Can 'New' Infrastructure Become an Engine of Growth for the Chinese Economy?

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Abstract

This paper explores the effect of new infrastructure on economic growth from the aspects of tangible and intangible assets. According to empirical analysis, we conclude that traditional infrastructure directly contributes to the Chinese economic growth via fixed asset formation, while new infrastructure has overall insignificant direct effect on growth, i.e., it is unrealistic for new infrastructure to become an engine of growth for the Chinese economy in the short run. But it is also worth noting that new infrastructure does have the potential to promote the upgrade of industry structure and therefore boost economy in the long run. Based on the modelling results as well as the nature of new infrastructure, it is suggested that new infrastructure investment is not suitable to act as a short-term stimulation especially under Covid-19 pandemic despite its great potential in the long term.

Keywords: new infrastructure; economic growth; tangible assets; intangible assets; Covid-19 pandemic

JEL: O11

1. Introduction

Infrastructure sectors are recognized as an effective driver of economic growth (Aschauer 1989a; Munnell and Cook 1990; Wang 2002; Khanna and Sharma 2020). Since opening up, China has achieved remarkable economic growth through fixed asset formation especially in the field of infrastructure. Particularly, in response to the global financial crisis in 2008, the 4-trillion stimulus package for infrastructure investment launched by the Chinese government has made a significant contribution to reversing the economic downturn in the short run. In the context of Sino-US trade frictions and China’s economic new normal, the concept of ‘new’ infrastructure was proposed by the central government, aiming to boost economic growth in China

(CEWC 2018)[1]. In March 2020, in response to the outbreak of the Covid-19 pandemic, increasing investment in public health services and accelerating the construction of new infrastructure sectors, such as 5G networks and data centres were once again emphasized (PBSC 2020).

To be precise, ‘new’ infrastructure refers to infrastructure in the technological innovation sector, including 7 major business industries: 5G base station construction, new energy vehicle charging piles, big data centres, artificial intelligence, industrial Internet, ultra-high-voltage (UHV) grid and intercity and urban rail transit (Guo, Wang, and Liu 2020). A broader definition of new infrastructure is clarified by the National Development and Reform Commission of People’s Republic of China in April 2020, emphasizing digitalization based on technological innovation (NDRC 2020)[2]. Despite the above nominal differences, there is no doubt that digitalization is the basic element of new infrastructure, and accordingly, ‘digital infrastructure’ has become the core of new infrastructure development (See Appendix 1 for the classification of new infrastructure).

Since digitalization is considered as an integral part of high-quality economic development in the near future (Goldfarb and Tucker 2019), many scholars believe that new infrastructure will exert an obvious positive effect towards China’s economy

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[1] The Central Economic Work Conference in 2018 clarified the classification of the ‘new’ infrastructure sectors: 5G, artificial intelligence (AI), industrial Internet and the Internet of Things (IOT).

[2] The National Development and Reform Commission (2020) explained that the new infrastructure is guided by new development concepts, driven by technological innovation, based on information networks, and facing the needs of high-quality development, with the aim to provide an infrastructure system to service digital transformation, intelligent upgrading, and integration innovation.

from both the long-term and short-term (Ren et al. 2020). In opposite, some arguments elaborate that new infrastructure is not suitable to be used as the promoter of short-term stimulus policy, and more prudence is needed to cope with the Covid-19 pandemic if it will be done through new infrastructure investment (Liu 2020a, 2020b; Wu, Zhong, and Huang 2020). However, due to the short time since the concept of new infrastructure being proposed, researches for the effect of new infrastructure on economic growth have mainly been qualitative. In order to fill the gap, this paper aims to quantify the relationship between new infrastructure and China's economic growth, and explain the similarities and differences between new and traditional infrastructure in promoting Chinese economic growth by adopting China's infrastructure industry data.

This paper explores the effect of new infrastructure on economic growth from two aspects: tangible assets and intangible assets, with special reference to the technology spillover and trickle-down effects of new infrastructure. According to model results, new infrastructure has not made directly and significantly positive contribution to China's economic growth, but it does contribute indirectly through technological progress, i.e., trickle-down effect, which will lead to the upgrade of industrial structure in the long run. This paper also provides a framework for industrial policy making about new infrastructure especially under Covid-19 pandemic.

The remainder of this paper is organized as follows. Section 2 reviews the literature on infrastructure investment and economic growth as well as the spillover and trickle-down effects. Section 3 analyzes the status quo of new infrastructure in China and proposes the main hypothesis that this paper tries to investigate. Section 4 describes the data and relevant empirical models adopted in this research. Then we present the estimation results of modelling in section 5. Section 6 concludes with discussion.

2. Literature Review

2.1 Infrastructure Investment and Growth

As a type of public asset, research on the role of infrastructure in economic development was sparked by Aschauer (1989a, 1989b), who first found evidence between increase of infrastructure stock and large rates of return. Following Aschauer's early work, although some research suggest little evidence of an effect from infrastructure to income growth (Hulten and Schwab 1991; Eakin and Schwartz 1995; Garcia-Mila, McGuire, and Porter 1996), a great number of studies using national (Luoto 2011; Khanna and Sharma 2020) and international data (Easterly and Rebelo 1993; Canning 1998; Wang 2002; Esfahni and Ramírez 2003; Calderón and Servén 2004; Kodongo and Ojah 2016) support the result that infrastructure is important to economic growth.

Owing to the rich experience of infrastructure investment, a mass of studies examines the relationship of infrastructure and economic aggregate in China and positive relationships are clearly detected. Using panel data for a sample of 24 Chinese provinces, Démurger (2001) suggests that transport infrastructure and telecommunication facilities account for a large contribution of growth. Fan and Zhang (2004) examine the role of infrastructure and regional economic in rural China, demonstrating that rural infrastructure investment is playing an important role in explaining higher productivity. Fan and Chan-Kang (2005) verify the contribution of road infrastructure to economic growth and poverty reduction in China. Ding, Haynes, and Liu (2008) indicate a significant and positive relationship between telecommunications infrastructure and regional economic growth in China by using GMM estimation on 29 Chinese regions from 1986 to 2002. Shi and Huang (2014) indicate a different economic efficiency of infrastructure investment by the nationwide

Chinese government based on Chinese provincial data from 1995 to 2011. Banerjee, Duflo and Qian (2020) suggest that proximity to transportation networks have a positive causal effect on per capita GDP levels across sectors.

