Infrastructure, the Economy and Policy

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Infrastructure, the Economy and Policy

--New Evidence on the Economic Effects of Infrastructure

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ABSTRACT

The role of infrastructure in economic growth and development has been the subject of continued debate, yet no consensus has been achieved in the literature. This thesis examines the economic effect of infrastructure based on new evidence from China. We add to understanding of this complex phenomenon by focussing at micro levels, i.e., firm-level and household level with a focus on three critical infrastructure sectors: transport, renewable energy and information communication technologies. We employ a series of datasets on infrastructure, firm performance, and household economy from China in our examinations. Our first empirical study focuses on the economic effects of city's ICT infrastructure on firm performance. We have found that the improvement of city's ICT infrastructure positively improved firm's profitability, marketing, and innovation. By taking advantage of an exogenous variation of city's ICT using the telecommunication upgrade as a natural experiment, we establish the causal impact of city's ICT infrastructure on firm profitability. We also identify the mechanisms in which ICTs impact firm performance, including the firm's efficiency, firm's labour, and firm cost. Our second empirical study focuses on the renewable energy sector and its influence on China's rural household economy over the past two decades. We provide empirical evidence in this under-investigated area of research, and have found that renewable energy, including bioenergy, solar energy, and hydropower

energy, indeed improved the rural household economy in China. In the third empirical study, we then focus on the impact of improved transport infrastructure connectivity on the litigation risks of listed firms in China. Based on a natural experiment on China's highspeed rail system construction, we have found that the improvement of transport infrastructure connectivity reduced firm's litigation risks. This study shows that the impact of improved transport connectivity on listed firms' litigation risk stem from the reduction of information asymmetry, and also the increase of external regulations and monitoring. Overall, we have found evidence that transport infrastructure, renewable energy infrastructure and ICT infrastructure played a positive and critical role in the economic development from the perspectives of firm performance and household economy, and also provide in-depth analysis of the underlying mechanisms. The findings in this thesis offer evidence for policymakers that improvement of infrastructure contributes to the productivity, economic growth and social development, and reasonable deployment of infrastructure could pay off.

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1. INTRODUCTION

1 RESEARCH BACKGROUND

As the foundation of economic activity, infrastructure, including transport, energy, telecommunication, electricity, and water system, has long been recognised for its essential role in economic functioning. As a crucial part of governmental expenditure, infrastructure is closely related to social welfare and economic benefits. Thus, to appropriately invest an infrastructural project and evaluate the economic effects of infrastructure investment is crucial for policy decision making (Frischmann, 2012).

The decline of productivity and growth in most western industrialised countries has often been linked to lower levels of infrastructure expenditures. Previously, in the 1980s, several studies point out that the slow government spending on the infrastructure is the main cause leading to the slowdown of economic growth in the US (Munnell, 1990, Aschauer, 1989b). The economic downturn in Europe is also referred to be related to the massively reduced government expenditures on infrastructure (European, 2009). Especially in the last three decades, the tremendous investment in infrastructure driving the economic growth in developing countries, like China, has triggered long-lasting, intense debates on whether infrastructure investment is positive, or negative, or sustainable for economic growth and development.

Despite the fact we may usually associate infrastructure with economic growth, the economic effects of infrastructure have not been well addressed in the literature until the late 1980s. Before that, either theoretically or empirically, economists paid little attention to the impact of infrastructure on economic activities (Gramlich, 1994, Bougheas et al., 2000). In 1989, Aschauer's three initial studies started to be conducted employing formal analysis to measure the effect of public capital on economic growth (Aschauer, 1989b, Aschauer, 1989c, Aschauer, 1989a). Since then, in the last three decades, interest in this issue regarding infrastructure has begun to increase (Duran-Fernandez and Santos, 2014, Thacker et al., 2019, Bröcker et al., 2019). A long-lasting debate has been triggered on investigating the impact of infrastructure deployment and investment on productivity and growth in the literature.

2 WHAT ARE INFRASTRUCTURE AND ECONOMIC EFFECTS?

It is easier to recognise infrastructure than to define. Infrastructure includes a wide range of public goods, such as transport infrastructure, energy supply infrastructure, educational infrastructure. To define infrastructure in terms of its characteristics, Hirschman (1958) provided a term called "social overhead capital", "capital that provides public services". Actually, the term of infrastructure has still not been used in Hirschman (1958)'s paper as it only came to prominence until the 1980s after the publication of America in Ruins (Choate and Walter, 1983), where infrastructure capital is previously usually presented as investment for the bulk of industries on building "basic industries" and public utilities in industrialisation. After that, under the umbrella term of infrastructure, the distinction is often recognised by development economists between economic (or hard) and social (or soft) infrastructure. Economic infrastructure refers to the large networks of physical fixed assets and goods essential for the functioning of the economy at local, regional, national, and international levels, including the fundamental commodities, facilities, services, and systems, such as transport systems, water and energy supply and telecommunications. Social infrastructure refers to the institutions, facilities, and services to sustain the health, education, cultural and other societal living conditions and standards of the population, such as education system, health care system and financial system. Although economic infrastructure and social infrastructure do overlap, when evaluating the economic effects of infrastructure, hard infrastructure, including transport, energy, electricity, communications, water supply and sanitation, is more usually referred to.

As a base of economic activity, infrastructure has a wide range of direct and indirect economic effects. Researchers have long suggested developing infrastructure to promote regional and national economic growth and development. The economic role of infrastructure can be dated back to Adam Smith in the Wealth of Nations (Smith, 1776). Rosenstein-Rodan (1943) also suggested that the lack of public transport facilities is a fragrant obstacle to economic growth for less developed countries, and thus constructing infrastructure may be the best start of development investment. Most recent studies measured the economic effects of infrastructure on productivity and growth, although the measures in the literature are varied across different studies. Studies usually estimate the elasticities of infrastructure expenditures using the real gross output of the private sector or real gross domestic product (GDP) exclusive of public sector output. Some studies also measured the effects of infrastructure on the welfare economy, such as the impact on poverty alleviation, inequality, and employment.

3 THE RESEARCH FOCI OF THE THESIS

As the foundation of economic activity, infrastructure, including transport, energy, and telecommunication, etc., has long been recognised for its important role in economic functioning. In the process of modernisation, infrastructure has been enormously invested ranging from roads for passengers to ICTs for office workers. As infrastructure deployment is a key part of governmental expenditure, and there has been substantial input in infrastructure, it is worthwhile to consider what real effect it may have on the economy. To appropriately evaluate the economic effects of infrastructure is also crucial for policy decision making (Frischmann, 2012, Hall et al., 2016). However, there is little academic consensus on the fundamental question regarding the economic impact of infrastructure, despite decades of close scrutiny.

This DPhil research project, Infrastructure, the Economy and Policy, part of the UK Infrastructure Transitions Research Consortium (ITRC-MISTRAL) programme, aims at addressing the research gaps in the extant literature and study the relationship between infrastructure and the economy more closely. The studies of this thesis aim at facilitating long term planning and deployment, optimising economic effects of infrastructure investment projects, providing policy suggestions on infrastructure assessment and governance. The overview of the DPhil project is as follows (Table 1).

Table 1 Overview of the DPhil project

	Topics	Details
1	Introduction	Overview of the thesis
2	Literature review	Research background, gaps, and future agenda
3	Methodology	Methodological review, methods, and data
4	ICT infrastructure and economic growth	City's ICT infrastructure and firm performance
5	Energy infrastructure and rural economy	Renewable energy and rural household economy
6	Transport infrastructure and business environment	High-speed rail and firm's litigation risk
7	Conclusion	Findings and Policy Implications

The thesis consists of seven parts, including the 1. Introduction, 2. Literature review: Infrastructure and the Economy, 3. Methodology, 4. ICT Infrastructure and Firm Performance, 5. Renewable Energy and Rural Household Economy, 6. Transport Infrastructure and Firm's Litigation Risk, and 7. Conclusion.

First, the introduction chapter provides the overall content of the thesis. Second, this thesis provides a review chapter on Infrastructure and Economic Effects, with an examination of the theoretical and empirical literature in the last three decades on infrastructure investment and economic effects, at the theoretical level, and empirical level. This review is beneficial to understand the previous research focuses and to identify the research gaps and future agendas. Third, we then review the methods that have been used in the literature. We identify methodological shortcomings and point out new methods, and we also introduce the data that are used in the three empirical studies. Fourth, this thesis starts to investigate the linkage between information communication technology infrastructure and the economy. We focus on the city's ICT infrastructure and its economic impact on firm performance based on Chinese listed firms. This study explores the mechanisms involved in the relationship between ICT infrastructure and firm productivity. Fifth, this thesis presents the evidence in another infrastructure sector: energy, with an emphasis on renewable energy. This empirical chapter focuses on the supply side of renewable energy infrastructure, with a research setting in rural areas, which are usually less-investigated and even ignored in the literature. Sixth, after conducting the two studies in information communication technology infrastructure and energy infrastructure, mainly in firm productivity and household economy, we then move to the influence of infrastructure to social and legal impact with a focus on the impact of the improvement of transport connectivity via high-speed rail system on firm litigation risk. Last, we conclude.

The work presented in Chapters 4 to 6 has appeared in or has been submitted to peer-reviewed journals:

1. Huang, J., Li, W., Guo, L., & Hall, J. W. City's ICT infrastructure and firm

productivity. (Under review)

2. Huang, J., Li, W., Guo, L., Hu, X., & Hall, J. W. Renewable Energy Investment and Household Economy in Rural China. 155, 669-676, 2020. *Renewable Energy*.

3. Huang, J., Li, W., Guo, L., Wang, Y., & Hall, J. W. The Effects of Transport Infrastructure on Firm Litigation Risk (Under review)

4 AN OVERVIEW OF THE THREE EMPIRICAL CHAPTERS

This DPhil thesis is mainly comprised of three empirical papers in three infrastructure sectors, including ICTs, renewable energy, and transport. The details of the three papers are as follows.

1: ICT Infrastructure and Firm Performance

Title: City's ICT infrastructure and Firm Performance: Evidence from Chinese Listed Firms

Objectives:

As infrastructure has different sectors, the effect of infrastructure might be various when we assess different sectors. Given the increasing importance of information technology and telecommunication, the demand for ICT infrastructure is surging around the world. To better understand the economic effects of ICT infrastructure and advise ICT infrastructure planning and construction, it is critical to conduct research assessing the economic benefits of ICT infrastructure.

Our study examines the economic effects of ICT infrastructure based on firm-level performance evidence. There are a couple of research questions that could be addressed in order to fill up the research lacuna. First, identifying and quantifying the economic benefits of ICT infrastructure for firms. Second, exploring the mechanisms of how ICT infrastructure benefits firm profitability.

We employed a series of panel data analysis to test the hypothesis whether the increase of the usage intensity of ICT infrastructure positively promotes firm productivity. We also generate an exogenous variation by employing a natural experiment based on telecommunication upgrades to establish the causality. This study then explores the mechanisms through how the improvement of ICTs infrastructure enhances firm profitability, as follows.

Mechanism 1: The higher level of labour quality of firms positively strengthens the economic impact of city's ICT infrastructure on firm profitability;

Mechanism 2: The higher efficiency of firms positively strengthens the economic impact of city's ICT infrastructure on firm profitability;

Mechanism 3: The lower cost of firms positively strengthens the economic impact of city's ICT infrastructure on firm profitability.

2: An Empirical Study: Energy Infrastructure Investment and Household Economy

Title: Rural Renewable Energy and Economic Growth

Objectives:

The issues on the economic returns of non-renewable energy and renewable energy have been controversial. Compared with conventional fossil energy, the cost, manufacturing processes and economic benefits of renewable energy are widely divergent. Many people are concerned that renewable energy demands a considerable amount of investment to set up and maintain, while economic benefits might be too small. On the other hand, others think that the sources of renewable energy are mostly free, and the marginal price of renewable energy can be very low, such as solar and wind, and the cost of generating renewable energy is declining thanks to the technologic improvement and expanding market, so it might produce sufficient economic return in the long run.

The economic returns of non-renewable-based energy have long been widely investigated in the literature, but such research on renewable energy is still scarce. Compared with conventional energy, renewable energy is very different and usually applied by households more independently; households are able to produce and use solar and bioenergy energy independently once they invest and install energy equipment. To understand the linkage between renewable energy and economic growth, we investigate the household deployment and development of renewable energy, including hydropower, bioenergy, and solar energy, and their effects on the rural economy.

3: Transport Infrastructure and Firm Litigation Risk

Title: Transport Connectivity and Litigation Risk: The Impact of China's High-speed Rail System

Objectives:

Extensive studies have sought to examine the economic effects of infrastructure investment, and most of the studies mainly focused on transport infrastructure. However, research on the impact on transport infrastructure on legal and social aspects remains under-investigated.

Unlike the extensive studies measure the economic effects of transport infrastructure, this study is based on a micro perspective and examines the effect of improved transport infrastructure at the individual firm level, with a focus on firm's litigation risk.

We employ the improvement of transport infrastructure as a quasi-natural experiment and explore the impact of improved transport connectivity on firm's litigation risk. Taking advantage of the inauguration of the high-speed rail as a source of exogenous variation, we examine whether the improvement of transport connectivity could reduce or increase firm's litigation risk. We further explore the mechanisms through how the improvement of transport infrastructure enhances firm performance, as follows:

Mechanism 1: The impact of improved transport connectivity on reducing listed firms' litigation risk stems from the reduction of information asymmetry.

Mechanism 2: The impact of improved transport connectivity on reducing listed firms' litigation risk stems from the increase of external regulation and monitoring.

REFERENCES

ASCHAUER, D. A. 1989a. DOES PUBLIC CAPITAL CROWD OUT PRIVATE CAPITAL. *Journal of Monetary Economics,* 24**,** 171-188.

ASCHAUER, D. A. 1989b. Is public expenditure productive? *Journal of monetary economics,* 23**,** 177-200.

ASCHAUER, D. A. 1989c. Public investment and productivity growth in the Group of Seven. *Economic perspectives,* 13**,** 17-25.

BOUGHEAS, S., DEMETRIADES, P. O. & MAMUNEAS, T. P. 2000. Infrastructure, specialization, and economic growth. *Canadian Journal of Economics-Revue Canadienne D Economique,* 33**,** 506-522.

BRÖCKER, J., DOHSE, D. & RIETVELD, P. 2019. Infrastructure and regional development. *Handbook of regional growth and development theories.* Edward Elgar Publishing.

CHOATE, P. & WALTER, S. 1983. *America in ruins: The decaying infrastructure*, Duke Press Paperbacks.

DURAN-FERNANDEZ, R. & SANTOS, G. 2014. An empirical approach to public capital, infrastructure, and economic activity: A critical review. *Research in Transportation Economics,* 46**,** 3-16.

EUROPEAN, C. 2009. Economic Crisis in Europe: Causes, Consequences and Responses. *European Economy.* Luxembourg.

FRISCHMANN, B. M. 2012. *Infrastructure: The social value of shared resources*, Oxford University Press.

GRAMLICH, E. M. 1994. Infrastructure investment: A review essay. *Journal of economic literature,* 32**,** 1176-1196.

HALL, J. W., TRAN, M., HICKFORD, A. J. & NICHOLLS, R. J. 2016. *The future of national infrastructure: A system-of-systems approach*, Cambridge University Press.

HIRSCHMAN, A. 1958. *Strategy of Economic Development,* New Haven, Yale University Press.

MUNNELL, A. H. 1990. Why has productivity growth declined? Productivity and public investment. *New England economic review***,** 3-22.

ROSENSTEIN-RODAN, P. N. 1943. Problems of industrialisation of eastern and south-eastern Europe. *The economic journal,* 53**,** 202-211.

SMITH, A. 1776. An inquiry into the wealth of nations. *Strahan and Cadell, London*.

THACKER, S., ADSHEAD, D., FAY, M., HALLEGATTE, S., HARVEY, M., MELLER, H., O'REGAN, N., ROZENBERG, J., WATKINS, G. & HALL, J. W. 2019. Infrastructure for sustainable development. *Nature Sustainability,* 2**,** 324-331.

2. LITERATURE REVIEW: RESEARCH IN INFRASTRUCTURE AND THE ECONOMY

Literature Review of Research in Infrastructure and the Economy

Abstract

Since Aschauer (1989)'s seminal work measuring the nexus between public infrastructure capital and productivity, there has been around three decades of academic research on the economic effects of infrastructure. Although much importance has been attached to infrastructure in the literature and public debates, the empirical evidence of its economic term is puzzling and fragmentary. It is thus necessary to survey what we have done from a holistic perspective and to reconsider how to better examine the economic effects of infrastructure. Motivated by this objective, this chapter reviews the literature in the last three decades, including theoretical foundation and empirical evidence. Research focuses and gaps are identified, and future directions on exploring the mechanism of the interaction between infrastructure and the economy are suggested.

1 INTRODUCTION

Broadly speaking, estimation and evaluation of the economic effects of infrastructure are not easy to generalise. Despite the previous efforts measuring the economic effects of infrastructure, a consensus has not been achieved in the literature, and many questions still need to be answered or reconsidered. What is the quantitative effect of public infrastructure on the economy? What have we learned from three decades of research in this domain? What should future studies focus on? What are the mechanisms underlying the effect and how to make optimal decisions on infrastructure investment?

We provide a literature review, which is critical and helpful for us to understand the general background, different results from the extant studies, and research gaps left for future studies. Specifically, section 2 illustrates the research focuses in the empirical studies. Section 3 identifies the recent research mainstream and suggests future agenda.

2 WHAT ARE THE KEY RESEARCH FOCUSES IN THE LITERATURE?

The last three decades have witnessed an increasing body of literature which attempts to investigate the link between infrastructure and the economy. In general, the literature focuses on the following research topics, including the correlation between infrastructure and productivity and growth, factors affecting infrastructure investment efficiency, infrastructure and welfare economy, and how to achieve the optimal economic benefits of infrastructure.

2.1 Does infrastructure investment promote productivity and growth?

A vast percentage of the literature on infrastructure and the economy has devoted effort to measuring the output elasticity of infrastructure investment in respect to productivity and growth. Among these studies, results vary widely, which are contingent on sample period, dataset, type of infrastructure and specification (Fernald, 1999). Although there appears to be a consensus on the economic benefits of infrastructure, some studies argue the effect is negative, some illustrate the effect is periodical, and some indicate the effect is insignificant.

2.1.1 Infrastructure investment has positive economic effects on growth

A considerable amount of literature has sought to clarify the link and has found positive economic effects of infrastructure. A subset of literature is illustrated below.

Seminal work was by Aschauer (1989), who analysed the impact of infrastructure on economic growth in the US. Based on an aggregate Cobb-Douglas production function in levels, Aschauer (1989)'s empirical results indicated that military capital had little impact on improving productivity, while core public investment in transport and water system, etc. had the most contributory power for productivity. Binswanger, Khandker, and Rosenzweig (1993)'s paper indicated that improved road investment enhanced agricultural output in India with an elasticity of about 0.20. Easterly and Rebelo (1993) reported an extremely high elasticity of 2 for transport and communication investment and an elasticity of 0.7 for general government investment. A study by Fernald (1999) lent some credence to the idea that public investment in transport had high returns. Fernald (1999)'s industry results were approximate to the high productivity of public capital in the pre-1973 period captured by Aschauer (1989)'s simple aggregate Cobb-Douglas production function.

Some other studies found modest elasticity. According to Baffes and Shah (1998)'s study, infrastructure capital exhibited unexpectedly low-output and nearly negligible elasticities from 0.01 to 0.05 in Africa, Asia, Europe and the Middle East. Most coefficients were less than 0.05, and the biggest coefficients were in Latin America with a relatively high average output elasticity of 0.15. When compared in countries at different income levels, the output elasticity of infrastructure capital remained low in either low-income countries, medium-income or high-income countries. Ligthart and Suárez (2011) conducted a meta-analysis and indicated that elasticity of public capital of 0.14 by using the random-effects model approach, which was slightly smaller than the result simply using an arithmetic average value of 0.20. Calderón, Moral-Benito, and Servén (2015)'s paper added to evidence which supported the positive effects of infrastructure, with a modest elasticity of 0.07-0.10 in respect to telecommunications, electric power and roads, by using data from 1960 to 2000 in 88 industrial and developing countries.

2.1.2 Infrastructure investment has negative economic effects on growth

A few studies, however, report that government infrastructure investments generate negative economic effects. Typically, Evans and Karras (1994a) corrected the obvious misspecifications of other studies and used instrumental variables. They presented more relatively robust results showing that government capital often had statistically negative productivity, by using panel data from 48 states in the US during 1970-1986. Except for the productive output found in government educational services, they concluded that no empirical evidence indicates that government investment activities measured were productive. Ghali (1998) applied a vector error-correction model to examine the long-run dynamic interactions between infrastructure investment and economic growth in Tunisia. His results indicated that public investment generated negative long-run effects on both private investment and economic growth. Ansar, Flyvbjerg, Budzier, and Lunn (2016) argued that infrastructure investment brought negative influence. They argued that overinvesting in underperforming infrastructure projects and poorly managed infrastructure investments in China exerted a negative impact on the economy and finance, which to a certain degree could lead to economic fragility.

2.1.3 Infrastructure investment has insignificant/no economic effects on growth

Some other researchers find that public infrastructure investment essentially has no role to play in affecting productivity, indicating no quantitatively substantial spillover impact. Hulten and Schwab (1991) conducted one of the first studies presenting that public infrastructure did not generate significant externalities, based on evidence from regional manufacturing productivity. Holtzeakin (1994) revealed that the best estimate of the elasticity of private output or productivity with respect to public capital was essentially zero, after carefully weighing the evidence available from state-level data and region-level data from 1969 to 1986 in the US. He also criticised that it appeared no merit for those attempts to associate the puzzling fall in productivity growth with slower public capital accumulation. Previous evidence of large and positive economic effects on productivity growth seemed to be the artefact of an inappropriately restrictive econometric framework. To obtain robust and precise results, Evans and Karras (1994b) used data during 1963- 1988 across countries including Belgium, Canada, Finland, Germany, Greece, the UK, and the US to measure the elasticity of the productivity of government capital. No statistically significant evidence was found indicating that government capital is productive. They showed that large and highly significant elasticity could be found only if the production function misuses the specifications by ignoring time variables. Under the most plausible specifications, the estimated elasticities are not statistically significant, which were different from zero at conventional levels. They concluded that no explanatory power of infrastructure for growth was found in these seven countries. Applying an accessibility-based approach, Rokicki and

Stępniak (2018) found that accessibility improvement of transport infrastructure weakly correlated with growth, and did not have a statistically significant impact output growth on urban areas.

2.1.4 Infrastructure investment has periodical economic effects on growth

As mixed results have been presented, some empirical studies also provided more intuitive findings. Bougheas, Demetriades, and Mamuneas (2000) provided evidence from cross-country regressions, using physical measures of infrastructure provision, demonstrating a robust non-monotonic relationship between infrastructure and growth. Bougheas et al. (2000) used infrastructure investment data and find an inverted-U relationship between infrastructure investment and economic growth in the US during 1987-1992.

In general, although mixed results have been reported, there is more consensus in the recent literature than in the past that infrastructure investment positively affects economic productivity and growth, but the effects appear to be lower than previously thought. Besides, the estimated return in transport and communications are much higher than the aggregate level of infrastructure, and those in other sectors as well, even without considering indirect benefits. The existing estimates of the economic effect of transport infrastructure tend to be larger in the US than in the Europe, according to a meta-analysis by Melo *et al.* (2013), based on a sample of 563 estimates obtained from 33 studies. The variation in the estimates of the economic output elasticity of infrastructure could be due to different methods and data used in previous studies, omitted variable bias, and also spurious correlations etc. (Melo *et al.* 2013; Elburz *et al.* 2017).

2.2 What external factors affect the economic effects of infrastructure investment?

A wide range of external factors may affect the economic effects of infrastructure investment. Although examining the external factors is still not mainstream in the literature, given its importance, this paper reviews the two most frequently concerned environments, including institutional environment and financial environment.

2.2.1 Institutional environment

There is a large literature on governance and institution environment of infrastructure (Brunet, 2019; Brunet & Aubry, 2018; Valverde & Moore, 2019). Given the long-lasting, large scale, stringent regulatory and high fund-demand nature of infrastructure investment, the literature has identified that the pattern of infrastructure investment and development, as well as the economic effects, are highly related to a country's characteristics, and extremely sensitive and strongly related to the political and institutional environment (Levy & Spiller, 1994; Spiller, 1993). A key characteristic is whether a country can provide a credible policy environment or not. In the literature, several studies focused on investigating the role of the institutional environment in infrastructure. By performing a two-century long historical analysis, Henisz (2002) found a political environment that limits the feasibility of policy change was a crucial determinant of cross-country variation in infrastructure investment. Keefer and Knack (2007) provided robust results with several specifications indicating that public investment was dramatically higher in nations with low-quality governance and limited political checks and balances or no competitive elections. It seemed that these governments attempted to seek rents through investing in infrastructure. Weak governance nations should maintain vigilant attention to the efforts in infrastructure investment and the risks from the institutional environment. In a more recent paper, Ashraf, Glaeser, and Ponzetto (2016) further highlighted the impact of incentives and institutions on infrastructure investment. Infrastructure might produce a large number of positive externalities, like waster sector infrastructure and health-related infrastructure. Even though the health-related infrastructure benefits the public greatly, and the benefit might transcend its direct physical expenditures, those expenses may still exceed the willingness of the individual and private sectors to pay. As institutional weakness might prevent the two conventional economic instruments, Pigouvian taxes or subsidies, to be effectively implemented, a complementarity between infrastructure and the institutional environment was essential to guarantee and foster the social and economic benefits. Gillanders (2014) pointed out that countries with more corruption had a high tendency to have worse infrastructure. This association varied in both significance and magnitude in different types of infrastructure and different countries.

2.2.2 Financial environment

The financial environment directly affects the willingness and effects of both private and public capital investment in infrastructure. Yet, few studies have examined the link between the financial environment and the economic effects of infrastructure. While many factors can influence the level of productivity and economic growth, it seems that the financial constraints preventing low-income countries from gaining full advantage of infrastructure investment and its economic effects lead to the great divergence between developed and developing countries (Aghion, Howitt, & Mayer-Foulkes, 2005). Dailami and Leipziger (1998)'s paper suggested that the financial environment, such as high credit risk premium and high inflation, might affect developing countries attracting foreign capital for infrastructure projects. As most infrastructure financings were in the form of project financing, without robust, sound and efficient financial environment, infrastructure investment cannot get necessary funding support either from international or domestic capital to shore up its long-term project development. In terms of the evaluation of the financial environment, adopting a case of a wastewater treatment facility in Scotland, Grimsey and Lewis (2002) systematically analysed the principles, practical experiences, assessing a framework to evaluate the risks of public-private partnerships for infrastructure projects. Given the importance of the financial environment, to avoid financial constraints and evaluate the financial risks was an obvious need to ensure the value-for-infrastructure could be achieved.

2.2.3 Geographical environment

Infrastructure is frequently regarded by neo-classical economics directly by aggregating infrastructure capital or creating a separate infrastructure capital stock. However, the concepts such as space, distance and transportation costs, have been ignored (Brakman, Garretsen, & Van Marrewijk, 2009; Schmutzler, 1999). Since the publication of Krugman (1993) "Geography and Trade", emerging literature has developed under New Economic Geography. The new economic geography is essentially a theory of the emergence of large agglomerations based on increasing returns to scale and transportation costs. Moreover, NEG also highlights the association between firms and suppliers as well as between firms and consumer, with a spatial scale (Schmutzler, 1999). When transportation costs are included as a key component that has an impact on location choices and economic outcome in the new economic geography, this impact on firms' location choices tends to be highly correlated with the level of transport costs. Based on this assumption, firms may choose to concentrate in a single place and serve other regions or decide to open up a second plant (Ascani, Crescenzi, & Iammarino, 2012). With a more spatial approach, new economic geography theory with growth allows for a representation of transport infrastructure (Carlsson, Otto, & Hall, 2013) and provides an explanation of the existence of large economic agglomerations (Fujita, Krugman, & Venables, 2001).

2.3 Does infrastructure investment contribute to the welfare economy?

While examining the impact of infrastructure, its economic externalities for welfare are often investigated. Research focuses on the association between infrastructure and welfare economy is mainly on poverty, employment and inequality issues.

2.3.1 Infrastructure and poverty alleviation

Khandker and Koolwal (2010) found that expansion in the infrastructure of irrigation, transport and electricity had led to higher rural farm and non-farm incomes, whilst this had not been translated into substantial poverty alleviation for the poorest households in the context of rural Bangladesh spanning the period of 1991-2001. More recently, Lenz, Munyehirwe, Peters, and Sievert (2017) evaluated the impact of large-scale infrastructure investment on alleviating poverty, based on new evidence of an impact evaluation of Rwanda's Electricity Access Roll-Out Programme at various users levels with a focus on households as the main beneficiaries. Findings from the existing literature suggested that infrastructure investment had mixed effects on poverty alleviation; the nexus between infrastructure and poverty alleviation needs further exploration.

2.3.2 Infrastructure and employment

Investing in infrastructure is a widely-used policy intervention to stimulate employment. Researchers have found a positive impact of infrastructure on employment, while policymakers should be cautious in deploying infrastructure projects (Haughwout, 1999). According to Ianchovichina, Estache, Foucart, Garsous, and Yepes (2013)'s assessment, to meet the demand for infrastructure and alleviate employment pressure, the Middle East needed to invest about 6% of its GDP annually on new infrastructure projects, which could create around 2.5 million infrastructure-related job opportunities. Their study also indicated that maintaining and spreading the momentum in infrastructure improves job creation. Based on the aggregate manufacturing sector of 12 OECD countries from 1972 to 1991, Demetriades and Mamuneas (2000) found the extent of contribution of public infrastructure capital to employment was smaller in the long-run than in the intermediate or short-run. Conversely, private investments on infrastructure had more substantial effects on employment in the long-run than in the intermediate or short-run. However, Puga (2002) reported that despite large regional policy expenditures in Europe, unemployment rates had become increasingly polarised. Akyelken (2015) indicated that a substantial part of the variation in employment was that significant links existed between the mutual impact of education and transport infrastructure and employment at a regional level in the context of Turkey. He also highlighted that when assessing the nexus between transport infrastructure and employment, non-economic factors and cross-level interaction effects should be taken into account.

2.3.3 Infrastructure and inequality

Empirical evidence on the links between infrastructure investment and inequality is sparse, inconclusive and largely anecdotal. Some results indicating that public infrastructure investment did promote growth and reduce inequality, which had been found in Latin America (De Ferranti, 2004) and China (Fan & Zhang, 2004). Wolff and Zacharias (2007) found that overall inequality was substantially alleviated by net government public expenditures, based on household-level data in the US in 1989 and 2000. By using decomposition analysis, their empirical evidence also indicated that the inequality alleviation effect of net government public expenditures owed far more to expenditures than taxes. But some other studies had come to the opposite conclusions. Expensive investment goods and too much public expenditure had an explanatory power of income inequality and economic tragedy in Africa, as documented by Artadi and Sala-i-Martin (2003). Chatterjee and Turnovsky (2012) showed that government public infrastructure spending increased wealth inequality over time, irrespective of how it was financed. They did find that pubic infrastructure investment improved average welfare, while the negative effects in causing an increase in dispersion could not be ignored. Their study alerted that pro-growth policies may not be effective at reducing inequality. Given the diversity of the empirical evidence, Turnovsky (2015) emphasised the necessity of proposing a well-specified analytical framework which could be comprehensively applied in assessing the association between infrastructure investment, economic growth and, inequality.

2.4 How to enhance the economic effects of infrastructure investment?

2.4.1 Constructing new infrastructure V.S. maintaining old infrastructure

When considering how to allocate resources for infrastructure investment, governments often prioritise building new infrastructure while neglect maintaining old infrastructure (Gibson & Rioja, 2017; Rioja, 2003). Inadequate maintenance can lead to the deterioration of infrastructure and thus result in the declining quality of infrastructure services. Despite the critical role of infrastructure maintenance, few systematic attempts have been involved in examining the relative economic merits of constructing new infrastructure and maintaining old infrastructure. The empirical evidence identified that maintenance spending was a key determining factor of productivity and growth, whose effects should be investigated by employing standard growth models with spending in new capital formation (Kalaitzidakis & Kalyvitis, 2004). To achieve the optimal level of maintenance, the share of new investment in existing infrastructure capital and the productivity of infrastructure should be considered, which was found in Rioja (2003)'s study using a dynamic general equilibrium model. His study quantitatively elucidated that reallocating capital from new infrastructure to old infrastructure maintenance can boost GDP in Latin American countries. Kalaitzidakis and Kalyvitis (2005) indicated that a decline in public infrastructure spending and relocation on new infrastructure investment and maintenance spending would promote economic development in Canada. An intuitive diagram was shown in Kalaitzidakis and Kalyvitis (2005)'s paper regarding the relationship between new investment and maintenance, as shown in figure 1. Agénor (2009) developed an endogenous growth framework to investigate the optimal allocation rules in a growing economy. In his model, maintenance expenditures affected the durability of both public and private capital. More recently, Gibson and Rioja (2017) underscored the role of infrastructure maintenance on economic growth and inequality. In a heterogeneous agent model, the size of maintenance spending caused the depreciation of both public and private capital. They found that allocating all additional resources to maintain existing infrastructure had a large impact on the distribution of wealth in Mexico.

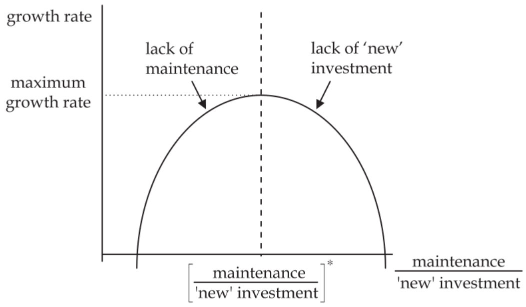

Figure 1 Constructing new infrastructure V.S. maintaining old infrastructure
[source: *Kalaitzidakis and Kalyvitis (2005)]*

Thus, as suggested in the few existing studies, to achieve the optimal economic effects of infrastructure, it is essential to investigate the issue of allocation of capital on building new infrastructure or maintaining old infrastructure in future studies and policymaking in infrastructure investment and management (Sánchez-Silva, Frangopol, Padgett, & Soliman, 2016).

2.4.2 Public infrastructure capital V.S. private infrastructure investment

The public-private nexus in financing infrastructure investment has been frequently discussed among researchers and policymakers: to enhance the economic effects of infrastructure, should capital come from the public, private or hybrid sources? For most of the post-war period, public capital from the government has been the principal financial source of infrastructure investment. In this new era of economic austerity, however, public capital from the government has become an increasingly scarcer resource (Becker, 2015). More recent studies also observed a shift away from the earlier findings that public subsidies often crowded out private capital to findings that subsidised typically stimulate private capital

(Cutler & Gruber, 1996; Voss, 2002). Rather than pure-public or pure-private infrastructure investment, public-private partnerships have been gradually accepted, which were first introduced by the John Major's government in the UK in 1991. Public-private partnerships offer innovative and entrepreneurial approaches to handle infrastructure projects via cooperative intuitional arrangements (Hodge & Greve, 2007). Cooperation between public and private sectors, by using private capital and delivering infrastructure services via long-term contracts, is enjoying continuing popularity globally. Currently, public-private partnerships have shifted from merely being an alternative for governmental infrastructure projects towards being a reliable solution entailed with a priority in policy decision making for the authorities (Bjarstig & Sandstrom, 2017). In addition, studies on the fiscal effects of infrastructure investment have also emerged, i.e. increasing indebtedness, which profoundly affects the nexus of public and private infrastructure capital (Krichel & Levine, 1995; Lavee, Beniad, & Solomon, 2011).

2.5 The next generation of infrastructure planning systems and its economic impact

In the recent studies, researchers have extended the scope of infrastructure economics and developed a unique capability in infrastructure systems analysis, modelling and decision making (Balboni, 2019; Bröcker, Dohse, & Rietveld, 2019; Hall, Tran, Hickford, & Nicholls, 2016). For example, the UK Infrastructure

Transitions Research Consortium (ITRC) has worked on developing and demonstrating an integrated analytics capability to inform strategic infrastructure decision making across scales and countries (Hall et al., 2016; Oughton, Usher, Tyler, & Hall, 2018; Thacker et al., 2019).

More studies have emerged to develop better measures of infrastructure that can be used in the economic modelling of economic growth and productivity (Banerjee, Duflo, & Qian, 2012; Kelly, Tyler, & Crawford-Brown, 2016). For example, geocode and network data (Donaldson, 2018; Faber, 2014), and night-time lights satellite data (Storeygard, 2016) have been used in measuring the economic impact of transport infrastructure. More studies have worked on improving the methodology for the appraisal of infrastructure investments. For example, natural experiments and exogenous variation using instrumental variables in the empirical examinations have been used in examining the economic impact of ICT infrastructure (Akerman, Gaarder, & Mogstad, 2015).

3 WHAT HAVE WE LEARNED FROM THE LITERATURE AND WHAT SHOULD WE DO IN THE FUTURE?

This chapter has surveyed the literature on investigating the relationship between infrastructure and the economy in the recent three decades. Research on the economic effects of infrastructure initially focused on the US, and then the earlier studies also tested the link between infrastructure and economic effects for

OECD countries (Evans & Karras, 1994b). Later, more empirical studies were conducted in developing nations, especially in Africa and Asia. The effects of infrastructure are inconsistent in different periods, developmental stages and countries. The following sections summarise the key points in the literature and identify research gaps and future directions.

First, economists have generally been sceptical regarding the economic effects of infrastructure, and thus many studies have attempted to examine the output elasticity of public capital on infrastructure. In general, most literature has illustrated the importance of public capital for economic productivity and growth. Although some anecdotal evidence arguing that the economic effects are negative, insignificant and nonlinear, there is, to some extent, more consensus than in the past that infrastructure investment positively affects economic productivity and growth, but the estimated effects appear to be lower than previously thought or even nearly negligible.

