therefore, hypothesis 2 proposed in this article is confirmed.

Table 3. Mechanism test results of sub-samples.

	Municipality			Province			Autonomous regions		
	ln*y* (1)	ln*ic* (2)	ln*y* (3)	ln*y* (4)	ln*ic* (5)	ln*y* (6)	ln*y* (7)	ln*ic* (8)	ln*y* (9)
$\ln k^{l}$	0.0439**	0.5461***	0.0238	0.1417***	0.2677***	0.1207***	0.4807***	−1.2900***	0.4402***
	(0.0218)	(0.1082)	(0.0245)	(0.0174)	(0.0753)	(0.0166)	(0.0601)	(0.2520)	(0.0666)
ln*ic*			0.0369*			0.0782***			−0.0315
			(0.0215)			(0.0096)			(0.0227)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	8.1203***	−2.8864**	8.2268***	6.8469***	−8.6103***	7.5204***	4.4014***	−5.0254***	4.2432***
	(0.2591)	(1.2874)	(0.2636)	(0.1175)	(0.5085)	(0.1379)	(0.3953)	(1.6559)	(0.4098)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sobel test		0.0201*(0.0122)			0.0209***(0.0064)			0.0406(0.0303)	
Bootstrap test		0.0201			0.0209***(0.0060)			0.0406(0.0357)	
		(0.0127)							
Proportion of mediating effect		45.79%			14.75%			0.00%	
Adj. R2	0.9967	0.9423	0.9968	0.9918	0.9512	0.9927	0.9895	0.9245	0.9896
Observations	100	100	100	550	550	550	125	125	125

Source: Authors.

Table 4. Regression results of samples of municipalities and provinces.

	ln*y* (1)	ln*ic* (2)	ln*y* (3)
lnk^I	0.1827*** (0.0162)	0.2965*** (0.0620)	0.1575*** (0.0156)
ln*ic*			0.0851*** (0.0100)
Control variable	Yes	Yes	Yes
Constant	6.7236*** (0.1120)	−8.9518*** (0.4290)	7.4855*** (0.1088)
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Adj. R2	0.9891	0.9508	0.9902
Observations	650	650	650
Sobel test		0.0252***(0.0060)	
Bootstrap test		0.0252***(0.0062)	
Proportion of mediating effect		13.79%	

Source: Authors.

Since the mediating effect of regional innovation capacity in the samples of autonomous regions is not significant, we remove autonomous regions from the total samples and re-estimate the model parameters. The regression results of the samples excluding autonomous regions are reported in columns (1) to (3) of Table 4. It is easy to find that coefficients of per capita infrastructure capital stock on regional innovation capacity (0.2965) and regional innovation capacity on per capita GDP (0.0851) are still significantly positive. The mediating effect (0.2965×0.0851) is 0.0252. In addition, the proportion of mediating effect is 13.79%, which is 10.52% higher than that in the baseline results. It means that in the total sample estimation, the autonomous regions weaken the mediating role of regional innovation ability.

4.3. Analysis of heterogeneity in different stages of development

During the sample period, the Chinese economy has gone through the initial stage of industrialization (1993 ~ 1999), the mid-term stage (2000 ~ 2011), and the late stage (2012 ~ 2017). Considering that the mediating effect of regional innovation capacity may be different at different stages of economic development in China, this article adds two dummy variables (yr1, yr3) to represent the period of 1993 ~ 1999 and 2012 ~ 2017, then multiplies them with infrastructure investment and regional innovation capacity to obtain new cross-terms, which are used to test the temporal heterogeneity of different stages of industrialization. All regression results are reported in Table 5.

