The Role of Infrastructure Capital in China's Regional Economic Growth

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Abstract

This paper investigates the role of infrastructure capital in China's regional economic development during 1990 to 2009 in a neoclassical economic growth model. Four types of infrastructure capital are discussed; electricity, road, rail, and land-line telephone. The results support a positive role of infrastructure in improving economic wellbeing in China. It shows that infrastructure has contributed to the convergence among China's provinces. However, declining growth momentum from rapid increase of road infrastructure, in particular for the Western region, suggests that road development in the region has been growing too fast. The results counter the conventional wisdom of "road leads to prosperity" widely accepted among national and local governments in China. Thus, the seemingly productive infrastructure capital, when invested beyond a proper level or speed, will become unproductive. The results echo the theoretical literature on the inverse U shaped growth impact of infrastructure capital and the dominant "crowding out" of private capital if there is too much infrastructure. They also address the puzzle in the current literature debates as to the direction and magnitude of the growth impact of infrastructure capital.

Keywords: infrastructure, economic growth, regional inequality, China

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I. Introduction

The literature often gives mixed results on the impact of infrastructure capital on economic development. On the one hand, the benefits of public infrastructure have long been recognized by classical studies on economic development. Rosenstein-Rodan (1943) and Nurkse (1952) and Hirschman (1957) have argued for a positive role of infrastructure capital. Large amount of infrastructure investment is regarded as a necessity before all other types of investment are possible. The nature of infrastructure investment, which requires large sunk costs and whose benefits usually cover a large number of people, is considered best with public provision. Samuelson (1954) in his classical studies on the pure theory of public expenditure has argued that theoretically there is no market solution to the optimal provision of collective consumption goods and they are better left with public hands.

On the other hand, Aschauer (1989a) finds that the infrastructure capital can have a dominant "crowding-out" effect on private investment. The usual complementary role of infrastructure capital is merely the result of a dominant "crowding-in" effect, which can be reversed. Barro(1990) using an endogenous growth model suggests there are conflicting forces of infrastructure investment that result in an inverse U-shape of its growth impact. An increase in public infrastructure initially raises growth rate, but then causes the growth rate to decline when infrastructure investment is beyond a certain level.

Such mixed results also manifest itself in the empirical literature. During the last wave of debate on the role of infrastructure in the early 1990s, Aschauer (1989b) provides results supporting the intuition that infrastructure has a positive role to play in the economic development of the 50 U.S. states. His results were challenged by Holtz-Eakin (1994), who concludes with no significant relationship between public capital and private productivity for 48 states in the U.S. over 17 years. A number of studies that follow give a quite diverse and uncertain picture of the role of infrastructure as reviewed in Fisher (1997).

Other economists have looked beyond the boundary of developed countries and explore a variety of experiences from the developing world. The last major wave of infrastructure investment led by Asian and other developing countries in the early 1990s has provided rich resources to reveal the nature and role of infrastructure in much wider and diversified contexts. An obvious example comes from the sharp contrast between China and India. The former relies much on massive public spending as an "engine" of economic growth and an accommodating reaction to huge increasing domestic demand. The result is phenomenal changes in its landscape from the start of its economic reform in the early 1980s. The latter, however, has seen comparable economic growth over the last decade, but with a sluggish public sector where ever growing traffic jams and mismanaged public infrastructure are commonplace, alongside with the prospering private sectors.

Cross country study of the relationship between the composition of public expenditure and growth in 43 developing countries over 20 years by Devarajan, Swaroop and Zou (1996) has shown that contrary to our conventional thoughts increasing the share of current spending has large and significant impact on growth while increasing capital spending shares exerts negative influence on growth. While their study focuses on the composition but not the level of public spending, it shows that developing countries have a different and interesting story to tell. Moreover, cross country studies on public infrastructure investment often ignore the diversity and dynamics that are within each country, despite giving new perspectives and understandings on the role of infrastructure, such as Calderon and Serven (2004).

Empirical studies on the infrastructure growth nexus in China are quite limited. Among the few, Demurger (2001) reviews the development of China's transport infrastructure and its relationship with regional economic growth in 24 provinces, excluding municipalities, from 1985 to 1998. Zhang et al (2006) investigates the determinants of infrastructure investments at the sub-national level with a political economic framework, but they haven't assessed the growth impact of infrastructure capital. Bai and Qian (2010) present an in-depth description of the infrastructure development in electricity, highways and railways at the national level with a review on the institutional features of these sectors, but no empirical testing has been performed. Fan (2004) explores the impact of infrastructure capital on economic development in rural China.

This paper, therefore, builds upon the existing studies on the infrastructure and growth nexus and explores in depth China's provincial economic growth and the role of infrastructure capital. It discusses four types of infrastructure - electricity, road, rail and telecommunications - knowing that any simple look at only one of them would miss the fact that they often influence each other. It covers the time span from 1990 to 2009 when the major reforms and economic progressions come into full play. Rather than taking the nation as a whole, it regards each of its 27 provinces and 4 municipalities as both independent and interconnected entities. This is more of the case when the country decides, from its central planning practices, to leave more decisions to the sub-national and local governments and to delineate enterprises from the government bodies so that they can react to the market conditions with more flexibility and effectiveness.

The paper asks the following questions. Have these four types of infrastructure played a positive role for the convergence of China's provinces? How much do different types of infrastructure contribute to the improvement of their economic prospects? Do the effects vary with time and across different economic regions?

The paper proceeds as follows. Part II gives an account of the provincial growth performances and major national reforms during the period under study. It then provides an overview of the infrastructure development across its geographic region. Part III presents a simple neoclassical model with infrastructure capital as a basis for the empirical analysis. Part IV lets the data tell the story about the role of infrastructure and interprets the findings from regressions. Alternative specification tests are performed with results reported. A conclusion is in Part V.

II. Provincial infrastructure coverage and regional economic growth in China

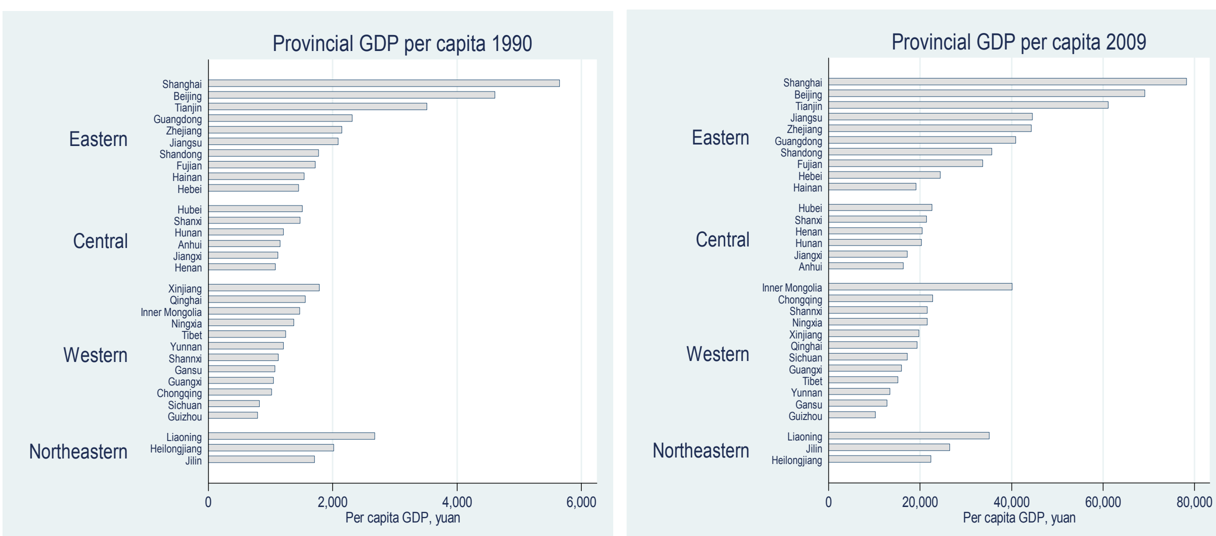
1. Regional growth performance

China's growth record has been well documented. Its GDP grew from RMB 1866.78 billion ($ 390.3 billion) in 1990 to RMB34050.69 billion (about $4984.7 billion) in 2009. Real GDP has been growing at an average rate of over 10% during the time. The standard of living as measured by GDP per capita has grown from RMB1, 644($343.7) to RMB 25,575 (about $3744) in 2009.