Second, apart from a large number of studies measuring the elasticity for infrastructure productivity and growth, some studies also try to investigate the factors which affect the economic benefits of infrastructure, welfare economy and infrastructure, and how to enhance the economic effects of infrastructure. But no matter in welfare economy of infrastructure or in promoting an optimal level of infrastructure investment, no unified conclusion has been formed.

Third, production function, cost function, spatial equilibrium, and vector autoregression models are among the most widely used approaches. The empirical strategy, the production function approach, started in the late 1980s and early 1990s, is now still a common methodology in the existing literature. Early estimates by using the production function approach on aggregate levels appear to magnify the economic effects of infrastructure on productivity and growth. Later studies using the same specification or having minor changes in the specification apparently present puzzling evidence in a wide range of research settings. Further studies using the cost production function approach reported remarkably lower estimates. To tackle the problems caused by the oversimplified perspective of the production function approach, spatial equilibrium models have been employed at the individual level, reporting modest economic returns of infrastructure investment, which lead to new empirical strategies.

Fourth, mixed evidence has been shown in the literature, which indicates that it is challenging to examine the actual impact of infrastructure on the economy. This difficulty in investigating this association could be partially related to the simultaneity between infrastructure and the economic impact. Methodology and data are important to address this issue in empirical studies. Emphasis should be placed on the measurement of infrastructure and the measurement of economic impact. Moreover, better methods should be used to establish an exogenous association between infrastructure and its economic impact. For instance, instrumental variables and natural experiments could be exploited in empirical studies.

After a survey of the literature, we can get a clearer picture of the field of infrastructure and the economy. The research lacunas in the literature to date point to avenues of future studies, including the mechanism of the interplay between infrastructure and the economy, research at the micro-level in different infrastructure sectors, and the impact from other dimensions in economic activities rather than productivity.

First, more research could be conducted at the micro-level or individual level. As infrastructure is heterogeneous and covers different sectors, to better capture its characteristics and impacts, research on economic effects of infrastructure at individual levels, including firm-level and household level, has increasingly emerged. At the firm level, there are emerging studies testing the effects of infrastructure on firms (Holl, 2006). From the supply side, some films may provide capital investing infrastructure projects, such as financial companies, and some firms need to construct infrastructure, such as road construction companies. From the demand side, firms need to use infrastructure and may highly rely on the availability and quality of infrastructure. A macro approach is usually problematic, while given the complexity of infrastructure and the economy, researchers need to focus more on micro and higher-resolution level, especially at firm-level, examining the economic effects on each individual firm, rather than flocking together on aggregate levels which have easier data accesses. Meanwhile, as one of the fundamental objectives of infrastructure is to benefit the individuals and households, more emphasis should be placed on investigating the economic effects of infrastructure at the individual or household level. For example, in renewable energy infrastructure investment, individuals or households may make a decision on using these renewable energy technologies, based on several key determinants, such as price, location, and governmental incentives. It should be more valuable and promising to examine the economic effects of renewable energy on the household, rather than only looking at the aggregate macroeconomy like GDP of a region (state/province/city). Future studies may need to subdivide the research level. For example, the research could measure at the rural level, rather than only examining the effects on an aggregate level.

Second, future research could consider moving to investigate the impacts of infrastructure on other dimensions in economic activities. As we have shown in the literature review, the prior studies have predominantly focused on the impact of infrastructure on productivity and economic growth. However, the impact of infrastructure is quite profound and broad influence on other aspects of economic activities. For example, future research could make more effects on the impact of infrastructure on other social dimensions, including its impact from ethical, legal and cultural perspectives.

Third, the mechanism of how infrastructure impacts the economy could be further investigated. The economic effects of infrastructure involve a complicated interaction between a set of different types of agents, including governments, public and private investors, households and individuals. To better understand how infrastructure impacts economic activities, more efforts could be made to explore mechanisms that how different sectors of infrastructure influence households, firms and the business environment.

REFERENCES

Agénor, P.-R., 2009. Infrastructure investment and maintenance expenditure: Optimal allocation rules in a growing economy. Journal of Public Economic Theory 11, 233-250

Aghion, P., Howitt, P., Mayer-Foulkes, D., 2005. The effect of financial development on convergence: Theory and evidence. The Quarterly Journal of Economics 120, 173-222

Akerman, A., Gaarder, I., Mogstad, M., 2015. The skill complementarity of broadband internet. The Quarterly Journal of Economics 130, 1781-1824

Akyelken, N., 2015. Infrastructure Development and Employment: The Case of Turkey. Regional Studies 49, 1360-1373

Ansar, A., Flyvbjerg, B., Budzier, A., Lunn, D., 2016. Does infrastructure investment lead to economic growth or economic fragility? Evidence from China. Oxford Review of Economic Policy 32, 360-390

Artadi, E.V., Sala-i-Martin, X., 2003. The economic tragedy of the XXth century: growth in Africa. National Bureau of Economic Research

Ascani, A., Crescenzi, R., Iammarino, S., 2012. New economic geography and economic integration: A review. Search WP, 24

Aschauer, D.A., 1989. Is public expenditure productive? Journal of monetary economics 23, 177-200

Ashraf, N., Glaeser, E.L., Ponzetto, G.A., 2016. Infrastructure and Development Infrastructure, Incentives, and Institutions. The American Economic Review 106, 77-82

Baffes, J., Shah, A., 1998. Productivity of public spending, sectoral allocation choices, and economic growth. Economic Development and Cultural Change 46, 291-303

Balboni, C.A., 2019. In harm's way? infrastructure investments and the persistence of coastal cities. The London School of Economics and Political Science (LSE).

Banerjee, A., Duflo, E., Qian, N., 2012. On the road: Access to transportation infrastructure and economic growth in China. National Bureau of Economic Research

Becker, B., 2015. Public R&D policies and private R&D investment: A survey of the empirical evidence. Journal of Economic Surveys 29, 917-942

Binswanger, H.P., Khandker, S.R., Rosenzweig, M.R., 1993. How infrastructure and financial institutions affect agricultural output and investment in India. Journal of Development Economics 41, 337-366

Bjarstig, T., Sandstrom, C., 2017. Public-private partnerships in a Swedish rural context - A policy tool for the authorities to achieve sustainable rural development? Journal of Rural Studies 49, 58-68

Bougheas, S., Demetriades, P.O., Mamuneas, T.P., 2000. Infrastructure, specialization, and economic growth. Canadian Journal of Economics-Revue

Canadienne D Economique 33, 506-522

Brakman, S., Garretsen, H., Van Marrewijk, C., 2009. The new introduction to geographical economics. Cambridge University Press.

Bröcker, J., Dohse, D., Rietveld, P., 2019. Infrastructure and regional development. In: Handbook of regional growth and development theories. Edward Elgar Publishing.

Brunet, M., 2019. Governance-as-practice for major public infrastructure projects: a case of multilevel project governing. International Journal of Project Management 37, 283-297

Brunet, M., Aubry, M., 2018. The governance of major public infrastructure projects: the process of translation. International Journal of Managing Projects in Business 11, 80-103

Calderón, C., Moral-Benito, E., Servén, L., 2015. Is infrastructure capital productive? A dynamic heterogeneous approach. Journal of Applied Econometrics 30, 177-198

Carlsson, R., Otto, A., Hall, J.W., 2013. The role of infrastructure in macroeconomic growth theories. Civil Engineering and Environmental Systems 30, 263-273

Chatterjee, S., Turnovsky, S.J., 2012. Infrastructure and inequality. European Economic Review 56, 1730-1745

Cutler, D.M., Gruber, J., 1996. Does public insurance crowd out private insurance? The Quarterly Journal of Economics 111, 391-430

Dailami, M., Leipziger, D., 1998. Infrastructure project finance and capital flows: A new perspective. World Development 26, 1283-1298

De Ferranti, D.M., 2004. Inequality in Latin America: Breaking with History? The World Bank, Washington DC.

Demetriades, P.O., Mamuneas, T.P., 2000. Intertemporal output and employment effects of public infrastructure capital: evidence from 12 OECD economies. The Economic Journal 110, 687-712

Donaldson, D., 2018. Railroads of the Raj: Estimating the impact of transportation infrastructure. American Economic Review 108, 899-934

Easterly, W., Rebelo, S., 1993. Fiscal policy and economic growth. Journal of monetary economics 32, 417-458

Elburz, Z., Nijkamp, P., Pels, E., 2017. Public infrastructure and regional growth: Lessons from meta-analysis. Journal of transport geography 58, 1-8

Evans, P., Karras, G., 1994a. Are government activities productive? Evidence from a panel of US states. The Review of economics and statistics, 1-11

Evans, P., Karras, G., 1994b. Is government capital productive? Evidence from a panel of seven countries. Journal of Macroeconomics 16, 271-279

Faber, B., 2014. Trade integration, market size, and industrialization: evidence from China's National Trunk Highway System. Review of Economic Studies 81, 1046-1070

Fan, S.G., Zhang, X.B., 2004. Infrastructure and regional economic development in rural China. China Economic Review 15, 203-214

Fernald, J.G., 1999. Roads to prosperity? Assessing the link between public capital and productivity. American Economic Review 89, 619-638

Fujita, M., Krugman, P.R., Venables, A.J., 2001. The spatial economy: Cities, regions, and international trade. MIT press.

Ghali, K.H., 1998. Public investment and private capital formation in a vector error-correction model of growth. Applied economics 30, 837-844

Gibson, J., Rioja, F., 2017. Public Infrastructure Maintenance and the Distribution of Wealth. Economic Inquiry 55, 175-186

Gillanders, R., 2014. Corruption and Infrastructure at the Country and Regional Level. Journal of Development Studies 50, 803-819

Grimsey, D., Lewis, M.K., 2002. Evaluating the risks of public private partnerships for infrastructure projects. International Journal of Project Management 20, 107-118

Hall, J.W., Tran, M., Hickford, A.J., Nicholls, R.J., 2016. The future of national infrastructure: A system-of-systems approach. Cambridge University Press.

Haughwout, A.F., 1999. State infrastructure and the geography of employment. Growth and Change 30, 549-566

Henisz, W.J., 2002. The institutional environment for infrastructure investment. Industrial and corporate change 11, 355-389

Hodge, G.A., Greve, C., 2007. Public–private partnerships: an international performance review. Public administration review 67, 545-558

Holl, A., 2006. A Review of the Firm-Level Role of Transport Infrastructure With Implications for Transport Project Evaluation. Journal of Planning Literature 21

Holtzeakin, D., 1994. Public-sector capital and the productivity puzzle. Review of Economics and Statistics 76, 12-21

Hulten, C.R., Schwab, R.M., 1991. Public capital formation and the growth of regional manufacturing industries. National Tax Journal, 121-134

Ianchovichina, E., Estache, A., Foucart, R., Garsous, G., Yepes, T., 2013. Job creation through infrastructure investment in the Middle East and North Africa. World development 45, 209-222

Kalaitzidakis, P., Kalyvitis, S., 2004. On the macroeconomic implications of maintenance in public capital. Journal of Public Economics 88, 695-712

Kalaitzidakis, P., Kalyvitis, S., 2005. "New" Public Investment and/or Public Capital Maintenance for Growth? The Canadian Experience. Economic Inquiry 43, 586-600

Keefer, P., Knack, S., 2007. Boondoggles, rent-seeking, and political checks and balances: public investment under unaccountable governments. The Review of Economics and Statistics 89, 566-572

Kelly, S., Tyler, P., Crawford-Brown, D., 2016. Exploring vulnerability and interdependency of UK infrastructure using key-linkages analysis.

Networks and Spatial Economics 16, 865-892

Khandker, S.R., Koolwal, G.B., 2010. How Infrastructure and Financial Institutions Affect Rural Income and Poverty: Evidence from Bangladesh. Journal of Development Studies 46, 1109-1137

Krichel, T., Levine, P., 1995. Growth, debt and public infrastructure. Economics of Planning 28, 119-146

Krugman, P.R., 1993. Geography and trade. MIT press.

Lavee, D., Beniad, G., Solomon, C., 2011. The effect of investment in transportation infrastructure on the debt-to-GDP ratio. Transport Reviews 31, 769-789

Lenz, L., Munyehirwe, A., Peters, J., Sievert, M., 2017. Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. World Development 89, 88-110

Levy, B., Spiller, P.T., 1994. The institutional foundations of regulatory commitment: a comparative analysis of telecommunications regulation. Journal of Law, Economics & Organization 10, 201

Ligthart, J.E., Suárez, R.M.M., 2011. The Productivity of Public Capital: A Meta-analysis. In: Jonkhoff W & Manshanden W (eds.) Infrastructure Productivity Evaluation. Springer New York, New York, NY, pp. 5-32.

Melo, P.C., Graham, D.J., Brage-Ardao, R., 2013. The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. Regional Science and Urban Economics 43, 695-706

Oughton, E.J., Usher, W., Tyler, P., Hall, J.W., 2018. Infrastructure as a complex adaptive system. Complexity 2018

Puga, D., 2002. European regional policies in light of recent location theories. Journal of Economic Geography 2, 373-406

Rioja, F.K., 2003. Filling potholes: macroeconomic effects of maintenance versus new investments in public infrastructure. Journal of Public Economics 87, 2281-2304

Rokicki, B., Stępniak, M., 2018. Major transport infrastructure investment and regional economic development–An accessibility-based approach. Journal of Transport Geography 72, 36-49

Sánchez-Silva, M., Frangopol, D.M., Padgett, J., Soliman, M., 2016. Maintenance and Operation of Infrastructure Systems: Review. Journal of Structural Engineering 142, F4016004

Schmutzler, A., 1999. The new economic geography. Journal of Economic Surveys 13, 355-379

Spiller, P.T., 1993. Institutions and Regulatory Commitment in Utilities' Privatization. Industrial and Corporate Change 2, 387-450

Storeygard, A., 2016. Farther on down the road: transport costs, trade and urban growth in sub-Saharan Africa. The Review of economic studies 83, 1263-1295

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., Hall, J.W., 2019. Infrastructure for sustainable development. Nature Sustainability 2, 324-331

Turnovsky, S.J., 2015. Economic growth and inequality: The role of public investment. Journal of Economic Dynamics and Control 61, 204-221

Valverde, M., Moore, A., 2019. The performance of transparency in public–private infrastructure project governance: The politics of documentary practices. Urban Studies 56, 689-704

Voss, G.M., 2002. Public and private investment in the United States and Canada. Economic Modelling 19, 641-664

Wolff, E.N., Zacharias, A., 2007. The distributional consequences of government spending and taxation in the U.S., 1989 and 2000. Review of Income and Wealth 53, 692-715

3. METHODOLOGY AND DATA

Methodology and Data

Abstract

We review the methodological issues in research on infrastructure and the economy, and introduce the methods used in the empirical studies of this thesis. To address the methodological issues and improve the scientific soundness, research methods should attempt to change from macro-growth accounting model to micro-level data econometrics, and from the measurement of infrastructure investment to infrastructure usage. We then introduce the methods that we use in the three empirical papers and the data sources for the corresponding studies.

1 METHODS IN THE LITERATURE

There are four methodological approaches to examining the nexus between infrastructure and economic effects used in the literature, including the production function, cost-profit function, spatial equilibrium models and vector autoregressive (VAR) approaches.

(i) Production function approach

After Aschauer (1989) estimated the aggregate production function of the public infrastructure in the US, the empirical strategy used in his seminal paper has been widely followed and commonly known in the economics literature as the production function approach. However, the econometric methodology adopted was criticised and the magnitude of the estimated positive effect of the infrastructure on production was questioned as it seemed to overstate the importance of public capital on economic activities (Garcia-Mila, McGuire, & Porter, 1996). Some later studies found smaller effects when the state-level data were used, and parts of the econometric problems were adjusted, whereas these studies were still not able to provide sufficiently robust estimates which would not be subject to change when different specification and estimation techniques were employed. The problem of the production function is that: a sufficient minimal structure on the data is required; otherwise, the estimated results of the parameters of the production function tend to be biased and not robust.

In recent studies, the previously underestimated complexity of the effect of public infrastructure on production has been revealed, and multiple layers of factors have been taken into account (Lakshmanan, 2011), including the specific effects of infrastructure in diverse industry sectors, and at local, regional, and national levels.

Nevertheless, the main issue is that the production function posits a merely technological relationship without explicitly considering firms' behaviour. Thus, in order to more comprehensively consider the effect, marginal productivity conditions should also be accounted for.

Further, the causality of the production function has also been cast in doubt. Critiques have suggested that the aggregate correlation between infrastructure and production could be spurious as the involved variables might not be static and stationary (Garcia-Mila et al., 1996). Even more severe could be the uncertainty of the direction of the causation, as it is not clear whether increasing public capital causes economic growth, or the production and economic activity leads to public investment in infrastructure.

(ii) Cost function approach

A cost function approach has evolved to solve some of the econometric problems, by considering and estimating the effect of public capital on firms' costs, production structure and performance, their demand for private factors, and marginal return rates. The main assumption is that firms minimise the production costs, considering technological changes and constraints, input demand, and scale economies. Public capital is viewed as publicly provided by the government as a free and external input to the firm which exerts an impact on the firms' optimisation decisions. As the public capital increases, the firms' production costs may be reduced in this sense, and thus the effect of public capital on production output could be measured by the reduction in the production costs.

Most empirical studies that follow a cost function approach have concluded with the results showing a positive effect of public capital on cost reductions and therefore economic growth; whereas, the effect estimated by this approach tends to be much smaller than that estimated by production function approach (Lynde & Richmond, 1993; Seitz & Licht, 1995). Some studies have extended the approach by explicitly accounting for the spill-over effects, and temporal and spatial autocorrelations, and have shown that public capital infrastructure has an impact on firms' demands for production factors. It is also suggested that public capital has distributive effects on firms' productivity and composition differentiates in different regions and industry sectors.

Although the cost function approach may have its advantages, the issue of causality remains a question, as public capital is taken as an exogenous variable. Besides, the analysis neglects some potentially important factors and effects of non-static, non-stationary, and non-contemporaneous nature, without accounting for the time sequences of the data, and the problems of spurious correlation and noncointegration.

(iii) Spatial equilibrium models

As indicated above, the production function approach views public capital as an exogenous productive factor, and the availability and variations of the public capital would influence firms' decisions and production processes. Cost function approach, however, assumes that firms minimise the costs and optimise the production process by deciding the quantity of the demanded private input factors, depending on the exogenous input prices and public capital stock. Thus, public infrastructure capital is assumed to have an impact on either productivity or cost structures. Although these two approaches hold different ideas of the exogenous factors to firms' production process, it is still challenging to apply these methods to describe the behaviours of individual competitive firms and to analyse production behaviours in complex factor markets at large aggregate regional levels.

A new approach empirically estimating the Roback spatial location equilibrium model has been proposed to solve this problem from the microeconomic perspective (Glaeser & Gottlieb, 2009; Kline & Moretti, 2014). In the model, labour is assumed as a mobile productive factor, while land is a fixed productive factor, and the regional wages and land rents are determined endogenously in the model. Different local factor prices would reflect the value of non-priced and non-traded regional characteristics including climate or infrastructure, and the prices would also respond to variations in both the productive characteristics such as infrastructure and non-productive local facilities and amenities. Thus, the effect of public infrastructure on production and output can be identified through all the regional differences, with considering the behaviours of firms, the assumed profit takers, and households, the utility takers. A hedonic regressions model and individual-level data are utilised to empirically estimate the above theoretical model. In the econometric specification, labour wages and land prices are related to regional characteristics and public infrastructure capital stock, with controlling individual characteristics of the workers and land features. Studies following this approach find a positive effect of infrastructure on productivity, and the relative price of input factors such as household wage income and land value (Chen & Haynes, 2015).

However, in the model, there are still some other conditions that have not been taken into account, such as the budget constraint on public expenditure and tax rates. If the financial sources for the increase of public infrastructure are not exogenous, the effect of infrastructure on production and wages would be different. The vector autoregressive approach has been developed to tackle this problem.

(iv) Vector autoregressive approach

Vector autoregressive (VAR) models, as an alternative approach to the research topic, do not make a priori assumption about causality but instead detect the existence of direct and indirect effects and relationships among the variables of interest, and whether it is a causal link between public infrastructure and production, or there is a feedback effect from output to public capital (Cavaliere, Nielsen, & Rahbek, 2015; Lütkepohl, 2011). This approach has been increasingly used in the current literature (Duran-Fernandez & Santos, 2014).

Studies using this approach have found positive effects of public capital on productivity, while some results show that the effect is smaller than that in early studies (Pereira & Andraz, 2005, 2006). Moreover, public investment is found to be negatively related with the lagged variations in aggregate private employment, and not correlated with the lagged variations in aggregate private investment. According to these results, it may be suggested that public expenditure would be influenced by the production output, that is, reverse causality, which points to future research directions.

2 METHODOLOGICAL DIRECTIONS

In sum, different theoretical framework and models, methodological approaches, empirical strategies, and econometric specifications have been employed to estimate the relationship between public infrastructure capital stock and the production output and economic growth. Four methodological issues could be identified in the literature (Brynjolfsson, 1993): (i) Mismeasurement of inputs of infrastructure; (ii) Lags due to learning and adjustment; (iii) Redistribution and dissipation of profits; and (iv) Mismanagement of economic outputs.

To circumvent some of these disadvantages, this thesis attempts to follow two directions: First, from macro-growth accounting model to micro-level data econometrics; Second, from the measurement of infrastructure investment to infrastructure usage, adoption and improvement. Third, from endogeneity issues to generate exogenous variation and using natural experiments.

First, attempts from the measurement of infrastructure investment to infrastructure usage. While infrastructure capital and investment data have been used in most econometric estimates, it may be a problematic measurement in examining the relationship between infrastructure improvement and economic impact. As a conventional measure, the capital data in infrastructure are more assessable, making scholars easier to collect these data and use them in their empirical examination. However, the monetary term of infrastructure capital data may have inherent disadvantages in the econometric estimates. These include: (i) infrastructure usually takes a long time to build and tend to have long useful lives. (ii) as the improvement on infrastructure usually can only be increased in large increments of capital investment, this limited divisibility makes it difficult to reflect the change of infrastructure precisely. For example, building aviation infrastructure can be extremely time-consuming, and the amount of time that needed can vary because of numerous factors. The median time for airports to build runways was estimated as more than ten years, according to a survey in 30 airports conducted by the US General Accounting Office. Simply using infrastructure capital data could have time lags and not adequately reflect the real-time change of infrastructure and may cause mismeasurement when estimating the economic impact of infrastructure. To address the mismeasurement and time lag issues, it may be more appropriate to use the measure on the usage or the intensity of infrastructure. In can directly reflect the tangible improvement of infrastructure. For example, when government invested various money on a high-speed road in a city in different years, we may not measure its economic return by using its capital investment, as this may not be available after the completion of the infrastructure projects; but we can easily capture its change when we measure the length of the high-speed road that they have built, or the number of passengers that they carry.

Second, attempts from macro-growth accounting model to micro-level data econometrics. It is possible that the benefit of infrastructure is large, but a proper proxy of its real economic effects has yet to be employed. The mismeasurement of the economic output of infrastructure by using macro-growth economy indicators such as GDP makes it difficult to establish causality. When we argue that infrastructure will increase the macroeconomy, attempts at estimating its economic benefit will be hampered by endogeneity. For example, when investigating the hypothesis that a country with better infrastructure will increase economic growth, it is a severe endogeneity issue that a country with better economic growth may also invest more in infrastructure. The redistribution and dissipation of economic benefit of infrastructure also make it difficult to test its direct impact on the macro economy. To more precisely measure the specific economic impact on the economy, more granular data are needed. These data may include housing level data or firm-level data. For example, when we measure the economic impact of infrastructure improvement on firm performance, the simultaneous reverse impact incurred by firms is much weaker, as infrastructure is usually funded by the public expenditure of city or countries rather than by firms.

Third, in the recent literature, some studies have been exploited methods generating exogenous variation. The application of instrumental variables and the use of natural experiments could be some useful methods that help to solve the endogeneity issues (Capello & Nijkamp, 2019; Mayer & Trevien, 2017). Some more examples of using natural experiments are as follows. Cattaneo, Galiani, Gertler, Martinez, and Titiunik (2009) used a natural experiment to show that a large-scale programme to replace dirt floors with cement floors in urban slums in Mexico significantly improved child health and also adult welfare. Winters et al. (2018) employed a natural experiment to assess the impact of the promotion of bicycle infrastructure on safety and health, and also health-related economic benefits in three Canada cities. Mayer and Trevien (2017) exploited a natural experiment provided by the opening and extension of Regional Express Rail in Paris and found that the change in transport infrastructure significantly improved employment, while they found no effect on overall population growth.

3 METHODS IN THE THESIS

To explore the effects of economic returns of infrastructure, given the complexity of infrastructure and economic effects, it is critical to use some appropriate econometric methods between infrastructure and the economy. Thus, different kinds of empirical and econometrical methods are employed in our studies, including difference-in-difference (DID) approach, instrumental variables (IV), propensity score (PSM) matching, and Granger tests. First, we design natural experiments with DID that make use of longitudinal data from treatment and control groups to obtain an appropriate counterfactual estimate, which helps to establish a causal relationship between infrastructure and its economic impact. Second, we employ the propensity score matching to reduce the bias that could be aroused because of confounding variables. Using the nearest neighbour matching, the PSM control for the difference to make the groups receiving treatment and not-treatment more comparable. Third, the method of instrumental variables is used to estimate the causal relationship between infrastructure and the economy, alleviating the issues that the explanatory variable of interest may be correlated with the error term. A larger number of panel datasets are used, which improve more accurate inference of model parameters, provide larger capacity for capturing the complexity of infrastructure and the economy than a single cross-section or time-series data, and reduce measurement errors.

(1) In paper 1 measuring the economic effects of ICT infrastructure on firm performance, we use data on the usage and intensity of mobile phone infrastructure, internet infrastructure, telephone infrastructure and telegraph infrastructure, and match the firm-level dataset to explore the economic contributions of ICT infrastructure improvement at the firm level. The principal component analysis is used to combine data of four key ICT components. A set of robustness checks are conducted, including tests on time-lag effects; tests using quantile regression and tests addressing possible measurement issues on geographical location. Instrumental regression is introduced to help to establish the causality relation. Moreover, we construct a natural experiment based on the telecommunication upgrade to generate exogenous variation and to establish the causal linkage between ICTs and firm profitability. To explore its mechanisms, we investigate the interaction effect of firm characterises, including firm's labour, efficiency and cost on the relation between ICT infrastructure and firm profitability.

(2) In paper 2 measuring the economic effects of renewable energy on the household economy, with panel estimation techniques and fixed-effect models, our research models establish cross-sectional dependence, heterogeneity across the provinces. We employed fixed effect panel regression with one-stage autocorrelation and panel Feasible Generalized Least Squares (FGLS) regression to test the relationship. Granger tests are applied to investigate the Granger causality. Alternative measures on household are also tested to ensure the robustness of the

results.

(3) In paper 3 measuring the economic effects of transport infrastructure, we used firm-level panel data measuring more than three thousand individual performance of firms. We use the improvement of China's construction of high-speed rail as a natural experiment, and use a difference-in-difference approach on examining the impact of the improvement of transport connections. We employ an instrumental variable by using the historic conventional rail construction to verify our results. We further explore the mechanisms of how transport infrastructure affects firm productivity, including information asymmetry and external regulation and monitoring. Methods include panel data fixed effects regressions, instrumental variables, placebo test, and difference-in-difference analysis by using natural experimental design settings.

4 DATA SOURCES OF THE THESIS

4.1 Data in paper 1

To measure the impact of city's ICT infrastructure on firm productivity, we collect data on both ICT and firm performance. We use physic-unit measures on ICT infrastructure usage or intensity rather than the conventional proxy by employing monetary measures. We first collect data on the usage and adoption data of Internet, telephone, mobile phone and telecom, and the size of the population in each city. With the usage data and population data, we then calculate the adoption intensity of ICT infrastructure in each city in each year. After standardising the variables and employing the principal component analysis approach to combine the indicators to a comprehensive proxy, we then get the ICT infrastructure density data in each city in each year. We also collect data on China's infrastructure upgrade as a natural experiment to generate an exogenous variation and employing a difference-in-difference approach to establish the causal impact of ICTs on firm profitability. We manually search and collect data on the information of Chinese cities, regarding their implementation of telecommunication upgrade from seven-digit telephone to eight-digit telephone during 1995-2018. Data sources in the city's infrastructure are from the National Bureau of Statistics, and data are also collected from the China Cities Database, and Economy Prediction System China Database. Data in innovation performance are from the National Intellectual Property Administration of China. We then get firm level data from the Chinese Stock Market and Accounting Research database. This study merges ICT usage data with firm performance data from 2001 to 2016. The sample covers more than 2775 firms and ICT data in 288 cities. We winsorised the variables at the 1% level by each year to eliminate the effects of extreme values. There are 23768 observations in our regression models.

4.2 Data in paper 2

We also try to solve the data issues, as data in renewable energy infrastructure are still scarce. By collecting data from different sources, we have been able to compose a panel data covering three key types of renewable energy, including bioenergy, solar energy and hydropower energy.

Unlike most studies employing energy consumption data on the energy consumption side, we first use data measuring the deployment and investment of renewable energy. Again, we do not investigate the capital investment of public infrastructure at the regional and national levels. After capturing household renewable energy deployment data, such as the number of biogas digesters and the number of rural solar heaters at households, physical unit data of infrastructure usage are available. We also capture data on the household economy to reflect the economy. Data are collected and compiled by multiple sources which are released by several different official institutions, including the National Energy Administration, the Ministry of Water Resources, and the National Bureau of Statistics of the P.R. of China. After combining the datasets from the China Agriculture, Rural Areas and Peasantry Database, China's Environment Dataset, China Construction Industry Statistics, and China Macro and Regional Economy Statistics, we have been able to compose a panel data for our analysis at the provincial level. These records provide information about China's renewable energy, household income and economic information.

4.3 Data in paper 3

We take advantage of the improvement of China's transport infrastructure as a quasi-natural experiment to study its impact on reducing firms' litigation risk. We use the inauguration of the high-speed rail as a source of exogenous variation, and construct a dataset from various sources, covering the period from 2001 to 2018. Our sample regarding corporate litigations starts in 2001 and ends in 2018. The sample of high-speed railways starts in 2003, the year that China inaugurated its first high-speed rail route, and the sample ends in 2018. Between 2003 and 2018, China inaugurated high-speed rail stations and services in 221 cities, and we get information on each city's inauguration. For the instrumental variable, as no pre-existing dataset contains relevant information, we constructed the dataset by manually searching and collecting historical data. As the listed firms in our sample are located in 404 cities in China, we manually collected historical information of the inauguration of the conventional railway in 404 cities since the year 1881. Our research sample of firms contains information on Chinese A-share listed firms from 2001 to 2018. The sample begins in 2001 due to some key variables of firms only available since 2001. The data on litigation risk information, as well as accounting and corporate governance, are acquired from the Chinese Stock Market and Accounting Research database (CSMAR). These data are collected from the firms' annual reports and cover all the listed firms' litigation cases. The litigation statistics include the total amount involved in the litigations, and the detailed litigation information includes the specific record of each court hearing. The variables are winsorised at the 1% level to alleviate the impact of outliers. We finally obtain 30,542 observations containing the information of 3,488 firms in 404 cities.

REFERENCES

Aschauer, David Alan. (1989). Is public expenditure productive? *Journal of monetary economics, 23*(2), 177-200.

Brynjolfsson, Erik. (1993). The productivity paradox of information technology. *Communications of the ACM, 36*(12), 66-77.

Capello, Roberta, & Nijkamp, Peter. (2019). *Handbook of Regional Growth and Development Theories: Revised and Extended Second Edition*: Edward Elgar Publishing.

Cattaneo, Matias D, Galiani, Sebastian, Gertler, Paul J, Martinez, Sebastian, & Titiunik, Rocio. (2009). Housing, health, and happiness. *American Economic Journal: Economic Policy, 1*(1), 75-105.

Cavaliere, Giuseppe, Nielsen, Heino Bohn, & Rahbek, Anders. (2015). Bootstrap Testing of Hypotheses on Co-Integration Relations in Vector Autoregressive Models. *Econometrica, 83*(2), 813-831.

Chen, Zhenhua, & Haynes, Kingsley E. (2015). Multilevel assessment of public transportation infrastructure: a spatial econometric computable general equilibrium approach. *The Annals of Regional Science, 54*(3), 663-685.

Duran-Fernandez, R., & Santos, G. (2014). An empirical approach to public capital, infrastructure, and economic activity: A critical review. *Research in Transportation Economics, 46*, 3-16. doi:10.1016/j.retrec.2014.09.001

Garcia-Mila, Teresa, McGuire, Therese J, & Porter, Robert H. (1996). The effect of public capital in state-level production functions reconsidered. *The Review of economics and statistics*, 177-180.

Glaeser, Edward L, & Gottlieb, Joshua D. (2009). The wealth of cities: Agglomeration economies and spatial equilibrium in the United States. *Journal of economic literature, 47*(4), 983-1028.

Kline, Patrick, & Moretti, Enrico. (2014). Local economic development, agglomeration economies, and the big push: 100 years of evidence from the Tennessee Valley Authority. *The Quarterly Journal of Economics, 129*(1), 275-331.

Lakshmanan, TR. (2011). The broader economic consequences of transport infrastructure investments. *Journal of transport geography, 19*(1), 1-12.

Lütkepohl, Helmut. (2011). *Vector autoregressive models*: Springer.

Lynde, Catherine, & Richmond, James. (1993). Public capital and long-run costs in UK manufacturing. *The economic journal, 103*(419), 880-893.

Mayer, Thierry, & Trevien, Corentin. (2017). The impact of urban public transportation evidence from the Paris region. *Journal of Urban Economics, 102*, 1-21.

Pereira, Alfredo M, & Andraz, Jorge M. (2005). Public investment in transportation infrastructure and economic performance in Portugal. *Review of Development Economics, 9*(2), 177-196.

Pereira, Alfredo M, & Andraz, Jorge M. (2006). Public investment in transportation infrastructures and regional asymmetries in Portugal. *The Annals of Regional Science, 40*(4), 803-817.

Seitz, Helmut, & Licht, Georg. (1995). The impact of public infrastructure capital on regional manufacturing production cost. *Regional studies, 29*(3), 231-240.

Winters, Meghan, Branion-Calles, Michael, Therrien, Suzanne, Fuller, Daniel, Gauvin, Lise, Whitehurst, David GT, & Nelson, Trisalyn. (2018). Impacts of Bicycle Infrastructure in Mid-Sized Cities (IBIMS): protocol for a natural experiment study in three Canadian cities. *BMJ open, 8*(1), e019130.

4. ICT INFRASTRUCTURE AND FIRM PERFORMANCE

CITY'S ICT INFRASTRUCTURE AND FIRM PERFORMANCE

Abstract

This study provides new empirical evidence that demonstrates the impact of city's information and communication technologies on firm performance. We assemble a series of panel datasets measuring the improvement of city's ICT infrastructure and the change of firm performance during the years 2001-2016 in China. We find that city's ICTs positively promoted firm performance, including financial profitability, marketing performance and innovation performance. We employ instrumental variables to verify the positive impact of city's ICTs infrastructure on firm profitability. Taking advantage of an exogenous variation of telecommunication upgrade as a natural experiment, we use the difference-in-difference approach and establish causality between city's ICT infrastructure and firm profitability. We further explore the mechanisms and have found that better level of labour, higher efficiency and lower level of costs are the three possible channels that ICTs influence firm profitability.

Keywords: ICT infrastructure, Firm Performance, Productivity, and City

JEL classification: M21, R11, O18

1 INTRODUCTION

The wide application of information and communication technologies (ICTs) has substantially influenced and reshaped the ways of how business is done. Some preponderant views persist that only countries with a large investment in ICT infrastructure and upgrade of ICT quality can lead in the global development and competition. This view has had a critical influence on public policies. In particular, it has provided further justification for ICT subsidies (Samarajiva & Zainudeen, 2008; Torero & Von Braun, 2006). The prevailing usage of information technology and telecommunication technology has catalysed the subject of "information economics", which is a branch of microeconomics that studies how information impacts the economy and economic decisions (Allen, 1990). Given the importance of ICTs, there is no surprise that scholars have been keen on exploring how ICTs impact the economy, while whether ICTs enhances productivity nevertheless remains a controversial issue.

There may be different explanations about the relation between ICTs and productivity growth, and the existing studies have documented various results (Cardona, Kretschmer, & Strobel, 2013). On the one hand, as an emerging technology, ICTs could be considered as a component of the production function. ICTs may add economic value because ICTs allow and expedite individuals, firms and organisations to make choices that may yield higher payoffs or utility than they could gain in the absence of ICTs. In the literature, some studies found ICTs enhanced economic performance and productivity. Hardy (1980), one of the pioneer scholars who investigated the impact of telecommunication infrastructure on economic growth, first detected a positive economic return. Using cross-sectional time-series data in 60 countries, Hardy found evidence that telephone did contribute to GDP. Roller and Waverman (2001) used evidence from 21 OECD countries over two decades and found a significant positive relationship between telecommunication infrastructure and economic growth. Whitacre, Gallardo, and Strover (2014) suggested that high levels of broadband adoption in US rural areas were positively associated with income growth. Researchers who used more micro-based data found a positive relationship between computers and productivity. For example, Krueger (1993) found that workers who used computers were paid approximately 10% to 15% more than similar workers who did not work with computers in the US. More recently, with the emerging of mobile internet, Bertschek and Niebel (2016) found that employees' use of mobile internet access led to higher labour productivity, based on a survey of manufacturing and business-related services firms.