First, as shown in column (1) of Table 5, the output elasticity of infrastructure capital stock in the mid-term stage, initial stage, and late stage of industrialization are respectively 0.1515, 0.1498(=0.1515-0.0017), and 0.1452 (=0.1515-0.0063). It shows that the impact of infrastructure capital stock on regional economic growth is inverted 'U' type, which coincides with the research of Mamuneas (2000). Second, as shown in columns (2) and (3) of Table 5, the coefficient of infrastructure capital stock on regional innovation capacity (β_I) in the mid-term stage, initial stage, and late stage of industrialization are respectively 0.2184, 0.1977 (=0.2184-0.0207) and 0.2121 (=0.2184-0.0063). The coefficient of regional innovation capacity on regional economic growth (φ) in the mid-term stage, initial stage, and late stage of industrialization are respectively 0.0875, 0.0397 (0.0875-0.0478), and 0.0856 $(0.0875 - 0.0019)$.

Table 5. Regression results at different development stages.

	ln*y* (1)	ln*ic* (2)	ln*y* (3)
$\ln k^I$	0.1515*** (0.0173)	0.2184*** (0.0674)	0.1593*** (0.0172)
$yr1 \times \ln k^I$	−0.0017 (0.0016)	−0.0207*** (0.0062)	0.0023 (0.0015)
$yr3 \times \ln k^I$	−0.0063*** (0.0012)	0.0028 (0.0046)	−0.0065** (0.0028)
$\ln ic$			0.0875*** (0.0098)
$yr1 \times \ln ic$			−0.0478*** (0.0094)
$yr3 \times \ln ic$			−0.0019 (0.0097)
Control variable	Yes	Yes	Yes
Constant	6.5378*** (0.1136)	−9.0470*** (0.4433)	7.2164*** (0.1384)
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Control variable	0.9897	0.9517	0.9912
Constant	650	650	650

Source: Authors.

Such results suggest that compared with the initial stage of industrialization, the impact of infrastructure capital stock on regional innovation capacity and the impact of regional innovation capacity on regional economic growth are enhanced in the mid-late stage of industrialization. Finally, the mediating effect ($\beta_I \times \varphi$) in the initial stage, mid-term stage, and late stage of industrialization are about 0.0078, 0.0191, and 0.0190, respectively. It shows that as China enters the mid-late stage of industrialization, the mediating role of regional innovation capacity is more evident. Therefore, hypothesis 3 proposed in this article is confirmed.

4.4. Robustness and endogenous analysis

4.4.1. Robustness analysis

To test the stability of the estimated parameters obtained from the baseline regression results, we use three methods to do the robustness test: choosing alternative indicators, adding control variables, and changing the way of sample processing.

First, we choose alternative indicators from three aspects: (1) we use the net capital stock of infrastructure and non-infrastructure to replace productive capital stock. Compared with productive capital stock, net capital stock cannot effectively reflect the actual production capacity and service efficiency of assets, but as an index of the capital stock value estimated by market price, it can be used as an alternative indicator of capital stock. The estimation of the net capital stock of inter-provincial infrastructure refers to OECD (2009; 2) Compared with the previous method of dividing by the number of employees to measure the per capita form, we use the GDP, infrastructure, and non-infrastructure capital stock of each region divided by the number of permanent residents to measure the per capita form. (3) We select the number of patent authorizations and sales revenue of new products as an alternative indicator of the number of patent applications to measure regional innovation capacity.

Second, we further consider the omitted variable bias and add other control variables that may affect regional economic growth or regional innovation capacity as follows: (1) There is no doubt that the region with more research institutes will attract more high-quality talents and R&D investment, thereby promoting the region's innovation capacity. Therefore, the scale of science and education resources (*se*) is

Table 6. Regression results of the robustness test.