The growth performance of China, however, varies greatly across provinces[1]. Figure 1 shows the provincial real GDP per capita in 1990 and 2009. On the whole, the Eastern region has been leading the economic growth, while the Central and Western regions, which cover over half of the land, have been lagging behind[2]. There is a wide gap among provinces. If the municipalities are excluded, which are at the same administrative level with the provinces, the lagging regions in the Western part of China have about one third of the per capita GDP of top provinces such as Zhejiang and Guangdong.

Figure 1 also shows the position of provinces relative to each other. The traditional resource rich heavy-industry endowed Northeastern provinces have been declining, while Henan in the Central region and Inner Mongolia in the Western region have been among the fastest growing provinces. The majority of the Western region provinces, however, are continuously ranked at the bottom.

Figure 1 GDP per capita across China's provinces 1990 vs. 2009



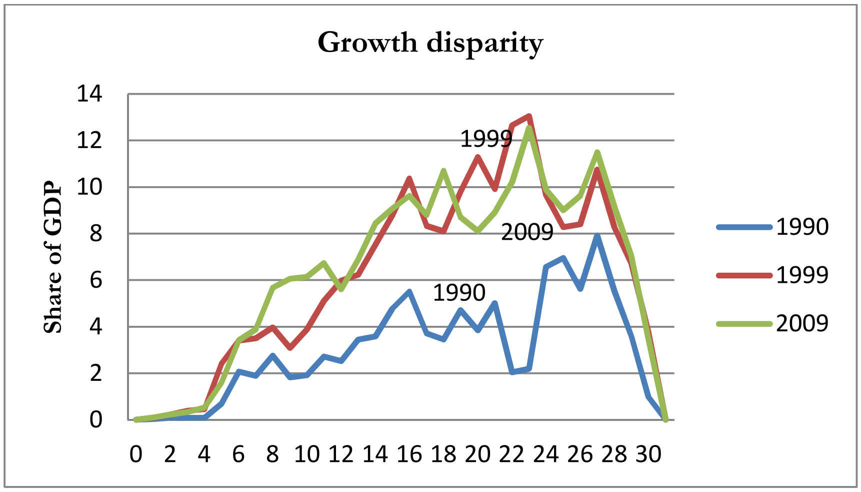
Different from the earlier studies that find a converging process during the mid 1980s, the 1990s has witnessed a widening gap between the rich and the poor regions. Figure 2 shows a Lorenz curve type graph with share of population on the x-axis and share of GDP output on the y-axis. The area under the curve has been growing from the year 1990 to 1999 and slightly decreasing by the year 2009. Although provinces

[1] A map of China's provinces can be found in Figure 3 in the appendix.

[2] The regions Eastern, Central, Western and Northeastern are classified according to their geographic locations, the nature and, virtually from the graph, performance of their economy. They are frequently named as the Four Major Economic Regions in China. This classification is also adopted by China's statistical yearbooks. There are 10 provinces in the Eastern region, 6 in the Central, 12 in the Western region and 3 in the Northeastern region.

become less far apart by the end of 2000s, the gaps among the provinces overall have been enlarging compared with the year1990.

Figure 2 Growth disparity among China's provinces 1990-2009



Note: The x-axis numbers refer to 27 provinces and 4 municipalities ranked by their share of the GDP output to their share of population. Because their relative rank changes over time, it's therefore expressed in numeric terms.

2. The role of infrastructure and its historical development

China has been mobilizing a large amount of resources for infrastructure investment during the last two decades. Its infrastructure investment reached about 6.5% of GDP in 1993, above the average level of 4% of GDP for developing countries (World Bank 1995). This was followed by an even faster growth in infrastructure investment around the year 1998, when the government decided to increase infrastructure spending to stimulate the economy. The investment gradually slowed down in the first half of the 2000s and again picked up during the late 2000s. By the end of 2009, investment in infrastructure had reached to about 15% to 20% of GDP for coastal provinces and all four municipalities, whereas the share of social sector investment, such as education and health spending, is between 2% to 4% of GDP.

Investment in the energy sector has seen dramatic increases in resource abundant provinces such as Yunnan, Sichuan in the Western region and Liaoning in the Northeastern region. Telecommunications investment, which includes telecommunications and the Internet, has reached about 0.5% to 2% of GDP across provinces around the turn of the century. The Western and Central provinces have seen skyrocketing transport investment. Their transport investment to GDP ratios have reached almost 5% while for the more developed coastal provinces such as Jiangsu, the transport investment to GDP ratio is much less (for Jiangsu, the investment- GDP ratio is about 2%).

A number of factors have provided a favorable environment for infrastructure to grow in China. China has gradually developed from an agrarian country with almost 50% population in agriculture into a manufacturing state. The increasing labor force and foreign capitals in the industrial sectors requires cities to expand and to be better equipped. Infrastructure bottlenecks have been felt in particular by the coastal cities such as Shanghai and provinces such as Zhejiang. These areas respond by investing heavily in infrastructure, in particular the transport infrastructure at a rate of over 40% per year recently. Such development, as shown in the empirical analysis, does exert positive effect on the improvement of economic standards in those areas.

As an integral part of the Special Economic Zone (SEZ) development across China, infrastructure development has been undergoing three major stages. If the year from 1980 to 1989 marks the beginning of the historic establishment of four SEZs, the two decades from the year 1990 is twenty years of mushrooming SEZs spreading from the coastal to more inland and lagging provinces. At the beginning, barren land in remote villages designated as SEZs require large infrastructure investment to shape them into production centers. In the second stage, infrastructure is accommodating to the growth of an export oriented economy. Since many special zones are far away from the major economic centers, they need roads, railways and energy to support the export industries. The third stage comes when the economy grows to a more advanced level. Congestion costs and rising factor prices have again become the bottleneck of the economy. Such bottleneck typically lies in the energy and transport infrastructure that are the backbone of the economy. China's accession into the WTO in 2001 further motivated a well-integrated infrastructure network, where energy, transport and telecommunications are supporting each other to fuel the economic growth.

The institutional arrangements associated with infrastructure development have also been the subject of market oriented reforms. There has been a gradual decentralization of decision-making to the lower levels of government and a delineation of enterprises from government functions Infrastructure provision in China is typically provided by its State Owned Units (SOUs)[3] given its public nature. Despite the declining share in all infrastructure sectors, state investment still dominates. SOU share in the energy sector fell from over 90% in the mid 1990s to about 40% by the end of 2008. On average the state share accounts for about 90% of the total for telecommunications investment. Although the transport sector has seen more private players for competition in the coastal region, state investment still accounts for more than 85% in most provinces. The reform of State Owned Enterprises (SOEs) in late 1990s has also greatly affected the way infrastructure investment is conducted.

Given the nature of large scale investment and close relation to macroeconomic stability, infrastructure development has been carefully guided by the national policy. In the early 1990s, transport sector, in particular the railway sector, was given special attention in the national development plan because of its critical role in transporting essential goods such as coal, oil products and grain. In the meantime, the the wasteful spending and inflationary pressure from rapid pace of SEZ development caused concern from the national government. It, therefore, started to regulate the development of SEZs. After the former Premier Zhu was sworn in 1998, he adopted a proactive fiscal policy. Infrastructure spending, for the first time in China's history, became an instrument for fiscal stimulus to spur nationwide growth. Furthermore, in the year 2000, the national government launched the long-contemplated Western Development Plan to bridge regional gaps in economic development. Achieving greater equality and promoting growth became the priorities of the government during the 2000s. Infrastructure again played a major role bringing along the lagging regions.

[3] State owned units (SOUs) by definition include the enterprises owned by various levels of government as well as government agencies.

3. Infrastructure coverage

Infrastructure in this paper refers to the economic infrastructure which generates services from public utilities, public works and other transport sectors[4]. It only covers the physical infrastructure, and does not include the "invisible" infrastructure such as the government's policy framework and the market institutions that generate economic activities and influence investment decision making. The specific types of infrastructure discussed are electricity, road, railway, and land-line telephone.

Table 1 shows the average stock of the four types of infrastructure between 1990 and 2009 in each region. The Eastern and the Northeastern regions have traditionally large production capacity of electricity, while the Central and Western regions have been catching up rapidly in electricity capacity building. Some provinces have even exceeded the capacity of the coastal regions by 2009.