Recently, the research interest has shifted to digital infrastructure (Woroch 2000; Shenglin et al. 2017) and several other relevant fields include ICT infrastructure (Toader et al. 2018; Pradhan, Mallik, and Bagchi 2018), telecommunication infrastructure (Zahra, Azim, and Mahmood 2008; Pradhan, Bele, and Pandey 2013), technology infrastructure (Tassey 1991; Tassey 2012) and Internet infrastructure (Cave and Mason 2001; Tranos 2012). Most of them recognize the significance of digital infrastructure on economic growth but it is also pointed out by Roller and Waverman (2001) that this positive effect would be weakened due to the insufficiency of digital infrastructure provision. Alongside the abundant empirical research on traditional types of Chinese infrastructure: transport, telecommunication and utilities, few studies examine the relationship between digital infrastructure, namely new infrastructure, and economic development in China. This study, focusing on the new infrastructure in China, empirically examines the effect of infrastructure on the economic growth.

2.2 Infrastructure Spillover Effect

The essence of new infrastructure is technological innovation (NDRC 2020). Different from the direct impact and spatial spillover effect of traditional infrastructure (Tong et al. 2013), the driving effect of new infrastructure on the economy can be mainly reflected in indirect mechanism such as technology or knowledge spillovers. Technological knowledge and digital revolution, more in general, are difficult to be confined within the boundary of the firm due to their ethereal nature (Fosfuri and

Rønde 2004). They have significantly positive influences on productivity at both industry level and firm level (Chyi, Lai, and Liu 2012). In addition, technological progress per se is a key driver of economic growth by accelerating industry transformation and upgrade (Antonelli 2005; Wu and Liu 2021).

In terms of new infrastructure in China, Liu (2020a) comments that the greater uncertainty of technological innovation makes new infrastructure riskier as short-term economic stimulus compared with traditional infrastructure. Using panel data of 30 provinces over 10 years in China, Wu, Zhong, and Huang (2020) claim that new infrastructure cannot significantly promote the upgrade of technological efficiency of emerging industry. While others believe that new infrastructure can promote the growth of China's economy through indirect effect such as encouraging enterprise innovation, improving production efficiency and optimizing industrial structure (Pan and Luo 2020; Ren et al. 2020; Guo, Wang, and Liu 2020). It is worth noting that there is still largely obscure on the empirically impact of new infrastructure on the economy. As a result, we try to extend our understanding about it by combining 'spillover effect', under the perspective of intangible assets, and 'trickle-down effect', in the view of tangible assets, in our empirical models. Later in the article, we introduce our methods of capturing these effects through mediation models.

3. Theoretical Framework and Hypothesis

To better understand the effect of new infrastructure on China's economy, it is meaningful to first clarify the difference between new infrastructure and traditional infrastructure in China. Public goods, featured with non-rival in consumption, are crucial to the functioning of society (Chan and Wolk 2020). And traditional infrastructures like railway, highway and dam are typically classified as public goods, even though part of their positive externalities depends on distributional and demographic characteristics to some extent (Fiorito and Kollintzas 2004). On the contrary, digital infrastructures are viewed as private goods that are basically provided by enterprises. Private ownership makes the investor a major beneficiary rather than the ordinary citizens that traditional infrastructure aims to target for. Considering such difference in nature between traditional and new infrastructures, their operating mechanisms diverge. From the perspective of demand side, the government is able to influence the fixed asset formation via investment in traditional infrastructure, through which the economic growth can be expected in return. In terms of new infrastructure, the central government cannot directly exert influence on economic growth, since it is not the supplier. Industrial policies towards specific areas like information industry can be an option for the government to boost the economy through new infrastructure. It is, however, indirect and the effect of such industrial policies is still controversial.

Furthermore, the direct force of new infrastructure to macro economy is minimal. According to national economic accounting, only a part of the investment turns into fixed asset formation as a constituent of GDP, and new infrastructure investment mainly influences the intangible assets of asset formation (Figure 1). The proportion of intangible assets in fixed asset formation of China's economic aggregate is, not surprisingly, only about 10% (Figure 2). When it comes to two industries closely linked to new infrastructure, i.e., information transmission, software and information technology services and scientific research and technical services, traditional infrastructure investment categories like construction and installation and purchase of equipment and tools also prevail. The proportions of intangible assets are about 30% of fixed asset formation (Figure 3, Figure 4). As a result, the expectation to promote growth rate via investment in new infrastructure appears unrealistic. We admit that new infrastructure may be crucial for the accumulation of total factor productivity, which indicates that the production models will become more efficient. The above effect is, nevertheless, indirect for growth which belongs to another aspect that we are going to discuss below.

It is commonly recognized that the level of the economic aggregate is often affected by externalities from private actions. Positive examples include knowledge goods that benefit private productivity or consumption, which we call 'spillover effect' (Stiglitz 1974; Romer 1990; Kam, Kao, and Lu 2020). Some empirical evidence highlights the significance of knowledge spillovers and even finds the return to private R&D largely accounted for by knowledge spillover channels (Eberhardt, Helmers, and Strauss 2013; Kam, Kao, and Lu 2020). Essentially, new infrastructure is characterized by new technologies like 5G, artificial intelligence and Internet of Things. And these high techs have the potential to penetrate into other fields of life and improve the productivity indirectly, namely the positive knowledge spillovers through the formation of intangible assets. To be specific, two dimensions of production environment are most likely to be improved by spillover effects of new infrastructure: industrial structural upgrading and production innovation.

Industrial structure upgrading refers to the transition of development force from low-value-added industries to high-value-added industries, e.g., transitions from primary industry to the secondary and tertiary industry. During such transitions, technological progress acts as a direct propellant for changes, and as a result, the development of new infrastructure contributes to the advancement of high-tech industry through lifting the production efficiency. And then those beneficial emerging high-tech industries will boost economic growth by gradually replacing traditional industries in the long run. In addition, new infrastructure can provide more convenience for people to effectively acquire technology and knowledge, promoting the flow of technology and knowledge in the regional innovation system. This is not only conducive to R&D innovation, but also provides a basic guarantee for the smooth transformation of R&D innovation results into actual productivity, products, services, and thereby economic growth.