	Change in explanatory variables: using net capital stock			Change in per capita form: divided by the number of permanent residents		
	ln*y*	ln*ic*	ln*y*	ln*y*	ln*ic*	ln*y*
$\ln k^I$	0.1828***	0.2779***	0.1595***	0.0556***	0.3941***	0.0259*
	(0.0162)	(0.0626)	(0.0156)	(0.0141)	(0.0681)	(0.0135)
ln*ic*			0.0837***			0.0753***
			(0.0099)			(0.0078)
	Change in mediating variable: the number of patent authorizations			**Change in mediating variable: sales revenue of new products**		
	ln*y*	ln*ic*	ln*y*	ln*y*	ln*ic*	ln*y*
$\ln k^I$	0.1827***	0.1989***	0.1713***	0.1827***	0.2140***	0.1824***
	(0.0162)	(0.0623)	(0.0159)	(0.0162)	(0.0725)	(0.0161)
ln*ic*			0.0574***			0.0193***
			(0.0102)			(0.0071)
	Add control variable: *se*			**Add control variable: *pd***		
	ln*y*	ln*ic*	ln*y*	ln*y*	ln*ic*	ln*y*
$\ln k^I$	0.1919***	0.3191***	0.1715***	0.2105***	0.3024***	0.1952***
	(0.0150)	(0.0602)	(0.0148)	(0.0158)	(0.0618)	(0.0159)
ln*ic*			0.0641***			0.0606***
			(0.0097)			(0.0102)
se	0.1255***	0.3096***	0.1056***	0.1199***	0.3003***	0.1002***
	(0.0121)	(0.0488)	(0.0121)	(0.0127)	(0.0490)	(0.0129)
pd				−0.4673***	−0.3591***	−0.4369***
				(0.0474)	(0.1184)	(0.0432)
	Change in sample processing method: winsorize $\ln k^I$ at 1%			**Change in sample processing method: winsorize $\ln k^I$ at 5%**		
	ln*y*	ln*ic*	ln*y*	ln*y*	ln*ic*	ln*y*
$\ln k^I$	0.1915***	0.2429***	0.1719***	0.2121***	0.2814***	0.1899***
	(0.0159)	(0.0619)	(0.0153)	(0.0169)	(0.0660)	(0.0163)
ln*ic*			0.0808***			0.0788***
			(0.0099)			(0.0098)

Note: All regressions use samples from municipalities and provinces, and include control variables, individual effects, and time effects.
Source: Authors.

added to the mediating effect model, where *se* is measured by the proportion of students in colleges and universities to the total population. (2) To control the influence of economic geographical factors, the shortest distance between municipalities/provinces and Tianjin, Shanghai, and Hong Kong which are the three most famous ports in China (*pd*) is added to the mediating effect model.

Third, to eliminate the influence of outliers of the core explanatory variable, we winsorize the per capita infrastructure capital stock at 1% and 5%.

Table 6 displays the regression results of the robustness test. It is easy to find that in the robustness test of each treatment method, coefficients of per capita infrastructure capital stock on regional innovation capacity and regional innovation capacity on per capita GDP are still significantly positive. That is to say, the mediating effect of regional innovation capacity in the influence of infrastructure capital stock on regional economic growth is robust. Meanwhile, we also find that the direct effect is always less than the total effect. Therefore, the conclusion that the effect of

Table 7. Regression results of endogeneity analysis.

	Eq. (1)		Eq. (2)		Eq. (3)	
	lnk^I (1)	ln$y$ (2)	lnk^I (3)	lnic (4)	lnk^I (5)	ln$y$ (6)
lnk^I		0.1953*** (0.0438)		1.0743*** (0.1716)		0.1048** (0.0469)
lnic						0.0802*** (0.0127)
$Mp\times year$	Yes		Yes		Yes	
Weak instrumental variable test	598.47 [11.40]		598.47 [11.40]		599.44 [11.40]	
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.7329*** (0.3560)	7.2123*** (0.2439)	3.7329*** (0.3560)	−12.142*** (0.1154)	4.3555*** (0.4022)	8.2053*** (0.3030)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Control variable	0.9840	0.9938	0.9840	0.9731	0.9843	0.9944
Constant	525	525	525	525	525	525

Source: Authors.

infrastructure capital stock on economic growth is partly mediated by regional innovation capacity is also robust.