Table 1 Selected infrastructure stock indicators across regions

Infrastructure indicators in averages	**Eastern**		**Central**		**Western**		**Northeastern**	
	1990	**2009**	**1990**	**2009**	**1990**	**2009**	**1990**	**2009**
Electricity generating capacity per million people (10 thousand kw)	17.69	69.85	10.7	62.02	11.83	88.87	19.38	55.7
Electricity production per million people (100 million kwh)	7.78	30	5.11	26.29	6.03	36.38	8.78	21.86
Road length km per million people	796.63	1814.47	795.71	3038.2	2219	5954.14	1136.5	3176
Road length km per sq.km	0.34	1.13	0.23	1.02	0.12	0.44	0.17	0.5
Rail length km per million people	72.06	44.67	42.03	63.56	84.35	132.17	131.4	128.86
Rail length km per sq.km	4.81e-6	3.16e-6	1.26e-6	2.01e-6	4.69e-7	8.52e-7	1.92e-6	2.02e-6
Telephone subscribers per 100 people	1.17	25.65	0.27	11.64	0.37	12.9	0.8	19.22
Source: China Statistical Yearbook, various issues, CEIC								

Road development has also been remarkable. At the beginning of 1990, road coverage in terms of geographical and population density was low compared with other developing countries. Yet road in terms of its geographic and population density has doubled or more than tripled in all regions by the end of 2009.

The traditional priority on rail transport has given rise to much technological improvement in the sector. Although Table 1 seems to show a "stagnant" single rail length in the Eastern and Northeastern regions,

[4] World Development Report (1994). For example, in public utilities, infrastructure refers to power, telecommunications, water supply, and sanitation; in public works, roads and major dam and canal works; and other transport sectors including urban transport, waterways, airports, ports and urban and interurban rails.

there has been substantial capacity building through electrification and double-tracking in the rail industry. Indeed rail plays a major role in freight traffic (Table 3) and is instrumental in passenger traffic especially during national holidays. The Northeastern provinces still undertakes much of the economic activities with rail. Central region has gradually becoming a major carrier linking the coastal regions with the inland provinces., The Western region, however, has yet to see its railway to support more freight and passenger transport, despite an even faster rail infrastructure growth.

Road transport, in the meantime, has gradually replaced the role of rail in short-length transport. Its role in supporting the manufacturing, especially the light industry, was greatly enhanced in the 1990s when the manufacturing sector soared with the export-oriented economy. Road traffic has in many cases increased tenfold across the regions (Table 2)

With the unique feature of a more flexible and door-to-door service, the Eastern and Central regions have been relying more on roads for their freight transport than railways.

Perhaps one of the most dramatic changes occurs in the telecommunication sector. The telephone has popularized both in the urban and rural areas. Its importance has gradually been declining in the coastal provinces due to the introduction of cell phones.

Table 2 Average transport freight and passenger traffic across regions

	Eastern		**Central**		**Western**		**Northeastern**	
	1990	**2009**	**1990**	**2009**	**1990**	**2009**	**1990**	**2009**
Road ton-km	130.14	1383.2	139.7	2132.8	77.4	646.4	121.5	934.6
Road passenger -km	113.71	589	134.31	576.5	50.83	279.7	73.85	268.5
Rail ton-km	306.34	687.2	505.2	1147.7	204.3	693.99	684	952.4
Rail passenger -km	84.65	245.2	130.72	461.5	46.51	144.8	193.25	306.8

**Unit: 100 million passenger-kms or ton-kms*
Source: China Statistical Yearbook, various issues; CEIC

Indeed infrastructure development has altered the landscape throughout China in the last two decades. Chinese people view the ability of building such an amount of infrastructure in a short period of time as a success. It is not clear, however, how much infrastructure capital contribute to regional economic growth in China. A simple set of graphs shows that the availability of infrastructure is highly correlated with the development status of the local economy. Almost all four types of infrastructure are positively correlated with the level of per capita GDP (Figure 4 in the appendix), except that the transport infrastructure has been declining with increasing migration and population growth. To answer this question, the next chapter introduces a theoretical framework to study the direction and magnitude of such a relationship.

III. The Model

The model follows the usual format of a Cobb-Douglas production function. An additional capital, infrastructure, enters into the production function as G_t. The assumption is that such capital is complementary to private capital and that it exhibits the usual decreasing returns to scale.

$$Y_t = (A_t L_t)^{1-\alpha-\beta-\gamma} K_t^{\alpha} H_t^{\beta} G_t^{\gamma} \qquad (1)$$

where Y is real GDP, K is the stock of private physical capital, H is the stock of human capital. As in the usual Solow growth model, L is the labor, A is a labor-augmenting technology, t refers to time in years. Assume the production function exhibits constant returns to scale (CRS) for all three types of capital, where $\alpha+\beta+\gamma<1$, and decreasing returns to scale for individual capital.

Assume the labor augmenting technology A_t follows the path:

$$A_t = A_0 e^{gt} F_t^{\theta}; \qquad (2)$$

together with $L_t = L_0 e^{nt}$ (3)

where n is the population growth rate, g is the exogenous rate of technological progress, F is a measurement for the openness of the economy. The openness variable has a positive effect on technology improvement, either through introducing more competition or through better management and technology adoption.

Assuming the accumulation of capital is in the form:

$$\frac{dK}{dt} = s_k Y_t - \delta K_t \qquad (4)$$

Human and infrastructure capital follow the same format with investment rate s_h and s_g respectively. Assume that the depreciation rate δ is constant over time and the same for all three types of capital.

At the steady state:

$$y^* = [s_k^{\alpha} \cdot s_h^{\beta} \cdot s_g^{\gamma} / (n+g+\delta)^{\alpha+\beta+\gamma}]^{1/(1-\alpha-\beta-\gamma)}, \text{ where } y^* = Y^*/AL \qquad (5)$$

Take natural logs on both sides of (5), and then:

$$\begin{aligned} \ln \hat{y}_t = \ln A_0 + g \cdot t &+ (\alpha/1-\alpha-\beta-\gamma) \cdot \ln [s_k/(n+g+\delta)] \\ &+ (\beta/1-\alpha-\beta-\gamma) \cdot \ln [s_h/(n+g+\delta)] \\ &+ (\gamma/1-\alpha-\beta-\gamma) \cdot \ln [s_g/(n+g+\delta)] \\ &+ \theta \cdot \ln F_t \qquad \text{where } \hat{y}_t = Y/L \end{aligned} \qquad (6)$$

Following Mankiw, Romer and Weil (1992), the economy approaches its steady state with a transition path around its steady state defined by the equation:

$$\ln y_{t0+h} = (1 - e^{-\eta t}) \ln y^* + e^{-\eta t} \ln y_{t0} \qquad (7)$$

where $\eta = (1-\alpha-\beta-\gamma)(n+g+\delta)$.

Substitute $\ln y^*$ with equation (7) and also with $\ln y_t = \ln(Y_t/AL) = \ln \hat{y}_t - \ln A_0 - gt - \theta \cdot \ln F_t$, and get:

$$\ln y_{t0+h} - \ln y_{t0} = (1 - e^{-\eta h})\ (\alpha/1\text{-}\alpha\text{-}\beta\text{-}\gamma)\cdot \ln [s_k/(n+ g+ \delta)]$$

$$+ (1 - e^{-\eta h})\ (\beta/1\text{-}\alpha\text{-}\beta\text{-}\gamma)\cdot \ln [s_h/(n+ g+ \delta)]$$

$$+ (1 - e^{-\eta h})\ (\gamma/1\text{-}\alpha\text{-}\beta\text{-}\gamma)\cdot \ln [s_g/(n+ g+ \delta)]$$

$$+ (1 - e^{-\eta h})\ \theta\cdot \ln F_t - (1 - e^{-\eta h})\ \ln y_{t0}$$

$$+ [(1 - e^{-\eta h})\ (t_0+h)g + e^{-\eta h}\ hg] + (1 - e^{-\eta h})\ \ln A_0 \qquad (8)$$

Therefore an estimable equation can be expressed as:

$$\ln(y_{t0+h}/y_{t0}) = b_k \cdot \ln [s_k/(n+ g+ \delta)] + b_h\cdot \ln [s_h/(n+ g+ \delta)]$$

$$+ b_g\cdot \ln [s_g/(n+ g+ \delta)]+b_f \cdot \ln F_t + b_c \cdot \ln y_{t0}$$

$$+ c_i + a_t + u_{it} \qquad (*)$$

where $\alpha=b_k/(b_k+b_h+b_g-b_c)$; $\beta=b_h/(b_k+b_h+b_g-b_c)$; $\gamma=b_g/(b_k+b_h+b_g-b_c)$; $\theta = - b_f/b_c$. α, β, γ are elasticities of growth of real per capita GDP. The dependent variable is the difference of real GDP per capita at time t with the initial level of real GDP per capita.