On the other hand, ICTs may fail to increase or even may decrease productivity. This productivity paradox could be dated back to the situation in the 1970s and 1980s that no evidence or negative associations between ICTs investment and growth in the US economy were found. The ICTs productivity paradox could be referred to Solow (1987)'s quip, "You can see the computer age everywhere but in the productivity statistics." Despite significant ICTs investments, national productivity growth in the US experienced a slowdown in those two decades. Early research found computers generated little impact on productivity and firms' economic performance. Baily and Gordon (1988) found little quantitative contributions of the growing use of computers to the US aggregate productivity improvement. One possible theoretical explanation for the paradox could be based on the economies of scale theory (Samuelson, 1948; Silberston, 1972) that the ICTs investments in the US during that period only accounted for a small percentage of the inputs to the economy to generate measurable returns. Later research conducted by Oliner and Sichel (1994) also found that computer hardware contributed negligible impact (only 0.16% annually) to the growth of gross output during 1970 to 1992 in the US, and even less to the growth of net output, as they argued that this was expected given the investment accounted for such a minor percentage of the total capital stock. Non-positive economic impacts of ICT were also found in other countries. For example, Tripathi and Inani (2016) found the Internet usage had a negative short-run impact on the economy in sub-Saharan African countries. Second, although ICTs have been advocated to be used in the workplaces since it may increase the working efficiency and enable communications without the constraints of geographical locations, ICTs may simply provide different ways to communicate or change the frequency of communications and do not have a fundamental effect on the functioning of the economy. The adoption of ICTs may be important for a firm, while Giuri, Torrisi, and Zinovyeva (2008) were not able to find significant evidence in favour of complementarity between ICTs and skills in Italian small and medium manufacturing firms. Although companies have poured billions of dollars into ICTs, Loveman (1994) argued that these companies were not obtaining their investment's worth. Using the introduction of ADSL broadband in the UK, DeStefano, Kneller, and Timmis (2018) found that ICTs could only improve firm's sales, but not productivity. Some issues brought by ICTs may even lead to pernicious impact. For instance, given that many employees highly rely on ICTs for work communication, employees may experience cyber incivility, higher affective and physical distress, which may decrease their productivity (Park, Fritz, & Jex, 2018). Researchers who explored at more micro levels also found insubstantial effects of ICTs on productivity. For instance, Vasileiadou and Vliegenthart (2009) came up with the views that the impact of internet use on research productivity was limited for the two observed EU research teams, while face-to-face collaboration was more productive. Third, the application of ICTs may change original market barriers, segmentations and orders, and trading manners etc. ICTs provide a potential to make the market more contestable and hence more competitive due to low sunk costs, based on the contestable market theory (Goel & Hsieh, 2002). In this sense, the overall cost of ICTs may outweigh its benefits.

The literature has presented mixed evidence regarding the question of whether ICTs enhance or impede productivity and growth. One reason why it is difficult to test this puzzle may be primarily due to the simultaneity between ICTs investment and economic growth, making the direction of this effect ambiguous. In other words, ICTs may impact regional productivity and growth, while regional productivity and growth could also influence the investment of ICTs. The simultaneity issue is particularly severe in some studies drawing on ICT investment monetary data and country-level examinations using GDP data at the aggregate level (Whitacre et al., 2014). There are also studies in business and management that measured the linkage between ICTs and firm performance, which are mainly based on firms' internal expenditure or adoption of ICTs (Gallego, Gutierrez, & Lee, 2015; Grimes, Ren, & Stevens, 2012; Haller & Lyons, 2015). However, it still faces the simultaneity issue; better firms may spend more on ICTs.

Building on the literature, this study aims to further examine the linkage between ICTs and economic performance with a new perspective and research setting, by investigating the impact of the adoption intensity of city's ICT infrastructure on firm performance, as a way to link the macro-level ICT infrastructure to the micro-level firm performance. Recent firm-level data and ICT infrastructure data at the city level are used to empirically gauge the contribution of ICTs to firm profitability in China from 2001 to 2016. We test the impact of ICTs infrastructure on firm performance based on profitability measured by return on assets (ROA) in the baseline model. Then, we test ICTs' impact on marketing-based and innovation-based performance measures. As robustness checks, we run tests with time lags, use alternative dependent variables, add more controls and use the propensity score matching method. Instrumental variable approaches are employed to help to establish the linkages between ICTs and firm performance. Moreover, taking advantage of an exogenous variation as a natural experiment, i.e., the telecommunication system upgrade from seven-digit to eight-digit, we conduct a difference-in-difference approach and establish the causal impact of city's ICT infrastructure on firm profitability. We then explore three possible mechanisms through which city's ICTs influence firm profitability.

We highlight that when a city improves its ICT infrastructure, it could attract workers that have a higher level of labour for firms, it could make firms more efficient, and it could also help firms reduce cost, which collectively contributes to firm productivity. We aim to contribute two broad strands of literature that this study is closely related to, including the literature on ICTs infrastructure and regional economic growth (Draca, Sadun, & Van Reenen, 2007; Stanley, Doucouliagos, & Steel, 2018), and also the literature on firm's ICT spending and firm productivity (Majumdar, Carare, & Chang, 2010).

The remainder is organised as follows. Section 2 introduces the background. Section 3 introduces the data and variables. Section 4 presents our main results. Section 5 examines mechanisms. Section 6 presents extended evidence, and Section 7 concludes.

2 BACKGROUND AND RESEARCH SETTING

ICTs include a wide range of technology fields, and the technologies of ICTs are evolving. Although there may not be an exact starting point of ICTs, if we may divide the contemporary technological development into different eras, we could have the electrical era and then the ICT era. Broadly speaking, after the electrical era, we have stepped into the era of ICT since the 1970s. As we had the first mobile phone in 1973, we may regard the year of 1973 as the start of the ICT era. When we simply look at the global GDP growth data (see Figure 1), however, we find that the global GDP growth experienced an unexpected downward trend since having entered the ICT era from the electrical era. Interestingly, almost every country has been vigorously advocating and promoting ICTs, while the global economic growth is getting slow or even malaise after the electrical era.

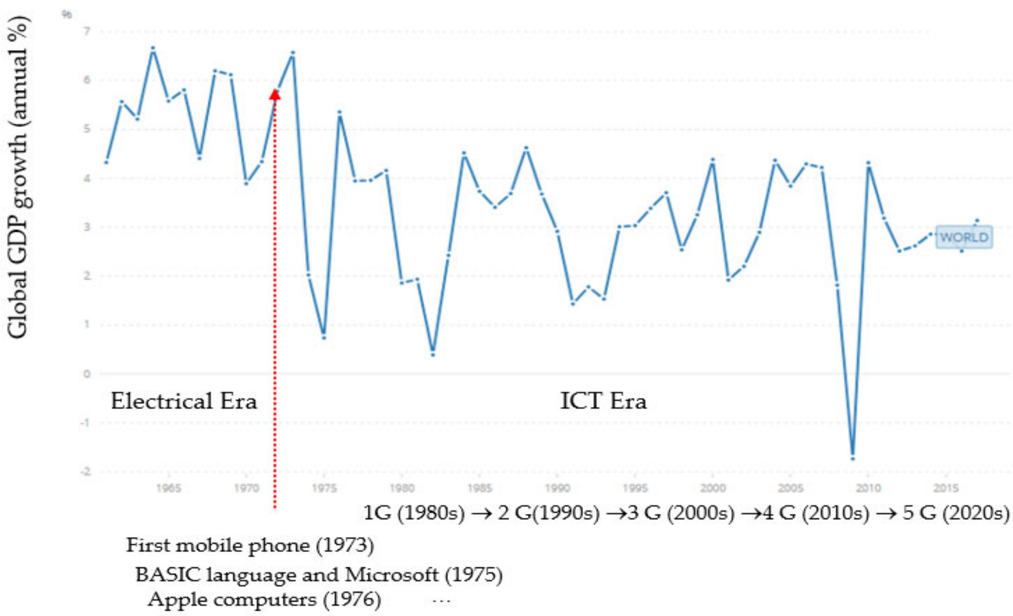

Figure 1 Global GDP growth after the 1970s

The economic growth in the United States and EU countries decreased and remained sluggish after 1973. However, the economic growth of China kept a rapid increase in the ICT era, quite different compared to global economic growth, and those developed economies like the US and the EU countries. The growth rate of the economy in the ICT era could provide some overall background on the global economy and ICTs, while we are not able to simply draw a conclusion on the economic contributions of ICTs on the economy without rigorous examination.

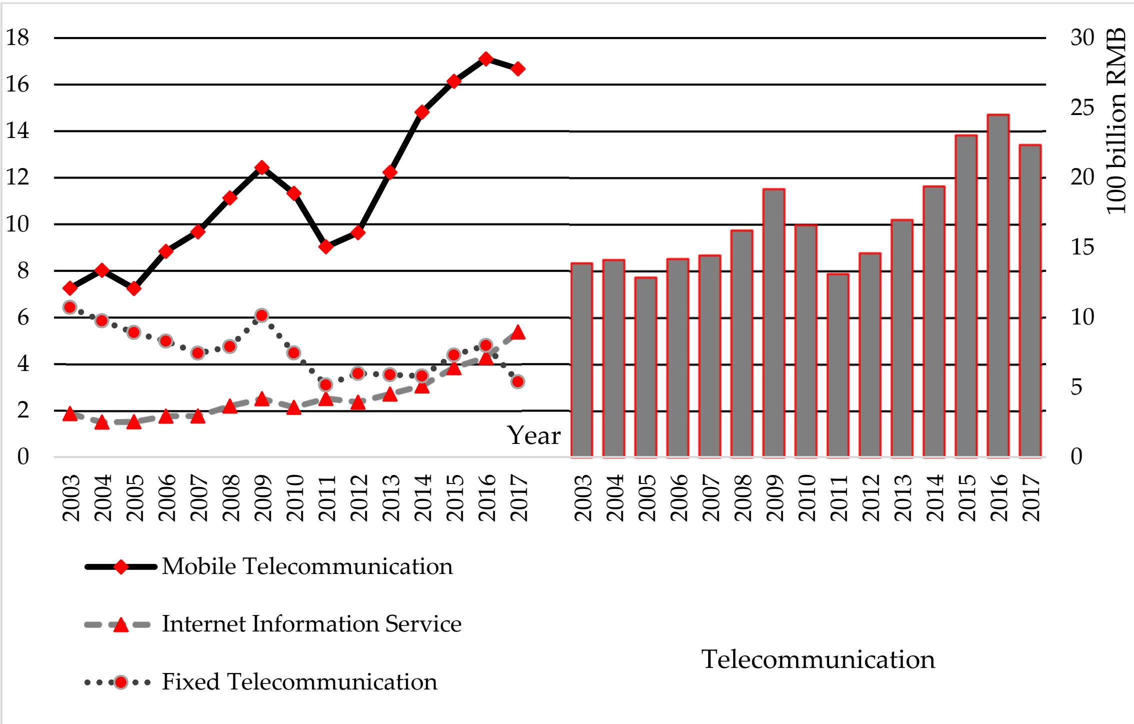

Figure 2 Investment in ICT infrastructure in China

Notes: Figure 2 shows the investment in mobile telecommunication, internet information service, fixed telecommunication on the left side, and also the total amount of investment in telecommunication on the right side. Investment is measured in fixed assets. Data are collected from the National Bureau of Statistics of China.

Given the increasing prominence of China's ICTs and economy, this study aims at examining this linkage in the context of China. China's ICT infrastructure development has experienced rapid development during the 1990s and 2010s.

During the past decades, the Chinese government has placed emphasis on and massive investment in ICT infrastructure. China's telecommunication infrastructure is dominated by three state-owned enterprises, including China Mobile, China Unicom, and China Telecom, which are directed by the Ministry of Industry and Information Technology of China. China Mobile is the world's largest mobile network operator by the number of subscribers, China Unicom is China's second-largest mobile service and telecommunication operator, and China Telecom is the largest fixed-line services and broadband internet operator. To establish a world-leading information communication technology system, China has been increasingly and intensively investing in the ICT infrastructure, as shown in Figure 2. Over the past years, the Chinese central government and China's ICT infrastructure operators have invested more than 1500 billion RMB (approximately 215 billion USD) each year on telecommunication, which has been more than the total amount of investment of the operators combined in all western Europe.

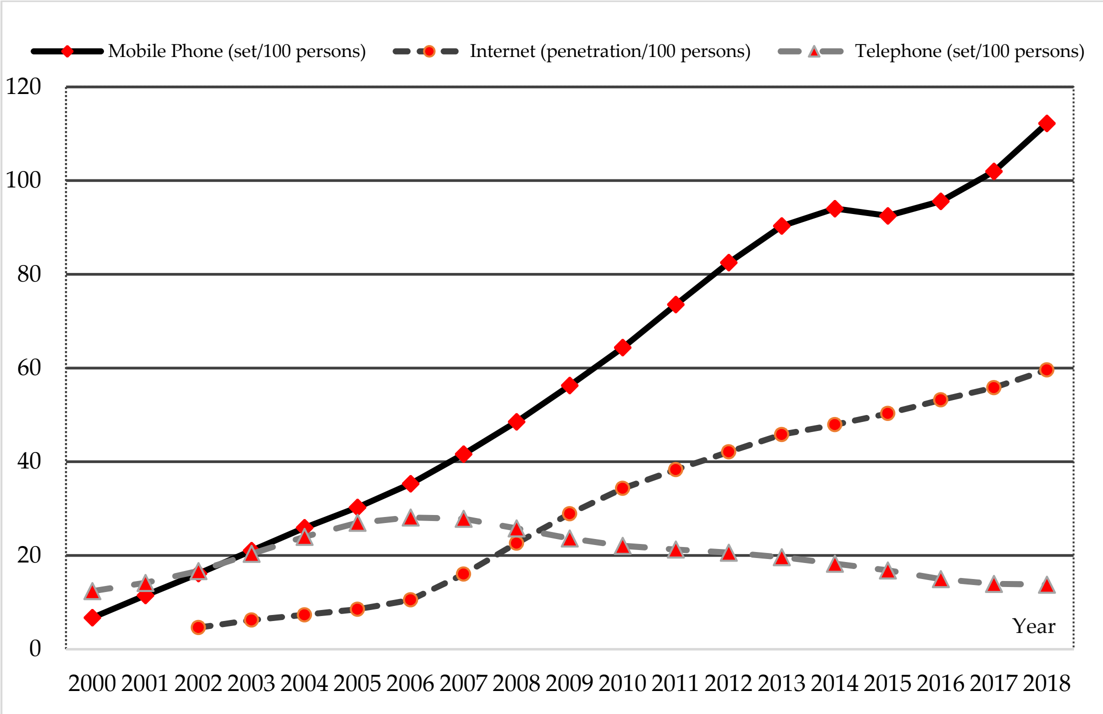

Figure 3 The change of telecommunication adoptions in China

Notes: Figure 3 shows the change in the number of adoptions of mobile phones, internet and telephones per 100 persons. Data are collected from the National Bureau of Statistics of China.

After the large-scale investment in the last two decades, China has leapt from a manufacturing centre to an advanced information technology superpower, with the largest fixed-line and mobile network capacity and the largest number of subscribers. Since 2008, China has become the country with the largest population on the Internet, and about 59.6% of the Chinese population were internet users in 2018, with a higher penetration rate than the global average (53%). In 2017 nearly everyone owned a mobile phone in China, with more than 1.3 billion mobile subscribers in its domestic market, and in 2018, the per capita mobile phone ownership surged to 1.12 (see Figure 3).

The tremendous investment and burgeoning development of China's ICT infrastructure call for the examination on its economic impact. Motivated by this, our study with an empirical research setting of China could provide evidence for us to better understand the linkage between ICTs infrastructure, firm performance and economic growth. Our study has a focus on Chinese listed firms, which plays a vital role in China's economic activities. Between 2014 and 2018, the average rate of the market capitalisation of listed domestic firms in China accounts for 63.16% of its GDP, as shown in Figure 4.

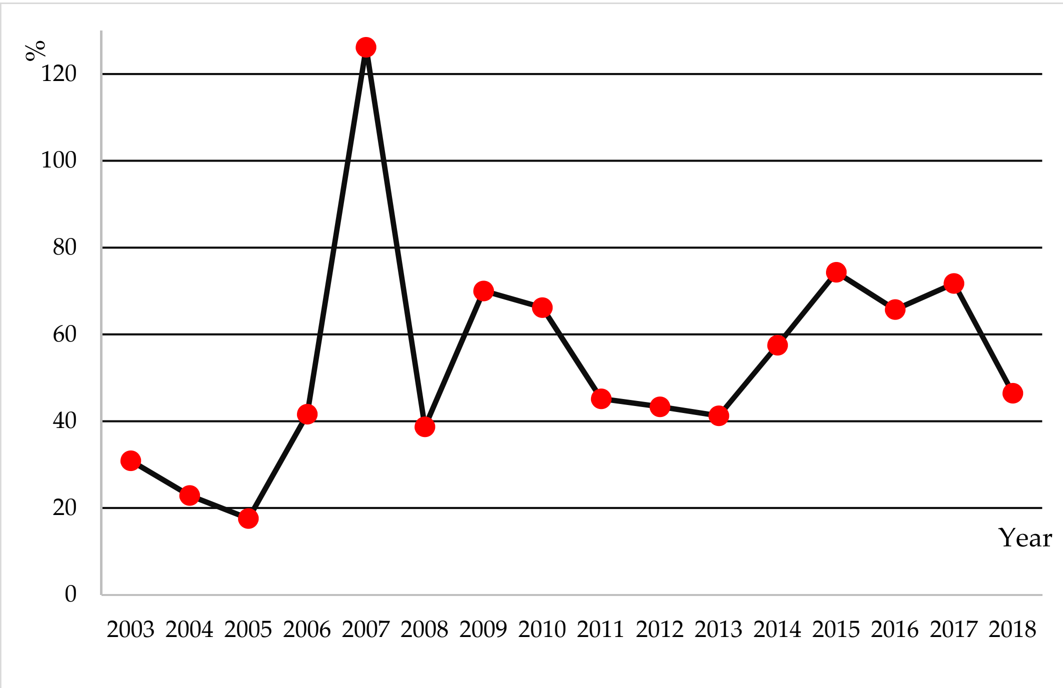

Figure 4 Market capitalisation of listed domestic companies in China (% of GDP)

Notes: Market capitalization (also known as market value) is the share price times the number of shares outstanding. Listed domestic companies are the domestically incorporated companies listed on the country's stock exchanges at the end of the year. Data are from the World Bank.

3 DATA AND VARIABLES

This study merges ICT usage data with firm performance data in China from 2001 to 2016. To mitigate the measurement issues encountered in the studies employing aggregate data at country level, we focus on the effects of ICTs on individual firm performance, and thus we collect data at the firm level by using China's listed company datasets.

To measure the usage and intensity of ICT infrastructure, we collect data on the usage and intensity of Internet, mobile phone device, telephone landlines and telecoms at the city level in China. Employing the principal component analytical approach, we then combine the four ICT components and generate a comprehensive indicator to measure ICT infrastructure. The sample covers more than 2,775 firms and ICT data in 288 cities. Data sources include the China Cities Database, Chinese Stock Market and Accounting Research (CSMAR) database, Economy Prediction System China Database, data from the National Bureau of Statistics and the National Intellectual Property Administration of China. Data on city's ICT infrastructure are from the China Cities Database and National Bureau of Statistics, which are collected from the Economy Prediction System China Database. We obtain data on the total number of internet users, telephone subscribers, mobile phone subscribers in each city. We also obtain data on the total amount of fee of telecom in each city, which covers the total fees on internet, telephone, mobile phone and other types of telecommunication services. Firm performance data are mainly from the CSMAR database.

To construct the instrumental variable using telecommunication system upgrade information, we manually search the information and data of implementation of the plan of 403 Chinese cities during 1995- 2018. Data are mainly collected based on the information released by each city's news when they implemented the plan, and we verified the information using each city's government website to ensure the accuracy of the data.

The main variables and their definitions in our empirical estimation models are summarised in Table 1. In the line of previous literature, we control for a vector of the firm and industry characteristics that may affect a firm's productivity and economic performance.

In terms of the measurement for ICTs, because ICTs include various categories, we use the principal component analysis (PCA) to construct the comprehensive ICT measure. The methods of using a composite variable through combining multiple proxies have been widely applied in the literature (Chen, Chen, Cheng, & Shevlin, 2010; Kim, Li, & Zhang, 2011; Lennox, Lisowsky, & Pittman, 2013). The rationale of using the PCA to extract a composite measure is to provide an objective, scientific measure of ICTs. The ICTs measure extracts information from multiple information communication technology component and usage proxies and therefore could be advantageous over any individual measure. In doing so, we optimise the measure and bring clarity to the existing literature that usually measured ICTs with only a single proxy or component while yielded mixed results (Lennox et al., 2013). More specifically, we utilise the city-level adoption intensity of internet, telephone, mobile phone, and telecom to construct the ICT index, shown in Table 1. To make these variables comparable, we use the equation $SVar_i = (Var_i - \mu_i)/\delta_i$ to exclude the impact of the variable unit, where Var_i is the original variable and μ_i is the mean of the Var_i, δ_i is the standard deviation of Var_i. After PCA calculation, the weights of these four factors are 0.5541, 0.1771, 0.5824 and 0.5678, respectively.

Table 1 Definitions of variables

Panel A. Components to construct the ICT measure

Component	Definition
Internet	The adoption intensity of internet (the total number of internet users divided by the population in the city)
Telephone	The adoption intensity of telephone (the total number of telephone subscribers divided by the population in the city)
Mobile	The adoption intensity of mobile phone (the total number of mobile phone subscribers divided by the population in the city)
Telecom	The adoption intensity of telecommunication (total amount of fee of telecommunication divided by the population in the city)

Panel B. Main variables in the empirical analysis

Type	Variable	Definition
Dependent	ROA_{t+1}	Return on the assets (in year t+1), which is the ratio of net profit to total assets
	ROE_{t+1}	Return on the equity (in year t+1), which is the ratio of net profit to total equity
	ROA_{t+2}	Return on the assets (in year t+2), which is the ratio of net profit to total assets
	ROA_{t+3}	Return on the assets (in year t+3), which is the ratio of net profit to total assets
Independent	ICT	Information and communications technology adoption intensity in year t. We employ the principal component analysis to combine internet, telephone, mobile phone, and telecom together to generate this measure.
Control	Size	Total assets in year t, which is the natural logarithm of total assets
	ER	Equity ratio, which is the ratio of debt to equity
	Growth	The growth rate of a firm's operating revenue
	Firm Age	Firm age, which is the gap between report year and IPO year
	Turnover	The ratio of total revenue to total assets
	Industry	A series of dummy variables of industry and we employ the first two digits of CSRC industry classification in 2012
	Year	A series of dummy variables of year

4 EMPIRICAL RESULTS

4.1 Descriptive statistics and correlation analysis

Panels A and B of Table 2 show the descriptive statistics and correlation coefficients of the variables. All variables are winsorised at the top and bottom 1% of each variable's distribution to minimise the effects of outliners. Panel A provides summary statistics by tercile and dispersion. All the firm-level variables, including ICT, Size, ER etc., are significantly correlated with the firm's economic performance variables (ROA and ROE).

Table 2 Descriptive statistics and correlation coefficients

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A. Summary statistics

	N	mean	sd	min	p25	p50	p75	max
ROA_{t+1}	23,768	3.377	5.406	-34.59	1.145	3.151	5.819	21.213
ROE_{t+1}	23,768	5.316	14.739	-246.763	2.41	6.331	10.948	37.759
ROA_{t+2}	20,888	3.235	6.839	-283.409	1.104	3.073	5.707	48.194
ROA_{t+3}	18,188	3.207	6.889	-283.409	1.072	2.996	5.646	48.194
ICT	23,768	0	1	-0.895	-0.587	-0.297	0.193	4.579
Size	23,768	21.833	1.205	19.383	20.959	21.666	22.503	26.101
ER	23,768	2.129	2.842	0.14	0.653	1.191	2.321	30.255
Growth	23,768	0.199	0.462	-0.673	-0.015	0.125	0.301	5.149
Firm Age	23,768	8.681	5.719	1	4	8	13	24
Turnover	23,768	0.646	0.463	0.046	0.34	0.532	0.807	3.058

Panel B. Correlation coefficients

	ROA_{t+1}	ROE_{t+1}	ROA_{t+2}	ROA_{t+3}	ICT	Size	ER	Growth	Firm Age
ROA_{t+1}	1								
ROE_{t+1}	0.834***	1							
ROA_{t+2}	0.512***	0.390***	1						
ROA_{t+3}	0.398***	0.295***	0.487***	1					
ICT	0.066***	0.061***	0.040***	0.036***	1				
Size	0.045***	0.116***	0.022***	0.009	0.094***	1			
ER	0.180***	0.044***	0.116***	0.104***	0.062***	-0.288***	1		
Growth	0.133***	0.127***	0.067***	0.058***	0.012*	0.054***	-0.055***	1	
Firm Age	-0.078***	-0.012*	-0.049***	-0.036***	0.090***	0.321***	-0.231***	-0.047***	1
Turnover	0.125***	0.128***	0.093***	0.083***	-0.014**	0.055***	-0.157***	0.072***	0.050***

4.2 Baseline results: ICTs' impact on firm profitability

We first test the impact of each ICT component, i.e., Internet, telephone, mobile phone and telecom, on firm performance, respectively, and present the results in Table 3. We include year fixed effects to account for intertemporal variations that are likely to affect the relation between ICTs and the economic performance of firms, and industry fixed effects to control for omitted industry sector characteristics that are constant over time. To tackle the possible heteroskedastic problems at the firm and city level, we adjusted the standard errors by clustering at firm and city level (Fang, Tian, & Tice, 2014; Petersen, 2009). We use the return on the assets (ROA) as the primary dependent variable, which is a widely used accounting-based financial measure of profitability (Zhao & Murrell, 2016). As shown in Table 3, the coefficients of Internet, Telephone, Mobile phone, and Telecom in model (1), (2), (3) and (4) are all statistically positive and significant, indicating that the increase of the adoption intensity of Internet, telephone, mobile phone and telecom are positively associated with the ROA of firms.

Table 3 The impact of different ICT components on firm performance

Notes: In this table, we test the impact of different ICT components on the firm's return on the assets in year t+1 (ROA_{t+1}), respectively. We include the year fixed effect and industry fixed effect in all the models. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)
VARIABLES	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}
Internet	0.0539***			
	(2.6462)			
Telephone		0.2304**		
		(2.1354)		
Mobile phone			0.0671***	
			(3.6653)	
Telecom				0.0471***
				(4.0725)
Size	0.4014***	0.4017***	0.4027***	0.3986***
	(6.1493)	(6.0636)	(6.1121)	(5.9446)
ER	0.3834***	0.3837***	0.3834***	0.3831***
	(13.6422)	(13.5944)	(13.7553)	(13.7056)
Growth	1.4752***	1.4714***	1.4701***	1.4725***
	(10.6309)	(10.5037)	(10.4974)	(10.5103)
Firm Age	-0.0902***	-0.0890***	-0.0885***	-0.0891***
	(-7.7089)	(-7.6912)	(-7.6766)	(-7.6535)
Turnover	1.9361***	1.9383***	1.9409***	1.9425***
	(10.0695)	(10.0082)	(10.0476)	(10.0551)
Observations	23,768	23,768	23,768	23,768
R-squared	0.1215	0.1216	0.1216	0.1215
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	67.23	72.14	66.15	65.10

Based on the results of each component of ICTs, this study employs the principal component analysis to combine Internet, telephone, mobile phone, and telecom together to construct a comprehensive measure for ICT infrastructure. In Panel A of Table 4, we first regress the independent variable ICT and the dependent variable ROA_{t+1} in model (1), and then include the controls in the model (2). The coefficient estimates of ICTs in model 1 and model 2 are both economically and statistically significant at the 1% level, which suggests that the increase of the adoption intensity of ICTs is positively associated with the ROA_{t+1} of firms.

In Panel B of Table 4, we use the variable of ROE_{t+1} (return on the equity in year t+1) to replace the ROA_{t+1}, to verify the impact of ICTs on firm profitability. As the coefficient of ICT remains positive and significant, we still find a positive association between ICTs and the return on the equity of firms.

In Panel C of Table 4, we test the ICT impact on firm performance with time-lag in different periods, as the economic impact of ICTs may have time delays. After testing the impact on firm performance with one or two more years of time lag, the coefficients of ICTs on ROA_{t+2} and ROA_{t+3} remain positive and significant at the 1% level, which indicates that the coefficients for the return on the assets in year t+2 and year t+3 are still significant, and thus ICTs have relatively long-term and lasting impact on firm performance. Moreover, to reduce the noise due to individual year variation, we also use the average of cumulative returns from t to t+2, and returns from t1 to t+3, as shown in the model (3) to model (6) in the Panel C of Table 4, which remain significant and positive, validating the robustness of the results.

To further address the concerns on the variation across cities, we introduce additional controls, including GDP growth of the cities, the average wage of employees of the cities, percentage of the service industry of the cities and population of the cities in the models. As shown in model (3) and model (4) in the Panel A of Table 4, after adding the additional controls at city level, the coefficients of ICTs are still significant and positive, indicating that our results are still consistent with what has been reported in model (1) and model (2). More specifically, one standard deviation increase in ICT could contribute to about 4.55% ROA increase relative to the average level (0.1535/3.377=4.55%), which is also economic significantly.

In addition, as a robustness check on the measure of the independent variable, we exclude telecom in the principal component analysis process and reconduct the regression by using an alternative compositional measure ICT''' using the Internet, Telephone, Mobile phone, as shown in Table A1 in the Appendix. The coefficients of ICT''' are positive and significant and the results are consistent, which also indicate the reliability and stability of the measure of the independent variable that we have used.

Table 4 Baseline results: ICTs and firm profitability

Notes: In Panel A, we show our baseline results on our key independent variable: ICT. The dependent variables of Panel A are ROA_{t+1}. In model (1), we only include ICT and ROA_{t+1}, and in the model (2), we include firm-level controls. In model (3) and model (4) of Panel A, we add more controls at the city level. In panel B, we use ROE_{t+1} as an alternative measure of ROA_{t+1} to verify the results. In Panel C, we use ROA_{t+2} and ROA_{t+3} to check the time lag effect of the variables in model (1) and model (2), and in model (3)-(6), we show the results of the time lags based on the impact of ICT on the average of cumulative returns from t to t+2, and returns from t1 to t+3. We include the year fixed effect and industry fixed effect in all the models. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Panel A. Baseline result

VARIABLES	(1) ROA_{t+1}	(2) ROA_{t+1}	(3) ROA_{t+1}	(4) ROA_{t+1}
ICT	0.2622***	0.1743***	0.1977**	0.1535**
	(3.85)	(4.28)	(2.30)	(2.38)
Firm-level controls				
Size		0.3997***		0.3720***
		(6.03)		(5.36)
ER		0.3823***		0.3740***
		(13.68)		(13.38)
Growth		1.4723***		1.4125***
		(10.57)		(10.22)
Firm Age		-0.0894***		-0.0877***
		(-7.6383)		(-7.1587)
Turnover		1.9376***		1.8218***
		(10.02)		(9.34)
City-level controls				
Wage			0.8547***	0.6442***
			(2.9968)	(2.9612)
GDP growth			0.0113	0.0082
			-0.8095	-0.5877
Service			(0.01)	(0.01)
			(-0.9358)	(-1.6474)
Population			0.1769	0.1776
			(0.99)	(1.27)
Observations	23,768	23,768	22,667	22,667
R-squared	0.0438	0.1217	0.0449	0.1192
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	14.84	65.37	7.012	40.22

Panel B. Alternative measure for performance (ROE)

VARIABLES	(1) ROE_{t+1}	(2) ROE_{t+1}
ICT	0.4604***	0.3193***
	(3.38)	(4.12)
Observations	23,768	23,768
R-squared	0.0334	0.0819
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	11.41	56.97

Panel C. Different time lag for ROA

VARIABLES	(1) ROA_{t+2}	(2) ROA_{t+3}	(3) $ROA_{(t0,1,2)}$	(4) $ROA_{(t0,1,2)}$	(5) $ROA_{(t1,2,3)}$	(6) $ROA_{(t1,2,3)}$
ICT	0.1502***	0.1484**	0.2446***	0.1525***	0.2545***	0.1691***
	(2.73)	(2.26)	(3.4114)	(3.5394)	(2.9930)	(2.9684)
Observations	20,888	18188	23,768	23,768	23,768	23,768
R-squared	0.0564	0.0454	0.0384	0.1295	0.0374	0.1041
Control	Yes	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
F	42.81	32.45	11.64	67.51	8.958	58.35

4.3 ICT's impact on marketing and innovation performance

We then examine whether positive evidence could still exist by using alternative measures of firm performance, including marketing-based firm performance and innovation-based firm performance. In Panel A of Table 5, we replace the key accounting-based profitability measures (ROA) by using marketing-based measures (MTB and Tobin Q) to examine ICTs' economic impact on the firm's marketing performance. As shown in the results, the coefficients of MTB in the model (1) and (2), and the coefficients of Tobin Q in the model (3) and (4) are all positive and significant at the 1% level, indicating that ICTs are positively associated with firm's marketing performance. Moreover, we also test the innovation-based firm performance by using Patent and Invention to replace the dependent variable. In Panel B of Table 5, the results show that ICTs are significantly and positively associated with firm's innovation performance.

Table 5 ICTs and firm's marketing and innovation performance

Notes: In this table, MTB, Tobin Q are measures for marketing-based performance, and Patent and Innovation are measures for innovation-based performance. MTB denotes the ratio of market to book, measured by the market value to book value. Tobin Q denotes the market value of a firm divided by the value of its assets. Patent denotes the number of the total patents of the firm. Invention denotes the number of invention patents of the firm. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel A. Market based performance measure

	(1)	(2)	(3)	(4)
VARIABLES	MTB_{t+1}	MTB_{t+1}	Tobin Q_{t+1}	Tobin Q_{t+1}
ICT	0.0951***	0.0816***	0.0952***	0.0816***
	(6.0491)	(5.2352)	(6.0492)	(5.2353)
Observations	23,243	23,243	23,243	23,243
R-squared	0.1669	0.3219	0.1669	0.3219
Controls	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	36.59	280.1	36.59	280.1

Panel B. Innovation based performance measure

	(1)	(2)	(3)	(4)
	Model 1	Model 2	Model 3	Model 4
VARIABLES	$Patent_{t+1}$	$Patent_{t+1}$	$Invention_{t+1}$	$Invention_{t+1}$
ICT	16.0031***	14.7217***	12.3209***	11.6165***
	(4.7531)	(6.1181)	(6.5286)	(7.0148)
Observations	20,491	20,491	20,491	20,491
R-squared	0.0397	0.1055	0.0238	0.0624
Controls	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	22.59	16.89	42.62	17.91

4.4 Firm-level ICT expenditure and firm profitability

We further validate our results by looking more closely at the firm's usage of ICTs and firm productivity. As we mainly focus on the examination of the ICTs at the city level, this study may not directly reflect firms' reliance on ICTs. To alleviate this concern, we collect firm-level ICT data based on the ICT expenditure from the foot-notes of expense in the financial statements and capture the expenditure related to ICTs, including telephone fare, internet fare, telecommunication fare etc. Specifically, as there is no single indicator on ICT expenditure, to measure ICT expenditure, we collect the ICT operating related expenditures by adding up 42 items of related expenditures in the categories of administrative expenses and sale expenses. We then use the logarithm of firm's ICT expenditure in the model (1) and (2), and the ratio of firm's ICT expenditure on total assets in the model (3) and (4) as the measurement for ICTs, and present the results in Table 6. All the coefficients of *Log Firm's ICT Expenditure* and all the coefficients of *Ratio of Firm's ICT Expenditure* are positive and significant, illustrating firm's ICTs expenditure is positively correlated with firm profitability.

Table 6 Results on firm-level ICT on firm performance

Notes: In this table, Log Firm's ICT Expenditure is an independent variable measuring firm-level expenditure on the ICTs, in the model (1) and (2). As a robustness check, the Ratio of Firm's ICT Expenditure is used to check the reliability of the results in other models. We include the year fixed effect and industry fixed effect in model (1)-(4). To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

	(1)	(2)	(3)	(4)
	model1	model2	model3	model4
VARIABLES	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}
Log Firm's ICT Expenditure	0.5846***	0.7569***		
	(9.6747)	(12.4223)		
Ratio of Firm's ICT Expenditure			54.6832***	50.1467***
			(13.4182)	(13.2637)
Observations	13,166	13,166	13,171	13,171
R-squared	0.0758	0.1468	0.0917	0.1494
Controls	No	YES	No	YES
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	93.60	41.16	180.0	52.99

4.5 Robustness checks

After having obtained the baseline results, we further conduct several robustness checks, including (1) addressing possible measurement issue of geographical locations and (2) possible concerns on listed firms that have many subsidiaries, (3) using quantile regression and (4) propensity score matching to assess whether impact differs.

(1) Measurement of firm geographical locations

One concern on the measurement of the location of firms is that the place where a firm operates may be different from the place where it registers or where its headquarter is located. For example, firms may move to other places, or a firm's main service may be mainly in their office address rather than its registered address. Therefore, if a firm's location is not well captured, the ICT infrastructure adoption intensity that we match through the firm's geographical location from the ICT dataset may be inaccurate. To alleviate the possible concern, as the geographical location we use in the previous tests is firm's registration address, we collect data on firm's office address to replace their registration address to reconduct the analysis. In Panel A of Table 7, the coefficients of ICTs are still positive and significant in both model (1) and (2), which implies that our results remain robust and consistent after checking the possible measurement issue of geographical locations of firms.

(2) Impact of listed firms' subsidiaries

A listed firm might have several subsidiaries in different regions, but our study only captures its ICT information in the registered address or office address. To address this concern, we calculate the firm's sales concentration, measured by Herfindahl index (HHI) in different regions. When the value of HHI is higher, it denotes the services and activities of the listed firm are more concentrated in its headquarter. We separately run the regression in the sample of firms with an HHI over 90%, 80%, 70% and 60%. In Panel B of Table 7, the coefficients of ICT in the model (1)-(4) are all positive and significant, showing that our finding is still valid after tackling the subsidiaries problems.

(3) Quantile regression

In Panel C of Table 7, we employ quantile regressions to replace the ordinary least squares regressions to assess whether impacts differ. According to the results in the model (1), model (2), and model (3), all the coefficients of Q1/4, Q1/2, and

Q3/4 are positive and significant, which are in line with the baseline results. Thus, the checks using quantile regression confirm the positive and significant effect of ICTs on the economic performance of firms, indicating our results are robust to different regression methods for estimating the economic impact of ICTs.