4.4.2. Endogenous analysis

To overcome the endogeneity of infrastructure capital investment, this article uses the instrumental variable (IV) to solve the problem. Referring to the research of Duranton and Turner (2011) and Michaels (2008) that propose to use historical road or railway planning distribution maps to predict the distribution of modern expressways, we choose the interaction term between the number of courier stations in each province in Ming Dynasty and year dummies ($mp\times year$) as the instrumental variable of the per capita infrastructure capital stock. On the one hand, the courier stations in Ming Dynasty were mainly built in strategically important and densely populated areas, and these courier stations had good accessibility. Therefore, the construction of the current transportation system in China is influenced by the courier stations in Ming Dynasty to a certain extent, and the statistical scope of infrastructure in this article mainly includes transportation infrastructure. The relevance assumption is satisfied. On the other hand, the construction of courier stations in the Ming Dynasty was mainly based on military purposes and they were built about 400 years ago, so the current level of economic development will not directly affect them, and the exogenous assumption is satisfied. However, the number of courier stations in the Ming Dynasty does not change over time, this article uses the interaction term between the number of courier stations in the Ming Dynasty and year dummies as the instrumental variable according to the approach of Angrist and Krueger (1991), to overcome the dimension limitation of cross-section data and fully reflect the influence of instrumental variable in different years on the endogenous variable. Table 7 reports the estimation results of the instrumental variable by using 2SLS estimation to estimate Eqs. (1)–(3).

According to Table 7, first, columns (1), (3), and (5) of Table 7 present first-stage regression results. The coefficients of $mp\times year$ are significant in most years, indicating that the instrument variable is significantly related to the per capita infrastructure capital stock. Meanwhile, the result of the weak instrumental variable test shows that the instrumental variable passes the 10% level of a significance test, further verifying the relevance assumption. Second, when regressing the instrumental variable to regional economic growth, we find that the estimated coefficients are insignificant in most years, which proves the exogenous assumption. Finally, columns (2), (4), and (6) of Table 7 show that coefficients of per capita infrastructure capital stock on regional innovation capacity and regional innovation capacity on per capita GDP are still significantly positive. Therefore, after considering endogeneity on the major explained variable, the conclusion that regional innovation capacity mediates the relationship between infrastructure capital stock and regional economic growth is still robust, and the mediating effect is 0.0862 ($=1.0743 \times 0.0802$), accounting for 44.14% ($=0.0862 \div 0.1953$) of the total effect.

5. Discussion

Plenty of theoretical and empirical research finds that infrastructure investment plays a significant role in promoting economic growth. Some studies have tried to explain how infrastructure investment affects economic growth from the aspects of reducing transportation costs and improving the degree of market integration (Donaldson, 2018; Duranton et al., 2014; Faber, 2014; Li & Li, 2013). However, few kinds of literature discuss whether infrastructure investment can affect economic growth through regional innovation capacity. Infrastructures not only enhance the independent innovation capacity of a certain region but also speed up the free flow of knowledge, information, and products between different regions, further promoting regional economic growth. Therefore, one innovation of this article is to analyse infrastructure capital investment, regional innovation capacity and regional economic growth into a unified analysis framework, further identifying the regional innovation capacity as a crucial mediator. Besides, unlike many previous studies (Ouattara & Zhang, 2019; Yu et al., 2012; Zeng et al., 2021), which devised the whole country into the east region, middle region, and west region to test spatial heterogeneity. This article reclassified it to provinces, autonomous regions, and municipalities directly under the central government according to different levels of economic development, which is maybe more scientific than just geographical division. Furthermore, this article also confirms that the mediation effect of regional innovation capacity has temporal heterogeneity by dividing different stages of industrialization development. Based on the results in section 4, the following conclusion can be drawn to confirm or reject hypotheses:

H1: Infrastructure capital investment has a positive effect on regional economic growth through promoting regional innovation capacity: *Confirmed.*

H2: In the regions with a higher level of economic development, the mediating effect of regional innovation capacity is more obvious: *Confirmed.*

H3: If a country is at the highly industrialized stage, the mediating effect of regional innovation capacity is more obvious: *Confirmed.*

Specific discussions on these results are as follows. Firstly, infrastructure investment not only has a significant positive effect on China's economic growth, which is in line with previous research carried out by Yu et al. (2012) and Zhang et al. (2021) but also enhances regional innovation capacity, which is in line with previous researches carried out by Wang et al. (2018), Cui and Tang (2022). Then we find out that the regional innovation capacity plays an important mediation role in the relationship between infrastructure capital investment and regional economic growth (Zeng et al., 2022). The mediating effect reaches 0.0071, accounting for 3.27% of the total effect. Because of the decreasing trend of the marginal output of capital, the infrastructure investment scale should be suitable. Therefore, regional innovation capacity is very important for the sustainable development of China's economy which was driven by investment in the past.