Equation (*) can also be expressed in levels instead of investment rates. That is, s_g can be rewritten as q_t because :

$$\ln(s_g) = \ln(Gt/Lt) - \ln At = \ln(Gt/Lt) - (\ln A_0 + gt + \theta\cdot \ln F_t) = \ln q_t - (\ln A_0 + gt + \theta\cdot \ln F_t) ,$$

where q_t is the per capita measure of a particular type of physical infrastructure stock. By simple substitution and calculation, unrestricted form of (*) is:

$$\ln(y_{t0+h}/y_{t0}) = b'_k \cdot \ln s_k + b'_h\cdot \ln h_{t\,+}\ b'_g\cdot \ln q_t + b_n\cdot \ln (n+ g+ \delta) + b_f' \cdot \ln F_t + b_c \cdot \ln y_{t0} + c_i + a_t + u_{it} \qquad (**)$$

Coefficients will be different from Equation (*). Equation (**) will be the basis of the following empirical analysis.

IV. Empirical analysis

A panel dataset of 31 of China's provinces and municipalities covering years 1990 to 2009 is constructed to test the relationship between infrastructure and regional growth. The data are from China statistical yearbooks, sector specific yearbooks and CEIC retrieved from Chinese Academy of Social Sciences. Provincial data at the national level statistics yearbook are reported wherever possible, because they tend to be more accurate than provincial reports. The list of names of provinces can be found in Figure 1.

The empirical model is based on equation (**) in Part III. More specifically, the estimating equation is as follows where q_{it} can also be replaced by investment rate s_g:

$$\ln(y_{it+1\_t+3}/y_{i,t-1}) = b'_k \cdot \ln s_{ik} + b'_h \cdot \ln h_{it} + b'_g \cdot \ln q_{it} + b_n' \cdot \ln(n_i+g+\delta) + b_f' \cdot \ln F_{it} + b_c \cdot \ln y_{i,t-1} + c_i + a_t + u_{it} \quad (***)$$

i. Description of variables

Table 3 shows the list of variables used to estimate the above equation. The dependent variable is the three-year forward moving average of real GDP per capita growth expressed as $\ln(y_{it+1\_t+3}/y_{i,t-1})$. The objective is to eliminate the short term fluctuations in the real GDP per capita series, and to control for reverse causality that goes from higher real GDP per capita to more demand on infrastructure[5]. The regression model assumes that the government and enterprises anticipate growth targets three years into the future to accelerate infrastructure investment today. Whenever the paper mentions partial growth effect, growth prospect or improvement of standard of living, it means partial effect of infrastructure capital on the three year forward moving average of real per capita GDP growth.

The first set of right-hand-side variables is the variables of interest X_{it}. The flexibility of the empirical model allows either a stock measure or investment rates. In particular, the infrastructure variable $q_{t.}$ is the level of each type of infrastructure stock scaled by permanent population. The assumption is that it is positive and significant. q_t can be the length of road or railway per million people, electricity production per million people[6], and telephone subscribers per 100 people. Private sector investment rate s_{it} is measured by real private investment in fixed assets to real GDP. The human capital stock h_{it} is measured by the share of the number of graduates from higher education to total permanent population for province i at time t. The openness variable F is measured by FDI flow per capita. It is assumed to be affecting the technology improvement.

Previous studies that use stock measures of infrastructure capital have encountered problems of aggregation. Hulten (1996) attempts to construct a measure of composite infrastructure stock to test the infrastructure and growth relationship. Zhang et al (2006) uses principle component analysis (PCA) to construct an aggregate infrastructure capital. Calderon and Serven (2004) adopt similar approach to measure infrastructure stock for a large sample of countries. A problem with aggregation is that it can hardly give a meaningful interpretation and the results vary by the way of construction. This paper, therefore, includes the physical measures of each

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[5] The use of three-year forward moving average to control for possible reverse causality is also found in Devarajan et al (1996).

[6] Electricity production per million people is used as a proxy for the electricity generating capacity, its stock measure to avoid missing data problem. In general the more electricity generating power, the more production there will be. Regression results show that a comparison using each measure yields similar results.

type of infrastructure. An advantage of this is that it eliminates some endogeneity in the infrastructure investment process. By putting four types of infrastructure in a single equation, it studies the partial effect of each type of infrastructure on economic growth holding the level of other types constant..

The one year lag real per capita GDP $rgdppc_{t-1}$ is included as an indicator for conditional convergence. If the previous lagging regions have been growing at a faster rate than the previously advance regions, there is conditional convergence among the regions. The coefficient on this variable is expected to be negative.

Population is measured as permanent population. By allowing for effects of migration, it can better measure the contribution such a population base has created and the services that it has received in that province. It is the registered population minus the registered population that reside out of state and plus the migration population residing over six months. A time average population growth rate n_i is calculated for each province from 1990 to 2009. Following Mankiw, Romer and Weil (1992), Knight et al (1993), $g+\delta$ is assumed to be 0.05. The assumption is that the results are robust to changes in $g+\delta$. Hence the variable *ngd* is the adjustment by population growth, technology improvement and capital depreciation. Coefficient on this variable is expected to be negative.

The second set of variables is controls Z_{it}. It includes time period and regional dummies as well as interaction terms to capture national policy change that affects sub-national performances. The dummy variables for economic region correspond to the Eastern, Central, Western and Northeastern regions respectively.

Time period dummies are chosen to reflect the leadership and policy changes that influence infrastructure investment. During the first period from 1990 to 1992, there was large and often wasteful spending on investment in fixed assets. The second time period is from 1993 to 1997 when the previous large amount of investment began to take its toll with double digit inflation. The third time period from the year 1998 to 2002 is a period when Premier Zhu Rongji initiated the reform for the SOEs and the policy endeavor using infrastructure investment as a fiscal stimulus. The last time period is from 2003 to the present, when the current leadership in China proceeded with bold and often more flexible policies to infrastructure investment. Corresponding variables are *p1* referring to years from 1993 to 1997, *p2* from 1998 t 2002 and *p3* from 2003 to 2006, and the base period from the year1990 to 1992. Note because of the three year forward moving average treatment of the dependent variable, it is virtually using the data until 2006. Nonetheless it is able to capture much of the time varying effects of infrastructure during the 17 years. Time period dummies are preferred to year dummies because the sign and magnitude of the coefficients on year dummies are prone to changes with different years included and some policy effects may be felt for a longer time period.

Another control is:

$rdep_{it}$: the dependence ratio, measured as the sum of number of population aged from "0-14" and from "65 and above" to the number of population aged from "15 to 64 years old". This is to control for population structure. The assumption is that the higher the rate, the more burdensome working age population will feel.

The unobserved part consists of c_i province specific effect that is constant over time, a_t time specific effect and the error term u_{it}. The regression adopts the fixed effect method to eliminate the portion c_i that causes endogeneity problem with the variables of interest. Robust standard errors are reported throughout to allow for heteroskedasticity and serial correlation in the error term.

Table 3 Description of Variables

Variables	Definition
$\ln(RGDPPC_{t+1\_t+3}/RGDPPC_{t-1})$	Three year forward average growth rate of real per capita GDP.
POP	Permanent population, 10 thousand persons
GRADS	Share of graduates from Higher Education to permanent population (%)
RDEP	Real dependence ratio
RSPINV	Share of real private investment in fixed assets to total GDP, in 1990 prices
RFDICYPC	Real FDI actually utilized, yuan
ln(ngd)	Adjustment by population growth, technology change and capital depreciation
ELECPDMP	Electricity production (100 million kwh per million people)
HWMP	Length of road km per million people
RDEXPMP, RDCLIMP, RDCLIIMP,RDCLIIIMP, RDCLIVMP, RDUCMP	Length of expressway, Class I road, Class II road, Class III road, Class IV road, and unclassified road, in km per million people
RWLENMP	Length of railway km per million people
TELESUBHP	Telephone subscribers per 100 persons
CELLHP	Cell phone units per 100 persons
ECOZONE	Eastern: 10 provinces and municipalities Central: 6 provinces Western: 12 provinces and municipality Northeastern: 3 provinces
Time periods	1990– 1992 1993– 1997 1998– 2002 2003 – 2006

A problem with the data is that they are riddled with persistent nature over time and a trending behavior. In order to avoid running a spurious regression, augmented Dicky-Fuller unit root tests with time trend are performed on all the variables used for estimation. The choice of lag length follows the method suggested by Schwert (1989) and the critical values follow Hamilton (1994) Table B.6. All results are based on 10% level of significance. Table 4 shows the list of time series properties of the variables.