In addition, new infrastructure is also likely to contribute to total factor productivity by providing relevant material facilities like 5G base station, big data centres, cloud computing cluster servers, urban rail facilities, i.e., tangible assets. Since these facilities will not take effect until the amount of them becomes substantial or reaches certain threshold, we name such effect as 'trickle-down effect', which is mainly driven by the tangible asset accumulation.

In either form, knowledge penetration takes long and thus, the value of new infrastructure to economic aggregate is expected to become more evident over a longer horizon, and the mechanism is indirect.

Considering that both of spillover effect (intangible assets) and trickle-down effect (tangible assets) will boost the economy, we proceed with the following two hypotheses in order to further explore the role and the effect of new infrastructure:

H1: Spillover effect provided by intangible assets of new infrastructure is prominent in boosting economy.

H2: Trickle-down effect provided by tangible assets of new infrastructure is prominent in boosting economy.

4. Data and Methodologies

4.1 The Data

Annual data of China are collected for empirical analysis. The data include the annual growth in tangible assets and intangible assets for both traditional infrastructure and new infrastructure each year. Following the classification conventionally adopted by most researches on infrastructure of China, we choose three industries as the proxy of traditional infrastructure: 'Transportation, Storage, and Postal Industry', 'Electricity, Heat, Gas, and Water Production and Supply Industry', and 'Water Conservancy, Environment, and Public Facilities Management'. And we also classify two industries as new infrastructure: 'Information Transmission, Software, and Information Technology Service Industry' and 'Scientific Research Technology Service Industry'. All these data are provided by TJD Research Institute, and the horizon of data ranges from year 2007 to 2019.

Additionally gathered are data on general economic indicators and technology spillover or trickle-down characteristics from WIND database: GDP annual growth, population, foreign direct investment, increment of national total number of patents from all enterprises, national total R&D expenditure, national total R&D man-hours, and industrial structure. The definition of variables used in this paper are summarized in Table 1.

For robustness research, we build auxiliary model using monthly data for total GDP, as well as the value added for the three main sectors. The data also includes monthly increment for intangible asset and tangible asset of new infrastructure and traditional infrastructure, which is also collected and estimated by TJD Research Institute.

4.2 Granger Causality Test

We apply the Granger test (1969) based on a simple Distributed Lag Regression model with Lagged dependent variables (DLR) in order to investigate the causal relationship between the assets of infrastructure and the economic development in China. Stationarity test results suggest that log of GDP and tangible assets of both new and traditional infrastructure in monthly data are stationary variables, based on which we perform Granger test. Granger test combined with DLR modelling is one of the most flexible and popular methods for emphasizing causality underlying in time-series data (Brooks 2014). With the basic concept that each variable is a linear function of past values of itself and the others, the Granger test measures whether current and past values of a variable help to forecast the future values of another variable. The hypothesis and the whole model of Granger test can be tested by an F-test and Wald-test. To date, the Granger causality test has gained popularity in analyzing time-series model for economic growth (Beyzatlar, Karacal, and Yetkiner 2014; Wang, Kim, and Kim, forthcoming). The following equations are estimated to test the direction of causality from tangible assets of new infrastructure to China's economic growth.

To test whether tangible assets of new or traditional infrastructure sectors Granger cause GDP growth to change:

$$\log(\mathrm{GDP}_t) = \sum_{k=1}^{2} \beta_k \log(\mathrm{GDPpercapita}_{t-k}) + \sum_{p=0}^{2} \theta_p \log\left(\mathrm{TangibleNew}_{t-12-p}\right) + u_t \quad (1)$$

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The design of these tests helps the study to identify whether a monthly-based data suggest causality between lagged assets accumulation and economic growth in the following year.

4.3 Dimension Reduction Modelling

Our main model is a mediator model, which assumes our regressors indirectly affect the explained variable through a number of mediators. However, we are faced with sample restrictions. The more mediators are used, the bigger the number of regressors, and the larger the sample size the model needs. Albeit our unique monthly macroeconomic data act as good tool of robustness support, we have to deal with the problem caused by the small sample size of the annual data. We use explanatory factor analysis (EFA) and principal component analysis (PCA) to condense the variables regarding industrial structural upgrades into one integral mediator. Since monthly data has no sample size issues, nor do we have many monthly collected variables regarding technological spillover or trickle-down, we do not apply EFA or PCA on monthly data.

4.4 Mediation Effect Model

To further explore the relationship between the development of new infrastructure and economic growth, tangible and intangible assets of new infrastructure are used as independent variables and GDP per capita are used as dependent variable to form the basic regression model. We are interested in, furthermore, the technological spillover or potential trickle-down effect of the new infrastructure. We therefore construct a mediation effect model, utilizing the principal component we constructed above that embodies information of technological advances as intermediary variables.

The mediation model is useful in analyzing the mechanism of the independent variable's indirect influence on the dependent variable, and thus has received increasing attention in recent years (Fritz and MacKinnon 2007; MacKinnon, Fairchild, and Fritz 2007; Preacher and Kelley 2011). Compared with researches that simply investigate the direct effect of independent variables on the dependent variable, mediation analysis not only refines the research method, but also helps to obtain more in-depth results. Considering the potential technological spillovers of intangible assets of new infrastructure and the possible contribution of tangible assets of new infrastructure through trickle-down effect, we assume that the effect of new infrastructure towards economic growth can be expressed through the principal component. As such, the mediation model follows the following form:

$$y_t = c_1 x_{1,t} + \sum_{j=1} \theta_j CV_{j,t} + e_{1,t} \quad (3)$$

$$M_t = \alpha_1 x_{1,t} + e_{2,t} \quad (4)$$

$$y_t = c_1^{'} x_{1,t} + \beta_1 M_t + \sum_{j=1} \theta_j^{'} CV_{j,t} + e_{3,t} \quad (5)$$

M_i refers to the sole mediator, the principal component containing variables relating to technological advances, in our models. The number of factors used to conclude technological advances is tested through EFA. CV_i and $x_{i,t}$ include all the terms regarding asset accumulation, i.e., tangible and intangible assets of new or traditional infrastructures, the specific roles of whom decided by the mediator models.