Second, the regional difference in the mediating effect of regional innovation capacity is visible (Zeng et al., 2022). For example, the mediating effect of regional innovation capacity is the most evident in the most economically developed municipalities, followed by the relatively developed provinces, while the mediating effect is not significant in the most backward autonomous regions. The possible explanation is that most of the autonomous regions are remote and border areas, with relatively backward economic development and insufficient infrastructure construction. It is difficult to assemble high-tech human resources, science-tech achievements, and science-tech investments. In addition, the construction of cross-regional network infrastructure enhances the accessibility between backward and developed regions, leading to a huge brain drain in backward areas (Wang et al., 2018). It indicates that a good economic foundation and mature infrastructure construction are the preconditions for the free flow of innovation elements. Therefore, China should upgrade the economic effect in the backward areas, and reduce the economic gap among areas to realize harmonious economic development.

Finally, the mediating effect of regional innovation capacity becomes more evident with deepening industrialization. Compared with the initial stage of industrialization (1993 ~ 1999), the mediating role of regional innovation capacity is enhanced in the mid-term stage (2000 ~ 2011) and the late stage (2012 ~ 2017). it is indicated that the regional innovation capacity plays an increasingly important role in the growth impact of infrastructure capital investment. This is closely related to China's innovation development in recent decades. According to the data released by the World Intellectual Property Organization (WIPO), China only submitted 1 patent application to WIPO in 1993, and only 276 until 1999. Since 2003, it has increased by more than 10% every year. In 2020, China applied for 68720 patents through the Patent Cooperation Treaty (PCT), ranking first in the world.

6. Conclusions and policy implications

By employing a balanced panel dataset for 31 Chinese provinces, autonomous regions, and municipalities covering 1993–2017 and the mediating effect model, this study aims to identify the influence channel of infrastructure capital stock on regional economic growth. Several interesting findings are highlighted, as follows: (1) Infrastructure capital investment shows a promotion effect on regional economic growth, because of the promotion effect mediated by regional innovation capacity.

And the mediating effect is 0.0071, accounting for 3.27% of the total effect. (2) In the sub-sample mechanism test, the mediating effect of regional innovation ability is highest in the samples of municipalities, followed by the samples of provinces. Conversely, the mediating effect is not significant in the samples of autonomous regions. In other words, the mediating effect of regional innovation capacity is more obvious in the regions with a higher level of economic development. After removing the samples of autonomous regions from the total samples, the mediating effect increases correspondingly. (3) Further analysis of heterogeneity shows that the mediating effect of regional innovation capacity is more obvious in the regions at the higher industrialized stage.

Some important policy implications can be deduced based on our findings. For example, in addition to increasing the number of patent applications, China should improve the quality of patent applications and fully play the buffering effect of regional innovation capacity on the diminishing marginal return mechanism of infrastructure capital. Besides, more emphasis should be placed on the development and deployment of infrastructure in backward areas. Policymakers should further strengthen the network infrastructure construction between developed and underdeveloped regions, promoting the interregional flow of innovation elements. Meanwhile, they should be alert to the siphoning effect between developed and underdeveloped regions due to the increasing accessibility. Policymakers in underdeveloped regions should constantly improve their comparative advantages and create a good innovation environment to retain innovative talents.