First differencing is performed on the I (1) variables, which, in the form of a natural log, becomes the growth rate of, for example, infrastructure stock. This will lose one more time period and difficulty in interpretation, as it is possible that it's the level that affects growth of standard of living not the growth rate. In addition, variable t is included in the regression analysis to allow for an explicit trend.

Table 4 Time series properties of the variables

Variable	Unit root	Trend
The dependent variable	No	Yes
Ln(RSPINV)	No	Yes
Ln(RFDICYPC)	No	No
Ln(GRADS)	No	Yes
Ln(RDEP)	Yes	No
Ln(ELECPDMP)	Yes	Yes
Ln(HWMP)	Yes	Yes
Ln(RDEXPMP)	No	No
Ln(RDCLIMP)	No	No
Ln(RDCLIIMP)	No	No
Ln(RDCLIIIMP)	Yes	Yes
Ln(RDCLIVMP)	No	Yes
Ln(RDUCMP)	Yes	Yes
Ln(RWLENMP)	No	Yes
Ln(TELESUBHP)	No	Yes
Ln (CELLHP)	No	No

ii. Regression analysis

The purpose of this part is to interpret the results on the growth impact of infrastructure capital across China's provinces from the year 1990 to 2009. In particular, it focuses on the following questions. Has infrastructure contributed positively to China's real per capita GDP growth? Do certain types of infrastructure have a stronger growth effect than others in certain regions and during certain time period? Has infrastructure played a positive role in bridging the gaps between lagging and leading regions? These questions have particular importance for policy implications of persistent large scale infrastructure investment as in China.

1. Average effect of infrastructure capital on China's provincial growth

Table 5 presents the results of a first look at the impact of infrastructure capital to China's provincial real per capita GDP growth. Equation 1.1 shows the average partial effects of the four types of infrastructure capital on 31 China's provinces and municipalities from 1990 to 2009. As the dataset spans a period of twenty years, the partial effects of the infrastructure capital may vary for different time periods. Results in Equation 1.2 shows whether it is the case from the data. Similarly, given the diverse development background, effects of infrastructure capital are likely to vary for different regions. Equation 1.3 shows the partial effects of these infrastructure capital for four regions, Central region, Western region, Northeastern region and the reference Eastern region. The partial effect on the dependent variable can be shown in the equation: $\Delta \ln (rgdppc_{f1\_f3}/rgdppc_{t-1}) \approx \Delta (rgdppc_{f1\_f3} - rgdppc_{t-1})/rgdppc_{t-1.}$ However, to simplify the interpretation, the partial effect will be referred to as the provincial growth effect in the context, meaning changes in the growth rate of the three year forward average of real per capita GDP.

The results from Eq. 1.1 in Table 5 are as follows. Among the four types of infrastructure, the rate of electricity production growth is significantly and positively related to the three year forward averages of real per capita GDP growth. Road growth in terms of per capita length has a negative growth effect. The significant non-linear effect indicated by the quadratic term shows that when road per capita length grows over 44%, its effect on provincial growth will start to become positive. There are only a few cases in the sample where such high growth rates are reached. Therefore the average effect from increasing growth rate of road per capita length reduces real per capita GDP growth. The effects of other infrastructure capitals have on average positive but not significant growth effect.

Eq. 1.2 shows the partial effects of road, railway and telecommunications infrastructure do vary for different time periods. Per capita road length growth exhibits non-linear partial effect on provincial real per capita GDP growth. During 1990 to 1997, all road development is associated with a negative growth effect. Starting from the year 1998, road development exhibits a U-shape growth effect. Road development in most provinces is associated with a negative growth effect. Only for provinces that have a road length growth above 35.4%, its growth effect is increasingly positive. During 2003 to 2006, however, on average road development has a positive growth effect. Rail infrastructure has also shown a U-shape partial effect. However, given the level of railway per capita length, its growth effect has been positive throughout time. The effect of telephone ownership seems to exert a significant growth effect throughout the time period until recently. Telephone ownership expansion is associated with a negative growth effect. The growth effect from increasing electricity production, however, does not seem to vary much across time. Its partial effect on growth is smaller than that in Equation 1.1. One percent increase in electricity production per capita will increase the future growth by about 0.07 percentage points.

Results from Eq. 1.3 show that the partial effects of infrastructure capital do differ across regions. The Eastern and Central provinces are benefiting from growth of per capita electricity production. One percent increase in per capita electricity production growth will increase on average future growth rate of about 0.21 percentage points. Electricity production per capita growth in the West, however, is associated with a much lower growth effect. Its growth effect in the Northeastern region has even turned to negative.

The effect of road per capita length growth exerts a non-linear growth effect. On average in the Eastern, Central and Western regions additional road per capita expansion is associated with a declining growth rate of future real per capita GDP, except for a few provinces. Road development in the Northeastern region, however, has a positive growth effect.

Railway length per capita on the other hand has on average positive but insignificant growth effect for all regions, except the Northeastern region. Additional per capita rail expansion is associated with significant negative growth effect. The effect of telephone ownership expansion is not significant as in Eq. 1.1.

Aside from the infrastructure capital, higher foreign capital level and human capital stock are both associated with a higher rate of future growth as shown in Eq. 1.1. Eq. 1.2 shows that foreign capital has on average a positive growth effect throughout time. The private capital and human capital are exerting a stronger positive growth effect over time. Eq. 1.3 shows that for the Western and Northeastern regions growth effects of private and foreign capital seem to be negative, whereas the growth effect of human capital is particularly strong and positive.

Table 5 Average effect of infrastructure capital on real per capita economic growth

(Dependent variable: Ln(three year forward moving average of RGDPPC $_{t+1\_t+3}$/RGDPPC$_{t-1}$); Method: fixed effects with robust standard errors)

	Nationwide Eq.(1.1)	Nationwide by time periods Eq.(1.2)	Nationwide by region Eq.(1.3)
ΔLn (ELECPDMP)	0.128**	0.0698*	0.212***
	(2.14)	(1.90)	(2.88)
ΔLn(HWMP)	-0.0910**	-2.799**	-0.129***
	(-2.20)	(-2.42)	(-3.35)
[ΔLn(HWMP)]^2	0.102**	17.61**	0.141***
	(2.12)	(2.33)	(3.04)
Ln(RWLENMP)	0.0449	0.0501**	0.0438
	(1.61)	(2.11)	(1.52)
Ln(TELESUBHP)	0.00293	0.0929***	-0.0153
	(0.15)	(2.93)	(-0.71)
Ln(RFDICYPC)	0.0212**	0.00705	0.0257***
	(2.63)	(0.99)	(3.03)
Ln(RSPINV)	0.0346	-0.0537*	0.0276
	(1.70)	(-1.93)	(1.19)
Ln(GRADS)	0.0644***	-0.0111	0.0379
	(3.56)	(-0.39)	(1.50)
ΔLn(RDEP)	0.0116	-0.107*	0.0140
	(0.46)	(-1.98)	(0.57)

t	0.0387****	0.0319****	0.0433****
	(4.73)	(3.69)	(5.32)
$Ln(RGDPPC)_{t-1}$	-0.560****	-0.575****	-0.545****
	(-7.76)	(-9.11)	(-7.69)
1998-2002(p2)		0.782***	
		(3.15)	
2003-2009(p3)		1.728***	
		(3.47)	
$Ln(RGDPPC)_{t-1}$*p1		-0.0135**	
		(-2.29)	
ΔLn(HWMP)*p1		2.541**	
		(2.20)	
ΔLn(HWMP)*p2		2.689**	
		(2.31)	
ΔLn(HWMP)*p3		2.748**	
		(2.33)	
[ΔLn(HWMP)]^2*p1		-19.21**	
		(-2.46)	
[ΔLn(HWMP)]^2*p2		-17.53**	
		(-2.32)	
[ΔLn(HWMP)]^2*p3		-17.60**	
		(-2.32)	
Ln(RWLENMP)*p2		-0.330***	
		(-2.90)	
Ln(RWLENMP)*p3		-0.517**	
		(-2.30)	
[Ln(RWLENMP)]^2*p2		0.0480***	
		(3.24)	
[Ln(RWLENMP)]^2*p3		0.0714**	
		(2.46)	
Ln(TELESUBHP)*p3		-0.139****	
		(-4.28)	
Ln(RSPINV)*p2		0.0649*	
		(1.86)	
Ln(RSPINV)*p3		0.100*	
		(1.97)	
Ln(GRADS)*p2		0.0578**	
		(2.63)	
Ln(GRADS)*p3		0.135***	
		(3.59)	
ΔLn(RDEP)*p1		0.158	
		(1.69)	
ΔLn(RDEP)*p2		0.149**	