(4) Propensity score matching

Parameter analysis might suffer from the impact of outliers. To alleviate this concern, we further employ non-parameter analysis, propensity score matching, to conduct a robust check. This method allows us to identify a control sample of firms in cities with lower ICT intensity exhibiting no observable differences in characteristics relative to firms in cities with higher ICT intensity. Specifically, the sample is segmented into three terciles. We choose the bottom tercile (lowest 1/3) as the control group and the top tercile (highest 1/3) as the treated group. The matching variables are the same control variables as in the previous baseline model. Finally, we apply a propensity score matching algorithm and nearest neighbour 1:1, 1:2, 1:3 and 1:4 matching to identify matches between firms in the top tercile and the bottom tercile. According to the results in Panel D of Table 7, the average differences between treatment and control groups before propensity score matching are positive and significant. After the propensity score matching, the value of Diff decreases, and tests remain positive and statistically significant. These results demonstrate that firms with higher ICT infrastructure usage intensity would generate higher productivity, validating the robustness of our previous findings.

Table 7 Robustness checks

Notes: In Panel A, we replace the registration address using the office address. In Panel B, we address the interference impact of the firm's subsidiaries. In Panel C, we use the quantile regression to check the robustness of the results. In Panel D, we use the propensity score matching. For the matching, we use the same control variables as what has been used as in the baseline model. We include the year fixed effect and industry fixed effect in all the models. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics (for panel A, B and D) and z-statistics (for Panel C) are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel A. Replace the registration address using the office address

	(1)	(2)
VARIABLES	ROA $_{t+1}$	ROA $_{t+1}$
ICT	0.2574***	0.1678***
	(3.3793)	(3.4420)
Observations	23,811	23,811
R-squared	0.0437	0.1210
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	11.42	65.40

Panel B. Addressing the concerns on firms' subsidiaries

	(1)	(2)	(3)	(4)
	HHI>90%	HHI>80%	HHI>70%	HHI>60%
VARIABLES	ROA $_{t+1}$	ROA $_{t+1}$	ROA $_{t+1}$	ROA $_{t+1}$
ICT	0.179***	0.167***	0.171***	0.173***
	(4.646)	(4.400)	(4.507)	(4.284)
Observations	13,655	14,798	16,037	17,373
Adjusted R-squared	0.128	0.127	0.124	0.122
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	82.00	77.52	76.65	71.29

Panel C. Quantile regression

	(1)	(2)	(3)
	Q1/4	Q1/2	Q3/4
VARIABLES	ROA $_{t+1}$	ROA $_{t+1}$	ROA $_{t+1}$
ICT	0.1406***	0.1226***	0.1178*
	(3.4423)	(3.0062)	(1.8738)
Observations	23,768	23,768	23,768
R-squared	0.1661	0.1708	0.1660
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

Panel D. Propensity score matching

Sample		High (treated)	Low (controlled)	Diff	Std. Err	T-statistic
Unmatched		3.7267	3.0279	0.6988	0.0700	9.98***
Matched	1:1	3.7171	3.4378	0.2793	0.1102	2.53***
	1:2	3.7171	3.5048	0.2123	0.1010	2.1**
	1:3	3.7171	3.5365	0.1806	0.0974	1.85*
	1:4	3.7171	3.5370	0.1801	0.0963	1.87*

4.6 Instrument variables

In this section, we employ an instrumental variable (IV) estimation approach to address the potential endogeneity concerns. We use three instruments in our study to verify the results and establish the linkage between ICTs and firm profitability.

Similar to the methods of Hausman (1996), Nevo (2000) and Cheng, Ioannou, and Serafeim (2014) that exploit the panel structure of the data, we use city and industry level ICT infrastructure intensity data to construct our first instrument, and use firm-level ICT expenditure data to construct the second and third instruments.

For the first instrument, city's ICT usage intensity is instrumented with the average of ICT usage intensity at the city level for the same province and the same sector in the same year excluding the current city's infrastructure usage intensity (ICTs/VA-j). The IVs employed here meets two main requirements: (1) There is a strong correlation between a city's ICT usage intensity and different adjacent cities within one province; (2) while it does not correlate with error terms and does not directly determine firm activity or productivity. Panel A of Table 8 reports results from two-stage panel regressions to estimate the causal relationship between ICTs and firm performance. In all four specifications, the signs and significance of the *Predicted ICT of Average* coefficients remain positive and significant, which confirm that ICTs leads to an increase in firm's economic performance.

We construct two more instruments using firm-level ICT expenditure. We follow Cheng et al. (2014) to use the sector average ICT and city average ICT for each city-industry pair and city-year pair as the instrumental variables. The underlying reason of using these two instruments is that the firm's ICT usage is affected by a time-invariant component that is correlated with its membership in the city-industry pair and a time-varying component at the city level. It could be intuitive that a focal firm's ICT usage could be systematically affected and associated with the ICT usage of other firms within the same industry-city pair and by the ICT usage of other firms within the same city over time. There is also literature that has demonstrated that ICT usage is affected by city and industry characteristics (Forman & van Zeebroeck, 2019; Gaspar & Glaeser, 1998). Moreover, ICT usage intensity might systematically vary over time within cities as a result of policies and regulations that mandate a city's ICT infrastructure deployment and firm's ICT expenditure (Graham, 1997). These two instruments also vary across firms even within the same city-industry and city-year pairs. Based on the rationale, we then use these two instruments to conduct more tests to evaluate their validity and relevance. In the Panel B of Table 8, the *Predicted ICT of Firm Level Average* also presents positively significant coefficients, verifying the robustness.

Table 8 Two-stages of panel IV regression

Notes: In Panel A, *IV of Average* is the provincial and sector average ICT measured by using city-level ICT data. The instrument is calculated by excluding the contribution of the focal city. In Panel B, *IV of Sector Average* is the industry level average ICT measured by using firm-level ICT expenditure, and *IV of City Average* is the city average ICT measured by using firm-level ICT expenditure. We include the year fixed effect and industry fixed effect in the models. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm level and city level and are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Panel A. Instrumental variable regression using city-level ICT average

VARIABLES	(1) First stage ICT	(2) Second stage ROA_{t+1}	(3) First stage ICT	(4) Second stage ROA_{t+1}
IV of Average (provincial and sector average ICT based on city level ICT intensity)	0.9384***		0.9382***	
	(3.5670)		(3.5591)	
Predicted ICT of Average		0.3928**		0.2687**
		(2.2736)		(2.2591)
Observations	21,944	21,944	21,944	21,944
R-squared	0.6418	0.0400	0.6423	0.1157
Control	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	12.72	5.169	12.71	68.95

Panel B. Instrument variable regression using firm-level ICT average

VARIABLES	(1) First stage ICT	(2) Second stage ROA_{t+1}	(3) First stage ICT	(4) Second stage ROA_{t+1}
IV of Sector Average	0.5904***		0.2842***	
(the sector average ICT	(10.1536)		(4.7183)	
based on firm-level expenditure)				
IV of City Average	0.9330***		0.7482***	
(the city average ICT	(67.4962)		(25.3923)	
based on firm-level expenditure)				
Predicted ICT of Firm-Level Average		1.0296***		1.2083***
		(6.9753)		(7.1600)
Observations	13,166	13,166	13,166	13,166
R-squared	0.2157	0.0155	0.4588	0.0957
Control	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	2339	48.66	412.6	42.01

4.7 Exogenous variation of ICT as a natural experiment

Although we have carried out many tests to address the endogenous problems, the endogenous concern may still exist. In this section, we further use an upgrade of the telecommunication system as a natural experiment. We provide an introduction on the exogenous variation of the city's ICT infrastructure regarding China's telecommunication upgrade as follows.

Before 1995, subscribers' telephone numbers in China were seven digits. Since then, a plan of an upgrade from seven-digit to the eight-digit numbering was started, by adding a digit to the front of existing fixed-line telephone numbers, which could ensure that there would be sufficient number resource pool to cater to the expanded telecommunication services, and also update the telecommunication system. However, this upgrade in telecommunication is not an easy task, which may require several years of preparation work before its implementation. It is a significant plan for the telecommunication system, which requires a tremendous amount of investment, including resources and labour in ICTs, and needs to ensure minimum service disruption and inconvenience to customers. Therefore, not all the cities have a strong determination on implementing this plan of upgrading the ICTs system after 1995. We thus manually collect all the information about the implementation of this plan and manually check the year of implementing this system upgrade in each city that implemented. After collecting all the data, we find that 122 cities among the total of 403 cities, approximately 30.23% of cities, have implemented this telecommunication upgrade, during the year 1995 to 2018, which is demonstrated in Figure 5.

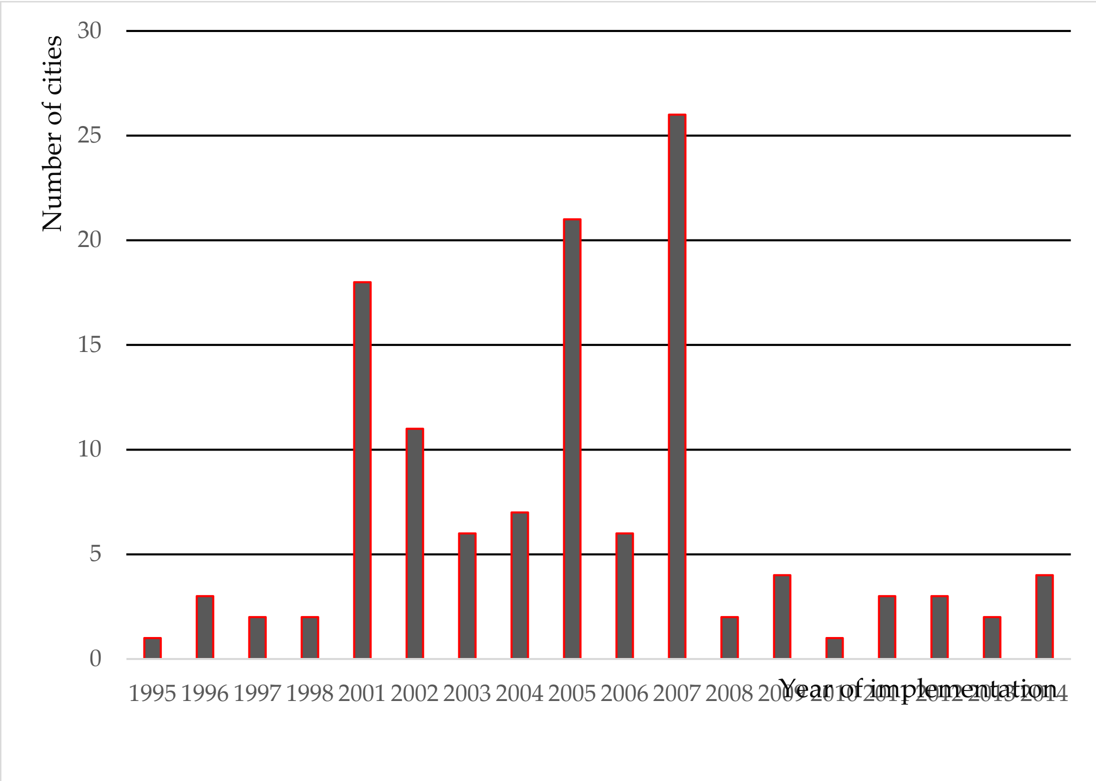

Figure 5 The implementation of telecommunication upgrade

This plan has been made in different cities in different years, but this system upgrade materially promotes ICTs development. To construct an instrument, we set that $Upgrade_{i,t}$ equals one if a city i has upgraded to eight-digit phone number system in year t, and zero otherwise. The rationale is that this measure of city's telecommunication upgrade is highly related to the explanatory variable, city's ICT infrastructure intensity, while this upgrade is unlikely to be affected by the firms and firms' characteristics. Thus, this upgrade is supposed to be an exogenous event and helps us to generate an exogenous variation of ICT.

We utilise this exogenous ICT Upgrade event as a natural experiment to carry out a staggered difference in difference (DiD) regression. The DiD setting is shown in equation 1. Different cities experience upgrade in different years and this strategy is different with the standard DiD analysis that the shock happens in a year. Nevertheless, we include the year fixed effect and firm fixed effect so that this strategy is similar to the standard DiD regression (Bertrand, Duflo, & Mullainathan, 2004; Bertrand & Mullainathan, 2003; Roberts & Whited, 2013). $Upgrade_{i,t}$ equals one if a city has upgraded its ICT system and is similar to the term Treat x Post in the standard DiD setting. A positive and significant coefficient β would represent that firms with ICT upgrade have a higher ROA than firms without ICT upgrade.

$$ROA_{i,t+1} = \alpha + \beta ICT\ Upgrade_{i,t} + \gamma Control_{i,t} + \delta_t + \theta_i + \varepsilon \qquad (1)$$

In Table 9, the coefficients of Upgrade in the model (1) and (2) are positive and significant, implying that ICT upgrade promotes the firm's earnings performance. This result is consistent with previous results and helps to establish the causal impact of the city's ICT infrastructure improvement on firm profitability.

Table 9 Difference-in-difference approach: Addressing the endogeneity concern

Notes: $Upgrade_{i,t}$ equals one if a city i has upgraded to eight-digit phone number system in year t. We include the year fixed effect and firm fixed effect in the models. *** p<0.01, ** p<0.05, * p<0.1

Panel A. Staggered difference in difference regression

	(1)	(2)
VARIABLES	ROA_{t+1}	ROA_{t+1}
Upgrade	0.3078*	0.3635**
	(1.7485)	(2.1256)
Observations	17,419	17,419
R-squared	0.4365	0.4637
Control	No	Yes
Year FE	Yes	Yes
Firm FE	Yes	Yes
F	3.057	87.87

5 POSSIBLE MECHANISMS

Our analysis so far shows a positive effect of city's ICT infrastructure on firm's profitability. The next natural question is what are the economic mechanisms that allow ICTs to spur firm profitability. This section examines three possible underlying mechanisms through which ICTs increase the profitability of firms, including (1) better labour, (2) higher efficiency, and (3) lower cost. Given the challenging fact of providing definitive proof of the mechanisms, our tests are only suggestive.

5.1 ICTs and labour

We first analyse how the effect of city's ICTs on firm's profitability may change by altering the labour of firms. Research on the impact of labour on firm performance, and also the impact of ICTs on labour has been investigated (Bertrand, Black, Jensen, & Lleras-Muney, 2019; Hambrick, Cho, & Chen, 1996). When a city improves its ICTs infrastructure, it may help to attract better workers, such as better skill and better education background, to work in this city and to work in the firms in this city. For firms with different levels of labour, they have various preferences, purposes and levels of capacity in employing ICTs in their operations and administrations, while the workers with a higher level of labour may tend to employ the ICTs more. Firms might have better performance if their employees attended more selective universities as they are more likely to have higher intelligent capabilities and advanced technical competences than those did not (Gottesman & Morey, 2010). ICTs could also affect the labour outcomes and productivity of different types of workers. For instance, Akerman, Gaarder, and Mogstad (2015) argued that the adoption of broadband Internet in firms complements skilled workers in performing nonroutine abstract tasks, but substitutes for unskilled workers in executing routine tasks. In this study, we anticipate that the change of labour could be a channel through which the city's ICTs spurs firm productivity.

We identify the change of the level of labour based on three indicators, including the skill level of labour, the education level of labour, and the intensity of labour. We introduce the interaction terms on these three indicators and conduct the tests respectively. In the results shown in Panel A of Table 10, the interaction term *High Skill Level of Labour x ICT* is positively and significantly correlated with ROA_{t+1}, while the coefficient of *Low Skill Level of Labour × ICT* is insignificant, which indicate that as the labour skill level of employees increases, the impact of the improvement of city's ICTs on ROA becomes more substantial. These results suggest that ICTs' promoting effect on firm profitability is stronger in firms with higher-skilled employees. In Panel B of Table 10, when we conduct a similar test on the education level of employees, we also find that ICTs' promoting effect on firm profitability is stronger in the firms with employees from a higher education background. After running the test in Panel C on the intensity of labour, we find that the improvement on the city's ICT infrastructure spurs non-labour-intensive firms more. These results may help us to understand that when a city improves its ICT infrastructure, it could help firms to attract a higher level of workers, including higher-skilled labour, better-educated labour, and also help firms that are non-labour intensive more. The changes in labour exerted by the improvement of the city's ICTs infrastructure may be critical for firms to ameliorate economic performance and increase profitability.

Table 10 Possible Mechanism: Labour

Notes: In Panel A, the skill level of employees is measured as the ratio of total labour expense to total employees. In Panel B, the education level of employees is a measure of the educational background of the firm's employees, using the ratio of directors with a bachelor's degree in director board as a proxy. In Panel C, the intensity level of labour is a measure of labour intensity using the number of total employees of the firm as a proxy. We set the variable $Skill\ Levle\ of\ Labour_{i,t}$ equals the original value for the group that the value is lower (higher) than the median and zero otherwise. The variable $Low\ Skill\ Levle\ of\ Labour_{i,t}$ ($High\ Skill\ Levle\ of\ Labour_{i,t}$) divides the group into two sub-groups, depending on whether the introduced variable $Skill\ Levle\ of\ Labour_{i,t}$ is above (below) the group's corresponding median. We use this method in the other mechanism tests. We include the year fixed effect and industry fixed effect in all the models. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel A. Impact of the skill level of labour		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Skill Level of Labour × ICT	0.003	-0.018
	(0.035)	(-0.243)
High Skill Level of Labour × ICT	0.405***	0.284***
	(3.392)	(3.617)
Low Skill Level of Labour	1.027***	0.792***
	(8.156)	(7.208)
Observations	23,720	23,720
Adjusted R-squared	0.053	0.126
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	43.60	79.85
Panel B. Impact of the education level of employee		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Level of Education × ICT	0.219**	0.139**
	(2.379)	(2.188)
High Level of Education × ICT	0.334***	0.228***
	(5.487)	(4.813)
Low Level of Education	-0.017	0.030
	(-0.135)	(0.265)
Observations	22,583	22,583
Adjusted R-squared	0.042	0.122
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	10.71	61.05
Panel C. Impact of the labour intensity		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Level of Labour Intensity × ICT	0.295***	0.198***
	(5.080)	(4.321)
High Level of Labour Intensity × ICT	0.225**	0.150**
	(2.176)	(2.096)
Low Level of Labour Intensity	0.361***	0.372***
	(3.126)	(2.647)
Observations	23,724	23,724
Adjusted R-squared	0.043	0.121
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	24.95	60.15

5.2 ICTs and efficiency

When a city improves its ICTs infrastructure, firms could get benefits from the advanced ICTs infrastructure and better use ICTs as a tool in firm management and operation, which may have a considerable impact on firm's efficiency. Mishra, Modi, and Animesh (2013) argued that the usage of ICTs could provide better information flows for firms, and the improvement of the ICTs capability played an essential role in enabling inventory efficiency. Becchetti, andres londono Bedoya, and Paganetto (2003) argued that the increased investment in software and telecommunication, and the introduction of information technology, like the introduction of e-mail, e-commerce, could facilitate the information flows and thereby could generate the opportunity for firms to make quicker decisions, accelerate business processes and facilitate customer services, which would affect firm's productive efficiency.

For cities with a lower level of ICTs infrastructure, firms may not have adequate opportunities to apply advanced information technologies, which may not help them to create a flexible operation and service systems, making them slothful to make a change and may lead to lower efficiency. For a city with better ICT infrastructure, the firms located in this city would have more opportunities to use diverse and advanced information communication technologies, making firms more efficient, which contributes to firm profitability. We anticipate that the engagement of the city's ICTs would have a more substantial influence on firms with higher efficiency in reducing the deficiencies and boosting their profitability.

We examine whether the effect of city's ICT improvement interacts with the efficiency of firms, which contributes to firm's profitability. We employ the rate of turnover as a proxy to denote firm operation efficiency. We follow a framework applied by the Bekaert, Harvey, and Lundblad (2005), Moshirian, Tian, Zhang, and Zhang (2018), and Amodio and Martinez-Carrasco (2018) to accommodate our mechanism variables and present our results. As shown in Table 11, after conducting an interaction test in exploring its mechanism, we find that the interaction term *High Efficiency* × *ICT* is positive and significant, which has a higher coefficient than *Low Efficiency* × *ICT*, meaning that in higher efficient firms, the increase of ICTs tends to enhance firms' profitability more significantly and positively, compared with the effects on lower efficient firms. This result is consistent with our conjecture that the improvement of efficiency appears to be one underlying mechanism through which city's ICTs enhance firms' profitability.

Table 11 Possible Mechanism: Efficiency

Notes: Firm efficiency is measured by the asset turnover ratio, which is calculated by dividing the total revenue by total assets. This is a proxy of a firm's efficiency with which a firm uses its assets to produce sales. We include the year fixed effect and industry fixed effect in the models. To save space, we suppress the coefficient estimates of all controls in the tables reported.

Impact of firm efficiency		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Efficiency × ICT	0.088**	0.092**
	(2.021)	(2.251)
High Efficiency × ICT	0.401***	0.236***
	(3.597)	(3.731)
Low Efficiency	1.448***	1.077***
	(11.956)	(7.196)
Observations	23,768	23,768
Adjusted R-squared	0.061	0.126
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	73.83	87.49

5.3 ICTs and cost

Bris, Pawlak, and Polak (2017) have found a negative association between ICT usage and transport expense. They argued that Internet penetration reduced household expenditure on transport. With the increased access and usage of ICT, workers could employ ICT to conduct some activities online remotely, and avoid the expense of travelling. Danzon and Furukawa found that that ICTs offered the potential for cost reduction and improved productivity in health care, which included savings in administrative cost, and costs due to improper care. They argued that although moving health-insurance and care processing and service to the ICTs-based process would require tremendous efforts, but savings could be large. Osorio and Fountain (2001) argued that the application of ICTs could significantly cut the costs at all levels of government. For example, when the government could provide online platforms for citizens, like filing tax returns or applications for permits and licenses online rather than posting, it would cut costs both to the government and to citizens. Morrison (1997) found empirical evidence that the increasing stock of ICT equipment could increase demand for capital and noncapital inputs, and saved the costs on materials inputs in manufacturing industries. Based on the prior studies, we anticipate that the reduction of cost of firms could be an underlying economic mechanism through which city's ICTs spur firm profitability.

In Panel A in Table 12, when we interact ICT with firm's cost, we obtain the positive and significant coefficients on the interaction term between ICT and Low Administrative Cost. In the empirical results in both model (1) and model (2) of, the coefficient of *Low Administrative Cost* × *ICT* is higher than the coefficient of *High Administrative Cost* × *ICT*, which indicates that the impact of ICT on firm profitability is more substantial from the firms with a lower administrative cost. We also find similar results when we run the robustness test on financial cost of firms, as shown in Panel B. Therefore, the results show that in firms with lower administrative cost, the benefit of ICTs on ROA is more substantial, which indicates that the impact of city's ICTs on firm profitability can stem from changes of firm costs.

Table 12 Possible Mechanism: Cost

Notes: In Panel A, the administrative cost is the ratio of total administration expense to total revenues. In Panel B, the financial cost is the ratio of total financial expense to total revenues. We include the year fixed effect and industry fixed effect in all the models. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel A. Impact of management expense		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Administrative Cost × ICT	0.326***	0.192***
	(2.908)	(2.607)
High Administrative Cost × ICT	0.196***	0.116**
	(3.732)	(1.976)
Low Administrative Cost	-0.329***	0.452***
	(-3.102)	(4.076)
Observations	23,761	23,761
Adjusted R-squared	0.043	0.121
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	12.94	56.74
Panel B. Impact of financial expense		
	(1)	(2)
	ROA_{t+1}	ROA_{t+1}
Low Financial Cost × ICT	0.350***	0.319***
	(3.076)	(3.606)
High Financial Cost × ICT	-0.005	-0.031
	(-0.093)	(-0.505)
Low Financial Cost	-2.731***	-1.968***
	(-23.066)	(-16.176)
Observations	23,768	23,768
Adjusted R-squared	0.107	0.146
Control	No	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
F	213.7	112.3

6 EXTENSIONS: FIRM'S HETEROGENEITY

We extend our work by examining the impact of ICTs of a city on firm profitability based on the heterogeneity of firms. First, due to data limitation, the sample of our work only includes listed firms, while there is a concern that the economic impact of ICTs may be different in middle and small-sized enterprises. As indicators on listed firms and non-listed small firms are indeed various, it is not reasonable for us to test the impact in listed and non-listed firms simultaneously, while as an alternative we conduct a test to check the impact of the size of firms. We test the moderating effect of the size of firms. We introduce an interaction term Small Firm Size × ICT, as shown in Table 13. The coefficient of the interaction term Small Firm Size × ICT is positive and significant, demonstrating that the impact of ICTs on relatively smaller firms remains strong. As the coefficient of Small Firm Size × ICT is smaller than the coefficient of Large Firm Size × ICT, our result shows that the positive effect of ICTs on ROA is indeed more substantial in larger firms. This evidence may help us to generalise our findings in smaller firms, although we still could not fully resolve the problem before we could have a new test on the non-listed firms. In addition, we also explore firm's other different characteristics that may alter the impact of ICTs on firm profitability. As shown in the model (5) and model (6), we find that the economic impact of ICTs is more substantial on firms that have more social connections. This evidence may suggest that for the firms that require more social connections and communications with the external environment, the role of the city's ICTs infrastructure seems to be more critical. Lastly, as Hassan Che Haat, Abdul Rahman, and Mahenthiran (2008) and Sharif and Lai (2015) suggested that the transparency was also an important factor that impacted firm's performance, we further test this impact. We find that the firm's transparency moderates the economic impact of ICTs on firms. This is could also reinforce our intuitive sense that ICTs play a role in firms' information acquisition and disclosure. Overall, the additional evidence presented in this section suggests the improvement of city's ICT infrastructure may facilitate firm's profitability differently when the firm has different features: the increase of the firm sizes, the increase of social connections and the increase of information transparency of firms.

Table 13 Additional tests

Notes: In this table, Size is measured by using the natural logarithm of total assets; Social Connections are measured by using the total number of connections that the part-time directors have in other firms; Transparency is measured by using the total number of analysts following the firm. We include the year fixed effect and industry fixed effect in all the models. To save space, we suppress the coefficient estimates of all controls in the tables reported. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Impact of the size, social connections, and transparency of firms						
	(1)	(2)	(3)	(4)	(5)	(6)
	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}	ROA_{t+1}
Small Firm Size × ICT	0.214***	0.139**				
	(3.58)	(2.57)				
Large Firm Size × ICT	0.307***	0.212***				
	(2.82)	(3.047)				
Small Firm Size	0.380***	0.485**				
	(3.40)	(2.36)				
Low Social Connections × ICT			0.185***	0.127***		
			(3.70)	(2.83)		
High Social Connections × ICT			0.329***	0.209***		
			(3.11)	(3.11)		
Low Social Connections			0.478***	0.477***		
			(4.39)	(4.94)		
Low Transparency × ICT					0.134***	0.077*
					(3.02)	(1.97)
High Transparency × ICT					0.339***	0.245***
					(4.02)	(3.09)
Low Transparency					2.753***	2.493***
					(27.01)	(21.70)
Observations	23,766	23,766	23,768	23,768	23,768	23,768
Adjusted R-squared	0.044	0.122	0.043	0.121	0.096	0.157
Control	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
F	17.37	62.68	17.63	68.02	475.9	206.5

7 CONCLUDING REMARKS

Given that many cities have realised the potential of the informatisation and digitalisation and the crucial role of ICTs in economic growth, they have followed favourable ICT policies to escalate economic growth, while the economic effects of ICTs remain unclear, especially in developing countries. To address this puzzle, we provide new empirical evidence on the relationship between city's ICT infrastructure and economic growth based on firm-level evidence. Overall, our findings support the hypothesis that ICTs positively and significantly contribute to firm performance in the context of China. Based on a natural experiment design on ICT infrastructure upgrade, we further establish the causal impact of city's ICT on firm profitability.

There may be complicated mechanisms through which ICTs impact firm performance. We identify three testable mechanisms and examine them in a variety of empirical analyses. We find that the improvement of ICTs more substantially enhances the profitability of firms that have higher efficiency, and more substantially helps firms with workers of a higher level of labour. The improvement of ICTs more substantially compensates firms with lower cost. Besides, our additional tests show that the improvement of ICTs more substantially facilitates larger firms, firms with more social connections and firms with higher transparency.

Our findings provide policy implications when viewed alongside previous work on how ICTs infrastructure investment contributes to growth and productivity. The mixed evidence on this question in the literature may suggest that countries need to be cautious and even cut ICT investment because massive investment in ICTs may generate little economic return. Our study does not examine the investment of ICT from a monetary term; however, as what we measure is the adoption intensity of city's ICT infrastructure, our evidence does imply that the improvement on city's ICT infrastructure deployment brings positive economic benefits for firms, based on evidence in the context of China. Our evidence shows that the increased deployment of ICT infrastructure could pay off, which could be achieved with the increased level of labour, the increased efficiency, and reduced cost for firms. This implication may serve as a reference in policy decision making for those countries that lack ICT infrastructure and are still concerned about its economic returns. Nevertheless, there is also a limitation to generalise the results, as the contexts of different firms in different regions and countries in different developing stages may vary.

APPENDIX IN CHAPTER 4

Table A1 The impact of the alternative independent variable (ICT''') on firm performance

Notes: As our key independent variable ICT is a composite measure after combining multiple factors, we run a robustness test on verifying this measure. For the ICT''', we do not include the factor of telecom, as what we have used to composite the ICT; we employ the principal component analysis to combine the other three information technology components only, including internet, telephone, mobile phone, together to generate this measure. In the table, the coefficients of ICT''' are all positive and significant in model (1), (2), (3) and (4), which indicates that ICT''' positively spurs firm profitability. To save space, we suppress the coefficient estimates of all controls in the tables reported. We include the year fixed effect and the industry fixed effect. T-statistics are corrected by clustering at the firm and city level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
VARIABLES	ROA_{t+1}	ROA_{t+1}	ROE_{t+1}	ROE_{t+1}
ICT'''	0.0792***	0.0536***	0.1423***	0.1025***
	(4.2771)	(4.7287)	(3.6348)	(3.7572)
Observations	23,768	23,768	23,768	23,768
R-squared	0.0437	0.1217	0.0334	0.0819
Controls	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
F	18.29	19.00	13.21	18.34

REFERENCES

Akerman, Anders, Gaarder, Ingvil, & Mogstad, Magne. (2015). The skill complementarity of broadband internet. *The Quarterly Journal of Economics, 130*(4), 1781-1824.

Allen, B. (1990). INFORMATION AS AN ECONOMIC COMMODITY. *American Economic Review, 80*(2), 268-273.

Amodio, Francesco, & Martinez-Carrasco, Miguel A. (2018). Input allocation, workforce management and productivity spillovers: Evidence from personnel data. *The Review of Economic Studies, 85*(4), 1937-1970.

Baily, Martin Neil, & Gordon, Robert. (1988). The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power. *Brookings Papers on Economic Activity, 19*(2), 347-432.

Becchetti, Leonardo, andres londono Bedoya, David, & Paganetto, Luigi. (2003). ICT investment, productivity and efficiency: evidence at firm level using a stochastic frontier approach. *Journal of Productivity Analysis, 20*(2), 143-167.

Bekaert, Geert, Harvey, Campbell R, & Lundblad, Christian. (2005). Does financial liberalization spur growth? *Journal of Financial Economics, 77*(1), 3-55.

Bertrand, Marianne, Black, Sandra E, Jensen, Sissel, & Lleras-Muney, Adriana. (2019). Breaking the glass ceiling? The effect of board quotas on female labour market outcomes in Norway. *The Review of Economic Studies, 86*(1), 191-239.

Bertrand, Marianne, Duflo, Esther, & Mullainathan, Sendhil. (2004). How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics, 119*(1), 249-275.

Bertrand, Marianne, & Mullainathan, Sendhil. (2003). Enjoying the quiet life? Corporate governance and managerial preferences. *Journal of Political Economy, 111*(5), 1043-1075.

Bertschek, I., & Niebel, T. (2016). Mobile and more productive? Firm-level evidence on the productivity effects of mobile internet use. *Telecommunications Policy, 40*(9), 888-898.

Bris, Myriam, Pawlak, Jacek, & Polak, John W. (2017). How is ICT use linked to household transport expenditure? A cross-national macro analysis of the influence of home broadband access. *Journal of Transport Geography, 60*, 231-242.

Cardona, Melisande, Kretschmer, Tobias, & Strobel, Thomas. (2013). ICT and productivity: conclusions from the empirical literature. *Information Economics and Policy, 25*(3), 109-125.

Chen, Shuping, Chen, Xia, Cheng, Qiang, & Shevlin, Terry. (2010). Are family firms more tax aggressive than non-family firms? *Journal of Financial Economics, 95*(1), 41-61.

Cheng, Beiting, Ioannou, Ioannis, & Serafeim, George. (2014). Corporate social responsibility and access to finance. *Strategic Management Journal, 35*(1), 1-23.

Danzon, M, & Furukawa, M. eHealth: Effects of the Internet on Competition and Productivity in Health Care (2001) In The Economic Payoff from the Internet Revolution, the Brookings Task Force on the Internet. In: Brookings Institution Press: Washington.

DeStefano, Timothy, Kneller, Richard, & Timmis, Jonathan. (2018). Broadband infrastructure, ICT use and firm performance: Evidence for UK firms. *Journal of Economic Behavior & Organization, 155*, 110-139.

Draca, M, Sadun, R, & Van Reenen, J. (2007). Productivity and ICT: A Review of the Evidence. The Oxford Handbook of Information and Communication Technologies. In: Oxfort: Oxford University Press.

Fang, Vivian W, Tian, Xuan, & Tice, Sheri. (2014). Does stock liquidity enhance or impede firm innovation? *The Journal of Finance, 69*(5), 2085-2125.

Forman, Chris, & van Zeebroeck, Nicolas. (2019). Digital technology adoption and knowledge flows within firms: Can the Internet overcome geographic and technological distance? *Research Policy, 48*(8), 103697.

Gallego, J. M., Gutierrez, L. H., & Lee, S. H. (2015). A firm-level analysis of ICT adoption in an emerging economy: evidence from the Colombian manufacturing industries. *Industrial and Corporate Change, 24*(1), 191-221.

Gaspar, Jess, & Glaeser, Edward L. (1998). Information Technology and the Future of Cities. *Journal of Urban Economics, 43*(1), 136-156.

Giuri, P., Torrisi, S., & Zinovyeva, N. (2008). ICT, skills, and organizational change: evidence from Italian manufacturing firms. *Industrial and Corporate Change, 17*(1), 29-64.

Goel, Rajeev K., & Hsieh, Edward W.T. (2002). Internet Growth and Economic Theory. *Netnomics, 4*(2), 221-225.

Gottesman, Aron A, & Morey, Matthew R. (2010). CEO Educational Background and Firm Financial Performance. *Journal of Applied Finance, 20*(2), 70.

Graham, Stephen. (1997). Telecommunications and the future of cities: debunking the myths. *Cities, 14*(1), 21-29.

Grimes, Arthur, Ren, Cleo, & Stevens, Philip. (2012). The need for speed: impacts of internet connectivity on firm productivity. *Journal of Productivity Analysis, 37*(2), 187-201.

Haller, Stefanie A, & Lyons, Sean. (2015). Broadband adoption and firm productivity: evidence from Irish manufacturing firms. *Telecommunications Policy, 39*(1), 1-13.

Hambrick, Donald C, Cho, Theresa Seung, & Chen, Ming-Jer. (1996). The influence of top management team heterogeneity on firms' competitive moves. *Administrative Science Quarterly*, 659-684.

Hardy, Andrew P. (1980). The role of the telephone in economic development. *Telecommunications Policy, 4*(4), 278-286.

Hassan Che Haat, Mohd, Abdul Rahman, Rashidah, & Mahenthiran, Sakthi. (2008).

Corporate governance, transparency and performance of Malaysian companies. *Managerial Auditing Journal, 23*(8), 744-778.

Hausman, Jerry A. (1996). Valuation of new goods under perfect and imperfect competition. In *The economics of new goods* (pp. 207-248): University of Chicago Press.

Kim, Jeong-Bon, Li, Yinghua, & Zhang, Liandong. (2011). Corporate tax avoidance and stock price crash risk: Firm-level analysis. *Journal of Financial Economics, 100*(3), 639-662.

Krueger, Alan B. (1993). How computers have changed the wage structure: evidence from microdata, 1984–1989. *The Quarterly Journal of Economics, 108*(1), 33-60.

Lennox, Clive, Lisowsky, Petro, & Pittman, Jeffrey. (2013). Tax aggressiveness and accounting fraud. *Journal of Accounting Research, 51*(4), 739-778.

Loveman, Gary W. (1994). An assessment of the productivity impact of information technologies. *Information technology and the corporation of the 1990s: Research Studies, 84*, 110.

Majumdar, Sumit K, Carare, Octavian, & Chang, Hsihui. (2010). Broadband adoption and firm productivity: evaluating the benefits of general purpose technology. *Industrial and Corporate Change, 19*(3), 641-674.

Mishra, Saurabh, Modi, Sachin B, & Animesh, Animesh. (2013). The relationship between information technology capability, inventory efficiency, and shareholder wealth: A firm-level empirical analysis. *Journal of Operations Management, 31*(6), 298-312.

Morrison, Catherine J. (1997). Assessing the productivity of information technology equipment in US manufacturing industries. *Review of Economics and Statistics, 79*(3), 471-481.

Moshirian, Fariborz, Tian, Xuan, Zhang, Bohui, & Zhang, Wenrui. (2018). Stock market liberalization and innovation. *Available at SSRN 2403364*.

Nevo, Aviv. (2000). Mergers with differentiated products: The case of the ready-to-eat cereal industry. *The RAND Journal of Economics*, 395-421.