However, some potential problems need to be studied more in the future. For instance, this article does not consider the spatial impact of adjacent areas and the heterogeneous impact of different types of infrastructure. In future research, it may be a very good and insightful novel topic to incorporate the above factors into the growth impact of infrastructure capital investment. Specifically, we can use a spatial econometric model and divide infrastructure into point infrastructure and network infrastructure, which is also conducive to strengthening the theoretical basis for us to further propose reasonable measures.

Disclosure statement

No potential conflict of interest was reported by the authors.

Note

1. According to page 92 of *the Measuring Capital OECD Manual (2009)*, the efficiency reduction parameter is set to 0.7 for infrastructure and 0.65 for non-infrastructure.

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References

Aboal, D., & Tacsir, E. (2018). Innovation and productivity in services and manufacturing: The role of ICT. *Industrial and Corporate Change*, *27*(2), 221–241. https://doi.org/10.1093/icc/dtx030

Acs, Z. J., Anselin, L., & Varga, A. (2002). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy*, *31*(7), 1069–1085. https://doi.org/10.1016/S0048-7333(01)00184-6

Angrist, J. D., & Krueger, A. B. (1991). Does compulsory school attendance affect schooling and earnings? *Quarterly Journal of Economics*, *106*, 1127–1170. https://doi.org/10.2307/2937954

Arvanitis, S., & Loukis, E. (2020). Reduction of ICT investment due to the 2008 economic crisis and ICT-enabled innovation performance of firms. *Journal of the Knowledge Economy*, *11*(1), 1–27. https://doi.org/10.1007/s13132-018-0577-2

Arza, V., & Lopez, E. (2021). Obstacles affecting innovation in small and medium enterprises: Quantitative analysis of the Argentinean manufacturing sector. *Research Policy*, *50*(9), 104324–104319. https://doi.org/10.1016/j.respol.2021.104324

Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics*, *23*(2), 177–200. https://doi.org/10.1016/0304-3932(89)90047-0

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173

Barro, R. J. (1990). Government spending in a simple model of endogenous growth. *Journal of Political Economy*, *98*(5, Part 2), S103–S125. https://doi.org/10.1086/261726

Ciftci, M., & Cready, W. M. (2011). Scale effects of R&D as reflected in earnings and returns. *Journal of Accounting & Economics*, *52*(1), 62–80. https://doi.org/10.1016/j.jacceco.2011.02.003

Cui, W. Y., & Tang, J. (2022). Does the Construction of transportation infrastructure enhance regional innovation capabilities: Evidence from China. *Journal of the Knowledge Economy*, (5), 1–18. https://doi.org/10.1007/s13132-022-01005-x

Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, *108*(4-5), 899–934. https://doi.org/10.1257/aer.20101199

Donaldson, D., & Hornbeck, R. (2016). Railroads and American economic growth: A 'market access' approach. *The Quarterly Journal of Economics*, *131*(2), 799–858. https://doi.org/10.1093/qje/qjw002

Duranton, G., Morrow, P. M., & Turner, M. A. (2014). Roads and trade: Evidence from the US. *The Review of Economic Studies*, *81*(2), 681–724. https://doi.org/10.1093/restud/rdt039

Duranton, G., & Turner, M. A. (2011). The fundamental law of road congestion: Evidence from US cities. *American Economic Review*, *101*(6), 2616–2652. https://doi.org/10.1257/aer.101.6.2616

Faber, B. (2014). Trade integration, market size, and industrialization: Evidence from China's national trunk highway system. *Review of Economic Studies*, *81*(3), 1046–1070. https://doi.org/10.1093/restud/rdu010

Franck, R., & Galor, O. (2021). Flowers of evil? Industrialization and long run development. *Journal of Monetary Economics*, *117*, 108–128. https://doi.org/10.1016/j.jmoneco.2019.12.001

Frankema, E. (2015). Labour-intensive industrialization in global history: A review essay. *Economic History of Developing Regions*, *30*(1), 44–67. https://doi.org/10.1080/20780389.2015.1035705