If coefficients are significant in the equation (3), they remain as the x_i in the equation (4)-(5). Otherwise, they will become a member of CV_i. We will present the exact form of our models in the next section. Summary statistics of variables used in the model are listed in Table 2.

To verify our findings, a similar model based on monthly data is used for robustness test. Restrained by the data accessibility, we use the industrial structure Is, expressed as the proportion of the tertiary and secondary industries in national GDP. An increase in Is means the industrial evolution in general and a shift towards the technology-intensive industries. Statistics for this complementary data set can be found in Table 3.

5. Empirical Results

5.1 Granger Causality Results

The Granger causality test is performed on part of the monthly data set, since monthly GDP, log of monthly GDP, monthly growth of GDP, tangible assets of both new and traditional infrastructure are stationary (See Table 4).

The results suggest that one-year-lagged terms of tangible assets from both new and traditional infrastructure Granger cause the growth. However, growth also Granger causes the two. As such, we cannot conclude beyond the strong correlation between economic growth and tangible assets accumulation, no matter the type of infrastructure. Table 5 shows the results of the Granger causality test, containing the contemporary terms, first lag, and second lag. Despite the results, we further justify using log of GDP and tangible assets as our main variable in the mediator models, considering the correlation verified.

5.2 PCA Results

Through maximum-likelihood estimation, the EFA gives results on the suitable number of factors to include in our model (Gorsuch 1997; Grice 2001; Hofmann 1978; Kaiser and Caffrey 1965). Figure 5 shows that the variables of concern in the mediation effect model can be compressed into one factor.

We then apply PCA to reduce the variables concerning technological advances, FDI, and industrial structures into one principal component (PC) for the annual model. The content of the PC includes annual country-total R&D expenditures based on a constant price, annual country-total R&D man hour, annual foreign direct investment based on a constant price, the proportion of the tertiary against secondary industries in GDP, the proportion of the tertiary and secondary industries in GDP.

Monthly model is spared from the complexity of the method, and we use industrial structure calculated through the proportion of the tertiary and secondary industries in GDP as the mediator.

5.3 Mediation Regression Results

GDP per capita, tangible and intangible assets for both new and traditional infrastructure as well as the PC (principal component) are utilized in the model. The regression results are summarised in Table 6.

Model (1) indicates that the lagged term for tangible assets of new infrastructure is eligible for the test of potential mediation effect. Reasons that lagged term for tangible assets of traditional infrastructure is dropped for next mediation analysis are not only its significance level is poor presented by the regression result, but also its role on economy is not the focus of this paper when comparing with new infrastructure. Therefore, only the lagged term for tangible assets of new infrastructure is selected for the following analysis.

Combining the results in model (2) and model (3), it is suggested that lagged tangible assets increment in new infrastructure has a significant positive mediation effect through PC but a significant negative direct effect on GDP growth, indicating a trickle-down effect of new infrastructure on economy through industrial upgrade and technological progress.

Traditional infrastructure only directly contributes to GDP growth through lagged tangible assets, but the mild effect becomes even more insignificant taking into account the mediation effect. Lagged intangible assets increment from either infrastructure, on the contrary, has either direct or indirect significant effect on GDP growth, indicating no significant spillover effect is detected by the model.

Due to the complex nature of the principal component, we cannot state that the scale of the estimated coefficients of the principal component has precise economic meaning. Fortunately, the significance and direction of the coefficients remain meaningful and reliable. We conclude that lagged change of tangible assets of new infrastructure significantly curbs the current economic growth, but positively impacts industrial upgrade. Meanwhile, lagged change of tangible assets of traditional infrastructure does not display evident impact on growth elevation. Intangible assets do not significantly drive economic growth in either direct or indirect ways.

5.4 Robustness Test

For robustness, monthly data are utilized in a similar mediation effect model as the former section. Restricted by the data accessibility, we choose the industrial structure, calculated by the proportion of the secondary and tertiary industries in GDP, as the new mediator. A lag period of 12 months in infrastructure terms is chosen in order to maintain the consistency of lag horizon, one year, in the model of annual data. The empirical results are shown in Table 7.

These results match the polarity and significance of the previous model in terms of the coefficients for tangible asset lagged terms of both new and traditional infrastructure. Unlike the case of annual data, industrial structure becomes insignificant in model (3). In this case, Sobel test (Sobel 1982; Wen, Hau, and Chang 2005) are utilized in deciding whether mediation effect, i.e., technological trickle-down, exists.

It is found that new infrastructure again presents positive technological trickle-down effect, along with a negative direct effect, on GDP growth. In the meantime, traditional infrastructure shows a significantly negative technological trickle-down effect, maintaining a positive direct effect, on GDP growth. In addition, the monthly model agrees that intangible assets are not as relevant.

Sobel test for these models adds to the robustness of our previous model. To start, lagged terms of tangible assets appear to be the only significant variables that participate in mediation effect on a monthly scope, reiterating the lack of relevance of intangible assets in the matter. The reason that model settings differ from the annual model by including lagged tangible assets of traditional infrastructure in the mediation process is that its significance has become nonnegligible, and Sobel test results agree so.

What matters, however, is that annual model and monthly model agrees with each other, especially when it comes to the effect of new infrastructure on the economy. In either model, mediation effects of the lagged tangible assets from new infrastructure are significantly positive. Albeit differs in magnitude and significance, the two models agree that the tangible assets of traditional infrastructure and produce either non-significant or adversary mediation effect on GDP growth, which indicates they are not making a positive contribution to economic growth. Lastly, there is no disagreement on the direction of negative direct effect of tangible assets of new infrastructure on GDP growth.

Due to the limitation of the accessible data, we have not been able to demonstrate a model that involves the regional development differences of new infrastructure or has a longer time dimension with more detailed information. We realize that our regression results of this paper may be related to these limitations of the data. With the development of new infrastructure, its effect on economic growth is still a topic worthy of in-depth study.