Oliner, Stephen D, & Sichel, Daniel E. (1994). Computers and Output Growth Revisited: How Big Is the Puzzle? *Brookings Papers on Economic Activity, 25*(2), 273-334.

Osorio, C, & Fountain, J. (2001). Public Sector: Early Stage of a Deep Transformation. The Economic Payoff From the Internet Revolution. R. Litan and A. Rivlin. Washington, DC. *Brookings Institution*, 235-268.

Park, Y., Fritz, C., & Jex, S. M. (2018). Daily Cyber Incivility and Distress: The Moderating Roles of Resources at Work and Home. *Journal of Management, 44*(7), 2535-2557.

Petersen, Mitchell A. (2009). Estimating standard errors in finance panel data sets: Comparing approaches. *The Review of Financial Studies, 22*(1), 435-480.

Roberts, Michael R, & Whited, Toni M. (2013). Endogeneity in empirical corporate finance1. In *Handbook of the Economics of Finance* (Vol. 2, pp. 493-572): Elsevier.

Roller, Lars-Hendrik, & Waverman, Leonard. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American Economic Review, 91*(4), 909-923.

Samarajiva, Rohan, & Zainudeen, Ayesha. (2008). *ICT infrastructure in emerging Asia: Policy and regulatory roadblocks*: IDRC.

Samuelson, Paul Anthony. (1948). Foundations of Economic Analysis.

Sharif, Saeed Pahlevan, & Lai, Ming Ming. (2015). The effects of corporate disclosure practices on firm performance, risk and dividend policy. *International Journal of Disclosure and Governance, 12*(4), 311-326.

Silberston, Aubrey. (1972). Economies of scale in theory and practice. *The Economic Journal, 82*(325), 369-391.

Solow, RM. (1987). We'd better watch out. New York Times, Book Review, 12 July.

Stanley, TD, Doucouliagos, Hristos, & Steel, Piers. (2018). Does ICT generate economic growth? A meta-regression analysis. *Journal of Economic Surveys, 32*(3), 705-726.

Torero, Maximo, & Von Braun, Joachim. (2006). *Information and communication technologies for development and poverty reduction: The potential of telecommunications*: Intl Food Policy Res Inst.

Tripathi, Manas, & Inani, Sarveshwar Kumar. (2016). Does internet affect economic growth in sub-Saharan Africa? *Economics Bulletin, 36*(4), 1993-2002.

Vasileiadou, E., & Vliegenthart, R. (2009). Research productivity in the era of the internet revisited. *Research Policy, 38*(8), 1260-1268.

Whitacre, Brian, Gallardo, Roberto, & Strover, Sharon. (2014). Broadband' s contribution to economic growth in rural areas: Moving towards a causal relationship. *Telecommunications Policy, 38*(11), 1011-1023.

Zhao, Xiaoping, & Murrell, Audrey J. (2016). Revisiting the corporate social performance-financial performance link: A replication of W addock and G raves. *Strategic Management Journal, 37*(11), 2378-2388.

5. RENEWABLE ENERGY INFRASTRUCTURE AND THE HOUSEHOLD ECONOMY

Renewable Energy and Household Economy in Rural China

Abstract

To understand the linkage between renewable energy and economic growth, this study investigates the development of renewable energy, including hydropower, bioenergy, and solar energy, and their effects on rural household economy, by employing a panel data analysis in China during the period of 2003 - 2017. Based on the evidence of renewable energy infrastructure in the last 20 years, we use a two-way fixed effect model to reveal the relationship between renewable energy investment and household income and consumption. Further, we conduct a panel Granger causality test to verify the impact of renewable energy on economic growth. Empirical results show that investment in renewable energy, including bioenergy, solar energy and hydropower, indeed improve the rural household economy in China.

Keywords: Renewable energy; Household economy; Rural China

1 INTRODUCTION

To reduce the negative effects of environmental pollution and the risks of climate change caused by fossil fuel consumption, it is critical to develop renewable energy replacing conventional energy and make the transition to a clean energy economy. Whilst such a transition will mitigate environmental and human health externalities, the impacts upon the economy are less clear, with some scholars arguing that the economic costs of transition will be high (Nordhaus, 1991, Nordhaus, 2017), whilst others suggest that the 'green economy' offers employment and growth opportunities (Mehmet, 1995, Markandya et al., 2016).

The effects non-renewable energy and renewable energy on economic growth are said to vary significantly (Shafiei and Salim, 2014). Non-renewable energy resources, such as coal, petroleum, natural gas and nuclear, are available in limited supplies and are bound to be exhausted some time in the future. Renewable resources, such as solar, water (hydro), biomass and wind are replenished naturally. As well as limiting environmental externalities, renewable energy can reduce the energy dependence of one country on others (Pacesila et al., 2016).

The economic returns of energy in general has long been investigated in the literature, with most of the focus on fossil fuels. However, the economic impacts of renewable energy have been under-examined and remain controversial. The cost, manufacturing processes and economic benefits of renewable energy are remarkably different from those of conventional fossil energy. There are concerns about the investment requirements for a transition to renewable energy, while the economic benefits might be too small (Menegaki, 2011, Bergmann et al., 2006). On the other hand, the marginal price of renewable energy can be very low, and the cost of solar and wind technologies is rapidly declining thanks to technological improvement and expanding markets (Andini et al., 2019, Connolly et al., 2012).

A particular feature of renewable energy (in particular solar photovoltaic panels and biofuels), distinct from conventional energy, is that it can be installed by households independently. Households are thereby able to utilise solar energy and bioenergy to produce electricity or satisfy other energy needs on their own.

This study intends to examine the economic returns of renewable energy with the following five contributions. First, as the research on the relationship between renewable energy and economic growth has been relatively sparse, this study aims to enrich the literature and furnish evidence on the economic returns of renewable energy. Second, contrary to most of the extant literature examining the nexus between energy consumption and GDP, this study focuses on the supply side rather than the demand side, i.e., the deployment and capability of renewable energy, which is more relevant to infrastructure investment and could better advise public policy. Third, unlike most studies looking at large centralised energy systems, this study focuses on renewable energy investment at the household level. These investments are made privately by households, especially in bioenergy and solar energy. Fourth, with a specific research setting in rural areas, which are experiencing a dramatic energy consumption surge yet usually given insufficient attention, this study contributes to our understanding of how rural areas can reach sustainable development outcomes. Fifth, we compose panel data and employ fixed effect models aiming to achieve more robust results. With panel estimation techniques, our research models establish cross-sectional dependence, heterogeneity across the provinces, and Granger causality tests are also applied to investigate the linkage.

Even though renewable energy is now fast developing around the globe, given the large discrepancy among different countries, we narrow the scope of our study on the biggest renewable energy producer country: China. Since the late 1990s, China has been promoting clean, renewable energy, and now has overtaken the US to be the largest renewable producer (Helveston and Nahm, 2019). Though an enormous number of renewable energy projects have been rolled out, little is known about their actual economic returns. Few studies have tried to address the association between China's renewable energy development and economic growth. This study investigates China's renewable energy with a relatively long time-span, from the earlier period when China started to invest in renewable energy at a large scale around 2003, to the recent year 2017 when it became a renewable energy giant.

The rest of the paper is organised as follows. Section 2 provides a summary of existing literature. Section 3 presents an overview of China's renewable energy.

Section 4 is the data and methods. Section 5 is the results. Section 6 discusses its possible economic reasoning. Section 7 concludes.

2 LITERATURE

Research examining the economic returns of non-renewable energy dates back to Kraft and Kraft (1978) around four decades ago. Their study revealed a unidirectional causality between gross energy inputs and gross national product (GNP) during the period of 1950-1970 in the US. However, Akarca and Long (1980) challenged Kraft and Kraft's findings, through a re-examination in which the investigated period was shortened by two years, and found no causal relationships between energy consumption and GNP. Eden and Hwang (1984) also lent support to the findings of Akarca and Long, by replicating the tests using updated US data during the period of 1947-1979, and they provided further results revealing no relationship between energy consumption and GNP. The linkage between energy consumption and the economy then became a subject of intense and heated debate around the globe, and subsequently more studies have been conducted in a wide range of countries. For example, there are also a couple of studies looking at developing countries, such as Pakistan (Aqeel and Butt, 2001), Turkey (Altinay and Karagol, 2004), Malawi (Jumbe, 2004), India (Paul and Bhattacharya, 2004), and Malaysia (Ang, 2008). Cross-country studies have also been conducted. Erol and Yu (1987) found evidence on the impact of energy consumption on income for West

Germany, while no impact for the UK, France and Canada, when employing Sims and Granger causality tests. Glasure and Lee (1998) found positive effect of energy consumption on GDP in both South Korea and Singapore when employing cointegration and error-correction models. However, when using the standard Granger causality tests, inconsistent results were found: the results of the standard Granger causality tests indicated no significant economic returns of energy consumption on GDP in South Korea, while causal association were shown in Singapore. Lee (2005) re-examined the energy consumption and GDP nexus in 18 developing countries from 1975 to 2001, and after employing the panel cointegration and error correction models, the results showed that energy consumption led to economic growth. A general conclusion from the literature is that there is no consensus on the nexus between energy consumption and economic growth (Ozturk, 2010, Elliott et al., 2015).

There has been an increasing level of interest in renewables studies from both academics and energy policy analysts. Although renewable energy has a relative short history, there is a growing literature that has looked at its relationship with the economy (Saad and Taleb, 2018b), which is summarised in Table 1.

Table 1 List of literature on the contribution of renewable energy on economic growth

Economy/Region	**Period**	**Independent variable**	**Dependent variable**	**Findings**	**Methods**	**Study**	**Publication**
20 OECD countries	1985-2005	Renewable energy consumption	GDP	+	Granger test	(Apergis and Payne, 2010)	Energy Policy
Turkey	1990-2010	Renewable energy consumption	GDP	-	ARDL approach	(Ocal and Aslan, 2013)	Renewable and Sustainable Energy Reviews
30 OECD countries	1990-2010	Renewable energy consumption	GDP	+	Unit root tests	(Inglesi-Lotz, 2016)	Energy Economics
Germany	1971-2013	Renewable energy consumption	GDP	+	Granger test (time series)	(Rafindadi and Ozturk, 2017)	Renewable and Sustainable Energy Reviews
38 countries	1991-2012	Renewable energy consumption	GDP	+	Panel	(Bhattacharya et al., 2016)	Applied Energy
27 European countries	1997-2007	Renewable energy consumption	GDP	0	Unit root tests (random effect)	(Menegaki, 2011)	Energy Economics
EU countries	1990-2009	Renewable energy consumption	GDP	+	ARDL approach	(Alper and Oguz, 2016)	Renewable and Sustainable Energy Reviews
Nine Black Sea and Balkan countries	1990–2012	The share of renewable energy consumption	The rate of GDP growth	+	Unit root tests, FMOLS and DOLS	(Koçak and Şarkgüneşi, 2017)	Energy Policy
MENA Net Oil Exporting Countries	1980-2012	Renewable electricity consumption	Real GDP	+	Panel cointegration approach	(Kahia et al., 2016)	Energy
US	1994-2006	Renewable electricity consumption	Real GDP	0	Toda-Yamamoto causality test (time series)	(Payne, 2009)	Applied Energy
51 Sub-Sahara African countries	1980–2009	Biomass consumption	GDP	+	Panel	(Ozturk and Bilgili, 2015)	Applied Energy

Notes: + denotes positive effect; - denotes negative effect; 0 denotes no effect

Most studies use the amount of renewable energy consumption and a country's GDP as the independent variable and dependent variable respectively, but few studies have examined the supply of energy infrastructure, probably owing to a lack of data. Across this work, there is no agreement on the existence of impact of renewable energy development on economic growth (Arora and Shi, 2016, Tang et al., 2016). While some have found positive, negligible effects, others argue for negative effects of renewable energy on economic growth. Moreover, most studies use national aggregate data on renewable energy and GDP; few studies have looked at provincial or city level, and even fewer studies have examined the renewable energy-growth nexus in rural areas. Despite the rapid development of China's renewable energy, it is surprising that little has been written. Motivated by the aforementioned controversies and knowledge gaps, this study fills the research lacuna by investigating the deployment of renewable energy and its economic effect in rural China.

3 RENEWABLE ENERGY IN RURAL CHINA

3.1 A Dramatic Surge of Energy Consumption in Rural China

Before introducing China's renewable energy in rural areas, it is essential to provide a background of its overall energy consumption, which will help us understand why more research should be focused on rural areas, and the urgency and necessity of renewable energy infrastructure investment and deployment in rural China.

China once experienced a long period of rural energy shortage, where biomass, such as burning wood and straw, was the only available fuel in these areas. Due to unprecedented economic growth and a profound social change, energy demand in China's rural areas has been rapidly increasing, which has been increasingly supplied from fossil fuel sources. In China's rural areas, energy is now not just demanded for agriculture, but also in all walks of life. China's efforts on promoting national strategical plan for rural vitalisation has now narrowed the urban-rural gap dramatically. As shown in Figure 1, there was a rapid surge in energy consumption in rural China. The rural residential energy consumption per capita was approximately 60 every 1 kg of standard coal (kgce) in 1980, which was less than one-sixth of their urban counterparts (332 kgce). In the early 2000s, however, China's rural residential energy consumption per capita had been soaring (to 390 kgce), and is currently almost equal to urban residential energy consumption per capita (around 395 kgce) in 2016.

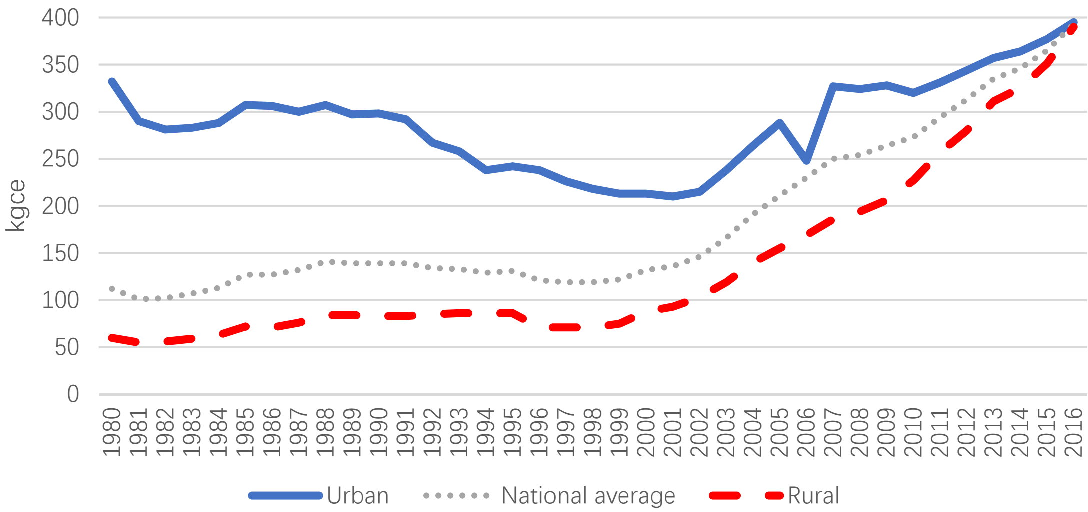

Figure 1 Residential energy consumption per capita, 1980-2016 (*Data source: National Bureau of Statistics of the P.R. of China*)

3.2 Renewable Energy in Rural China

Driven by policy incentives on energy infrastructure investment to balance growth and environmental concerns and ultimately to reduce the reliance on coal and petroleum, China's rural renewable energy has experienced rapid growth. Rural renewable energy is used in a wide range of daily and productive activities, which not only is necessary for meeting subsistence needs but also forms an integral part of economic production. For instance, in rural areas, solar thermal can provide household hot water, farm machinery with energy supply from hydro plants can be used in harvesting, and bioenergy can provide fuel for cooking food. There are mainly three types of renewable energy in rural China, i.e. hydropower, bioenergy and solar energy.

(i) Hydropower

Hydropower is a mature technology that has been long applied in China's rural areas. It is presently one of the most crucial sources for electricity generation, especially in remote and mountainous areas. Hydropower can provide relatively stable energy supply, in contrast to solar and wind whose supply are intermittent and fluctuating. Therefore, hydropower energy has been widely used in rural China. Although the number of hydropower plants decreased after 1980, the power generating capability was still increasing. There were 47,529 rural hydropower plants, which generated approximately 268 billion kilowatt-hours of electricity (see Figure 2). Once a hydropower plant is operational, it provides pure form of energy, and produces no direct waste. However, it is not easy to build a hydropower plant and the upfront investment costs tend to be high. Moreover, building dams across the river can abruptly disturb the natural flow and affect wildlife leading to a series of ecological impacts.

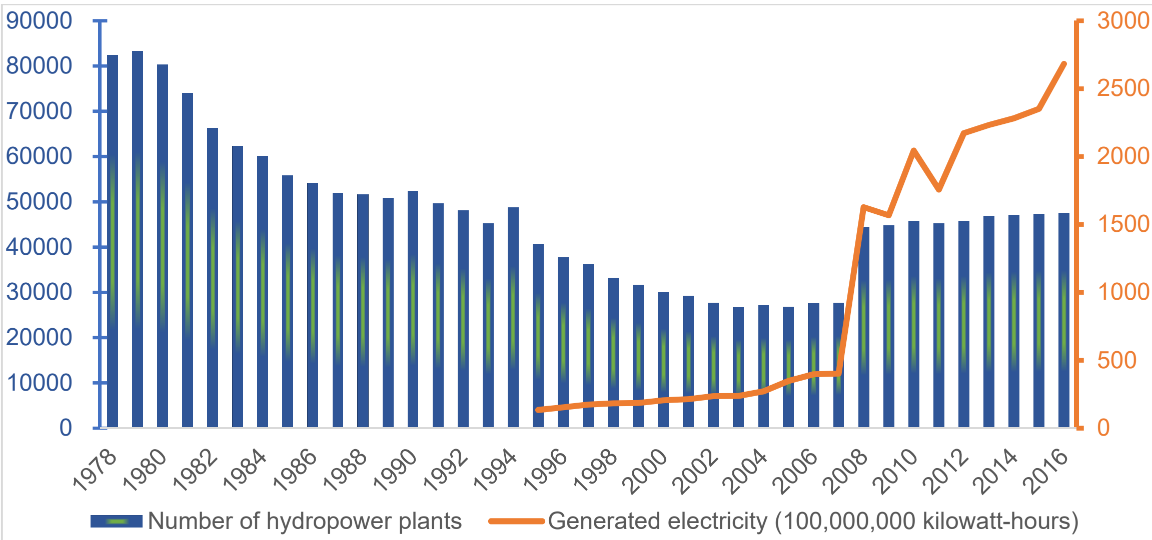

Figure 2 China's hydropower development in rural areas, 1978-2016 *(Data source: Ministry of Water Resources, and National Bureau of Statistics of the P.R. of China)*

(ii) Bioenergy

For a long time, biomass in the form of crop residues, firewood and animal wastes, has been the only available fuel in many rural areas in developing countries. In rural China, biomass was usually used in traditional settings. For example, crop residues were commonly burned in fields, which had low energy efficiency and resulted in air pollution. Since 2000 however, the Chinese government began to implement strict environmental regulations on biomass combustion in rural areas in order to achieve a more sustainable development pathway, whereby a large number of renewable energy infrastructure projects were promoted. China has now built more than 2500 million m^3 of large- and medium-scale biogas projects. The gas production of rural biogas digesters has increased by more than five folds from 2590 million m^3 in the year of 2000 to 1.54 billion m^3 in the year of 2015. Bioenergy can be used for multiple purposes, including the production of electricity, heat and fuel, and is beneficial when its waste is converted into things of value. Yet, as we can observe from Figure 3, the development of rural biogas had been stagnating since 2011. This is also consistent with the recent finding of an econometric analysis conducted by Zhang et al. (2014), which demonstrated that China's bioenergy consumption fell modestly with income growth. There are several reasons for the resistance of rural bioenergy infrastructure. First, due to China's urbanisation, there is proportionately less rural population and less labour available for collection of biomass, the key materials of biogas production. Second, bioenergy requires substantial transport support, and the transit cost is high, due to the scattered layout of rural biogas digesters. Third, low efficiency of biogas also largely limits its application. Biogas plants tend to experience persistent leakage and seepage problems, and gas production rate is low. Fourth, it is difficult to deal with stockpiles and management of biogas, its raw materials and fertilizer. These obstacles meant that China's rural bioenergy development faced many difficulties, and thus a common and easier way that had been conventionally used is open burning of some biomass, with adverse environmental impacts. To deal with the difficulties in developing bioenergy in rural areas, technology needs to be improved and more effective policies should be implemented to increase the economic value of bioenergy, ensuring that it can be accepted as a clean and low-cost solution for heating and power in rural areas.

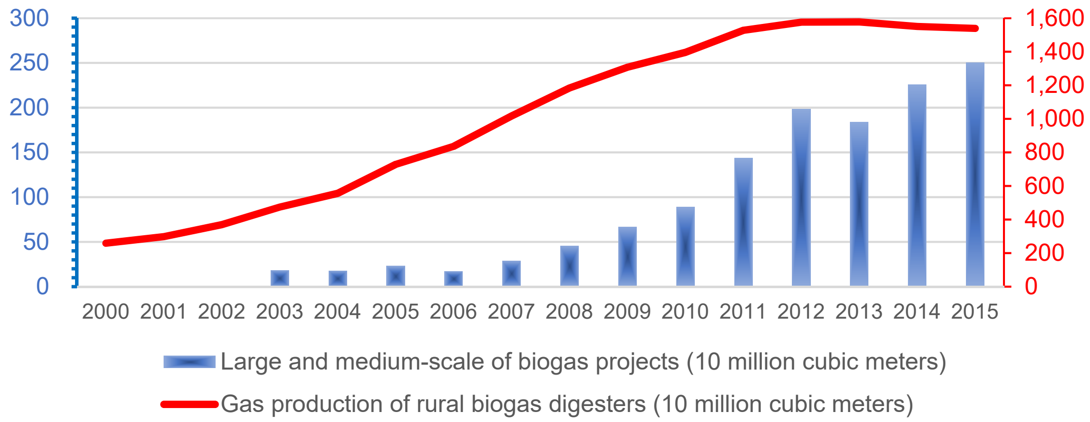

Figure 3 China's bioenergy development in rural areas, 2000-2016 *(Data source: Ministry of Environmental Protection, and National Bureau of Statistics of the P.R. of China)*

(iii) Solar energy

With the boom of solar energy manufacturing, rapid market expansion and technological improvement, the cost of using solar power has dramatically declined (Zhao et al., 2013). The deployment and use of solar energy has been strongly incentivised by the Chinese government, which has prioritised the utilisation of renewable energy in rural China. Therefore, solar power nowadays is gradually becoming more affordable and commonplace in rural homes. In these areas, millions of households have been using solar cookers and solar water heaters for daily activities. According to Figure 4, the number of solar cookers increased from 0.33 million in 2000 to 2.33 million in 2015. Meanwhile, the number of solar water heaters increased sharply from 11.08 million square meters to 82.33 million square meters in the same 15-year period. The growth of solar energy from 2000 to 2015 has been partially driven by governmental subsidies, tax concessions, and other incentives. Nonetheless, solar energy accounts for just around one percent of China's total energy consumption, and great potential exists for further deployment in rural areas.

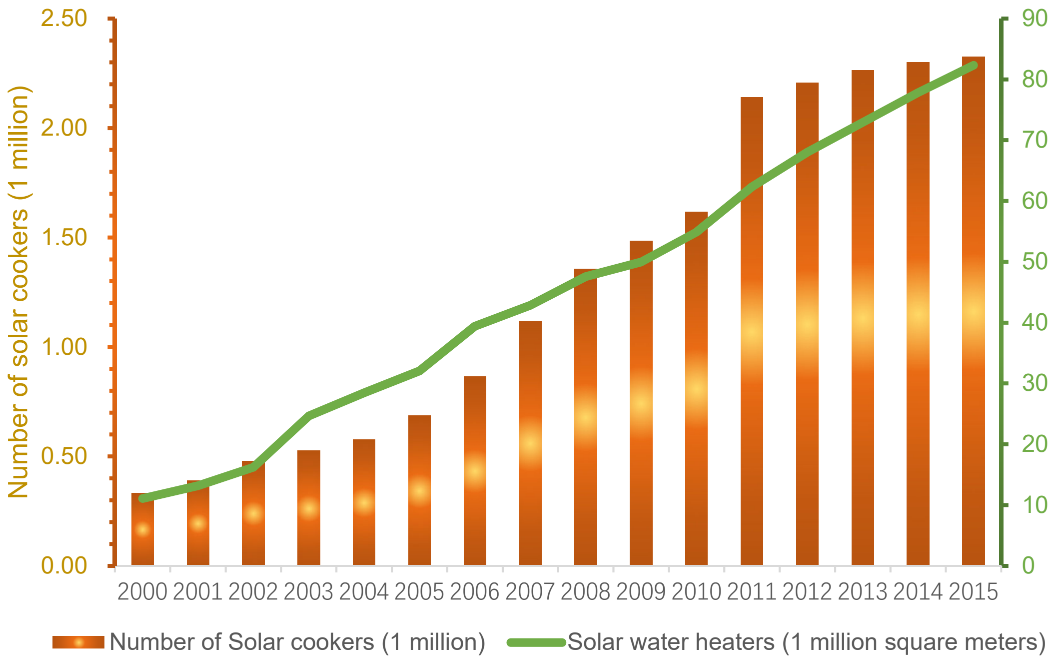

Figure 4 China's solar energy development in rural areas, 2000-2016 (*Data source: Ministry of Environmental Protection, and National Bureau of Statistics of the P.R. of China)*

4 DATA AND METHODS

4.1 Data and variables

The data used in this study were collected and complied from multiple sources which are released by several different official institutions, including the National Energy Administration, the Ministry of Water Resources, and the National Bureau of Statistics of the P.R. of China. Data on hydropower were collected from China Water Statistical Yearbook, data on bioenergy and solar energy were collected from China Statistical Yearbook on Environment. Data on total energy consumption were collected from China Energy Statistical Yearbook. Data on rural household economy, including rural household income and household consumption, were collected from China Rural Statistical Yearbook and Rural Areas and Peasantry Database. These data resources are all available to the public. After combining the datasets from different sources, we have been able to compose a panel data for our analysis at the provincial level. These records provide information on China's rural renewable energy, and rural household economy information.

We examine three types of renewable energy sources: hydropower, solar energy and bioenergy. As previously mentioned, in contrast to the most extant studies on consumption, our measures on renewable energy are on the supply side which measures energy deployment and investment. Solar energy is measured by the number of rural solar energy heaters (per 10 thousand square meters), hydropower is measured by the rural hydropower generating capability (per 10 kilo-watt), and bioenergy is measured by the amount of rural gas production by biogas digesters (per 10 million cubic meters). To make the household income comparable among different provinces and periods, we use the growth rate of rural disposable income (per RMB), which is deflated to the price level of year 2000, to measure the household income. Besides, the rural household consumption (per RMB), which is deflated to the price level of year 2000, is employed as the alternative measure to carry out the robust checks. In addition, renewable energy consumption might follow the same trend with the total energy consumption. To alleviate this effect, we include the total energy consumption (10 thousand tons of standard coal) as the control variable. Finally, all the variables are winsorised at 1% level to alleviate the impact of outliers.

We choose the China province-level data from 2003 to 2017 to examine impact of renewable energy and household economy. We begin the sample from 2003 because most of renewable energy data are not available before 2003. Our sample ends by 2017 because the latest available data ends by 2017. For statistical purposes, the data analysis mainly includes the provinces in mainland China, and the Hong Kong SAR, Macau SAR and Taiwan Province of China are not included because these areas have significant difference in the economic system with the mainland China. Besides, Tibet and Shanghai are excluded because some key variables are missing. Finally, we acquire a sample of 29 provinces and 435 province-year observations.

4.2 Methodology

The function for household economy and the impact of different types of renewable energy is shown in Equation 1.

$$Economy_{i,t} = f(Hydropower_{i,t},\ Bioenergy_{i,t}, Solar\ energy_{i,t},\ Total\ Energy_{i,t}) \quad (1)$$

We employ the log-linear function to measure the effect of renewable energy. To alleviate the effect of unobservable effect of the region and time, we include the provincial fixed effect and year fixed effect in the model, as shown in Equation 2.

$$lnEconomy_{i,t} = \alpha + \beta_1 lnHydropower_{i.t} + \beta_2 lnBioenergy_{i.t} + \beta_3 lnSolar\ engergy_{i.t} + \sum Province_i + \sum Year_t + \varepsilon_{i.t} \quad (2)$$

where i denotes the id of a province, and t=2003, …, 2017 denotes the time period. $Economy_{i,t}$ denotes the dependent variable, rural household economy*. ε denotes the error term. The summary statistics and correlation matrix are listed in Table A1 and Table A2 in the appendixes.

In terms of econometrical methods, a large proportion of literature used time series data and techniques. For example, Tang et al. (2016) used annual time series data on conventional energy consumption and GDP of Vietnam in the neoclassical Solow growth framework. Arora and Shi (2016) investigated the linkage between conventional energy consumption and GDP in the US using a multivariate time varying model. Pao and Fu (2013) used yearly statistics in Brazil to compare the

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* Because economy is the growth rate and range from -1 to +1, we take the natural logarithm of economy plus one.

relationship between renewable energy, non-renewable energy and GDP by employing vector error correction models. However, given the defects of time series data, panel data have several advantages which better uncover the dynamic relationships, and there have been increasingly longitudinal studies on exploring the relationship in energy economics. For instance, both Saad and Taleb (2018a) and Alper and Oguz (2016) used panel analysis to explore the impact of renewable energy on GDP in European countries.

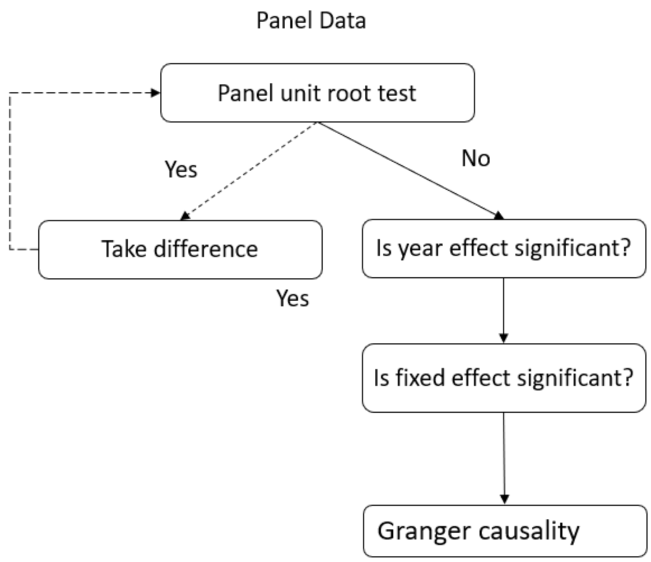


Figure 4 Empirical strategy flowchart

To examine the relationship between renewable energy and household economy in rural areas, we employ longitudinal data at province level in China to conduct a series of tests. First, we carry out the panel unit root test to examine whether the data are stationary, and the results show that all the variables are stationary. Next, we choose whether to include year fixed effects by examining whether the time effect is significant. We further investigate whether the province fixed effect matters in our regressions. Both tests show that year and province level fixed effects are significant. Thus, we use two-way fixed effect panel models to control for the province level fixed effect and year fixed effect. Such models could control for unobserved heterogeneity when the heterogeneity is invariant over time. This heterogeneity can be removed from the data. However, fixed effect models cannot tackle the problems of group-wise heteroskedasticity and cross-sectional independence. Thus, we adjust the standard errors by clustering at the province level and year level to alleviate the impact of heteroskedasticity.

Lastly, in line with existing literature (Ahmed and Azam, 2016), we use the Granger causality test to examine the nexus between renewable energy and the economy. This study implements a recent technique with procedures proposed by Dumitrescu and Hurlin (2012) (DH), to detect the Granger causality in panel datasets.

In the Granger causality test, we suppose the independent variables ($x_{i,t,}$) and the dependent variable ($Economy_{i,t}$) are two variables for province i in period t. The relationship between $x_{i,t}$ and $Economy_{i,t}$ is expressed as Equation 3.

$$Economy_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{i,k}\, Economy_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k}\, x_{i,t-k} + \varepsilon_{i,t} \tag{3}$$

The regression coefficients are different among different provinces but time-invariant. The lag order K is supposed to be the same for all provinces and there must be a balanced panel. DH test assumes that causality exists in some provinces but not necessarily for all provinces. Thus, the null hypothesis and alternative hypothesis are expressed as Equation 4 and 5:

$$H_0: \beta_{i1} = \cdots = \beta_{iK} = 0 \qquad \forall\ \mathrm{i} = 1, \ldots, \mathrm{N} \tag{4}$$

$$H_1: \beta_{i1} = \cdots = \beta_{iK} = 0 \qquad \forall\ \mathrm{i} = 1, \ldots, \mathrm{N}_1$$

$$\beta_{i1} \neq 0\ \ or\ \cdots or = \beta_{iK} \neq 0 \qquad \forall\ \mathrm{i} = \mathrm{N}_1 + 1, \ldots, \mathrm{N} \tag{5}$$

In Equation 4, $\mathrm{N}_1 \in [0, \mathrm{N} - 1]$ is unknown. If $\mathrm{N}_1 = 0$, all provinces have causalities in the panel. N must be larger than N_1, otherwise no province has causality and H_1 would be same with H_0.

We run the regression in Equation 3 at first and then conduct the F-tests for hypothesis 1 to acquire the Wald statistic W_i for each province and compute the final Wald statistic $\overline{\mathrm{W}}$(W-bar) by averaging all the W_i, shown in Equation 6.

$$\overline{\mathrm{W}} = \frac{1}{N} \sum_{i=1}^{N} W_i \tag{6}$$

In the DH test, W_i is assumed to be independent and identically distributed across provinces, and can be expressed as the standardized statistic $\overline{\mathrm{Z}}$ when $\mathrm{T} \rightarrow \infty$ first and then $\mathrm{N} \rightarrow \infty$, which follows a standard normal distribution in Equation 7:

$$\overline{\mathrm{Z}} = \sqrt{\frac{N}{2K}} (\overline{\mathrm{W}} - K) \xrightarrow{T,N \rightarrow \infty} N(0,1) \tag{7}$$

Using this technique, we are able to compute the p-values and critical values related to the Z-bar ($\overline{\mathrm{Z}}$) via a bootstrap procedure, which is beneficial in the case of cross-sectional dependence (Lopez and Weber, 2018).

5 RESULTS

5.1 Main results

First, we conduct the panel unit root test to check whether all the variables are stationary. Next, we carry out F test to examine whether the year and province fixed effect model should be incorporated in the model. These results are shown in Table A4 in the appendixes. All the p values are smaller than 0.01, indicating that fixed effect model is more effective than random effect model.

In Table 2, we regress the rural household economy variable with the hydropower, bioenergy and solar energy variables in models 1-3 separately. Then, we include all the variables in model 4. The values of R-squared are higher than 0.3, indicating that renewable energy has high explanatory power for the household economy. The coefficients of hydropower are positive and significant at the 5% level in both model 1 and model 4, indicating that hydro electricity production promotes the household economy. Bioenergy also has significantly positive coefficients in both model 2 and model 4, illustrating that it has positive effects on the household economy of rural areas. Finally, the coefficients of solar energy in model 3 and model 4 are significant and positive, demonstrating that the development of solar energy promotes household economy.

Table 2 Results of fixed effect panel regression

VARIABLES	(1) model1 lnGrowth2	(2) model2 lnGrowth2	(3) model3 lnGrowth2	(4) model4 lnGrowth2
Bioenergy	0.011**			0.011**
	(0.004)			(0.004)
Hydropower		0.008*		0.008*
		(0.004)		(0.005)
Solar Energy			0.004*	0.004***
			(0.002)	(0.001)
Energy	-0.002	-0.002	0.000	-0.011
	(0.036)	(0.036)	(0.039)	(0.034)
Constant	-0.071	-0.063	-0.007	-0.107
	(0.340)	(0.352)	(0.354)	(0.348)
Observations	435	435	435	435
Adjusted R-squared	0.335	0.330	0.329	0.336
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes

Standard errors are adjusted by clustering at both province and year level, and are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1

To further verify the relationship between renewable energy and the household economy, we employ the xtgcause command in Stata to conduct the Granger casual test and the results are shown in Table 3. The p values of Z-bar are smaller than 0.05, rejecting the null hypothesis that they are not Granger-cause. Hence, hydropower, bioenergy and solar energy have the Granger causal effects on rural household economic growth.

Table 3 Result of the Granger casual test

	W-bar	Lag	Z-bar	Z-bar p
Hydropower	5.670	3	5.870	0.000
Bioenergy	4.435	3	3.156	0.002
Solar energy	6.911	3	8.599	0.000

Based on the Granger tests in Table 3, and the results of fixed effect regression in Table 2, we can roughly estimate that: One standard deviation (SD) increase in rural solar energy heater increases rural household economy by

11.7%(0.004*1.504/0.051) SD of economic growth; one SD increase in rural biogas (biogas digesters) increases rural household economy by about 36.45% (0.008*2.324/0.051) SD of economic growth. Besides, one SD hydropower improvement would contribute to 32.89% SD of economic growth. Thus, the renewable energy has substantial effect on economic growth of China rural areas.