		(2.34)	
ΔLn (ELECPDMP)*Western			-0.182** (-2.04)
ΔLn (ELECPDMP)*Northeastern			-0.340**** (-4.36)
ΔLn(HWMP)* Northeastern			0.432*** (3.62)
[ΔLn(HWMP)]^2*Northeastern			-0.613*** (-3.11)
Ln(RWLENMP)*Northeastern			-0.335* (-1.73)
Ln(RSPINV)*Northeastern			-0.0483** (-2.20)
Ln(RFDICYPC)*Northeastern			-0.0367*** (-2.89)
Ln(GRADS)*Western			0.0648** (2.11)
Ln(GRADS)*Northeastern			0.0734** (2.29)
ΔLn(RDEP)*Northeastern			-0.0922* (-2.00)
Constant term	2.478**** (9.35)	1.987**** (7.68)	2.566**** (8.45)
No. of Obs.	457	457	457
No. of Provinces	31	31	31

t statistics in parentheses
$^{*}p<0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$, $^{****}p < 0.001$

2. Regional impact of infrastructure capital

The previous results show that infrastructure can play a positive role in China's regional economic growth. Additional infrastructure investment, however, can either increase or decrease the real per capita GDP growth. In fact, road and railway has already shown strong signs of negative growth effect for some regions and during some periods of time. Therefore the relevant question is to what extent infrastructure such as transport development can still be relevant in China's provincial growth? Given the vast differences across China's regions and changing policy focuses over time, this section performs an analysis on subsamples of each economic region to capture the regional and time variations of the impact from infrastructure capital.

Equations 2.1 to 2.4 in Table 6 present a summary result for partial effects of infrastructure capital in each of the four, Eastern, Central, Western and Northeastern, regions. Since the purpose of this section is to capture both the regional and time variation of the growth impact of infrastructure capital, it will present in a way that compares the partial effects across region from each type of infrastructure capital over time.

An increase in the electricity production per capita growth in the Eastern and Northeastern regions is initially associated with a strong and significant growth effect. The growth effect from electricity production expansion in the Central and Western regions has been relatively smaller, but increasingly positive during the period from 1993 to 1997. Growth effect from electricity production in the Eastern region has on average been positive, except for years from 1998 to 2002. Similarly for the Northeastern region, its growth effect has been declining and even become negative during 1998 -2006.

Road development growth in the Eastern region has offered a very interesting scenario. Eq. 2.1 shows that road per capita growth in the Eastern region initially exhibits a non-linear growth effect from 1990 to 1997. If the rate of road per capita growth exceeds a certain threshold, additional increase in road growth rate is associated with higher future economic growth in the province. Below that threshold, increase in road length growth rate is associated with a decline in future growth rate. Given a sample of 12 Eastern provinces, most provinces have a road length growth rate that is below the threshold during the entire sample time period. From 1998 to 2002, road per capita expansion has shown to have an inverse U-shape. Road development in most provinces is associated with a higher growth effect. A few provinces such as Jiangsu and Tianjin municipality are expanding roads beyond the optimal level, suggesting a too rapid road development. From 2003 onward, road development again exhibits U-shape growth effect. Most provinces have experienced negative growth effect from road expansion.

Road development in the Central and Western regions are perhaps one of the most prominent considering its less populated area with a much higher initial road per capita length. Yet the growth effects of such expansion seem to be less desirable.

For the Central region, Eq. 2.2 shows increasing the rate of growth in road stock has a significantly negative growth effect from 1990 to 2002. Its negative effect, however, has become smaller over time and during the year 2003 to 2006 has turned to a small but positive growth effect. The average rate of road network growth has increased from – 0.1% during early 1990s to over 12% after the year 2003. Given this rate of growth in road per capita stock comparable to the Eastern region; more roads in the Central region don't seem to yield stronger growth momentum as in the Eastern region.

Eq. 2.3 presents the results for Western region. Growth rate of road per capita length in the Western region is almost zero at the beginning of 1990. During 1993 to 1997 it has increased to an average of 0.9%. Since the year 1998 that initiated the Western Development Plan, road per capita length grows at about 6% annually, a much higher rate than the early 1990s. After the year 2003, the annual road per capita growth reaches to an average of about 15%!

Growth effects from such skyrocketing road expansion seem to contradict to our expectations. Increasing growth rate of the road per capita length growth has been associated with negative growth effect since the year 1990. Road development during the Western Development Plan doesn't seem to provide the growth momentum expected by the policymakers for the region. Its average growth effect is still negative and significant after the year 1998. From 2003 onward, with an average road per capita growth of 15%, its negative growth effect has become smaller, but is still significantly negative. Heavy investment in road expansion doesn't seem to have a desirable effect in the West. Much of the investment may be buried in a barren land.

Growth rate of road per capita length has been increasing over time in the Northeastern region. During the initial period, its grow rate is on average almost zero and is around 3% on average from 1998 onward. It starts to accelerate after the year 2006 to an average of 16.5%. Similarly with the Central and Western regions, Eq. 2.4 shows road development in the Northeastern region has been associated with a negative growth effect on average. Its negative effect has been declining, yet still significantly negative in recent years.

Eq. 2.1 shows that rail expansion in the Eastern region has been positive and significant throughout the year. Rail development in the Central region has been in general favorable to its economic growth, except for the period between 1998 and 2002. The Western region, shown in Eq. 2.3, has seen steady increase in the growth effect of its rail expansion. Initially rail development is associated with a negative growth effect. From the year 1998 onward, rail development has been contributing more to the growth momentum of this vast and less populated region. Rail development has almost zero growth effect in the Northeastern region throughout the year. Comparing road and rail infrastructure, the Western region seems to show a contrasting scenario in relation to economic growth.

Throughout the years, land-line telephone ownership has expanded rapidly across China's regions. Table 6 shows that its growth effect in the Eastern is positive but not significant from the year 1990 to 2002. Afterwards, additional telephone ownership has been associated with a declining growth effect. The Western region also enjoys a positive and significant growth effect initially. From the year 2003 onward, its growth effect has turned to negative and significant. Northeastern region has benefited from telephone popularization during 1993 to 2002, whereas in other years, its growth effect is negative. One possible reason to explain the declining role of telephone ownership to growth is that its role has been gradually replaced by the introduction of cell phone. It is particularly true in the latter half of the time period. The effect of cell phone usage will be discussed in the following chapter that may explain the lessening effect of telephone.

Table 6 Regional impact of infrastructure capital

(Dependent variable: Ln (three year forward moving average of RGDPPC $_{t+1\_t+3}$/ RGDPPC$_{t-1}$); Method: fixed effects with robust standard errors)

	Eastern Eq.(2.1)	Central Eq.(2.2)	Western Eq.(2.3)	Northeastern Eq.(2.4)
Ln(RGDPPC)$_{t-1}$	-0.611****	-0.897****	-0.108	-0.778*
	(-10.79)	(-12.86)	(-0.58)	(-4.18)
ΔLn (ELECPDMP)	0.365**	-0.0430	-0.695****	0.863**
	(3.03)	(-0.75)	(-11.03)	(5.73)
ΔLn(HWMP)	-9.750****	-5.592*	-0.0737*	-2.861***
	(-4.85)	(-2.55)	(-2.00)	(-30.33)
[ΔLn(HWMP)]^2	61.66***			
	(4.50)			
Ln(RWLENMP)	0.0501***	0.146***	-0.164***	0.00412
	(3.47)	(4.49)	(-4.10)	(0.03)
Ln(TELESUBHP)	0.0148	0.108**	0.137**	-0.180*
	(0.28)	(3.54)	(2.83)	(-3.43)
Ln(RFDICYPC)	-0.00673	0.0283***	-0.00655	0.0233
	(-0.29)	(6.63)	(-0.82)	(1.99)
Ln(RSPINV)	-0.0986**	0.104**	0.111***	-0.138**
	(-2.43)	(2.84)	(3.30)	(-5.26)
Ln(GRADS)	0.0699*	0.177*	-0.0698*	0.00987
	(2.19)	(2.22)	(-1.85)	(0.22)
ΔLn(RDEP)	-2.270***	0.0953	0.166***	-0.0904
	(-4.21)	(1.62)	(3.32)	(-0.83)
t	0.0560**	0.0434**	0.0285	0.0673**
	(3.14)	(3.42)	(1.44)	(6.19)
1993-1997(p1)	1.106***			
	(4.03)			
1998-2002(p2)	1.186****	-0.488**		
	(5.65)	(-2.72)		
2003-2009(p3)	0.332	-3.049***		1.018**
	(1.82)	(-5.75)		(8.46)
Ln(RGDPPC)$_{t-1}$*p1	-0.133**		-0.340****	
	(-3.22)		(-6.29)	
Ln(RGDPPC)$_{t-1}$*p2			-0.413****	
			(-7.01)	
Ln(RGDPPC)$_{t-1}$*p3		0.422**	-0.196	
		(3.78)	(-2.18)	
ΔLn (ELECPDMP)*p1		0.378*	0.722****	-0.665***
		(2.34)	(6.28)	(-17.87)
ΔLn (ELECPDMP)*p2	-0.383*		0.711****	-0.883**
	(-1.90)		(9.20)	(-6.89)
ΔLn (ELECPDMP)*p3			0.731***	-0.968*