6. Conclusion and Discussion

This paper explores the effect of new infrastructure on economic growth from two aspects, i.e., tangible assets and intangible assets, using annual data of China from TJD database ranging from 2007 to 2019. By indicating that new infrastructure is a collection of knowledge goods which distinguishes it from traditional infrastructure, and it may exert influence through positive externalities on technological advances and industrial structure, we investigate the technology spillover and trickle-down effects of new infrastructure through mediation effect model. The modelling results, however, suggest that no mediation effect is observed between economic growth and intangible assets, regardless of the infrastructure types. Therefore, existing evidence is insufficient to support the existence of spillover effects of new infrastructure at this stage. Therefore, H1 is rejected.

Nevertheless, empirical analysis sheds light on the diverge mechanisms by which new and traditional infrastructure act on the economic growth regarding tangible assets:

(i) It is found that although the effect of traditional infrastructure in industrial upgrading and technological progress is insignificant, a significant positive impact of traditional infrastructure on economic growth cannot be ignored.

(ii) In accordance with the characteristic as a collection of knowledge goods, new infrastructure clearly promotes the industrial upgrading and technological progress by increasing tangible assets input. However, its direct effect on growth of GDP per capita proves that the tangible assets of new infrastructure slow down the rate of economic growth. Afterall, trickle-down effect is detected and we therefore accept H2.

These findings are in accord with the theoretical framework of section 3 in this paper and prove the complexity of the role of new infrastructure in economic growth compared with the traditional infrastructure. To sum up, traditional infrastructure contributes to the Chinese economic growth via direct fixed asset formation while new infrastructure, as private knowledge products, has to go through a necessary process from initial fixed asset investment to integration with industry production, indirectly acting on the economic growth. It is worth noting that new infrastructure does have the potential to promote the upgrade of industry structure and therefore boost economy in the long run.

6.1 Immaturity of New Infrastructure in the Short Term

Compared with the traditional infrastructure, although the new infrastructure has obvious advantage in promoting industrial upgrade and technological progress, it has not effectively facilitated economic growth so far. Our research shows that new infrastructure cannot replace, if not worse, its traditional counterpart as an engine of China's economic growth, at least in the short run. The private attributes of both tangible and intangible assets of the new infrastructure dictate that the investment towards new infrastructure cannot directly drive economic growth like traditional infrastructure does, whose assets have already been disseminating positive externalities by forming public goods and providing facilities. In other words, new infrastructure can only create more value when it actually came into service for production, before which capitals, usual in a considerable amount, are absorbed by R&D, thereby reducing economic growth in the short term. New infrastructure is just emerging, and thus the insufficiency of investment intensity is rather evident compared with the case of traditional infrastructure. It is therefore reasonable that new infrastructure has not yet played a role in promoting significant economic development.

Despite the potential of new infrastructure being true, policymakers should expect to wait for a necessary time horizon before these potentials are realized. For comparison, China has been continually increasing its investment in traditional infrastructure since the 1990s, especially after the 1998 and 2008 financial crisis. This sort of investment spending has been treated as a proactive fiscal policy to some extent. New infrastructure, if not more time consuming, should take no significantly shorter time than its predecessors. Moreover, most new infrastructures are invested by private sector, facing greater uncertainty in technical success, which restricts the investment volume of new infrastructure as explained in Section 3. Meanwhile, the volume of tangible assets for new infrastructure is underestimated because of the statistical overlaps between new and traditional infrastructure. For example, urban rail transit and UHV are considered as typical new infrastructures while investment in them is counted as traditional infrastructure investment, which potentially leads to the insignificant relationship between 'reduced' tangible assets of new infrastructure and economic growth.

Although it is commonly anticipated that the development of new infrastructure will lead to technology spillovers, our results indicate that intangible assets are not significantly related to economic growth, therefore denying the existence of spillover effect. The absence of technological spillover effects may point to several possibilities that renders the knowledge and techniques refined by new infrastructure still inapplicable. One is that the deployment of production methods facilitated by new infrastructure in China is still immature, which is the potential reason behind the insignificance of knowledge spillover effect of new infrastructure. The finding is similar to the standpoint of Roller and Waverman (2001). It is also possible that the relationship between the new infrastructure and economic growth is nonlinear, i.e., economic growth will be inhibited under preliminary stage of new infrastructure, and growth will be significantly promoted only when the level of new infrastructure development reaches the threshold. In other words, when the constructions of new technologies, new data and new platforms for new infrastructure are immature and uneven, the potential positive effects of new infrastructure on knowledge spillovers are difficult to achieve. And if in view of the natural lag between investment and output due to necessary time for production after or along with investment, failing to capture the contemporary mediation relation between intangible assets of new infrastructure and economic growth is acceptable.

In terms of traditional infrastructure, as its development is relatively mature, it is capable of directly affecting economic growth through investment of public sectors. Although problems such as low efficiency exist, the models partially agree that traditional infrastructure is still a powerful tool in directly promoting economic growth. As opposed to new infrastructure, a drag effect of traditional infrastructure on industrial upgrade is observed in our model. We conclude this negative mediation effect as a piece of evidence pointing to investment inefficiencies. It is possible that investing in traditional equipment and machineries hinders the longer-term technological promotion. This phenomenon may be stressing the importance of new infrastructure regarding technological materialization in the long run.

6.2 Great Potential of New Infrastructure in the Long Term

The above discussion is not the doomsday judgement for the role of new infrastructure in the economy. The negative effect of new infrastructure's tangible asset on economic growth is indeed disappointing. Nevertheless, positive effect of new infrastructure towards the upgrade of industrial structure is revealed. This cheering trickle-down impact distinguishes the new infrastructure; therefore, policymakers should stay optimistic about the prospects for investing in new infrastructure in the long run. The deployment of new facilities such as data centres, cloud computing servers, high speed urban rails and UHV grid are perhaps pumping production efficiencies already. As our models suggest, albeit real roads or pipelines being built by new infrastructures, tangible assets of new infrastructure are positively linked with technological advances signalled by higher volumes of patent, higher R&D expenditures country-wide, and higher R&D man-hour invested, all of which takes tremendous time to realize into hardware and infrastructures on a large scale, and benefit total factor production rate once they are realized. The findings may be in line with the aforementioned analysis that high techs of new infrastructure will influence the economy through the improvement of the productivity which will generally take effect over a longer horizon rather than in the short term.