5.2 Robust checks- alternative measure for household economy

We employ the amount of total household disposable consumption in the rural area (economy2) to replace the original measure on household economy expenditure per capital. The results are presented in Tables A5 in the appendix and we find that the results are consistent with our prior findings, further verifying our results

6 DISCUSSION

Based on the results, we find evidence that the development of new renewable energy, including bioenergy, solar energy and hydropower, is positively and significantly associated with the rural household economy. Why does the deployment of renewable energy contribute to the rural household economy? In this section, we attempt to discuss several possible economic mechanisms. First, investment in renewable energy facilities usually require external funding, and China's central and local governments have been providing substantial financial incentives in rural areas, including subsidies, tax-related incentives, loans, and pricing incentives, which also influence saving rates or debt servicing in rural household economy. For example, during 2003- 2009, it was estimated that the Chinese governments had provided 19 billion RMB as financial investment and incentives for the biogas industry. Among them, 82% was invested in household biogas digesters, which significantly stimulated bioenergy infrastructure development (Wang et al., 2016). However, the government would usually just provide strong incentives at the early stage of an emerging industry, and then the development of renewable energy would be mainly driven by the market. The manufacture, construction and installation of these energy facilities will impact demand for various economic sectors and employment. Where greater renewable energy deployment exists, rural households tend to get more employment (Lehr et al., 2008). Moreover, with persistent governmental encouragement and support in rural renewable energy development, larger scale manufacturing and deployment of renewable energy facilities reduce the marginal cost, which also contributes to higher economic returns (Pillai and McLaughlin, 2013). In addition, higher renewable energy investment may activate a sense of entitlement because government and individuals perceive a higher importance of new technology and innovation, which contributes to a more sustainable business environment and phase out outdated, low-efficiency and low-output technology (Liu and Liang, 2013). This transition could further contribute to rural household economy. Last, with renewable energy, rural households will gradually replace the use of conventional energy with higher marginal costs, which may save the cost of daily energy consumption and reduce the living expense burden for households (Gan and Yu, 2008). Surplus renewable energy can be sold, which creates profits for rural households. Other processes could also explain the results. Future research is necessary to establish which of these, or other, mechanisms explain why higher renewable energy deployment could have positive economic returns.

7 CONCLUSION

This study has added new evidence to energy-economy nexus literature, from the supply side, at household level and a rural perspective on renewable energy. Based on evidence of a largescale longitudinal panel spanning 15 years, the results of this empirical study show that renewable energy in rural China is beneficial for economic growth. Specifically, the development of renewable energy, in the form of bioenergy, solar energy and hydropower, both promote China's rural economy. This study estimates that one standard deviation increase in rural solar thermal energy, in rural biogas and in hydropower, would contribute to an increase of 11.7%, 36.45% and 32.89% of rural household economy, respectively. Our findings imply that improvement in renewable energy deployment could increase the household economic wealth in rural areas.

APPENDIXES IN CHAPTER 5

Table A1 shows the descriptive statistics of the renewable energy variables and rural household economy variables in our sample. Table A2 shows the correlations between our variables. Table A3 presents the results of panel unit root test. Table A4 shows the fixed effect test results. Table A5 demonstrates the robustness tests of the results when we use the amount of total household consumption in the rural area (economy2) as an alternative measure.

Table A1 Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Economy	435	0.011	0.051	-0.123	0.136
Economy2	435	0.021	0.056	-0.113	0.200
Hydropower	435	9.775	1.525	5.669	12.288
Bioenergy	435	11.836	2.324	6.131	15.221
Solar energy	435	4.432	1.504	-0.357	7.020
Total energy	435	9.176	0.740	6.963	10.522

Table A2 Correlation matrix

	Economy	Economy2	Hydropower	Bioenergy	Solar energy
Economy	1				
Economy2	0.575***	1			
Hydropower	0.015	-0.011	1		
Bioenergy	0.092*	0.039	0.544***	1	
Solar energy	-0.062	-0.065	0.451***	-0.085*	1
Total energy	-0.069	-0.06	0.413***	0.05	0.456***

*** p<0.01, ** p<0.05, * p<0.1

Table A3 Results of Panel Unit Root test

	Levin-Lin-Chu test		
	Unadjusted T	Adjusted T	p value
Economy	-15.430	-7.425	0.000
Hydropower	-23.495	-21.922	0.000
Bioenergy	-10.044	-7.581	0.000
Solar energy	-12.057	-8.860	0.000

Table A4 Results of fixed effect test

	Year effect		Province effect	
	F	p value	F	p value
Model 1	14.107	0.000	1.715	0.014
Model 2	14.382	0.000	1.422	0.078
Model 3	14.579	0.000	1.625	0.025
Model 4	13.994	0.000	1.627	0.025

Table A 5 Results of fixed effect panel regression (alternative measure)

	(1)	(2)	(3)	(4)
	Model 1	Model 2	Model 3	Model 4
VARIABLES	Economy2	Economy2	Economy2	Economy2
Bioenergy	0.014*			0.014*
	(0.007)			(0.007)
Hydropower		0.012*		0.012*
		(0.006)		(0.006)
Solar Energy			0.007***	0.007***
			(0.001)	(0.001)
Energy	-0.022	-0.023	-0.021	-0.036
	(0.032)	(0.027)	(0.033)	(0.027)
Constant	0.091	0.093	0.180	0.039
	(0.290)	(0.319)	(0.305)	(0.322)
Observations	435	435	435	435
Adjusted R-squared	0.330	0.325	0.324	0.337
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes

Standard errors are adjusted by clustering at both province and year level, and are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1

REFERENCES

[1] W.D. Nordhaus, To slow or not to slow: the economics of the greenhouse effect, The Economic Journal 101(407) (1991) 920-937.

[2] W.D. Nordhaus, Revisiting the social cost of carbon, Proceedings of the National Academy of Sciences 114(7) (2017) 1518-1523.

[3] O. Mehmet, Employment creation and green development strategy, Ecological Economics 15(1) (1995) 11-19.

[4] A. Markandya, I. Arto, M. González-Eguino, M.V. Román, Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union, Applied Energy 179 (2016) 1342-1350.

[5] S. Shafiei, R.A. Salim, Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis, Energy Policy 66 (2014) 547-556.

[6] M. Pacesila, S.G. Burcea, S.E. Colesca, Analysis of renewable energies in European Union, Renewable and Sustainable Energy Reviews 56 (2016) 156-170.

[7] A.N. Menegaki, Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis, Energy Economics 33(2) (2011) 257-263.

[8] A. Bergmann, N. Hanley, R. Wright, Valuing the attributes of renewable energy investments, Energy Policy 34(9) (2006) 1004-1014.

[9] C. Andini, R. Cabral, J.E. Santos, The macroeconomic impact of renewable

electricity power generation projects, Renewable Energy 131 (2019) 1047-1059.

[10] D. Connolly, H. Lund, B.V. Mathiesen, E. Pican, M. Leahy, The technical and economic implications of integrating fluctuating renewable energy using energy storage, Renewable Energy 43 (2012) 47-60.

[11] J. Helveston, J. Nahm, China's key role in scaling low-carbon energy technologies, Science 366(6467) (2019) 794-796.

[12] J. Kraft, A. Kraft, On the relationship between energy and GNP, The Journal of Energy and Development (1978) 401-403.

[13] A.T. Akarca, T.V. Long, On the relationship between energy and GNP: a reexamination, The Journal of Energy and Development (1980) 326-331.

[14] S. Eden, B.-K. Hwang, The relationship between energy and GNP: further results, Energy Economics 6(3) (1984) 186-190.

[15] A. Aqeel, M.S. Butt, The relationship between energy consumption and economic growth in Pakistan, Asia-Pacific Development Journal 8(2) (2001) 101-110.

[16] G. Altinay, E. Karagol, Structural break, unit root, and the causality between energy consumption and GDP in Turkey, Energy Economics 26(6) (2004) 985-994.

[17] C.B. Jumbe, Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi, Energy Economics 26(1) (2004) 61-68.

[18] S. Paul, R.N. Bhattacharya, Causality between energy consumption and economic growth in India: a note on conflicting results, Energy Economics 26(6) (2004) 977-983.

[19] J.B. Ang, Economic development, pollutant emissions and energy consumption in Malaysia, Journal of Policy Modeling 30(2) (2008) 271-278.

[20] U. Erol, E.S. Yu, On the causal relationship between energy and income for industrialized countries, The Journal of Energy and Development (1987) 113-122.

[21] Y.U. Glasure, A.-R. Lee, Cointegration, error-correction, and the relationship between GDP and energy:: The case of South Korea and Singapore, Resource and Energy Economics 20(1) (1998) 17-25.

[22] C.-C. Lee, Energy consumption and GDP in developing countries: a cointegrated panel analysis, Energy economics 27(3) (2005) 415-427.

[23] I. Ozturk, A literature survey on energy–growth nexus, Energy Policy 38(1) (2010) 340-349.

[24] R.J. Elliott, P. Sun, Q. Xu, Energy distribution and economic growth: An empirical test for China, Energy Economics 48 (2015) 24-31.

[25] W. Saad, A. Taleb, The causal relationship between renewable energy consumption and economic growth: evidence from Europe, Clean Technologies and Environmental Policy (2018) 1-10.

[26] N. Apergis, J.E. Payne, Renewable energy consumption and economic growth: evidence from a panel of OECD countries, Energy Policy 38(1) (2010) 656-660.

[27] O. Ocal, A. Aslan, Renewable energy consumption–economic growth nexus in Turkey, Renewable and Sustainable Energy Reviews 28 (2013) 494-499.

[28] R. Inglesi-Lotz, The impact of renewable energy consumption to economic

growth: A panel data application, Energy Economics 53 (2016) 58-63.

[29] A.A. Rafindadi, I. Ozturk, Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test, Renewable and Sustainable Energy Reviews 75 (2017) 1130-1141.

[30] M. Bhattacharya, S.R. Paramati, I. Ozturk, S. Bhattacharya, The effect of renewable energy consumption on economic growth: Evidence from top 38 countries, Applied Energy 162 (2016) 733-741.

[31] A. Alper, O. Oguz, The role of renewable energy consumption in economic growth: Evidence from asymmetric causality, Renewable and Sustainable Energy Reviews 60 (2016) 953-959.

[32] E. Koçak, A. Şarkgüneşi, The renewable energy and economic growth nexus in Black Sea and Balkan countries, Energy Policy 100 (2017) 51-57.

[33] M. Kahia, M.S.B. Aïssa, L. Charfeddine, Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs), Energy 116 (2016) 102-115.

[34] J.E. Payne, On the dynamics of energy consumption and output in the US, Applied Energy 86(4) (2009) 575-577.

[35] I. Ozturk, F. Bilgili, Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries, Applied Energy 137 (2015) 110-116.

[36] V. Arora, S. Shi, Energy consumption and economic growth in the United States,

Applied Economics 48(39) (2016) 3763-3773.

[37] C.F. Tang, B.W. Tan, I. Ozturk, Energy consumption and economic growth in Vietnam, Renewable and Sustainable Energy Reviews 54 (2016) 1506-1514.

[38] R. Zhang, T. Wei, S. Glomsrød, Q. Shi, Bioenergy consumption in rural China: Evidence from a survey in three provinces, Energy Policy 75 (2014) 136-145.

[39] Z.-y. Zhao, S.-Y. Zhang, B. Hubbard, X. Yao, The emergence of the solar photovoltaic power industry in China, Renewable and Sustainable Energy Reviews 21 (2013) 229-236.

[40] H.-T. Pao, H.-C. Fu, Renewable energy, non-renewable energy and economic growth in Brazil, Renewable and Sustainable Energy Reviews 25 (2013) 381-392.

[41] W. Saad, A. Taleb, The causal relationship between renewable energy consumption and economic growth: evidence from Europe, Clean Technologies and Environmental Policy 20(1) (2018) 127-136.

[42] M. Ahmed, M. Azam, Causal nexus between energy consumption and economic growth for high, middle and low income countries using frequency domain analysis, Renewable and Sustainable Energy Reviews 60 (2016) 653-678.

[43] E.-I. Dumitrescu, C. Hurlin, Testing for Granger non-causality in heterogeneous panels, Economic Modelling 29(4) (2012) 1450-1460.

[44] L. Lopez, S. Weber, Testing for Granger causality in panel data, The Stata Journal 17(4) (2018) 972-984.

[45] C. Wang, Y. Zhang, L. Zhang, M. Pang, Alternative policies to subsidize rural

household biogas digesters, Energy Policy 93 (2016) 187-195.

[46] U. Lehr, J. Nitsch, M. Kratzat, C. Lutz, D. Edler, Renewable energy and employment in Germany, Energy Policy 36(1) (2008) 108-117.

[47] U. Pillai, J. McLaughlin, A model of competition in the solar panel industry, Energy Economics 40 (2013) 32-39.

[48] H. Liu, D. Liang, A review of clean energy innovation and technology transfer in China, Renewable and Sustainable Energy Reviews 18 (2013) 486-498.

[49] L. Gan, J. Yu, Bioenergy transition in rural China: Policy options and co-benefits, Energy Policy 36(2) (2008) 531-540.

6. TRANSPORT INFRASTRUCTURE AND FIRM RISK

Transport Connectivity and Litigation Risk: The Impact of China's High-speed Rail System

ABSTRACT

We take advantage of the improvement of China's transport infrastructure as a natural experiment to study its impact on reducing firms' risk from litigation. Using the construction of the high-speed rail as a source of exogenous variation, empirical estimates indicate that the inauguration of high-speed rail in a city reduces the amount of corporate litigation by about 18 per cent. We show that the impact of improved transport connectivity on listed firms' litigation risk stems from the reduction of information asymmetry, as well as the increase of external regulations and monitoring. Our analysis shows that the inauguration of high-speed rail contributes more to reducing the litigation risk of non-state-owned firms and firms that have fewer social connections.

Keywords: High-speed Rail, Transport Connectivity, Firm, Litigation Risk

JEL Codes: M21; R40; K4

1 INTRODUCTION

The improvement of infrastructure is arguably one of the most consequential policy stimuli for a government to impact the economy and society. Many scholars have explored the impact of infrastructure on productivity at the macro-level (Aschauer, 1989, Bröcker et al., 2019), and also on labour and employment (Dinkelman, 2011). There is also some emerging literature that has documented the impact of infrastructure investments from micro perspectives, for instance, on the economic performance of firms (Datta, 2012, Holl, 2016). Despite the enormous body of existing evidence on the effects of infrastructure, there has been limited work on the impact of transport infrastructure improvement from an ethical and legal perspective.

Regarding ethical and legal aspects, governments are under high pressure to create a sound legal system and to optimise the business environment in today's intertwined and globalising market. Misconduct and violations of regulations by firms undermine perceptions of the ease of doing business and threaten business confidence. Engagement in litigation is an unusual incident for firms, litigation risk is a sensitive issue and critical for corporate success. In many parts of the world, the business environment is increasingly litigious, so firms are perceiving higher litigation risk (Koh et al., 2014). Litigation may incur a wide range of significant consequences for the firms involved, including legal costs and increasing capital loss (Haslem, 2005). For listed firms, involvement in litigation risk might immediately trigger a steep plunge in their stock price, and incur a harsh punishment for the firms being used that might have committed infringements (Gande and Lewis, 2009, Bhattacharya et al., 2007). Second, litigation risk may hinder corporate operation and reduce efficiency. Managers' attention would be distracted and they might not be able to focus on their regular business and services (Johnson et al., 1999). Meanwhile, being involved in litigation, firms might face the risk of losing customers; their credit may also be eroded, making it more difficult to obtain future financing and investment (Arena and Julio, 2015). Since litigation is likely to be reported by the media, the adverse publicity might make it difficult for firms to repair damaged reputation and return back to normal (Shapira, 2016). Under enormous litigation pressure, managers and the accused personnel are expected to be at greater risk of losing their jobs (Liu et al., 2016). If firms are involved in litigation, their economic performance, reputation, and even survival may be impacted. As such, mechanisms to reduce litigation risk are vital for firms, the public and governments. While there may be various factors affecting corporate litigation risk, we delineate a new mechanism by looking at the impact of transport infrastructure on litigation risk.

Does improving transport infrastructure lead to less or more litigation risk for firms? On one hand, it is commonly argued that better transport infrastructure facilitates mobility, which will provide more opportunities for firms to imitate tricks and infractions from other firms, and increase coordinated misconduct between firms for the aims of profit maximization (Bertrand and Lumineau, 2016). For instance, according to the peer effect theory (Cao et al., 2019, Leary and Roberts, 2014), with more interaction opportunities provided by the availability of advanced transport, firms could imitate and conduct more deceitful behaviour with their peers in other cities. On the other hand, transport infrastructure improvement may reduce corporate litigation risk. According to the action regulation theory (Baldwin et al., 2012, Shaffer, 1995), given the availability of more convenient transport infrastructure, there is easier access to quicker inflow and outflow of information between firms, making the market more transparent. In this calculus, if firms are located in areas with more advanced transport infrastructure networks, they are less likely to misbehave and would thus be exposed to less litigation risk, compared with other firms without sufficient transport infrastructure endowment. Hence, both of these two scenarios of either triggering or deterring litigation risk would be possible if firms could be endowed with better transport infrastructure conditions.

In this study, we examine how corporate litigation is affected by transport infrastructure improvement, based on a natural experiment investigating the impact of the inauguration of China's high-speed rail (HSR) on listed firms' litigation risk.

The highlight of this research design is based on the sudden exogenous changes in transport infrastructure, rather than continuous changes. Distinct from previous conventional railways, the high-speed railways were newly built during the duration of our dataset, between 2003-2018. The selection of specific cities for construction and inauguration of high-speed rail is not decided by the firms in that city. The running line of a high-speed railway usually connects different counties and cities across different provinces, and the decision on the line and selection of station locations are usually made by the central governmental departments, including National Development and Reform Commission, the Ministry of Transport, China State Railway Group Co. Ltd., and previously the Ministry of Railways that has now been dismantled. These decisions are based on economic and political criteria. Management of litigation risk in the cities where stations are located was not, as far as we are aware, a consideration in, though general promotion of mobility and communication was.

There are three advantages of examining the impact of high-speed rail in this natural experiment. First, China's high-speed trains have made a revolutionised change to China's transport infrastructure, which has a profound impact on corporate behaviour. Second, the impact of the inauguration of high-speed railways on corporate litigation risk could be, to a certain extent, considered as exogenous. The effects of these shocks tease out possible influential factors on corporate litigation, which help to strengthen the robustness of the results. Third, the difference between before and after the inauguration of the high-speed rail provides a natural experiment design for us to measure the change between the control group and treatment group.

To conduct our analysis, we construct a new panel dataset containing information on the launch and operation of China's high-speed rail from 2003 to 2018, the period since China had the first high-speed train, as well as performance and litigation information of 3,488 firms listed firms in 404 cities between 2001 and 2018. The measurement of the transport infrastructure improvement is whether a high-speed railway has been built across the city that a listed firm is located in.

This study uses fixed effect panel data analysis in our baseline analysis testing the association between post high-speed rail and firm litigation. We include firm fixed effect, city fixed effect, and time fixed effect. We also examine the impact of high-speed rail on alternative identification strategies, such as specific risk for sued firms, and firms' misconduct as well. To further establish the linkage, we employ a parallel trend assumption and a placebo test. Historic transport infrastructure instrument provides identifying variation in more recent measures of high-speed rail. Our results remain robust and consistent after testing the three identification strategies above.

This study examines two potential accounts of why transport infrastructure improvement may have reduced litigation risk in China. The first account builds on the decrease in information asymmetry. We assume that information asymmetry is mitigated with the launch and operation of high-speed rail. The second account is based on the intervention of external monitoring and regulations. This assumption – accurate or not – could have helped firms reduce litigation risk. We examine these two accounts for the following reasons. In China's business environment, information asymmetry is a key factor of litigation risk due to China's vast territory, long geographical distance for travelling, and low cost of online fraud. The advent of high-speed rail has greatly reduced travel time and travel costs, which could help firms and the related parties have more face-to-face communications and more effectively resolve dispute and reduce litigation risks when decreasing information asymmetry. Meanwhile, the impact of China's local government protectionism for firms is also a key factor. The advent of high-speed rail has enabled external regulators, including central government and securities and regulatory commission, to monitor firms easier and more frequently. Under a stringent regulatory environment, as a consequence, firms may be less likely to take risk, and the possibility of firms' getting involved in litigation would also be reduced. To test these two possible accounts, we disaggregate litigation side by side after distinguishing the extent of information asymmetry and external monitoring. Our findings show that the shocks of high-speed rail inaugurations mitigate the accounts of information asymmetry and also facilitate external regulation and monitoring, which significantly contribute to the reduction in firm litigation risk.

This study uncovers evidence supporting these two channels, though of course, other channels could be operating simultaneously. This study does consider and extend evidence on the differential effect based on a firm's heterogeneity. We find that high-speed rail contributes more substantially to non-state-owned firms and firms that have fewer social connections, which also further verifies the two channels of external monitoring and information asymmetry. This extension also corroborates the robustness of the results about the association between high-speed rail and litigation risk.

Taken broadly, our findings support the proposition that infrastructure improvement matters in reducing litigation risk and shaping the business environment. In this research domain, some previous studies have provided evidence on the importance of infrastructure for the business environment (Collier and Venables, 2016, Gibbons et al., 2019, Limao and Venables, 2001). Our study builds on the work by delineating how a particular profound transformation of transport infrastructure can play a critical role in business and the economy. Our work is closely related to two broad strands of literature.

First, it contributes to the large literature that seeks to investigate the economic impact of transport infrastructure. Most existing studies focus on the conventional railway or road infrastructure, which essentially reduces barriers in the circulation of goods. Such impacts have been intensively investigated in the aggerate economy: these improvements in conventional transport enable and increase trade volumes, facilitate manufacturing and production, and ultimately increases aggregate economic productivity (Donaldson, 2018, Faber, 2014). A small number of recent studies have demonstrated the impact of infrastructure on firms in various scenarios. For example, Datta (2012) examined the impact of improved highways on Indian firms' production, and Holl (2016) estimated the effect of access to highways on manufacturing firms' productivity in Spain. Their underlying logic focused more on economic benefits such as decreased trade costs and increased real income levels. In our study, in contrast to conventional transport in the existing literature, high-speed rail is dedicated to passenger transit and rarely allows large scale freight shipments. This distinction of high-speed rail focusing on easier flow of people and thus more communication, as well as its impact on firms' conduct and behaviours in business activities would fill the gap in the literature in this regard.

Our evidence also aligns with emerging literature on corporate misconduct and litigation risk. Studies have found that litigation would lead to firms' economic and financial loss. Some early literature can trace back to the studies by Cutler and Summers (1988), and Bhagat et al. (1994). The economic loss caused by corporate litigation has received considerable attention, and the magnitude of the market value loss varies tremendously depending upon the type of misconducts (Murphy et al., 2009). Some studies also found that some consequences caused by litigation risk are much more difficult to quantify, such as corporate reputations. Built on Karpoff and Lott Jr (1993)'s seminal work on the reputational penalty firms bear from committing criminal fraud, other studies corroborated that litigation risk could provoke substantial damage to reputation (Karpoff et al., 2008, Karpoff et al., 2005). Prior studies also attempted to explore the factors that influence the likelihood of corporate litigation, including political value and culture of a firm (Hutton et al., 2015), executive turnover (Aharony et al., 2015), and gender of managers (Adhikari et al., 2019). Prior studies mainly focused on internal factors in corporate governance, while this study contributes to the understanding of how transport infrastructure, one of the external factors, influences corporate litigation risk.

Linking the infrastructure and the corporate litigation literature, we seek to contribute to the research literature by providing a new perspective to study the crucial topic on the impact of infrastructure on firms and businesses: the influence of improved transport infrastructure on firm litigation risk, with a research setting of the inaugurations of China's high-speed rail.

The remainder of this study is organised as follows. Section 2 introduces the background of China's business environment and corporate litigation, also introduces the development of China's high-speed rail. Section 3 discusses mechanisms through which transport infrastructure improvement can influence corporate litigation risk. Section 4 describes our data and outlines the empirical strategy. Section 5 presents the results and extensions, and section 6 concludes.

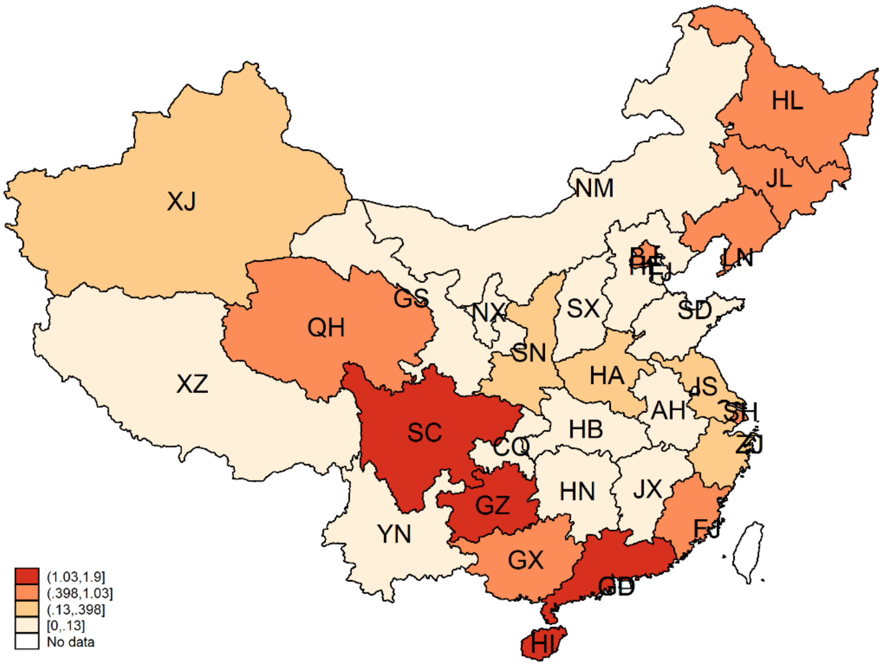
2 BACKGROUND

In the following, we discuss why China's current business environment seems to be breeding increasing legal risks, and then introduce the development of high-speed rail, and discuss its possible influence on business activities and environment.

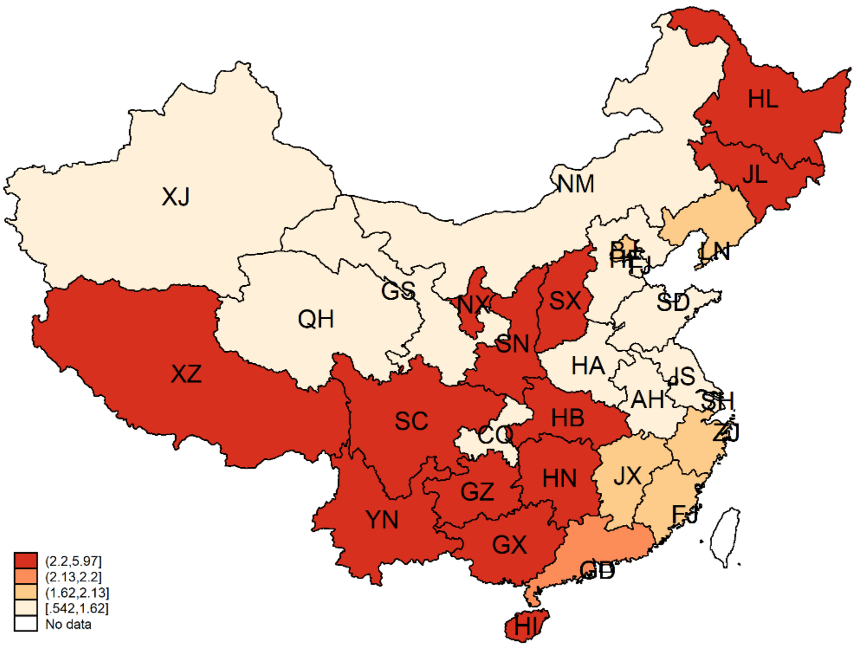
Business Environment and Corporate Litigation in China

China's culture is rooted and strongly influenced by three schools of traditional philosophies, including Confucianism, Buddhism, and Taoism, which provides some cultural context for the current issues of litigation risk. Confucianism and Taoism provide ethical guides to the "proper" behaviour of individuals. Confucianism is the main one that seeks to promote a proper way for individuals to behave. Taoism promotes inner peace of individuals and harmony with their surroundings. Buddhism seeks full awakening through attaining perfection in morality and knowledge while endeavouring to assist others on their path towards enlightenment. In this regard, China's cultural institutional environment provides moral and spiritual support that helps to encourage well-defined norms of behaviour and to create a sound environment (Wang and Li, 2016). However, while China has taken rapid and great strides in transforming its centrally-planned economy to a market-oriented economy, China's business environment has often been considered as more complicated, and it may often deviate from China's social expectations. When it is driven by economic interests, moral constraints might lose its controls on corporate behaviour, and an effective regulatory and legal system might have not yet been well-established and enforced. Since the reform and opening up after 1978, China's capital market and business environment, to some extent, did suffer from the situation that some firms disregard the management norms, moral standards of society, order of market, regulations and laws, when firms attempt to boosting rapid profitability and growth. Some listed firms may pursue efficiency, while they disdain equity. They emphasise innovation, while they neglect integrity and credibility. These features of China's business environment may affect corporate litigation risks (Lo and Tian, 2004).

Litigation is the practice of taking a case to court of law so that a judgement can be made to resolve a dispute or charge someone with a crime. Due to the immature business environment, firms in China face great legal risks during their development. Based on the data that we have collected from the Chinese Stock Market and Accounting Research database, we find that for listed firms, 45, 330 litigation cases have been declared from 1996 to 2018. The number of litigation cases of listed firms has been increasing. According to our data, the average value of a litigation case of listed firms is around 76,643,029.53 RMB. This is a large figure and could pose great risk on the listed firm's business and service. We show the geography of litigation risk in China in Figure 1. We can find that litigation risk of firms has been appearing in more provinces and increasing dramatically in most provinces in China from 2001 to 2018. We can also find that in many provinces in 2018, the average value of litigation of the listed firms is two times larger than the average total assets of the listed firms, which demonstrates an enormous risk that listed firms are facing in the business environment in many provinces.



1a. Litigation risk for firms in China in 2001



1b. Litigation risk for firms in China in 2018

Figure 1 The geography of litigation risk in China

Notes: In the Figure 1a and 1b, litigation risk in different provinces is measured by the total value of litigation of all the listed firms in each province divided by the total assets of the listed firms in the province.

China's High-Speed Rail

The investment and development of high-speed rail in China started more than two decades later than in developed countries, such as Germany, France, and Japan. However, China has witnessed a rapid development of high-speed rail since the beginning of the 21st century. China is the first, among countries with GDP per capita below USD 7, 000, to build high-speed rail, and now it has built the world's longest and most extensively used high-speed rail network, accounting for more than two-thirds of the total high-speed rail networks in the world (Lawrence et al., 2019).

Initially, the primary objective of high-speed rail was to provide additional passenger capacity to complement the overloaded conventional railway networks, and to provide improved service for medium distance travel. The Qinhuangdao-Shenyang passenger railway, the first newly built passenger-dedicated high-speed rail, started construction in 1999 and was inaugurated on 12 October 2003, marking the beginning of China's high-speed rail era. From 2003 to 2018, China put more than 29, 000 kilometres of high-speed rail lines into operation, and built 93 high-speed rail routes that connect 221 cities, nearly half of the Chinese cities. China's high-speed rail has made a wide range of impacts beyond the railway sector per se. With the rapid development of high-speed rail, its underlying rationale has extended as a critical way to build the regional and national connection networks, to stimulate economic development, reduce regional disparity and promote urbanisation.

Also known as bullet trains, China’s high-speed trains keep a fast running speed of 200 to 350kph (124 to 217 mph). They have been regarded as one of the most convenient and popular ways of travelling around China, because of their punctuality, speediness, safety, comfort, and cost-effectiveness. China’s high-speed trains have been patronised by a wide range of the population. High-speed train tickets are relatively affordable for the population, around a quarter of the base fares of high-speed train in Europe. Although the price of China’s high-speed train tickets is generally three to four times higher than that of very cheap “hard seat” tickets on conventional trains, a large majority of passengers are willing to choose the high-speed rail and pay a bit more for its high-quality service (Lawrence et al., 2019). In 2018, China’s high-speed rail traffic has grown to 2.001 billion passenger trips.

Apart from the unprecedented changes that high-speed rail has made to the transport sector, high-speed rail may also make substantial economic and social impacts (Jiao et al., 2017). Before the opening of high-speed rails, limited number of people would travel to other places because of long travel time and low frequencies of conventional transportation, or the high price and limited routes of airlines. Now, the developed high-speed rail networks and the reasonable ticket prices have made travel easier, convenient and affordable, which has become a crucial part of travel. High-speed rail is also accessible for different kinds of people if their cities have opened and been operating high-speed rail. For people and firms being located in cities along the high-speed railway lines, the high-speed rail may open up new economic opportunities for them.

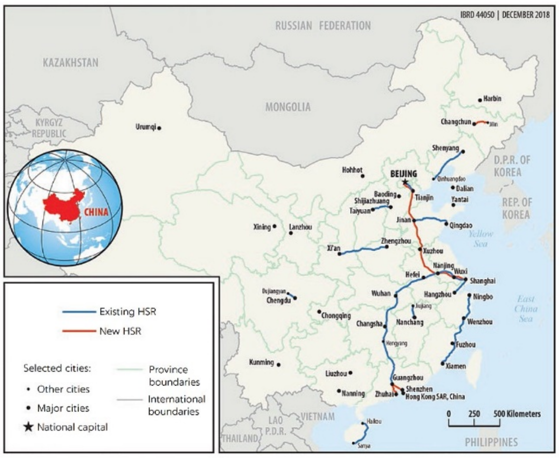
High-speed rail has substantively influenced individual's travel behaviour, business activities and communications, firm behaviour and performance, and rural and urban development (Chen and Vickerman, 2017). These benefits may include shortened travel time, increased labour mobility, promoted communication and exchange, facilitated business interactions, and improved safety during travel (Vickerman, 2018, De Rus and Inglada, 1997).

According to survey results from the World Bank, the predominant group of passengers took the high-speed rail for business purpose. For example, business trips accounted for 62% and 52% of passengers on Jinghu and Changji high-speed rail (Zhou et al., 2016). As the huge impact of high-speed rail has reached many aspects and a large proportion of passengers are for business trips, we need to address the effect of high-speed rail at the firm level, and more research is needed to develop a more comprehensive understanding of its influences and mechanisms. In this study, we will specifically draw our attention to the ethical and legal impact and its underlying mechanisms, in terms of how high-speed rail may have influenced business communication and firm behaviour, conduct, and litigation risk.

FIGURE 2
The Development of China’s High-Speed Rail Network

2a. High-speed rail network in 2008

2b. High-speed rail network in 2011



2c. High-speed rail network in 2014

2d. High-speed rail network in 2017

Sources of Fig. 2a-2d: China's High-Speed Rail Development (2019), World Bank; and the International Bank for Reconstruction and Development (IBRD)

3 THEORETICAL FRAMEWORK AND MECHANISMS

Theoretical Rationale

Our mechanisms are based on the following theoretical framework. There are two important preconditions that may lead to corporate misconduct and hence litigation: (1) opportunities for deception, fraud or other business malpractices that stem from the prevalent business environment, and (2) inadequate or ineffective restrictions that could keep firms away from exploiting these opportunities. The former is related to information asymmetry, and the latter is linked to external monitoring and regulations. As we have discussed in China's business environment, the long-distance for travelling and the e-commercial environment may cause more pitfalls for firms. Meanwhile, local protectionism may result in ineffective enforcement of regulations. We illustrate both in the following paragraphs and argue that high-speed rail may help to remedy them. These two processes will be discussed separately, but they could be intertwined.

First, information asymmetry could be a chief culprit that leads to a pitfall making firms get involved in litigation. Information asymmetry usually means one party has less or worse information than the other (Leland, 1979). Due to information asymmetry, it is highly likely that a firm with less information could not identify a "pitfall" and fall into the trap. On the other hand, even though the suspected offender could realise the risk to make misconduct, they may take advantage of the non-transparency and make covert operations that their peers, customers, and other stakeholders are unaware of. Thus, information asymmetry can foment misconduct and subsequent involvement in litigation risk (Werbel and Balkin, 2010).

Second, when firms operate where external legal restrictions barely exist or are ineffectively enforced, they may commit more misconduct and thus face a higher risk of being sued by other stakeholders (Vollaard and Van Ours, 2011). Under external regulation and monitoring, firms are forced to follow rules, such as promoting just and equitable principles of trade, protecting investors and the public interests. More external regulations and monitoring are crucial for firms, which could reduce the possibility of circumventing legal restrictions against misconduct. Therefore, when there are more regulations and monitoring from the external environment, firms realise the legal constraints and would be forced to regulate their behaviour, which reduces the litigation risk (Cheng et al., 2010, Glaeser and Shleifer, 2001).

In the following, we elaborate the theoretical framework based on the two mechanisms accounting for the impact of transport improvement. If the decreased information asymmetry account holds, inaugurating high-speed rail should lower litigation risk. Meanwhile, if the increased external regulation and monitoring account hold, inaugurating high-speed rail should also lower litigation risk.

Mechanism

Transport improvement and decreased information asymmetry

One account of how transport infrastructure improvement influences corporate litigation risk focuses on the rationale that different levels of information asymmetry may be associated with the different likelihood of litigation risk. For listed firms, information asymmetry would influence corporate internal management, including different departments at different levels, different branches and subsidiaries in different locations etc (Cai et al., 2015). Also, information asymmetry would influence the relations with customers, suppliers, competitors, investors, and the media etc (Krishnaswami and Subramaniam, 1999). Without adequate transport connections and communications, firms may be subject to information asymmetry. With the improvement of transport infrastructure, there will be more opportunities for personnel interactions and information exchanges among firms, which will decrease the level of information asymmetry (Brush and Artz, 1999, Coff, 1997). Due to information asymmetry, firms may make more mistakes, as they do not get sufficient information to follow the guidance and could not have adequate awareness of the restrictions, including regulations and laws. They may also take more risk in their operation, such as black case work and secretive handling. Thus, information asymmetry might trigger more litigation risk. In contrast, for firms connected with better transport infrastructure, they have quicker and frequent information flows and a higher level of transparency, which may reduce their involvement in litigation risk. For instance, Field et al. (2005) also found evidence demonstrating that information disclosure potentially deterred certain types of litigation. In this sense, litigation risk might be lower with the reduction of the level of information asymmetry.