Fritsch, M., & Slavtchev, V. (2011). Determinants of the efficiency of regional innovation systems. *Regional Studies*, *45*(7), 905–918. https://doi.org/10.1080/00343400802251494
Gao, Y. Y., & Zheng, J. H. (2020). The impact of high-speed rail on innovation: An empirical test of the companion innovation hypothesis of transportation improvement with China's manufacturing firms. *World Development*, *127*(3), 104838–104816. https://doi.org/10.1016/j.worlddev.2019.104838
Haraguchi, N., Martorano, B., & Sanfilippo, M. (2019). What factors drive successful industrialization? Evidence and implications for developing countries. *Structural Change and Economic Dynamics*, *49*(6), 266–276. https://doi.org/10.1016/j.strueco.2018.11.002
Hasan, I., & Tucci, C. L. (2010). The innovation-economic growth nexus global evidence. *Research Policy*, *39*(10), 1264–1276. https://doi.org/10.1016/j.respol.2010.07.005
Horvat, T., Bendix, H., Bobek, V., & Skoko, H. (2021). Impacts of investments in infrastructure projects on emerging markets' growth: the case of East African countries. *Economic Research-Ekonomska Istraživanja*, *34*(1), 2135–2161. https://doi.org/10.1080/1331677X.2020.1860799
Hulten, C. R., Esra, B., & Sylaja, S. (2006). Infrastructure, externalities, and economic development: A study of the Indian manufacturing industry. *The World Bank Economic Review*, *20*(2), 291–308. https://doi.org/10.1093/wber/lhj007
Hwang, W. S., & Shim, D. (2021). Measuring the impact of ICT-driven product and process innovation on the Korean economy. *Global Economic Review*, *50*(3), 235–253. https://doi.org/10.1080/1226508X.2021.1884114
Jia, N., Huang, K. G., & Zhang, C. M. (2019). Public governance, corporate governance, and firm innovation: An examination of state-owned enterprises. *Academy of Management Journal*, *62*(1), 220–247. https://doi.org/10.5465/amj.2016.0543
Jiang, Z. J., & Lin, B. Q. (2013). China's energy demand and its characteristics in the industrialization and urbanization process. *Energy Policy*, *60*(9), 583–585. https://doi.org/10.1016/j.enpol.2013.04.059
Jones, S., & Salazar, C. (2021). Infrastructure improvements and maize market integration: Bridging the Zambezi in Mozambique JEL codes. *American Journal of Agricultural Economics*, *103*(2), 620–642. https://doi.org/10.1111/ajae.12103
Jung, Y., Kim, E., & Kim, W. (2021). The scientific and technological interdisciplinary research of government research institutes: Network analysis of the innovation cluster in South Korea. *Policy Studies*, *42*(2), 132–151. https://doi.org/10.1080/01442872.2019.1593343
Li, H., & Li, Z. (2013). Road investments and inventory reduction: Firm level evidence from China. *Journal of Urban Economics*, *76*(7), 43–52. https://doi.org/10.1016/j.jue.2013.02.002
Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, *22*(1), 3–42. https://doi.org/10.1016/0304-3932(88)90168-7
Mackinnon, D. P., Warsi, G., & Dwyer, J. H. (1995). A simulation study of mediated effect measures. *Multivariate Behavioral Research*, *30*(1), 41–62. https://doi.org/10.1207/s15327906mbr3001_3
Malen, J., & Vaaler, P. M. (2017). Organizational slack, national institutions and innovation effort around the world. *Journal of World Business*, *52*(6), 782–797. https://doi.org/10.1016/j.jwb.2017.07.001
Mamuneas, D. T. P. (2000). Intertemporal output and employment effects of public infrastructure capital: Evidence from 12 OECD economies. *Economic Journal*, *110*(465), 687–712. https://doi.org/10.1111/1468-0297.00561
Marsiglio, S., & Tolotti, M. (2018). Endogenous growth and technological progress with innovation driven by social interactions. *Economic Theory*, *65*(2), 293–328. https://doi.org/10.1007/s00199-016-1017-9
Michaels, G. (2008). The effect of trade on the demand for skill: Evidence from the interstate highway system. *Review of Economics and Statistics*, *90*(4), 683–701. https://doi.org/10.1162/rest.90.4.683

Mu, R. P., Ren, Z. B., Song, H. F., & Chen, F. (2010). Innovative development and innovation capacity-building in China. *International Journal of Technology Management*, *51*(2/3/4), 427–452. https://doi.org/10.1504/IJTM.2010.033813

OECD. (2009). *Measuring capital-OECD manual*. OECD Publishing.