Furthermore, China's macroeconomy has been under the transition process from 'high-speed oriented' towards 'high-quality oriented' and the importance of growth rate has been weakened to some extent. As a result, traditional investment, though being effective in contributing to the growth rate, is not that important for development. On the contrary, new infrastructure featured with new technology is committed to the improvement of the mode of production, and it is hard for extant economic statistical system to reflect this kind of innovation-driven regime. From this point of view, new infrastructure does have great potential in high-quality development of China's economy in the long term.

6.3 Stimulus Policy under Covid-19 Pandemic

The year 2020 is suffering from Covid-19 pandemic. Over one million people have died for it according to the tally by Johns Hopkins University and the global economy has also been hit hard. Though performed relatively better, China’s GDP growth rates in the first three quarters only reach -6.8%, 3.2% and 4.9%, respectively, which are considerably lower than normal level. In order to accelerate the recovery of economy, a moderate package of stimulus policy is called for but based on our modelling results, new infrastructure investment seems not suitable to act as a short-term stimulation for its effect will appear in the longer horizon. In addition, the innovative characteristics of new infrastructure signify that its development path should be determined by market power, and administrative intervention may be counterproductive. In opposite, though traditional infrastructure investment has been criticized for inefficiency, it exerts a significant positive effect towards macroeconomy promptly, and it is a better choice of short-term stimulus for traditional infrastructure investment in the context of pandemic.

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Appendix

A. *The classification of new infrastructure*

The broad classification of new infrastructure

Aspects	Definition	Contents
ICT Infrastructure	Infrastructure based on the evolution of new generation information technology	5G, IOT, Industrial Internet, AI, Cloud Computing, Blockchain, Data Centre, Intelligent Computing Centre, etc.
Upgraded Infrastructure	Transformed and upgraded traditional infrastructure using the Internet, big data, AI and other technologies	Smart transportation infrastructure, smart energy infrastructure, etc.
Innovation Infrastructure	Public welfare infrastructure supporting scientific research, technology development, and product development	Science and technology infrastructure, science and education infrastructure, industrial technology innovation infrastructure, etc.

Source: NDRC

Table 1. The Definition of Variables

Variable	Definition
$GDPpercapita$	Calculated by GDP over population
$IntangibleNew$	Intangible assets of new infrastructure in China
$IntangibleOld$	Intangible assets of traditional infrastructure in China
$TangibleNew$	Construction cost and equipment fee of new infrastructure in China
$TangibleOld$	Construction cost and equipment fee of traditional infrastructure in China
$IndustrialStructure$	The proportion of the tertiary and secondary industries in GDP
PC	The principal component that reduce the number of patents filed each year in China, annual country-total R&D expenditures based on a constant price, annual country-total R&D man hour, annual foreign direct investment based on a constant price, the proportion of the tertiary against secondary industries in GDP, the proportion of the tertiary and secondary industries in GDP
$Patent$	The number of patents filed each year in China
$RDexpenditure$	Annual research and experiment expenditures based on a constant price
FDI	Annual foreign direct Investment based on a constant price
$Corporate$	number of state-owned enterprises and corporates with scale

Table 2. Descriptive Statistics for Annual Data

Variable	Obs	Mean	Sd	Median	Min	Max
$GDPpercapita$	13	3.928064	1.571596	3.856805	1.825457	6.368673
$IntangibleNew$	13	1821.963	1043.624	1730.139	632.3116	3607.911
$IntangibleOld$	13	740.3135	441.8935	704.5574	230.016	1494.028
$TangibleNew$	13	4665.669	2081.962	3799.04	2741.155	8907.665
$TangibleOld$	13	53951.54	15316.55	47597.89	34892.46	78525.6
$IndustrialStructure$	13	183501.8	120418.4	143847	31945	360919
$Patent$	13	11869.43	5862.069	11846.6	3710.2	22143.6
$RDexpenditure$	13	1141.7	189.4747	1175.86	747.68	1381.346
FDI	13	380050.8	38037.65	377888	325609	452872

Table 3. Descriptive Statistics for Monthly Data

Variable	Obs	Mean	Sd	Median	Min	Max
GDP	164	50313.49	14967.43	49361.51	23504	84314.64
$IntangibleNew$	164	161.5926	97.87584	146.5323	35.036	431.75
$IntangibleOld$	164	65.78523	41.54175	59.6503	11.9762	181.093
$TangibleNew$	164	407.3128	248.2242	344.1495	55.27222	1351.805
$TangibleOld$	164	4593.573	2099.387	4514.166	945.1415	9322.741
$IndustrialStructure$	164	1.049241	0.134919	1.00787	0.890877	1.688523

Table 4. Results of the Stationarity Test

Variable X	P-value and Significance	Stationarity
$log(GDP)$	0.01**	Stationary
$growth$	0.01**	Stationary
$TangibleNew$	0.01**	Stationary
$TangibleOld$	0.01**	Stationary
$IntangibleNew$	0.3986	Non-stationary
$IntangibleOld$	0.325	Non-stationary

Table 5. Results of the Granger Causality Test

Variable X	X > Y	Y > X
$TangibleNew_{t-24}$	3.430897e-05***	2.281413e-06***
$TangibleOld_{t-24}$	7.871463e-09***	0.0001366215***

Null hypothesis is H_0: X $does\ not\ granger\ cause\ Y$. Y is always $\log(\mathrm{GDP_t})$. Variables and data taken from monthly data set gathered and estimated by TJD.