China has a vast territory and it is difficult to travel between different cities. From a corporate operation perspective, the long-distance and its barriers on transport may lead to information asymmetry between different parties, as found by Basu and Chevrier (2011) and Boeh and Beamish (2012). A common case is that firms may not cheat other firms in the same city that they know each other, while they tend to cheat visitors and firms in other cities. Although the rapid application of online information technology may increase information flows and business services, they could not really effectively reduce the dispute and misconduct in business; conversely, they actually make the business environment more vulnerable and may increase corporate litigation risk (Ho¨ rnle, 2003). Due to its strong concealment, and low costs of breaking laws, the application of mobile internet, artificial intelligence and other new technologies has formed a threat to commercial integrity (Kraemer-Mbula et al., 2013). The online technologies have created fresh avenues for fraudsters to breach data and target prospective victims, which seriously deteriorates the business environment (Maimon and Louderback, 2019). One example is that the percentage of online fraud and cybercrime in China is increasing, and trading scams rank the first place as the largest category of all telecom and online fraud, with 39.6% of the total, according to statistics from the China Telecom and Online Fraud Governance Report in 2019. Without adequate face-to-face interaction, oral conversation, and field investigation, legal and intimate relations in business are difficult to be built. The difficulty of travelling and infrequent face-to-face communication lead to the mistrust, and firms could not resolve the disputes easily. The geographical and operational constraints may increase illegal and unethical behaviour of firms, and thus lead to more disputes and litigations.

Transport improvement and increased external monitoring and regulation

The second account of transport improvement and litigation risk builds on the impact of external monitoring and regulations. From a regulatory perspective, the effect of local protectionism on listed firms in China should also be highlighted. Since China's decentralisation reform in the 1990s, local governments tended to protect listed firms (Jin et al., 2005). Decentralisation has given local governments greater autonomy and authority in their own districts, greater incentives to develop the economy, and greater power in financial decision-making. However, although local governments have more control over financial spending, the central government has more control over financial revenue; thus, local governments have a higher pressure to maintain a balance between financial revenue and spending, and to increase more revenue (Barwick et al., 2017). Listed firms inevitably become regarded by local governments as a channel for financing. Moreover, the promotion of government officials highly relies on the local GDP performance, the local officials also have a great incentive to increase GDP, and to protect the functioning of listed firms, and even rescue some listed firms in trouble. Local protectionism from local government plays an important role in conniving local listed firms (Lee, 1998). With local protectionism, firms may commit more unethical and illegal behaviour, which leads to a higher risk of litigation that the firms will be involved in.

Transport is fundamental to connect firms and external regulators. The improvement of transport enables more monitoring and regulation activities to take place (Baldwin et al., 2012). High-speed trains substantively shorten the travel time between cities, and high-quality service increases the willingness of travelling (Chen, 2017). For regulators, it means a better opportunity to visit and monitor firms more easily. For example, given that China is vast in territory, it was traditionally challenging to reach other cities, which might take more than one day for travelling by conventional trains. Airlines are an alternative option, while the airlines in China could not connect so many cities as high-speed trains (Fu et al., 2012). Meanwhile, given its price and attributes, there are more and complex approval processes for administrative staff to take aeroplanes in China's political and administrative system, so travel by air is not that ideal option. These facts made regulators reluctant and difficult to monitor firms. As an old Chinese saying goes, "the heaven is high, and the emperor is far away", showing the difficulty of monitoring and regulating caused by the inconvenience of travel. However, since the inauguration and operation of high-speed trains in 2003, it has become easier for regulators to monitor firms. Once the targeted firms could be connected to high-speed rail, the time and cost of travel to conduct the external monitoring and regulations would be reduced, which certainly increases more monitoring and regulations and thus might deter firm's misconduct and litigation risk.

4 DATA AND METHODS

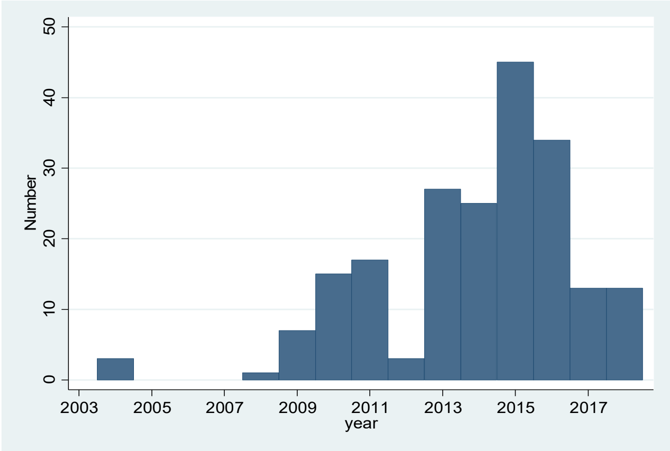
Testing our research question and the possible accounts require data tracking transport infrastructure and firm litigation risk in China. In the literature, to measure the improvement of transport infrastructure, various proxies and complicated approaches have been used (Baum-Snow, 2007, Donaldson and Hornbeck, 2016). In our study, we use the operation of high-speed rail as the measure of transport infrastructure improvement. We construct a dataset from various sources, covering the period from 2001 to 2018. Our sample regarding corporate litigation starts in 2001 and ends in 2018. The sample of high-speed railways starts in 2003, the year that China inaugurated its first high-speed rail route, and the sample ends in 2018. Based on the data, we find that, between 2003 and 2018, China inaugurated high-speed rail stations and services in 221 cities. As there is a distinction between conventional trains and high-speed trains, most high-speed railways and stations are newly built after 2003, which provides a shock in transport infrastructure and could serve as a natural experiment for us to examine its impact.

For the instrumental variable, as no pre-existing dataset contains relevant information, we constructed the dataset by manually searching and collecting historical data. As the listed firms in our sample are located in 404 cities in China, we manually collected historical information of the inauguration of the conventional railway in 404 cities since the year 1881. Other details of our datasets are as follows.

Transport Infrastructure Data

We first collect the information about the opening date of each city's high-speed rail. The data of high-speed rail are collected from the Chinese official website that provides official information on high-speed rail (http://www.gaotie.cn/). In November 2017, this official website released the date of the inauguration of each high-speed route. As the routes link different city stations, we could then know the date of the opening of the stations in different cities connected by this route. Information on the most recent data in 2018 is updated after checking the inauguration dates of the new routes. Figure 3 presents the distribution of high-speed rail inauguration year.

FIGURE 3
Distribution of High-Speed Rail Opening Year



Litigation and Firm-Level Data

Our research sample of firms contains information on Chinese A-share listed firms from 2001 to 2018. The sample begins in 2001 due to some key variables of firms only available since 2001. The data on litigation risk information, as well as accounting and corporate governance, are acquired from the Chinese Stock Market and Accounting Research database (CSMAR). These data are collected from the firms' annual reports and cover all the listed firms' litigation cases. The litigation statistics include the total amount involved in the litigation, and the detailed litigation information includes the specific record of each court hearing.

In our data analysis, firms with special treatment, including firms with prefix ST, *ST, PT in front of their trading stock code, are excluded, because these firms have been detected as poorly-performing firms and are facing a high risk to be delisted. Firms in the financial industry are also excluded because financial firms have different financial statements. In addition, firm-year observations in the first IPO year are excluded because their stock returns might experience huge volatility. The variables are winsorised at the 1% level to alleviate the impact of outliers. We finally obtain 30,542 observations containing the information of 3,488 firms in 404 cities.

Table 1 presents the distribution of pilot firms (treated firms, i.e., the firms in cities that have constructed high-speed rail) and non-pilot firms (non-treated or control firms, i.e., the firms in cities that do not have high-speed rail) in our sample from the year 2001 to 2018. In the sample, there are 16,862 items of non-pilot firms, and 13,680 items of pilot firms. The variation of pilot firms and non-pilot firms in different years shows a reasonable distribution of our research sample as a natural experiment.

TABLE 1
Distribution of Pilot Firms and Non-Pilot Firms

Year	Non-pilot	Pilot	Total
2001	926	0	926
2002	982	0	982
2003	1,028	0	1,028
2004	1,047	16	1,063
2005	1,122	16	1,138
2006	1,108	15	1,123
2007	1,114	12	1,126
2008	1,252	14	1,266
2009	1,210	156	1,366
2010	1,170	268	1,438
2011	1,117	666	1,783
2012	1,098	990	2,088
2013	1,043	1,204	2,247
2014	822	1,373	2,195
2015	582	1,710	2,292
2016	448	2,081	2,529
2017	386	2,325	2,711
2018	407	2,834	3,241
Total	16,862	13,680	30,542

Variables

In this study, we measure transport infrastructure improvement by identifying whether a high-speed railway has been built across the city, represented by the variable *Post HSR*. As the dates of opening high-speed rail are different, the impact of different opening dates might be different, considering the time lag of its impact. In our data analysis, if high-speed rail is inaugurated in the city in the year t, we set the opening year as year t, i.e., *Post HSR* is assigned as 1 in year t (in our data analysis, if high-speed rail is inaugurated in the city after 1 July of the year t, we set the opening year as year t+1, i.e., *Post HSR* is assigned as 1 in year t+1). If the city has not launched any high-speed rail, *Post HSR* is assigned as 0.

Litigation risk is measured by the total amount of litigation that a firm is involved in, and this study uses the natural logarithm of litigation amount to alleviate the extreme value. In the litigation risk variable, we cover both formal and informal options on dispute resolution, which include litigation via courts, and also arbitrage procedures. This study chooses the specific amount of litigation that listed firms perform as the defendant in each court to conduct a robust check. A litigation case might involve several court hearings, and this study only uses the litigation amount in the first court hearing for each case in each year, in our robust check. Besides, this study also divides the amount of litigation by total assets as another alternative variable.

This study selects the variables of firm-level characteristics that have been frequently considered in previous literature (de La Bruslerie and Le Maux, 2018, Lowry and Shu, 2002) to control their impact on firms' litigation risk, including firm size (Size), financial leverage (Lev), sales growth (Growth), return on assets (ROA), cash holding (Cash), and firm age (Age). Besides, weak corporate governance is considered as a crucial factor affecting litigation risk (Kim and Skinner, 2012), so this study also incorporates corporate governance characteristics, including institutional ownership (Institutional), number of board directors (Board Size), frequency of board meetings (Board Meeting), independent director ratio (Independence), and analyst following (Analysts). The definitions of variables are shown in Table 2.

TABLE 2
Variable Definitions

Variables	Definitions
Litigation	The natural logarithm of total litigation amount that the listed firm is involved in
Post HSR	1 for the year t if the city has launched and been operating high-speed rail, and 0 otherwise
Size	The natural logarithm of firms' total assets
ROA	Return on assets, which is the ratio of net earnings to total assets
Lev	Financial leverage, which is the ratio of total liabilities to total assets
Growth	The growth rate of sales in year t
Cash	Cash holding level, which is cash and cash equivalents scaled by total assets
Age	The number of years that the firm has been listed
Institutional	Total shareholding of institutional investors
Board Size	The natural logarithm of the number of board directors
Meeting	The natural logarithm of the number of board meetings
Independent	The percentage of independent directors in the director board
Analysts	The natural logarithm of one plus the number of analysts who follow the firm

Empirical Model

By using the inauguration of China's high-speed rail, this study investigates the impact of transport infrastructure improvement on corporate litigation risk based on a difference-in-difference approach. This staggered inauguration of China's pilot programme at different time and different cities allows this study to include the city and year fixed effect in the model, which represents a general case of standard difference-in-difference strategy (Bertrand and Mullainathan, 2003, Bertrand et al., 2004, Roberts and Whited, 2013). The regression model is shown in equation 1 and this study not only controls the city, year fixed effects but also includes firm, and industry fixed effects. A negative and significant coefficient on *Post HSR* would illustrate that the inauguration of high-speed rail reduces firm litigation risk. On the contrary, a positive and statistically significant coefficient on *Post HSR* implies inauguration of high-speed rail increases firms' litigation risk.

$$Litigation = \alpha + \beta Post\ HSR + \gamma Control + \sum City, Year, Firm \qquad (1)$$

5 EMPIRICAL RESULTS

Descriptive Statistics

Panel A of Table 3 reports the summary statistics for the main variables. The mean of *Post HSR* is 0.448, showing that 44.8% of firm-year observations are affected by high-speed rail. In the sample, firms on average get 3.4% return on assets, and have 44.9% leverage, 19.7% sales growth, 15.8% cash holding, 6.0% institutional ownership, and 35.4% independent director ratio.

Panel B and C of Table 3 present the results of the Pearson correlation analysis. The largest correlation coefficient among independent and control variables is 0.411, which is smaller than 0.5 and unlikely to cause multicollinearity problems. Besides, the mean-variance inflation factor of equation 1 is 1.43 and the largest VIF is 2.05, which are smaller than 5, indicating a low likelihood of multicollinearity problems.

TABLE 3
Summary Statistics

Panel A: Descriptive Statistics

Variable	N	Mean	Std. Dev	Min	Max
Litigation	30,542	2.953	6.643	0.000	22.001
Post HSR	30,542	0.448	0.497	0.000	1.000
Size	30,542	21.927	1.244	19.178	26.297
ROA	30,542	0.034	0.061	-0.528	0.220
Lev	30,542	0.449	0.200	0.035	0.901
Growth	30,542	0.197	0.447	-0.802	5.223
Cash	30,542	0.158	0.121	0.004	0.703
Age	30,542	9.090	6.176	1.000	26.000
Institutional	30,542	0.060	0.076	0.000	0.482
Board Size	30,542	2.171	0.210	1.609	2.833
Meeting	30,542	2.157	0.392	0.693	3.296
Independent	30,542	0.354	0.080	0.000	0.600
Analysts	30,542	1.307	1.159	0.000	3.850

Panel B: Pearson Correlation Analysis

	Litigation	Post HSR	Size	ROA	Lev	Growth
Litigation	1					
Post HSR	0.157***	1				
Size	0.088***	0.209***	1			
ROA	-0.136***	0.027***	0.064***	1		
Lev	0.087***	-0.092***	0.411***	-0.343***	1	
Growth	0.001	0.003	0.059***	0.202***	0.042***	1
Cash	-0.070***	0.027***	-0.194***	0.262***	-0.395***	0.019***
Age	0.174***	0.149***	0.357***	-0.112***	0.284***	-0.045***
Institutional	-0.045***	0.044***	0.234***	0.251***	0.020***	0.100***
Board Size	-0.054***	-0.175***	0.179***	0.017***	0.143***	-0.008
Meeting	0.129***	0.181***	0.253***	-0.039***	0.171***	0.105***
Independent	0.050***	0.241***	0.161***	0.037***	-0.010*	0.014**
Analysts	-0.051***	0.181***	0.449***	0.373***	-0.047***	0.108***

Panel C: Pearson Correlation Analysis

	Cash	Age	Institutional	Board Size	Meeting	Independent
Cash	1					
Age	-0.166***	1				
Institutional	0.093***	0.079***	1			
Board Size	-0.051***	0.026***	0.022***	1		
Meeting	-0.069***	0.125***	0.131***	-0.091***	1	
Independent	0.006	0.133***	0.127***	-0.336***	0.209***	1
Analysts	0.108***	-0.028***	0.527***	0.047***	0.186***	0.221***

Notes: Sample is from 2001 to 2018. All the continuous variables are winsorised at the 1st and 99th percentiles to mitigate the impact of outliers. *p < .10, ** p < .05, *** p < .01

Estimated Impact of High-Speed Rail on Corporate Litigation Risk

Baseline estimates

Table 4 shows the main regression results on the relationship between high-speed rail and litigation risk. In Panel A, the first two columns report the univariate regression without control variables. The next two columns incorporate firm-level characteristics as control variables. The final two columns add corporate governance characteristics as control variables. The columns (1), (3), and (5) only control the city and year fixed effects. The columns (2), (4), and (6) include firm and industry fixed effects.

In all the columns, the coefficients of *Post HSR* are negative and significant at the 1% level, indicating that there was a larger decline for pilot firms' litigation risk from pre-HSR to post-HSR inauguration than non-pilot firms. More specifically, the magnitude of *Post HSR* is 15.85%[2] relative to the average litigation level, illustrating that the inauguration of high-speed rail would reduce about 15.85% litigation risk and the impact is economically significant.

For the control variables, *ROA* has a significantly negative coefficient, indicating that firms with high earnings performance are associated with lower litigation risk. Besides, the coefficients of *Analyst* and *Top1* are also negatively

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[2] Based on the coefficient of *Post HSR* on column 6 of Panel A in Table 3, the magnitude of high-speed rail inauguration is -0.468/2.953=-18.18%

significant, illustrating that firms with more analyst followings and larger ownership are associated with less litigation concern.

Alternative measurement strategies

After the baseline estimates, we examine the impact of *Post HSR* on litigation risk by using alternative measures. The first alternative measure on litigation risk is the specific litigation amount that a listed firm involved as a defendant in its first litigation court. The second alternative measure on litigation risk is the ratio of litigation amount to total assets. In addition, we also consider the impact of *Post HSR* on a firm's misconduct. We use the natural logarithm of the number of firm's misconducts. The measurement of misconduct is counted based on the number of punishments, mainly due to their financial frauds or law violations.

Panel B of Table 4 reports the results of alternative measurement for litigation risk. The coefficients of *Post HSR* in column (1), and (2) are both negatively significant, showing that even when we use alternative measurement on litigation risk, we still find that the inauguration of high-speed rail reduces firms' litigation risk substantially. This is in line with previous results. The coefficient of *Post HSR* in column (3) is negatively significant, indicating that high-speed rail reduces firms' misconduct. These results in the three alternative dependent measures further verify the legal and ethical impact on firms due to the inauguration of high-speed rail.

TABLE 4
Baseline Results

Panel A Baseline Estimates

VARIABLES	(1) Litigation	(2) Litigation	(3) Litigation	(4) Litigation	(5) Litigation	(6) Litigation
Post HSR	-0.683***	-0.478***	-0.602***	-0.470**	-0.590***	-0.468**
	(-3.839)	(-2.600)	(-3.432)	(-2.565)	(-3.363)	(-2.556)
Size			-0.137*	-0.025	-0.063	0.006
			(-1.843)	(-0.173)	(-0.770)	(0.040)
ROA			-11.501***	-7.473***	-10.174***	-7.126***
			(-11.757)	(-7.460)	(-10.022)	(-7.004)
Lev			1.900***	0.715	1.580***	0.573
			(4.189)	(1.289)	(3.443)	(1.032)
Growth			0.276***	0.034	0.226**	0.016
			(2.789)	(0.377)	(2.284)	(0.182)
Cash			0.226	-0.374	0.395	-0.362
			(0.439)	(-0.692)	(0.762)	(-0.669)
Age			0.116***	4.935**	0.111***	4.966**
			(7.754)	(2.385)	(7.330)	(2.430)
Institutional					-1.875**	0.368
					(-2.354)	(0.466)
Board Size					-0.290	-0.355
					(-0.851)	(-0.874)
Meeting					0.921***	0.568***
					(5.909)	(4.045)
Independent					-1.245	-1.190
					(-1.140)	(-1.081)
Analysts					-0.151**	-0.147**
					(-1.986)	(-1.981)
Constant	3.259***	3.167***	4.627***	-41.152**	2.523	-41.931**
	(29.516)	(38.469)	(2.985)	(-2.173)	(1.424)	(-2.234)
Observations	30,542	30,542	30,542	30,542	30,542	30,542
Adjusted R-squared	0.120	0.390	0.149	0.395	0.152	0.395
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	Yes	No	Yes	No	Yes
Firm FE	No	Yes	No	Yes	No	Yes

Notes: Panel A presents the effect of high-speed railway opening on firms' litigation risk. The dependent variable is firms' litigation risk, measured as the natural logarithm of total litigation amounts. Column (1), (3), and (5) only control the city and year fixed effects and column (2), (4), and (6) include firm and industry fixed effects. The first two columns report the univariate regression without control variables. Next two columns incorporate firm-level characteristics as control variables. The final two columns add corporate governance characteristics as control variables.

Panel B: Alternative Measure for Dependent Variables

VARIABLES	(1) Specific amount of litigation	(2) Ratio of litigation amount to total assets	(3) Misconduct
Post HSR	-0.195*	-0.153*	-0.011*
	(-1.688)	(-1.650)	(-1.884)
Observations	30,542	30,542	30,542
Adjusted R-squared	0.233	0.270	0.084
Control	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

Notes: In Panel B, the dependent variable in column (1) is the specific litigation amount which a listed firm is a defendant in a court. The dependent variable in column (2) is the ratio of litigation amount to total assets (unit: percentage). The dependent variable in column (3) is on their misconduct, which is the natural logarithm of one plus the number of punishment due to the financial fraud or law violation. We include the same control variables of the baseline estimate tables but do not tabulate them for the sake of brevity. This study also controls for firm, industry, city and year fixed effects and clusters standard errors at the firm level. T-statistics are reported in parentheses. Standard errors at the firm level and T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

Further Evidence: Impact of Corporate Addresses, Subsidiaries and Cities

Impact of firms' addresses

Our baseline estimates are based on the matching of the listed firm with the city by using their registered address, while a listed firm might be located in another city that is not the same city as where they are registered. For example, they might be mainly located in their office addresses (actual operating addresses) or they have moved to new places. To alleviate this concern, we collect the data of listed firms' office addresses. Then, we replace the registered address by using the office address and present the results in panel A of Table 5. The coefficients of *Post HSR* are still negative and significant. This result demonstrates that the reliability of our matching on corporate addresses, and the result is consistent with our baseline estimates.

Impact of firms' subsidiaries

As the firms in our sample are all listed firms, they are all large firms and may have different subsidiaries or branches in different cities, while one limitation is that this study only matches the high-speed rail information with the city via their registered addresses (or office addresses). Although listed firms' headquarters arguably play the most important role for these firms, and the infrastructure conditions in the cities that their headquarters are located in are quite critical, there still might be the concerns on the measurement of the location. To tackle this concern, this study needs to identify and test the firms that have a higher level of activities in their headquarters.

By introducing a proxy that measures sales concentration in regions, we calculate firms' sales concentration in regions by using the Herfindahl index, shown in equation 3. $Sales_{i,s,t}$ denotes the sales in region j of firm i in year t. $Num_{i,t}$ is the number of regions that firm i covers in year t. A higher value of HHI denotes a higher sales regional concentration.

$$HHI_{i,t} = \sum \left(\frac{Sales_{i,j,t}}{Num_{i,t}} \right)^2 \tag{3}$$

We keep the sample with an HHI index over 90%, 80%, 70%, and 60% respectively and report the results in panel B of Table 5. The coefficients of *Post HSR* are negatively significant in all groups, showing that the main results are still robust and valid when the regional diversified firms are excluded. When we compare the magnitude of *Post HSR* in column (1), (2), (3) and (4), we can find that high-speed rail has a larger impact for firms that have more services in their headquarters and that have fewer subsidiaries.

Impact of major strategic cities.

Another concern in this study is that the governments might launch high-speed rail earlier in the major strategic cities, like provincial capital cities, and sub-provincial municipalities. To alleviate this concern, this study interacts *Post HSR* with whether a city is a provincial capital city, a sub-provincial municipality or a major city (either a provincial capital city or a sub-provincial municipality). From the results on Panel C of Table 5, we find that the coefficients of *Post HSR* × *Provincial Capital City*, *Post HSR* × *Sub-Provincial City*, and *Post HSR* × *Major City* are insignificant. Some reasons might help to understand why no evidence that high-speed rail these major strategic cities impact firms' litigation risk could be found. For example, major strategic cities have better legal systems and advanced transport networks, so firms would engage lesser in misconduct behaviour and the inauguration of high-speed rail has less impact on these firms. However, the coefficients of *Post HSR* × *Non-Provincial Capital City*, *Post HSR* × *Non-Sub-Provincial City, and Post HSR* × *Non-Major City* are all negative and significant. These results indicate that the effect of high-speed rail is more pounced in the non-major cities.

In addition, for Chinese listed firms that their headquarters are located in the major largest cities, due to limited space and high costs in these major cities, they have a higher possibility to have more subsidiaries in other cities. For the listed firms in smaller cities, their services and activities tend to be more concentrated, and the impact of high-speed rail is likely to be larger, which is also consistent with the evidence that we find in the last section on the impact of firms' subsidiaries.

TABLE 5

Further Evidence on High-Speed Rail and Litigation Risk

Panel A: Replace the Register Address with the Office Address

This study uses the office address to replace the register address to match the city-level data.

VARIABLES	(1) Litigation	(2) Litigation
Post HSR	-0.375**	-0.356**
	(-2.075)	(-1.978)
Observations	30,542	30,542
Adjusted R-squared	0.398	0.402
Control	No	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Firm FE	Yes	Yes

Notes: This table presents further evidence based on the baseline regressions. We include the same control variables of the previous tables and also control for the firm, industry, city and year fixed effects and cluster standard errors at the firm level. T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

Panel B: Excluding the Firms with A Low Regional Sales Concentration

VARIABLES	(1) >90% Litigation	(2) >80% Litigation	(3) >70% Litigation	(4) >60% Litigation
Post HSR	-0.701***	-0.661***	-0.634***	-0.660***
	(-3.167)	(-3.064)	(-3.013)	(-3.216)
Observations	23,045	23,791	24,683	25,634
Adjusted R-squared	0.432	0.428	0.424	0.417
Control	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Notes: As listed firms are large firms, and their service may not in the headquarter address, which is what we used to match the location of firms and the location of high-speed train service. To address the concern that listed firms may have multiple operation addresses and services in different areas, we try to address this by using excluding firms that have low regional concentration. The regional sales concentration is calculated by the sales distribution in different areas, shown as the following equation. $Sales_{i,s,t}$ represents the sales in region j of firm i in year t. $Num_{i,t}$ is the number of regions firm i covers in year t. A higher value of HHI denotes a higher sales regional concentration. This study only keeps the firms with HHI over 90%, 80%, 70%, 60% in column 1 to column 4.

$$HHI_{i,t} = \sum \left(\frac{Sales_{i,j,t}}{Num_{i,t}} \right)^2$$

Panel C: Impact of Major Cities in China

VARIABLES	(1) Litigation	(2) Litigation	(3) Litigation
Post HSR × Provincial Capital City	-0.109		
	(-0.340)		
Post HSR × Non-Provincial Capital City	-0.616***		
	(-2.966)		
Post HSR × Sub-Provincial Municipality		-0.496	
		(-1.411)	
Post HSR × Non-Sub-Provincial Municipality		-0.457**	
		(-2.279)	
Post HSR × Major City			-0.306
			(-1.092)
Post HSR × Non-Major City			-0.586***
			(-2.694)
Observations	30,542	30,542	30,542
Adjusted R-squared	0.395	0.395	0.395
Control	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes

Notes: Following the efforts to address firms that may have activities in different cities, we further address this issue when examining their impact on firms in different cities. Firms in the largest cities tend to have more subsidies in other smaller cities, so we assume that the firms in the largest cities may not produce measurement issues in terms of firms' location. In this test, Major City denotes that cities are either provincial-capital cities, or sub-provincial municipalities.

Robustness of Main Results

Parallel trend assumption.

To better establish the causal effect of high-speed rail on firm litigation risk, this study further uses the parallel trend assumption. We first examine whether the sample satisfies the parallel trend assumption, which is an important assumption of difference-in-difference design. Treated firms should have no substantial differences with control firms before the launch of high-speed rail (Roberts and Whited, 2013, Atanasov and Black, 2019). To examine this assumption, this study carries out the dynamic model, shown in equation 2. *Before2*, *Before1*, *Current*, *After1*, and *After2+* is set as one in the year -2, -1, 0, 1+, 2+. *Before2* and *Before1* measure whether litigation difference between treated firms and control firms is statistically parallel during the two years before the high-speed rail's inauguration. In addition, this approach could reveal the dynamic effect of high-speed rail's inauguration and could alleviate endogeneity concerns (Bertrand and Mullainathan, 2003, Amiram et al., 2017).

$$Litigation = \alpha + \beta_1 Before2 + \beta_2 Before1 + \beta_3 Current + \beta_4 After1 + \beta_5 After2\,plus$$
$$+\gamma Control + \sum City, Year, Industry, Firm \qquad (2)$$

Table 6 presents the results of the parallel trend examination. Both the coefficients of *Before2* and *Before1* are not significant, implying that there are no substantial distinctions between pilot firms and non-pilot firms before the inauguration of high-speed rail. In contrast, the coefficients of *After2+* is significantly negative with *Litigation*, showing that the impact of high-speed rail is only effective after two years of its inauguration.

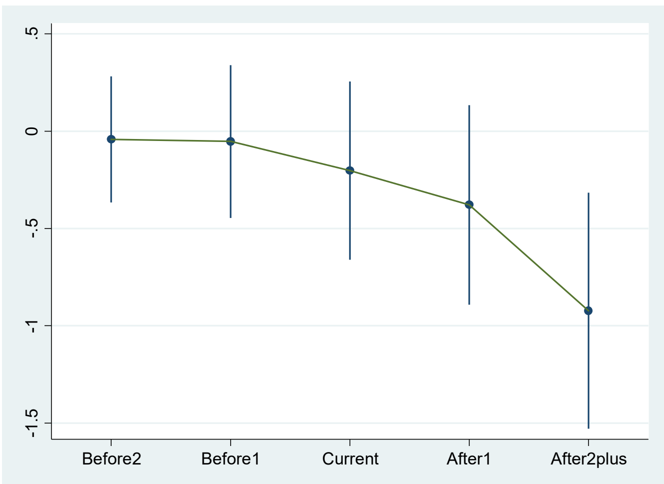
Figure 4 plots the distribution of coefficients by year. In the first two years before the inauguration of high-speed rail, the coefficients are close to zero and stable, consistent with the parallel trend assumption. The coefficients' magnitudes become larger as the time increases, indicating that the impact of high-speed rail is increasingly stronger.

TABLE 6
Parallel Trend Assumption

VARIABLES	(1) Litigation	(2) Litigation
Before2	-0.023	-0.042
	(-0.136)	(-0.256)
Before1	-0.053	-0.053
	(-0.263)	(-0.264)
Current	-0.192	-0.203
	(-0.818)	(-0.867)
After1	-0.399	-0.379
	(-1.522)	(-1.450)
After2+	-0.930***	-0.922***
	(-2.987)	(-2.985)
Observations	30,542	30,542
Adjusted R-squared	0.391	0.396
Control	No	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Firm FE	Yes	Yes

Notes: This table presents the results of the parallel trend assumptions. Before2, Before1, Current, After1, After2+ denote the year for -2, -1, 0, +1, +2 onwards, and year 0 denotes the year that the city opens the high-speed rail. This study includes the same control variables of the previous tables but does not tabulate them for the sake of brevity. This study also controls for firm, city and year fixed effects, and clusters standard errors at the firm level. T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

FIGURE 4
Parallel Trend Assumption

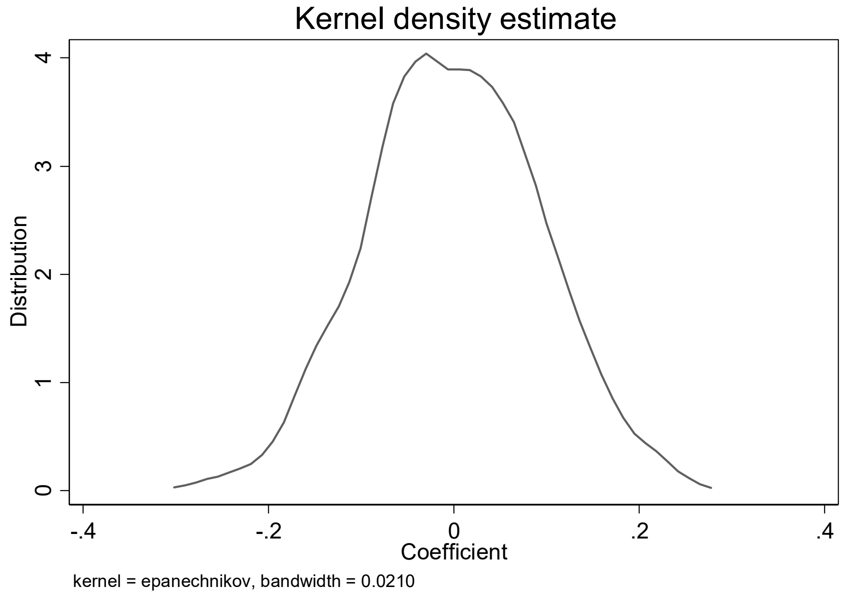


Notes: This figure plots the coefficient in column (2) of table 4. These coefficients denote the treated group in year -2, -1, 0, 1+, 2+. The vertical axis is the magnitude of the regression coefficient.

Placebo test.

To verify that the impact of high-speed rail is a causal effect rather than a random result, we further employ a placebo test. We randomly assign the inauguration of high-speed rail to the sample firms and conduct the regressions. After repeating these procedures for 1,000 times, we obtain 1,000 regression coefficients of *Post HSR*. In Figure 5, the coefficients of *Post HSR* are normally distributed around zero, which is substantially different from the baseline regression results in Table 4. Besides, we also examine whether the mean and median are different from zero. The p-value of the T-test and Wilcoxon Signed-Rank Test are larger than 0.1 and it shows that the coefficient is not different from zero. These results indicate that the impact of high-speed rail is causal rather than random.

FIGURE 5
Placebo Test



	Mean T-test	Wilcoxon Signed-rank Test
Mean/Median	0.002	0.000
T statistic/ Z Statistic	0.665	0.677
P value	0.506	0.498

Notes: This study carries out a placebo test. We randomly assign the opening year for each corporate and run the regression. After repeating these procedures for 1,000 times, we acquire 1,000 coefficients of Post. We also present the results of the Mean T-test and Median Wilcoxon Signed-Rank Test.

Instrumental variable.

Unlike the studies examining the economic return of infrastructure improvement that may cause reverse impact, our empirical design on corporate litigation risk would not suffer from this concern. In other words, corporate litigation is not likely to lead to the inauguration of high-speed rail in a city (Donaldson and Hornbeck, 2016). Perhaps an empirical concern is that the inauguration of the high-speed rail could be affected by some endogeneity issue, which may lead to a spurious correlation between the inauguration of high-speed rail and the decrease of corporate litigation risk. Although the inauguration of high-speed rail and its route was designed and arranged by related departments of the state rather than simply by the local governments and enterprises, endogeneity concerns may still exist. Some variations in the construction and inauguration of high-speed rail might be influenced by terrain, politics or incentives to connect particular cities. Thus, to some extent, the inauguration of high-speed rail is not randomly assigned. For instance, cities that are economically developed and human-intensive, are more likely to launch high-speed rail. These cities are usually with a better legal system and strong regulations that make corporate litigation risk lower than other cities. Thus, firms located in these cities might engage less in misconduct behaviour.

We use an instrumental variable (IV) to alleviate this concern. To be valid instruments, the instruments must only predict the recent inauguration of high-speed rail through their influences on the inauguration of modern transport networks, conditional on other covariates. The correlation is expected to be strong. Second, the instrument cannot be correlated with the error term (unobserved variables) that influences corporate litigation risk. This means that the instrument cannot suffer from the same problem as the original predicting variable, which needs to satisfy the exclusion restriction. This study generates an exogenous variation by employing the inaugurations of conventional rail in history as instruments for the inaugurations of recent modern high-speed rail. The validity of this instrument is based on the fact that conventional rail and modern high-speed rail were built in different historical background and served quite different purposes. We anticipate that the instrument, the railway age of conventional rail, influences corporate litigation risk only through their effects on the inaugurations of modern high-speed rail. Our identification strategy is similar to that of Baum-Snow (2007), Hsu and Zhang (2014), Duranton et al. (2014), and Baum-Snow et al. (2018), who used historic transport instruments. This study uses the historic railway information, the earliest year a city inaugurated a conventional rail station, as the instrument; more specifically, the number of years that a city has conventional rail, Railway Age.

For example, the first railway in China in history was inaugurated in Tangshan City in Hebei Province in the Northern China in the year of 1881, which was the seventh year of Guangxu's reign in the Qing Dynasty. This first railway, Tangxu Railway, connected Tangshan Station and Xugezhuang Station within Tangshan

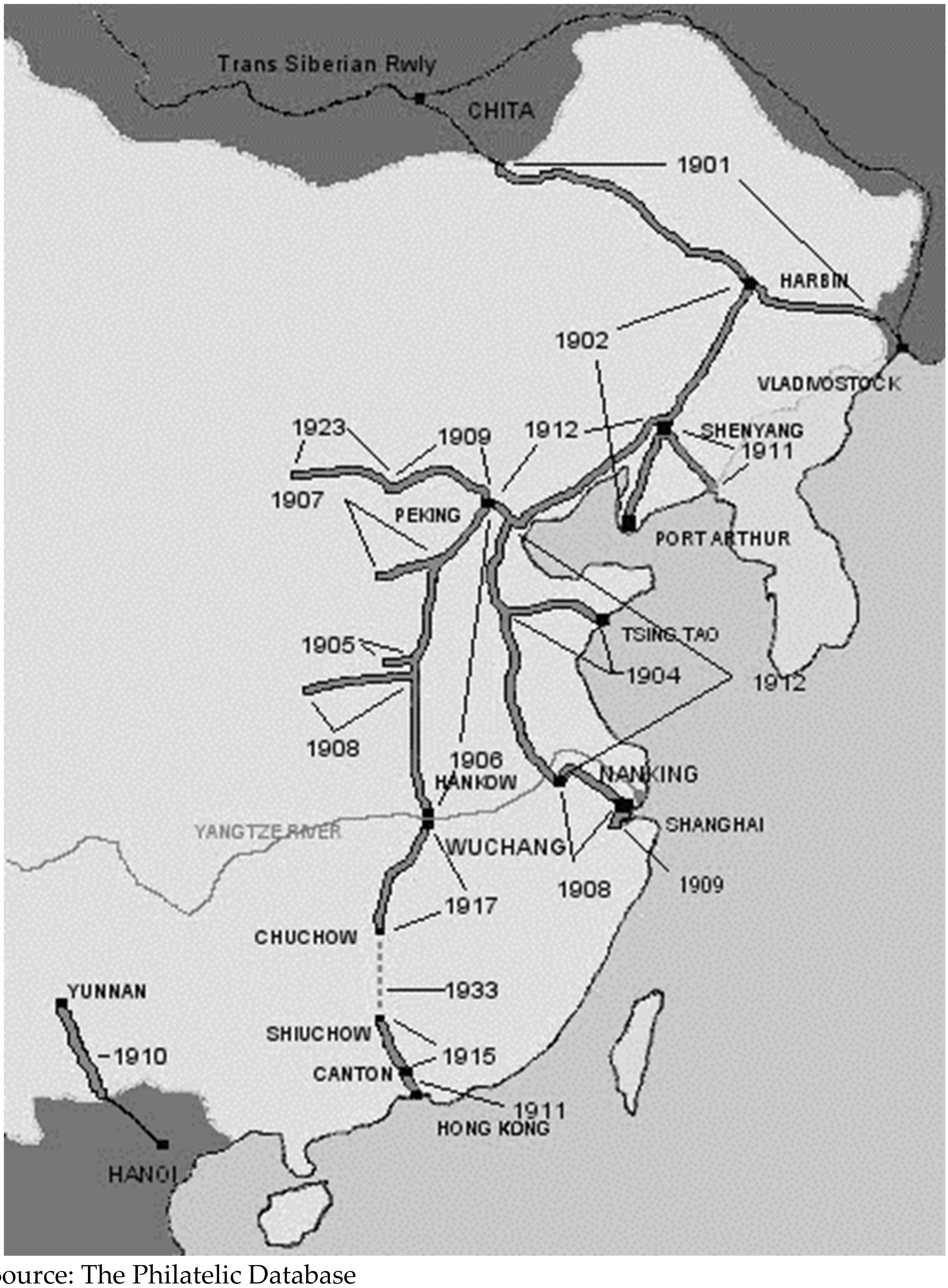
City, which was originally designed for carrying coal. After more than one hundred years, Tangshan City inaugurated its first high-speed rail in 2013. After obtaining the historic railway inauguration data, we can now get the time gap between the current year (2018) and the earliest conventional railway opening year (1881), *Railway Age*, for Tangshan is 137 years. If the observed year is 2010, *Railway Age* for Tangshan is 129, which keeps the instrumental variable time-variant. We manually searched and checked the historical data about the first inauguration of the conventional railways of other 403 cities and calculated their information of *Railway Age*.