Ouattara, B., & Zhang, Y. F. (2019). Infrastructure and long-run economic growth: Evidence from Chinese provinces. *Empirical Economics*, *57*(1), 263–284. https://doi.org/10.1007/s00181-018-1429-4

Qi, H. G., Liu, S. H., Qi, W., & Liu, Z. (2019). Geographical concentration of knowledge-and technology-intensive industries and city innovation in China. *Sustainability*, *11*(18), 4840. https://doi.org/10.3390/su11184840

Ritala, P., Olander, H., Michailova, S., & Husted, K. (2015). Knowledge sharing, knowledge leaking and relative innovation performance: An empirical study. *Technovation*, *35*(1), 22–31. https://doi.org/10.1016/j.technovation.2014.07.011

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5, Part 2), S71–S102. https://doi.org/10.1086/261725

Sawada, Y. (2019). Infrastructure investments, technologies and jobs in Asia. *International Journal of Training Research*, *17*(sup1), 12–25. https://doi.org/10.1080/14480220.2019.1629724

Scaringella, L., & Chanaron, J. J. (2016). Grenoble-giant territorial innovation models: Are investments in research Infrastructures worthwhile? *Technological Forecasting and Social Change*, *112*(11), 92–101. https://doi.org/10.1016/j.techfore.2016.05.026

Shively, G., & Thapa, G. (2017). Markets, transportation infrastructure, and food prices in Nepal. *American Journal of Agricultural Economics*, *99*(3), 660–682. https://doi.org/10.1093/ajae/aaw086

Thompson, M. (2018). Social capital, innovation and economic growth. *Journal of Behavioral and Experimental Economics*, *73*, 46–52. https://doi.org/10.1016/j.socec.2018.01.005

Tomizawa, A., Zhao, L., Bassellier, G., & Ahlstrom, D. (2020). Economic growth, innovation, institutions, and the Great Enrichment. *Asia Pacific Journal of Management*, *37*(1), 7–31. https://doi.org/10.1007/s10490-019-09648-2

Wang, X., Xie, Z., Zhang, X., & Huang, Y. (2018). Roads to innovation: Firm-level evidence from people's republic of China. *China Economic Review*, *49*(6), 154–170. https://doi.org/10.1016/j.chieco.2017.12.012

Yi, M., Fang, X. M., & Zhang, Y. (2019). The differentiated influence of technology absorption on regional economic growth in China. *Sustainability*, *11*(2), 450–412. https://doi.org/10.3390/su11020450

Yu, N., De, J. M., Storm, S., & Mi, J. (2012). The growth impact of transport infrastructure investment: A regional analysis for China (1978–2008). *Policy and Society*, *31*(1), 25–38. https://doi.org/10.1016/j.polsoc.2012.01.004

Zeng, S. X., Liu, Z. M., & Sun, D. X. (2022). How do highways enable firm productivity? The role of innovation. *IEEE Transactions on Engineering Management*, (6), 1–14. https://doi.org/10.1109/TEM.2022.3174883

Zeng, Z. X., Zhao, L., & Wang, X. J. (2021). Does improved transportation promote innovation? evidence from China's cities. *Applied Economics*, *11*, 1–16. https://doi.org/10.1080/00036846.2021.1992344

Zhang, J. R., Zhang, R. L., Xu, J. Z., Wang, J., & Shi, G. Q. (2021). Infrastructure investment and regional economic growth: Evidence from Yangtze River Economic Zone. *Land*, *10*(3), 320. https://doi.org/10.3390/land10030320