Table 6. Mediation Model Results

	Dependent variable:		
	log(gdppc)	pc	log(gdppc)
	(1)	(2)	(3)
lag(new_intangible, 1)	−0.001		0.002
	(0.002)		(0.001)
lag(old_intangible, 1)	0.005		−0.004
	(0.005)		(0.003)
lag(new_tangible, 1)	-0.0003^{*}	0.001^{***}	-0.0002^{*}
	(0.0001)	(0.0001)	(0.0001)
lag(old_tangible, 1)	0.00002^{+}		0.00001
	(0.00001)		(0.00001)
pc			0.250^{**}
			(0.062)
Constant	0.651^{+}	-4.741^{***}	1.435^{**}
	(0.276)	(0.638)	(0.248)
Observations	12	12	12
R^2	0.962	0.878	0.990
Adjusted R^2	0.940	0.866	0.981
Residual Std. Error	0.098 (df = 7)	0.788 (df = 10)	0.055 (df = 6)
Note:			$^{+}p<0.1$; $^{*}p<0.05$; $^{**}p<0.01$

Table 7. Auxiliary Robustness Model Results

	Dependent variable:		
	log(gdp)	is2	log(gdp)
	(1)	(2)	(3)
lag(new_intangible, 12)	−0.003		−0.004
	(0.005)		(0.005)
lag(old_intangible, 12)	0.014		0.016
	(0.012)		(0.012)
lag(new_tangible, 12)	-0.0004^{*}	0.0002^{***}	-0.0004^{*}
	(0.0002)	(0.00003)	(0.0002)
lag(old_tangible, 12)	0.0001^{***}	-0.00002^{***}	0.0001^{***}
	(0.00001)	(0.00000)	(0.00002)
is2			0.732
			(0.457)
Constant	10.316^{***}	0.943^{***}	9.645^{***}
	(0.049)	(0.005)	(0.421)
Observations	152	152	152
R^2	0.872	0.256	0.874
Adjusted R^2	0.869	0.246	0.870
Residual Std. Error	0.102 (df = 147)	0.024 (df = 149)	0.102 (df = 146)
Note:			$^{+}p<0.1$; $^{*}p<0.05$; $^{**}p<0.01$

Table 8. Sobel Test Results

Key Explanatory Variable	Mediator	Hypothesis	P-value and Significance	Effect
$TangibleNew_{t-12}$	Is_t	$H_0: \alpha_{11}\beta_1 = 0$	0.061+	Positive
$\text{TangibleOld}_{t-12}$	Is_t	$H_0: \alpha_2\beta_1 = 0$	0.059+	Negative

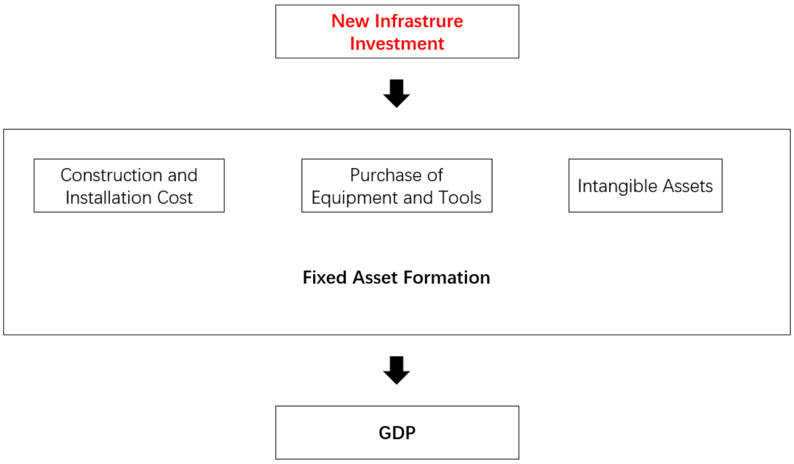

Figure 1. The Influence Mechanism of New Infrastructure Investment to Economic Aggregate

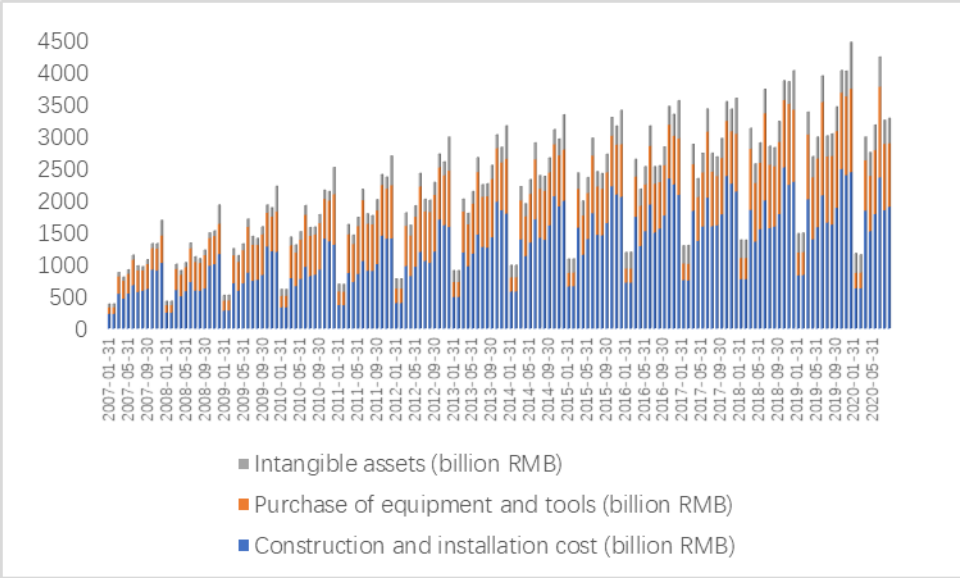

Figure 2. The Structure of Fixed Asset Formation of Economic Aggregate of China

Data source: TJD Research Institute

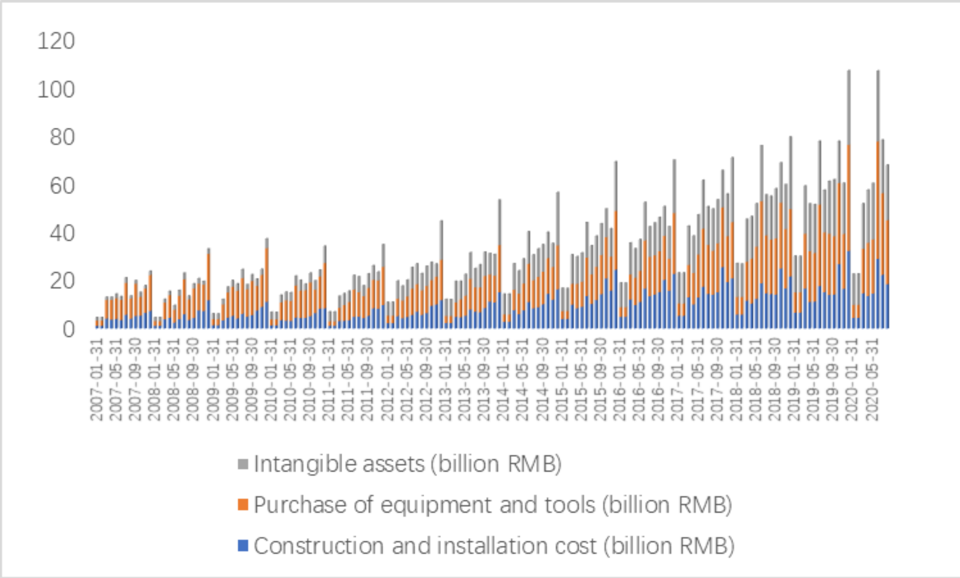

Figure 3. The Structure of Fixed Asset Formation of Information Transmission, Software and Information Technology Services of China