			(3.24)	(-4.19)
ΔLn(HWMP)*p1	9.605**** (4.90)	5.147* (2.34)		
ΔLn(HWMP)*p2	9.867**** (4.93)	5.538 (2.55)		2.836**** (32.47)
ΔLn(HWMP)*p3	9.733**** (4.97)	5.693** (2.62)	0.0586 (1.21)	2.773*** (27.83)
[ΔLn(HWMP)]^2*p1	-63.80*** (-4.70)			
[ΔLn(HWMP)]^2*p2	-61.82*** (-4.51)			
[ΔLn(HWMP)]^2*p3	-61.63*** (-4.52)			
Ln(RWLENMP)*p1		-0.163** (-3.33)	0.146**** (8.55)	
Ln(RWLENMP)*p2	-0.558**** (-5.11)		0.310**** (9.52)	
Ln(RWLENMP)^2*p2	0.0819**** (4.83)			
Ln(RWLENMP)*p3			0.376**** (8.65)	
Ln(TELESUBHP)*p1			-0.0489* (-2.12)	0.204** (5.83)
Ln(TELESUBHP)*p2			-0.0794** (-2.30)	0.185** (6.71)
Ln(TELESUBHP)*p3	-0.0893* (-1.89)		-0.492**** (-5.75)	
Ln(RSPINV)*p1	0.134*** (3.47)	-0.181** (-3.25)	-0.199*** (-4.33)	0.253*** (16.72)
Ln(RSPINV)*p2	0.137*** (3.53)		-0.122*** (-3.18)	0.103*** (16.58)
Ln(RSPINV)*p3		-0.280**** (-7.72)	-0.106** (-2.92)	0.397*** (29.90)
Ln(RFDICYPC)*p1	0.0776*** (3.63)			-0.0714*** (-15.11)
Ln(RFDICYPC)*p2	0.0667** (2.58)			-0.0740*** (-13.64)
Ln(RFDICYPC)*p3	0.0643** (2.72)			-0.0607** (-6.19)
Ln(GRADS)*p1			0.101*** (4.08)	-0.222** (-7.62)
Ln(GRADS)*p2	-0.0815** (-2.66)	-0.114* (-2.07)	0.170**** (4.63)	

Ln(GRADS)*p3		-0.231**	0.235****	-0.154
		(-3.28)	(9.46)	(-2.41)
ΔLn(RDEP)*p1	2.225***			
	(3.92)			
ΔLn(RDEP)*p2	2.254***		-0.174	
	(3.99)		(-1.70)	
ΔLn(RDEP)*p3	2.340***			0.194
	(4.62)			(1.29)
Constant term	2.500****	3.812****	1.535***	2.768
	(10.52)	(8.07)	(3.31)	(1.68)
No. of Obs.	151	96	162	48
No. of Provinces	10	6	12	3

t statistics in parentheses
$^{*}p<0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$, $^{****}p < 0.001$

3. The catching up process

Figure 2 shows that China's provinces are diverging, where a greater share of GDP has been enjoyed by a smaller share of population in leading provinces. This part again visits the issue to see whether there is evidence of conditional convergence among the provinces. Given the neoclassical growth model introduced in the previous chapter, the coefficient on the lagged term of real per capita GDP is expected to be negative to if there is evidence of conditional convergence among provinces. This shows that lagging provinces which have a lower initial level of economic development will grow faster and eventually catch up with other provinces.

Equations 1.1 to 1.3 in Table 5 show there is evidence of conditional convergence among all provinces across the country. Equations 2.1 to 2.4 present further evidence that such conditional convergence is felt by all four regions. If considering both time and regional varying effects, Eq. 3 and Eq. 4 in Table 9 show that both random effect and fixed effect methods yield similar results in terms of the catching up process. Random effect estimation shows that the catching up process is faster in particular for the Central region throughout time. The catching up process slows down and there are signs of diverging after the year 2003 in the random effect estimation. The effects from the fixed effect estimation, however, show a much stronger catching up process. Considering possible correlation between the explanatory variables and the unobserved heterogeneity, the results from the fixed effect approach seems to be more appropriate.

4. Marginal effects of an increase in infrastructure network

In order to compare the regional and time effect of different infrastructure capital, this section envisages the effect of a marginal increase in either the growth rate or the stock of a particular type of infrastructure capital. The purpose of this section is to present a more concrete example of the effect of infrastructure capital on regional growth. What type of infrastructure has played a more important role in promoting and facilitating economic growth? What type of infrastructure still has the potential to drive the regional economy?

For road per capita length growth rate and electricity production growth rate, a 1% increase in the growth rate of infrastructure capital is considered. For example, an increase in the road length growth rate from 2% to 3%. For railway per capita length and telephone ownership per 100 people, a 10% increase in the infrastructure network is considered. An example of this would be an increase of the railway length per million people from 30 km to 33 km.

Table 7 presents the estimated marginal effect on growth prospect. The numbers in the table refers to percentage point increase (or decrease) in the three year forward real per capita GDP growth rate. A one percent increase in the growth rate of electricity production and highway length seems to give a contrasting growth effect. On average, electricity production has contributed to the growth of all the regions except for the Northeastern region, whereas road expansion on average has been associated with negative growth, except for the Northeastern region. Railway expansion does not seem to have much growth momentum either in the Northeastern region. Telephone ownership expansion, on average, seems to have a negative but not significant growth effect across the country.

Table 7 Marginal growth effect to an increase in the stock or growth rate of infrastructure capital

Marginal growth effect across region				
	Eastern	**Central**	**Western**	**Northeastern**
Electricity production growth	0.212*	0.212*	0.03*	-0.178*
Highway length growth	-0.115*	-0.109*	-0.112*	0.252*
Railway length	0.438	0.438*	0.438	-2.912*
Telephone ownership	-0.153	-0.153	-0.153	-0.153
Marginal growth effect by region over time				
	1990-1992	**1993-1997**	**1998-2002**	**2003-2009**
Electricity production growth				
Eastern	0.365*	0.365*	-0.018*	0.365*
Central	-0.043	0.335*	-0.043	-0.043
Western	-0.695*	0.027*	0.016*	0.036*
Northeastern	0.863*	0.198*	-0.02*	-0.105*
Highway length growth				
Eastern	-9.25*	-0.215*	0.1*	-0.008*
Central	-5.592*	-0.445*	-0.054*	0.101*
Western	-0.0737*	-0.0737*	-0.0737*	0.0151
Northeastern	-2.861*	-2.861*	-0.025*	-0.088*
Railway length				
Eastern	0.501*	0.501*	0.136*	0.501*
Central	1.46*	-0.17*	1.46*	1.46*
Western	-1.64*	-0.18*	1.46*	2.12*
Northeastern	0.0412	-6.61*	0.0412	0.0412
Telephone ownership				
Eastern	0.148	0.148	0.148	-0.745*
Central	1.08*	1.08*	1.08*	1.08*
Western	1.37*	0.881*	0.576*	-3.55*
Northeastern	-1.8*	0.24*	0.05*	-1.8*

**At least 10% significance level*

Table 7 also presents the projection of a marginal change in the four types of infrastructure capital. The marginal change discussed here is either a 1% increase in the growth rate of a type of capital or a 10% increase in the stock of a type of capital.