We explain the details of the validity of our instruments as follows. First, a city with a longer conventional railway history is more likely to launch high-speed rail. To construct railways, a critical condition is to explore routes by searching for an easy route to travel and lay tracks. Furthermore, building both conventional railroad tracks and high-speed railroad tracks requires strong and stable subgrade. The construction of high-speed railways tends to follow routes of the old railways, and some old railways may also be converted to high-speed rail by saving the cost of levelling and grading a roadbed (Duranton et al., 2014). Therefore, the history of conventional rail in a city is likely to impact and predict the inauguration of modern high-speed rail.

Second, the instrumental variable, *Railway Age*, is unlikely to be correlated with the error term that affects firms' litigation risk directly, as explained below.

Railways started to be built in China during the Qing Dynasty in the late 19th century. The lack of industrialisation and the Qing government's conservative and hostile attitude toward railways led to the late arrival of railway construction. After Qing China's defeat in the First Sino-Japanese War, the government recognised the importance of modernisation, and in 1895 the government began to grant rail concessions to foreigners due to their compelling. In this historical context, China experienced rapid development in rail during 1895 – 1911. In the early twentieth century, major railways were built to connect north-south and aimed to link political and commercial cities. A major expansion of conventional rail networks was financed by Russia and Japan in the northeast (Manchuria). The earlier conventional rail system built before 1949 were designed to expedite the extraction of agricultural products and raw materials. In 1945, just after the Second Sino-Japanese War, over 27, 000 km (17, 000 mi) of rail networks were constructed. Among these railways, nearly half – 13, 000 km were located in Manchuria (Ginsburg, 1949). A large percentage of Chinese conventional rail networks had been constructed and inaugurated before the establishment of People's Republic in 1949, although a number of railways were unusable due to the Second Sino-Japanese War of 1937-1945, and Chinese Civil War during 1945-1949. From the 1950s to the 1970s, the Soviet influenced the construction of rail networks, and during this period, the rail networks expanded to link the resource-rich regions of western China with manufacturing centres in eastern China (Baum-Snow et al., 2017).

FIGURE 6
Early Development of China's Historic Railways (1905-1911)



Source: The Philatelic Database

With significant distinction, the distribution of firms now tends to be determined by external trade, service sectors, supply to domestic market etc. The economic geography of the recent two decades has changed largely and become quite different from the situation around 100 years ago. Contrary to the era highly influenced by foreign powers like Japan and the Soviet, the recent two decades have now been prone to the market. Due to the variety of actors, motivations and drivers behind the construction of the conventional railways in the period with tremendous historical changes, it is not likely that the conventional rail networks built and inaugurated in the earlier epoch in China's history would impact on the post-2003 internal reorganisation of city conditions, corporate characteristics and environment (Baum-Snow et al., 2017). Hence, using a historic rail instrument is reasonable.

After providing the rationale why *Railway Age* meets the two critical requirements for an instrumental variable, Table 7 presents the two-stage IV regression results. P-value of the under-identification test is 0.002, indicating that the IV regressions do not suffer from under-identification problems. Besides, the Cragg-Donald Wald F statistic is larger than the 10% Stock-Yogo weak ID test critical values, showing that there are no weak-instrumental variable problems. In column (1) and (3), the coefficient of *Railway Age* is positive and significant at the 1% level, illustrating that *Railway Age* of conventional rail has a positive effect on the inauguration of high-speed rail. In other words, cities which have longer rail station history are more likely to be earlier to inaugurate a high-speed rail. In column (2) and (4), the coefficients of *Predicted Post HSR* are both negatively significant, implying that our previous estimates that the inauguration of high-speed rail reduces corporate litigation risk are robust after considering the possible endogeneity concern.

TABLE 7
Instrumental Variable Regression

	(1) Post HSR	(2) Litigation	(3) Post HSR	(4) Litigation
Railway Age	0.031***		0.031***	
	(4.015)		(3.995)	
Predicted Post HSR		-9.100**		-8.813**
		(-2.115)		(-2.087)
Observations	30,093	30,093	30,093	30,093
Adjusted R-squared	0.707	-0.212	0.707	-0.191
Control	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Under identification test	9.866		9.825	
	0.002		0.002	
Weak identification test	119.125		120.419	
10% Stock-Yogo weak ID test critical values	16.38		16.38	

Notes: This table reports the instrumental variable regression. The instrumental variable *Railway Age* is the time gap between the current year (2018) and the earliest conventional railway opening year in a city in the history. This study includes the same control variables, and also controls for firm, city and year fixed effects and clusters standard errors at the firm level. T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

Disaggregating Litigation Effects to Examine the Possible Accounts

This study further disaggregates the effect of high-speed rail on firm litigation risk to explore accounts of why these effects reduce. Firstly, we separately examine the effects on specific types of firms to see where effects are concentrated. According to the results in Table 8, the coefficient of *Post HSR* is significant and negative in the low transparency group while insignificant in the high transparency group, indicating that high-speed rail contributes most to corporate information asymmetry and thus reduces corporate litigation risk. We also examine corporate information dissemination and asymmetry by using a proxy of media coverage, where firms have higher media coverage tend to have more information dissemination and lower information asymmetry. Similarly, the coefficients of *Post HSR* is significant and negative in the group that have less media coverage while insignificant in the other group. These results indicate that the impact of high-speed rail on groups with less media coverage contributes most to the overall effects that high-speed rail has on litigation risk.

We further verify the robustness of the results by conducting a parallel trend examination. The coefficients of *Post HSR* in the low transparency (or high information asymmetry) group of *After2* is significantly and negatively associated with litigation risk. These results are still consistent when we use the media coverage proxy in the parallel trend examination. The same pattern of results continues to hold, and from what we have overserved, this also suggests the results are unlikely to be driven by bias in measurement.

Overall, this pattern of results indicates that high-speed rail effect on firm litigation risk stems from information dissemination and information asymmetry.

TABLE 8

Impact of Information Dissemination and Asymmetry

Panel A: Impact of Information Asymmetry

VARIABLES	(1) Litigation	(2) Litigation	(3) Litigation	(4) Litigation
	Low Analyst Coverage	High Analyst Coverage	Low Media Coverage	High Media Coverage
Post HSR	-0.674***	-0.080	-0.580***	-0.351
	(-2.665)	(-0.318)	(-2.724)	(-1.271)
Observations	16,525	14,017	16,606	13,936
Adjusted R-squared	0.421	0.426	0.410	0.424
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Panel B: Parallel Trend Examination

Before2	-0.080	-0.036	0.018	0.118
	(-0.327)	(-0.152)	(0.084)	(0.447)
Before1	-0.409	0.204	0.118	-0.056
	(-1.425)	(0.680)	(0.470)	(-0.178)
Current	-0.474	0.144	-0.234	-0.089
	(-1.459)	(0.406)	(-0.821)	(-0.243)
After1	-0.747**	0.073	-0.442	-0.231
	(-2.087)	(0.187)	(-1.386)	(-0.579)
After2+	-1.284***	-0.337	-1.005***	-0.713
	(-3.132)	(-0.730)	(-2.693)	(-1.593)
Observations	16,525	14,017	16,606	13,936
Adjusted R-squared	0.421	0.426	0.410	0.424
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Notes: This study uses analyst following and corporate transparency as the proxy of information asymmetry. Based on different levels of corporate transparency, the sample is divided into two parts according to whether the analyst coverage or media coverage is above the average level in the industry or not. Analyst coverage is the number of analysts who follows the firms. Media coverage is the total number of media coverage about the firms. We include the same control variables of the previous tables, control for the firm, industry, city and year fixed effects and cluster standard errors at the firm level. T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

Second, we examine if reduced litigation risk after high-speed rail stem from the external regulations and monitoring. We disaggregate litigation risk into those that involved less or more external regulations and monitoring. Table 9 shows this decomposition. The coefficient of *Post HSR* is significant and negatively associated with litigation risk in the firms under the low level of SEC monitoring, while insignificant in the group of the high level of SEC monitoring. This indicates that the impact of high-speed rail in low SEC monitoring firms contributes most to the overall effect that high-speed rail has on corporate litigation risk. Similarly, the magnitude of the coefficients of *Post HSR* in the low-level monitoring from Big-four auditors is also significant and negatively associated with corporate litigation risk.

We also validate the results by introducing a parallel trend examination in terms of external monitoring. We find that in the *After2*, having a high-speed rail significantly and negatively reduce corporate litigation risk in those have a lower level of SEC monitoring, which suggests that after the inauguration of high-speed rail, firms with insufficient external monitoring are more inclined to be changed and high-speed rail will substantively reduce their litigation risk. Similarly, this effect also remains significant in the specification when taking account for monitoring from Big-four auditors.

Our results support the ideas when we propose the mechanisms that improvement of transport infrastructure reducing corporate litigation risk stem from the change of information asymmetry and external monitoring. However, we do not intend to interpret these two channels as two exclusive mechanisms, and we do not make a causality claim in these two channels. Here we would like to make it clear that this is only two potential channels through which high-speed rail could have exerted effects on corporate litigation risk, which further verify the robustness and demonstrate the economic reasoning of the association, and there could be others in effect simultaneously. We also consider a firm’s heterogeneity and present evidence in other aspects.

TABLE 9

Impact of External Regulations and Monitors

Panel A: Impact of External Monitoring

VARIABLES	(1) Litigation Low Monitoring	(2) Litigation High Monitoring	(3) Litigation Low Auditing	(4) Litigation High Auditing
Post HSR	-0.389**	-0.832	-0.577***	2.073**
	(-2.129)	(-0.973)	(-3.075)	(2.454)
Observations	27,340	3,202	28,654	1,888
Adjusted R-squared	0.398	0.384	0.406	0.421
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Panel B: Parallel Trend Examination

Before2	0.083	3.268	-0.088	1.862**
	(0.509)	(1.573)	(-0.528)	(2.301)
Before1	0.021	4.529**	-0.180	3.344***
	(0.108)	(2.118)	(-0.881)	(3.206)
Current	-0.083	3.298	-0.373	4.012***
	(-0.357)	(1.584)	(-1.560)	(3.266)
After1	-0.253	2.856	-0.590**	4.446***
	(-0.967)	(1.290)	(-2.204)	(3.216)
After2+	-0.778**	2.408	-1.051***	4.035**
	(-2.489)	(1.032)	(-3.326)	(2.486)
Observations	27,340	3,202	28,654	1,888
Adjusted R-squared	0.398	0.386	0.407	0.429
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Notes: This study separates the sample based on the SEC regulatory monitoring as the proxy of external regulations and monitoring. SEC regulatory monitoring is the number that SEC enquires the firms. We use the proxy of Big-four auditors as a robustness check. Big-four auditors denote that firm's annual reports are audited by Deloitte, or Ernst & Young (EY), or KPMG, or PricewaterhouseCoopers (PwC). We include the same control variables of the previous tables, control for firm, industry, city and year fixed effects, and cluster standard errors at the firm level. T-statistics are reported in parentheses. *p < .10, ** p < .05, *** p < .01

An Extension on Corporate Heterogeneity

In this section, we further examine the impact of high-speed rail on corporate litigation risk based on the heterogeneity of firms. We present the results in Table A1 in the appendixes.

In Panel A of Table A1, the results indicate that high-speed rail significantly reduces non-state-owned enterprises' litigation risk, which contributes most to the overall impact that high-speed rail has exerted on litigation risk. As non-state-owned enterprises are usually under a lower level of external regulations and monitoring, our finding also supports the abovementioned results of the second channel regarding how high-speed rail impacts litigation risk.

The other possible heterogeneity of firms that we examine is based on a firm's social connections. According to Panel B of Table A1, we find that high-speed rail significantly and negatively associates with firm litigation risk that has fewer social connections, which contributes most to the overall impact of high-speed rail on litigation risk. One conjecture is that for firms that have fewer social connections, these firms usually have lesser information transparency and face higher information asymmetry, and thus this results also consistent with our first account.

These two tests detecting a firm's heterogeneous effects provide suggestive evidence that high-speed rail does reduce corporate litigation risk, and this effect may be varied based on the different characteristics of firms. This supporting evidence also further corroborates the robustness of our baseline relationship and the two channels that how high-speed rail impacts corporate litigation risk. There are, of course, other heterogeneous effects, and we do not exclude the possibility of other heterogeneities.

6 CONCLUDING REMARKS

Building on the important topic regarding the economic impacts of infrastructure improvement, this study examines the effects of the construction of high-speed rail on corporate litigation risk, in the context of China over 2001-2018. With a natural experiment design, our analysis examines how listed firms' litigation risk change after having high-speed rail to strengthen their transport infrastructure networks. Our baseline estimates demonstrate that the construction of high-speed rail substantially reduced corporate litigation risk. We further employ a parallel trend assumption of the difference-in-difference approach and also employ a placebo test to verify the robustness of our main results. Furthermore, we exploit historical data on the railway age of the first conventional railway in each of the 404 cities as instruments. We explore the mechanisms through which the high-speed rail exerts different impacts on the firm litigation risk, e.g. the level of information asymmetry within the firms and the external regulation and monitoring. The results suggest that in firms with a relatively higher level of information asymmetry and less transparency, high-speed rail plays a stronger role in reducing the risk of litigation.

In the context of China that has a vast territory and a wide application of information technology to online business, it may make it difficult for people to build trust, while the high-speed rail reduces the barrier of geographical distance, makes the information communication via face-to-face meetings easier, and thus reduces the information asymmetry level and also the misconduct behaviours of these firms. For firms facing lower level of external regulation and monitoring, the high-speed rail again plays a stronger role in reducing the litigation risk, as the high-speed rail makes the external monitoring easier due to reduced travel time and cost for regulators, increases the level of monitoring, decreases the level of local protectionism, and thus reduces the misconduct behaviour and litigation risk of these firms.

APPENDIX IN CHAPTER 6

Table A1: An extension on firm's heterogeneity

Panel A: Impact of firm ownerships

VARIABLES	(1) Litigation	(2) Litigation
	Institutional Ownership	
	Non-SOE	SOE
Post HSR	-0.574***	-0.156
	(-2.700)	(-0.515)
Observations	19,810	10,732
Adjusted R-squared	0.428	0.430
Year FE	Yes	Yes
City FE	Yes	Yes
Firm FE	Yes	Yes
Industry FE	Yes	Yes

Notes: This study tests the impact of HSR on litigation risk based on the heterogeneity on firms by disaggregating whether firm is state-owned enterprises (SOE). SOE equals one when a firm's actual controller is government. We include the same control variables of the previous tables, controls for firm, industry, city and year fixed effects, and also cluster standard errors at the firm level. T-statistics are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Panel B: Impact of social connections

VARIABLES	(1) Litigation	(2) Litigation	(3) Litigation	(4) Litigation
	CEO or Chairman Connection		Board Connection	
	Low	High	Low	High
Post HSR	-0.438**	-0.406	-0.422*	-0.435
	(-1.986)	(-1.431)	(-1.835)	(-1.621)
Observations	21,537	9,005	18,736	11,806
Adjusted R-squared	0.421	0.450	0.413	0.429
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Notes: This study uses number of CEO/Chairman and board directors jointly/part-time in other firms as the proxy of social connection, respectively. This study includes the same control variables of the previous tables. We control for firm, industry, city and year fixed effects and cluster standard errors at the firm level. T-statistics are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

REFERENCES

ADHIKARI, B. K., AGRAWAL, A. & MALM, J. 2019. Do women managers keep firms out of trouble? Evidence from corporate litigation and policies. *Journal of Accounting and Economics,* 67**,** 202-225.

AHARONY, J., LIU, C. & YAWSON, A. 2015. Corporate litigation and executive turnover. *Journal of Corporate Finance,* 34**,** 268-292.

AMIRAM, D., BEAVER, W. H., LANDSMAN, W. R. & ZHAO, J. 2017. The effects of credit default swap trading on information asymmetry in syndicated loans. *Journal of Financial Economics,* 126**,** 364-382.

ARENA, M. & JULIO, B. 2015. The effects of securities class action litigation on corporate liquidity and investment policy. *Journal of Financial and Quantitative Analysis,* 50**,** 251-275.

ASCHAUER, D. A. 1989. Is public expenditure productive? *Journal of Monetary Economics,* 23**,** 177-200.

ATANASOV, V. A. & BLACK, B. S. 2019. Online Appendix for the Trouble with Instruments: The Need for Pre-Treatment Balance in Shock-IV Designs. *Available at SSRN 2859113*.

BALDWIN, R., CAVE, M. & LODGE, M. 2012. *Understanding Regulation: Theory, Strategy, and Practice*, Oxford University Press.

BARWICK, P. J., CAO, S. & LI, S. 2017. Local protectionism, market structure, and social welfare: China's automobile market. National Bureau of Economic Research.

BASU, N. & CHEVRIER, M. 2011. Distance, information asymmetry, and mergers: evidence from Canadian firms. *Managerial Finance,* 37**,** 21-33.

BAUM-SNOW, N. 2007. Did highways cause suburbanization? *The Quarterly Journal of Economics,* 122**,** 775-805.

BAUM-SNOW, N., BRANDT, L., HENDERSON, J. V., TURNER, M. A. & ZHANG, Q. 2017. Roads, railroads, and decentralization of Chinese cities. *Review of Economics and Statistics,* 99**,** 435-448.

BAUM-SNOW, N., HENDERSON, J. V., TURNER, M. A., ZHANG, Q. & BRANDT, L. 2018. Does investment in national highways help or hurt hinterland city growth? *Journal of Urban Economics*.

BERTRAND, M., DUFLO, E. & MULLAINATHAN, S. 2004. How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics,* 119**,** 249-275.

BERTRAND, M. & MULLAINATHAN, S. 2003. Enjoying the quiet life? Corporate governance and managerial preferences. *Journal of Political Economy,* 111**,** 1043-1075.

BERTRAND, O. & LUMINEAU, F. 2016. Partners in crime: The effects of diversity on the longevity of cartels. *Academy of Management Journal,* 59**,** 983-1008.

BHAGAT, S., BRICKLEY, J. A. & COLES, J. L. 1994. The costs of inefficient bargaining and financial distress: Evidence from corporate lawsuits. *Journal of Financial Economics,* 35, 221-247.

BHATTACHARYA, U., GALPIN, N. & HASLEM, B. 2007. The home court advantage in international corporate litigation. *The Journal of Law and Economics,* 50, 625-660.

BOEH, K. K. & BEAMISH, P. W. 2012. Travel time and the liability of distance in foreign direct investment: Location choice and entry mode. *Journal of International Business Studies,* 43, 525-535.

BRÖCKER, J., DOHSE, D. & RIETVELD, P. 2019. Infrastructure and regional development. *Handbook of regional growth and development theories.* Edward Elgar Publishing.

BRUSH, T. H. & ARTZ, K. W. 1999. Toward a contingent resource-based theory: the impact of information asymmetry on the value of capabilities in veterinary medicine. *Strategic Management Journal,* 20, 223-250.

CAI, J., LIU, Y., QIAN, Y. & YU, M. 2015. Information asymmetry and corporate governance. *Quarterly Journal of Finance,* 5, 1550014.

CAO, J., LIANG, H. & ZHAN, X. 2019. Peer effects of corporate social responsibility. *Management Science*.

CHEN, C.-L. & VICKERMAN, R. 2017. Can transport infrastructure change regions' economic fortunes? Some evidence from Europe and China. *Regional Studies,* 51, 144-160.

CHEN, Z. 2017. Impacts of high-speed rail on domestic air transportation in China. *Journal of Transport Geography,* 62**,** 184-196.

CHENG, C. A., HUANG, H. H., LI, Y. & LOBO, G. 2010. Institutional monitoring through shareholder litigation. *Journal of Financial Economics,* 95**,** 356-383.

COFF, R. W. 1997. Human assets and management dilemmas: Coping with hazards on the road to resource-based theory. *Academy of Management Review,* 22**,** 374-402.

COLLIER, P. & VENABLES, A. J. 2016. Urban infrastructure for development. *Oxford Review of Economic Policy,* 32**,** 391-409.

CUTLER, D. M. & SUMMERS, L. H. 1988. The Costs of Conflict Resolution and Financial Distress: Evidence from the Texaco-Pennzoil Litigation. *The RAND Journal of Economics,* 19**,** 157-172.

DATTA, S. 2012. The impact of improved highways on Indian firms. *Journal of Development Economics,* 99**,** 46-57.

DE LA BRUSLERIE, H. & LE MAUX, J. 2018. Litigation risk: Measurement and impact on M&A transaction terms. *Journal of Business Finance & Accounting,* 45**,** 952-996.

DE RUS, G. & INGLADA, V. 1997. Cost-benefit analysis of the high-speed train in Spain. *The Annals of Regional Science,* 31**,** 175-188.

DINKELMAN, T. 2011. The effects of rural electrification on employment: New evidence from South Africa. *American Economic Review,* 101**,** 3078-3108.

DONALDSON, D. 2018. Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review,* 108, 899-934.

DONALDSON, D. & HORNBECK, R. 2016. Railroads and American economic growth: A “market access” approach. *The Quarterly Journal of Economics,* 131, 799-858.

DURANTON, G., MORROW, P. M. & TURNER, M. A. 2014. Roads and Trade: Evidence from the US. *Review of Economic Studies,* 81, 681-724.

FABER, B. 2014. Trade integration, market size, and industrialization: evidence from China's National Trunk Highway System. *Review of Economic Studies,* 81, 1046-1070.

FIELD, L., LOWRY, M. & SHU, S. 2005. Does disclosure deter or trigger litigation? *Journal of Accounting and Economics,* 39, 487-507.

FU, X., ZHANG, A. & LEI, Z. 2012. Will China’s airline industry survive the entry of high-speed rail? *Research in Transportation Economics,* 35, 13-25.

GANDE, A. & LEWIS, C. M. 2009. Shareholder-initiated class action lawsuits: Shareholder wealth effects and industry spillovers. *Journal of Financial and Quantitative Analysis,* 44, 823-850.

GIBBONS, S., LYYTIKÄINEN, T., OVERMAN, H. G. & SANCHIS-GUARNER, R. 2019. New road infrastructure: The effects on firms. *Journal of Urban Economics,* 110, 35-50.

GINSBURG, N. S. 1949. Manchurian railway development. *The Journal of Asian*

Studies, 8, 398-411.

GLAESER, E. L. & SHLEIFER, A. 2001. A reason for quantity regulation. *American Economic Review,* 91, 431-435.

HASLEM, B. 2005. Managerial opportunism during corporate litigation. *The Journal of Finance,* 60, 2013-2041.

HÖRNLE, J. 2003. Online Dispute Resolution: The Emperor's New Clothes? *International Review of Law, Computers & Technology,* 17, 27-37.

HOLL, A. 2016. Highways and productivity in manufacturing firms. *Journal of Urban Economics,* 93, 131-151.

HSU, W.-T. & ZHANG, H. 2014. The fundamental law of highway congestion revisited: Evidence from national expressways in Japan. *Journal of Urban Economics,* 81, 65-76.

HUTTON, I., JIANG, D. & KUMAR, A. 2015. Political values, culture, and corporate litigation. *Management Science,* 61, 2905-2925.

JIAO, J., WANG, J. & JIN, F. 2017. Impacts of high-speed rail lines on the city network in China. *Journal of Transport Geography,* 60, 257-266.

JIN, H., QIAN, Y. & WEINGAST, B. R. 2005. Regional decentralization and fiscal incentives: Federalism, Chinese style. *Journal of Public Economics,* 89, 1719-1742.

JOHNSON, M. F., NELSON, K. K. & PRITCHARD, A. C. 1999. In re Silicon Graphics Inc.: Shareholder wealth effects resulting from the interpretation of the

Private Securities Litigation Reform Act's pleading standard. *Southern California Law Review,* 73**,** 773.

KARPOFF, J. M., LEE, D. S. & MARTIN, G. S. 2008. The cost to firms of cooking the books. *Journal of Financial and Quantitative Analysis,* 43**,** 581-611.

KARPOFF, J. M., LOTT, J., JOHN R & WEHRLY, E. W. 2005. The reputational penalties for environmental violations: Empirical evidence. *The Journal of Law and Economics,* 48**,** 653-675.

KARPOFF, J. M. & LOTT JR, J. R. 1993. The reputational penalty firms bear from committing criminal fraud. *The Journal of Law and Economics,* 36**,** 757-802.

KIM, I. & SKINNER, D. J. 2012. Measuring securities litigation risk. *Journal of Accounting and Economics,* 53**,** 290-310.

KOH, P. S., QIAN, C. & WANG, H. 2014. Firm litigation risk and the insurance value of corporate social performance. *Strategic Management Journal,* 35**,** 1464-1482.

KRAEMER-MBULA, E., TANG, P. & RUSH, H. 2013. The cybercrime ecosystem: Online innovation in the shadows? *Technological Forecasting and Social Change,* 80**,** 541-555.

KRISHNASWAMI, S. & SUBRAMANIAM, V. 1999. Information asymmetry, valuation, and the corporate spin-off decision. *Journal of Financial Economics,* 53**,** 73-112.

LAWRENCE, M., BULLOCK, R. & LIU, Z. 2019. *China's High-Speed Rail Development*, The World Bank.

LEARY, M. T. & ROBERTS, M. R. 2014. Do peer firms affect corporate financial policy? *The Journal of Finance,* 69**,** 139-178.

LEE, P. K. 1998. Local economic protectionism in China's economic reform. *Development Policy Review,* 16**,** 281-303.

LELAND, H. E. 1979. Quacks, lemons, and licensing: A theory of minimum quality standards. *Journal of Political Economy,* 87**,** 1328-1346.

LIMAO, N. & VENABLES, A. J. 2001. Infrastructure, geographical disadvantage, transport costs, and trade. *The World Bank Economic Review,* 15**,** 451-479.

LIU, C., AHARONY, J., RICHARDSON, G. & YAWSON, A. 2016. Corporate litigation and changes in CEO reputation: Guidance from US Federal Court lawsuits. *Journal of Contemporary Accounting & Economics,* 12**,** 15-34.

LO, V. I. & TIAN, X. 2004. *Law and investment in China: the legal and business environment after China's WTO accession*, Routledge.

LOWRY, M. & SHU, S. 2002. Litigation risk and IPO underpricing. *Journal of Financial Economics,* 65**,** 309-335.

MAIMON, D. & LOUDERBACK, E. R. 2019. Cyber-dependent crimes: an interdisciplinary review. *Annual Review of Criminology*.

MURPHY, D. L., SHRIEVES, R. E. & TIBBS, S. L. 2009. Understanding the penalties associated with corporate misconduct: An empirical examination of earnings and risk. *Journal of Financial and Quantitative Analysis,* 44**,** 55-83.

ROBERTS, M. R. & WHITED, T. M. 2013. Endogeneity in empirical corporate finance. *Handbook of the Economics of Finance.* Elsevier.

SHAFFER, B. 1995. Firm-level responses to government regulation: Theoretical and research approaches. *Journal of Management,* 21, 495-514.

SHAPIRA, R. 2016. Reputation through Litigation: How the Legal System Shapes Behavior by Producting Information. *Washington Law Review,* 91, 1193.

VICKERMAN, R. 2018. Can high-speed rail have a transformative effect on the economy? *Transport Policy,* 62, 31-37.

VOLLAARD, B. & VAN OURS, J. C. 2011. Does regulation of built-in security reduce crime? Evidence from a natural experiment. *The Economic Journal,* 121, 485-504.

WANG, K. T. & LI, D. 2016. Market reactions to the first-time disclosure of corporate social responsibility reports: Evidence from China. *Journal of Business Ethics,* 138, 661-682.

WERBEL, J. & BALKIN, D. B. 2010. Are human resource practices linked to employee misconduct? A rational choice perspective. *Human Resource Management Review,* 20, 317-326.

ZHOU, N., BULLOCK, R., JIN, Y., LAWRENCE, M. & OLLIVIER, G. 2016. High-Speed Railways in China: An Update on Passenger Profiles. *World Bank: China Transport Topics No. 15.*

7. CONCLUSION

Conclusion

This thesis has examined a critical question in policy-making whether infrastructure has served to promote the economy. We have presented evidence that city's ICT infrastructure substantially improves firm performance, renewable energy infrastructure improves the rural household economy, and the improvement of transport infrastructure connectivity reduces firm litigation risk. To conclude, we have found that infrastructure assets are a critical determinant for firm growth and development, and also the household economy. These outcomes of our studies are an important input into policy choices in China and other developing economies.

1 WHAT HAVE WE LEARNT FROM THIS WORK?

First, we have found that infrastructure indeed matters for the economy. We have been aware that some prior studies on the economic return of infrastructure investment have found that global infrastructure project investment produced "probably very little" economic gains (Capello & Nijkamp, 2019; Warner, 2014). However, our work would like to make it clear that the economic return of infrastructure improvement could be positive and significant. It is not about whether in theory public investments could drive economic growth, but rather whether the improvement of the infrastructure itself could spur the economic activities, as the investment should serve its purpose on improving infrastructure.

Therefore, an important policy message that we would like to deliver is that: infrastructure improvement does matter for the economy. We would like to stress that when policymakers question the economic return of infrastructure, rather than simply questioning that the improvement of infrastructure could not contribute to economic activities, they should pay more attention to the issue that whether the investment itself has really contributed to the infrastructure deployment and construction, such as whether the infrastructure investment in developing countries would be invalid because of corruption and bad governance (Kyriacou, Muinelo-Gallo, & Roca-Sagalés, 2019; Owusu, Chan, & Darko, 2019). As we do not use monetary term data in our measurement, our results help to remit the concerns on the infrastructure return, rather than discouraging policymakers to improve the infrastructure in developing countries to serve the people and enterprise, and in turn stimulate the development of the economy and society.

Second, this thesis sheds light on how the improvement of infrastructure contributes to the economy and offers implications for policymakers that this deployment of infrastructure could pay off. There are a number of economic reasonings. Improvement of rural household renewable infrastructure could contribute to rural household economy via providing better energy service and opening up markets and opportunities. With renewable energy, rural households will gradually replace the use of conventional energy and may save the cost of daily energy consumption and reduce the living expense burden for households. Surplus renewable energy can be sold, which creates profits for rural households. Improvements of city's ICTs could increase firm productivity by reducing the costs of production, increasing firm efficiency, and widening the pool of labour from which firms can choose and benefit. Improvement of transport infrastructure and connectivity could also provide a better business environment for firms, through reducing the barrier of geographical distance via decreased travel time and cost, facilitating communication and reducing information asymmetry, and also help to construct a better governance environment that could reduce corporate risks. Thus, for the developing countries that are still in shortage of infrastructure, policymakers should still highlight the positive economic impact of infrastructure improvements and list infrastructure improvements as one of their priorities.

Third, this thesis also provides methodological implications. To provide high-quality evidence on the policy impact of real-world infrastructure programmes, we need to be aware that methodology is critical in making the evaluations. The important methodological consideration is to measure infrastructure and its economic impact appropriately and also resolve the endogeneity concerns using reliable methods. As infrastructure and its economic impact are difficult to measure and examine, we need to be careful in capturing infrastructure using accurate measurements for the variables and exogenous variations (Leduc & Wilson, 2013). In this thesis, we have employed different types of measures by using a number of datasets and several econometrical approaches in different research designs to address the possible concerns. To generate exogenous variations, we have employed two natural experiments, which provide the scenarios that allow for the random or seemingly random assignment of study subjects to different groups, and thus could be exploited to investigate the causal linkage between infrastructure and the economy. The methods applied in our work can help to make the generation of robust evidence of infrastructure programme and policy impact more feasible (Fuchs-Schündeln & Hassan, 2016). Future studies could identify more infrastructure programmes or policies that could be appropriated as natural experiments (Cantoni & Yuchtman, 2020).

2 WHAT COULD BE DONE IN FUTURE STUDIES?

There are still some research limitations and future work could be done. First, for the studies examining the impact of infrastructure on firms, we mainly use listed firm data. Although listed firms play a major role in the overall economy, the limitation is that the research sample could not represent all different kinds of firms, especially small enterprises. Future studies could be done by using data covering small enterprises. Second, although we introduce measurements of the exogenous variation in terms of infrastructure improvement by using natural experiments, randomised controlled trials (RCTs) could be designed in the future studies to make the assignment of the sample to an intervention or control group more randomly (Banerjee, Chandrasekhar, Duflo, & Jackson, 2019; Banerjee, Duflo, Glennerster, &

Kinnan, 2015), despite that RCTs could usually be very expensive, difficult to conduct in the field of infrastructure studies, and may be subject to many ethical issues (Leatherdale, 2019). Besides, this thesis mainly uses econometric methods, while the economic effects of infrastructure involve a complicated interaction between a set of different types of agents, including governments, public and private investors, households and individuals. Future studies could introduce some new methods to validate our empirical results, such as bottom-up approaches using Agent-based Modelling (ABM), which could simulate the mechanism of economic effects of infrastructure, when more interaction data of various infrastructure system components come available in the future (Farmer & Foley, 2009; Rai & Henry, 2016). Third, this thesis mainly examines the effect of infrastructure on the economy using empirical approaches, and future studies could emphasise more on the development of theory (Agénor, 2010; Ferrari, Bottasso, Conti, & Tei, 2018). Last, as the topic in infrastructure, the economy and policy is quite complex and the development stages and policy systems are quite different in various countries, future studies can be done in the context of other different countries with different political systems and business environment.

REFERENCES

Agénor, Pierre-Richard. (2010). A theory of infrastructure-led development. *Journal of Economic Dynamics and Control, 34*(5), 932-950.

Banerjee, Abhijit, Chandrasekhar, Arun G, Duflo, Esther, & Jackson, Matthew O. (2019). Using gossips to spread information: Theory and evidence from two randomized controlled trials. *The Review of Economic Studies, 86*(6), 2453-2490.

Banerjee, Abhijit, Duflo, Esther, Glennerster, Rachel, & Kinnan, Cynthia. (2015). The miracle of microfinance? Evidence from a randomized evaluation. *American Economic Journal: Applied Economics, 7*(1), 22-53.

Cantoni, Davide, & Yuchtman, Noam. (2020). *Historical Natural Experiments: Bridging Economics and Economic History* (0898-2937). Retrieved from

Capello, Roberta, & Nijkamp, Peter. (2019). *Handbook of Regional Growth and Development Theories: Revised and Extended Second Edition*: Edward Elgar Publishing.

Farmer, J Doyne, & Foley, Duncan. (2009). The economy needs agent-based modelling. *Nature, 460*(7256), 685-686.

Ferrari, Claudio, Bottasso, Anna, Conti, Maurizio, & Tei, Alessio. (2018). *Economic Role of Transport Infrastructure: Theory and Models*: Elsevier.

Fuchs-Schündeln, Nicola, & Hassan, Tarek Alexander. (2016). Natural experiments in macroeconomics. In *Handbook of Macroeconomics* (Vol. 2, pp. 923-1012):

Elsevier.

Kyriacou, Andreas P, Muinelo-Gallo, Leonel, & Roca-Sagalés, Oriol. (2019). The efficiency of transport infrastructure investment and the role of government quality: An empirical analysis. *Transport Policy, 74*, 93-102.

Leatherdale, Scott T. (2019). Natural experiment methodology for research: a review of how different methods can support real-world research. *International Journal of Social Research Methodology, 22*(1), 19-35.

Leduc, Sylvain, & Wilson, Daniel. (2013). Roads to prosperity or bridges to nowhere? Theory and evidence on the impact of public infrastructure investment. *NBER Macroeconomics Annual, 27*(1), 89-142.

Owusu, Emmanuel Kingsford, Chan, Albert PC, & Darko, Amos. (2019). Thematic overview of corruption in infrastructure procurement process. *Journal of Infrastructure Systems, 25*(2), 02519001.

Rai, Varun, & Henry, Adam Douglas. (2016). Agent-based modelling of consumer energy choices. *Nature Climate Change, 6*(6), 556-562.

Warner, Mr Andrew M. (2014). *Public investment as an engine of growth*: International Monetary Fund.