Data source: TJD Research Institute

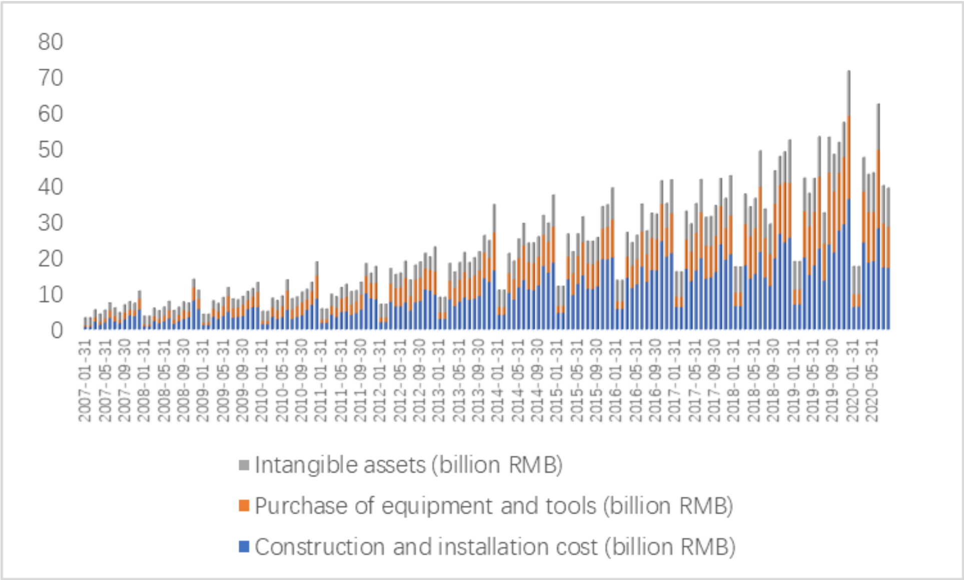

Figure 4. The Structure of Fixed Asset Formation of Scientific Research and Technical Services of China

Data source: TJD Research Institute

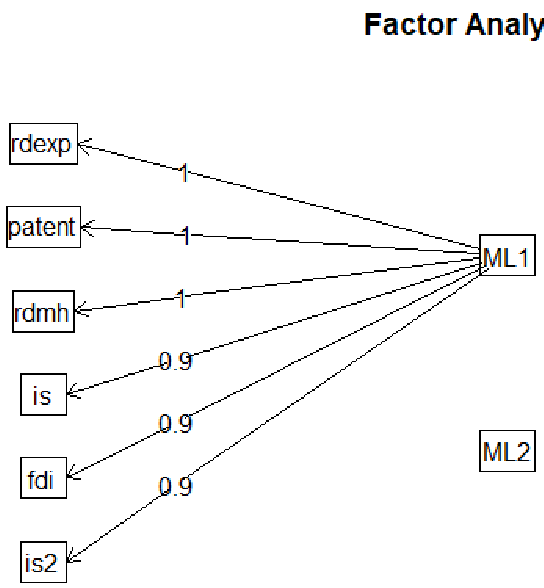

Figure 5. The Factor Analysis Result regarding the Number Choice of Principal Factors

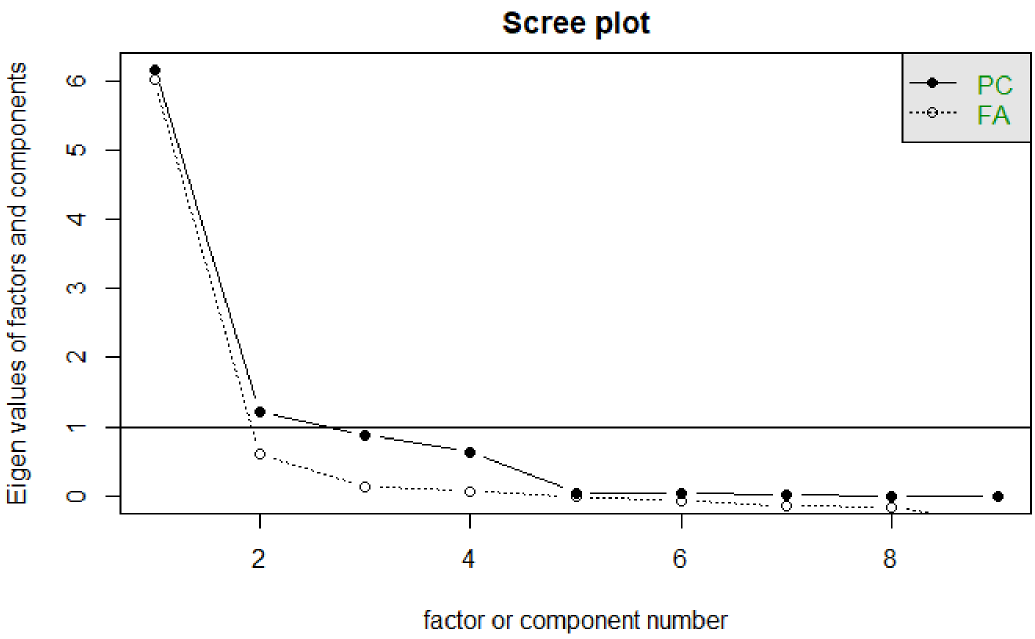

Figure 6. The Scree-plot Result to Aid the Selection of the Number Choice of Principal Factors