Increase in the electricity production growth rate has in general a strong growth effect in the Eastern region compared with other regions, except for the years from 1998 to 2002. Electricity infrastructure investment seems to play an increasing role in the regional development of the Western provinces. A marginal increase in the growth rate of electricity production per capita is initially associated with a reduction in the growth of per capita GDP. Over time its growth effect has turned to positive, although not as strong as that for the Eastern region. The Northeastern region, on the other hand, has seen a gradually decreasing role of the electricity infrastructure. A marginal increase in electricity production per capita has contributed less to the provincial growth over time. Its growth effect has even turned to negative in the latter half of the time period. Electricity infrastructure in the Central region has on average played a minimum role, except during the year 1993 to 1997.

Road infrastructure growth has in general a negative growth effect to the provincial real per capita GDP for the Eastern and Northeastern regions, except for the period from 1998 to 2002 in the Eastern region. The role of road infrastructure to economic growth in the Central region seems to be increasing. Road infrastructure investment in the Western region has seen a persistent reduction to its provincial growth. Its growth effect has turned to positive but insignificant in recent years.

Railway infrastructure investment has boded well in general for the Eastern and Central regions, except during the year 1993 to 1997 for the Central region. Railway infrastructure has becoming more important for the Western region. Its network expansion initially has a negative growth effect. Its growth effect has turned to positive in the latter half of the time period. Railway development seems to have a negligible growth effect for the Northeastern region, except that its growth effect has become very negative during 1993 to 1997.

Telephone infrastructure has contributed positively to the provincial growth in Eastern and Western regions until recently. Its growth effects have become negative for both regions after the year 2003. Telephone infrastructure investment seems to benefit the Central region on average, whereas its growth effect fluctuates over time for the Northeastern region.

The above results projected have several implications for regional economic development in China. First, electricity infrastructure investment drives the energy-demanding Eastern region and the Western region where it has abundant energy resources and energy producers. Second, consistent rapid growth in road infrastructure investment does not seem to provide further growth momentum to its regional economic growth. Rather such large investment scale has diverted resources that would be more productive in other areas. Railway development, on the other hand, seems to have more growth potential for the Eastern, Central and Western regions, in particular for the West. Perhaps in the Western area, building railway capacity is more compatible to the industrial sectors than building roads that few people tread. Third, the role of telephone infrastructure has gradually been declining. Alternative investment may yield higher growth effect. This is further discussed in the alternative model specification including cell phone development in the next section.

Infrastructure investment enhances production capacity and in itself creates employment which can boost provincial growth. It can also complement the growth of production in other sectors by reducing production cost or adjustment coast, as shown in electricity production and railway development in some regions. Infrastructure investment, however, does not always yield desirable results. There is evidence of overinvestment in certain types of infrastructure capital, such as road. Contrary to our conventional wisdom, road does not seem to lead to prosperity. Road that leads to nowhere can only divert valuable resources from more productive sectors.

iii Alternative specifications and results

1. Endogenous investment decision

Previous results are based on the assumption that private and foreign entities make their investment decisions taking infrastructure capital as given. A more realistic situation is that a better investment climate often encourages expansion of private and foreign investment, because of lower cost of transportation and other infrastructure services. For example, see a discussion on the private adjustment cost from Anderson et al (2006). A simple way of testing is to include interaction terms of infrastructure with private or foreign investments. The aforementioned infrastructure capital variables are demeaned to show the marginal effect of FDI or private capital with infrastructure above the national average level. Table 8 shows the results of the endogenous investment using this simple test.

The growth effect of real private capital is much greater in provinces where the telephone ownership exceeds the national average, suggesting the benefit of telephone communications to productivity enhancement and mobilization of the people. The growth effect of real private capital is also stronger for provinces with a higher than average railway network per million people. Its effect, however, is lower for regions with a higher than average road network per million people. Road network expansion seems to divert economic activities rather than attracting more private capital.

Road length per million people above the average level will enhance the positive effect of FDIs, whereas higher electricity production per million people will lower the contribution of FDI. Perhaps foreign direct investment is more concentrated in provinces with more manufacturing sector than the energy sector.

Table 8 Impact of infrastructure capital with endogenous investment

(Dependent variable: Ln(three year forward moving average of RGDPPC $_{t+1\_t+3}$/ RGDPPC$_{t-1}$); Method: fixed effects with robust standard errors)

Ln(RGDPPC)$_{t-1}$	-0.535**** (-7.49)
Ln(RSPINV)*tele0	0.0506*** (3.27)
Ln(RSPINV)*hw0	-0.0419** (-2.54)
Ln(RSPINV)*rw0	0.0520** (2.09)
Log(RFDICYPC)*elep0	-0.0300**** (-4.41)
Ln(RFDICYPC)*hw0	0.0151** (2.40)
ΔLn (ELECPDMP)	0.0600 (1.64)
ΔLn(HWMP)	-0.0310 (-1.09)
Ln(RWLENMP)	0.194*** (2.83)

Ln(TELESUBHP)	0.0173
	(0.82)
Ln(RFDICYPC)	0.00308
	(0.71)
Ln(RSPINV)	-0.00670
	(-0.40)
Ln(GRADS)	0.0810****
	(4.63)
ΔLn(RDEP)	-0.0310
	(-1.23)
t	0.0337****
	(4.38)
Constant term	1.671****
	(3.77)
No. of Obs.	457
No. of Provinces	31

t statistics in parentheses
* $p<0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$

2. Road classifications and cell-phone usage

The objective of modern transportation development gradually shifts from road connectivity to the speed and quality of travel. High speed train, subway and higher quality expressway are all examples of the current transportation development in China. It is therefore, interesting to explore whether the quality and speed of transportation contributes to the provincial growth. Given data limitation, a regression with a smaller sample from 1999 to 2009 is performed with roads of detailed classifications (Table 10).

The development of Class III and IV roads may exert a negative growth effect, although such effect is not significant on average. Expressway development seems to yield a much stronger growth impact in the Western region, whereas its effect on the other regions may actually be negative. Developing Class I and II roads has a strong positive growth effect for the Northeastern region.

Telecommunications development shows that the more mobile the population the less desirable a telephone ownership would be. In fact cell phone ownership has a strong positive growth effect, replacing the effect of telephone. Such effect is particularly evident in the Central region, but negative for Northeastern provinces.

V. Conclusions

This paper investigates the relationship between infrastructure capital and economic growth in China's provinces. The results show that infrastructure has a positive role to play in China's regional economic growth. This is particularly evident in the analysis of the electricity and railway infrastructure for the lagging regions.

The findings of the paper, however, also yield what, at first glance, seem very surprising results. More infrastructure capital is not always better. China's provinces have already shown strong evidence of investing too fast in road infrastructure. This is particularly true for the Western regions, which are often the recipients of large central transfers and favorable credits for infrastructure projects. Such results reveal a remarkable truth that infrastructure when invested beyond a proper level or speed can be detrimental economic growth. This result contrasts many studies that conclude with a policy recommendation for more roads in the Western and Central regions.

These empirical findings should not be so surprising from a theoretical perspective. There is a limit to the growth effect of infrastructure capital in general and more public infrastructure may actually crowd-out private capital. Thus seemingly productive infrastructure investment may become unproductive if there is an excessive amount of them. It, however, seriously questions the conventional wisdom that road development lead to prosperity. A large resource waste from building roads can lead to nowhere.

This conclusion, however, cannot be over-interpreted as there should be a specific level of infrastructure investment. Instead it shows that there is a level of infrastructure investment that's comparable to the level of development. Any type of infrastructure, if investing beyond the current economic conditions will be detrimental. A certain level of infrastructure may become favorable to growth again if there is a demand. For example large amount of road investment may solve the bottlenecks in the urbanization of China's metropolitan areas and speed up growth. In addition, infrastructure development may come out of an equity concern in the public investment decision making.

If the empirical findings discussed can hold with further scrutiny, they will have important policy implications. The recommendation for more road infrastructure in lagging regions may be misleading. Spending too much on building roads may not be a better option than developing the energy or railway sector.

These findings open up new questions for further research. What are the economic explanations for sub-national governments to invest too much in public infrastructure? How much effect infrastructure spending can be and continue to be an effective tool of fiscal stimulus, as it is often the case during possible economic downturn? The results from more rigorous methods may better support the findings. Considering the interaction between private investment, FDI and infrastructure spending in a simultaneous equation model and a GMM approach may yield additional support to the conclusions here.

The results in this paper also contribute to the recent effort to empirically test the neoclassical economic growth model. By exploring the diversity of China's growth experience, the findings support the role of foreign, human, private capital investment and its relation to infrastructure.

APPENDIX

Figure 3 Map of China

Figure 4 Types of infrastructure capital and GDP per capita

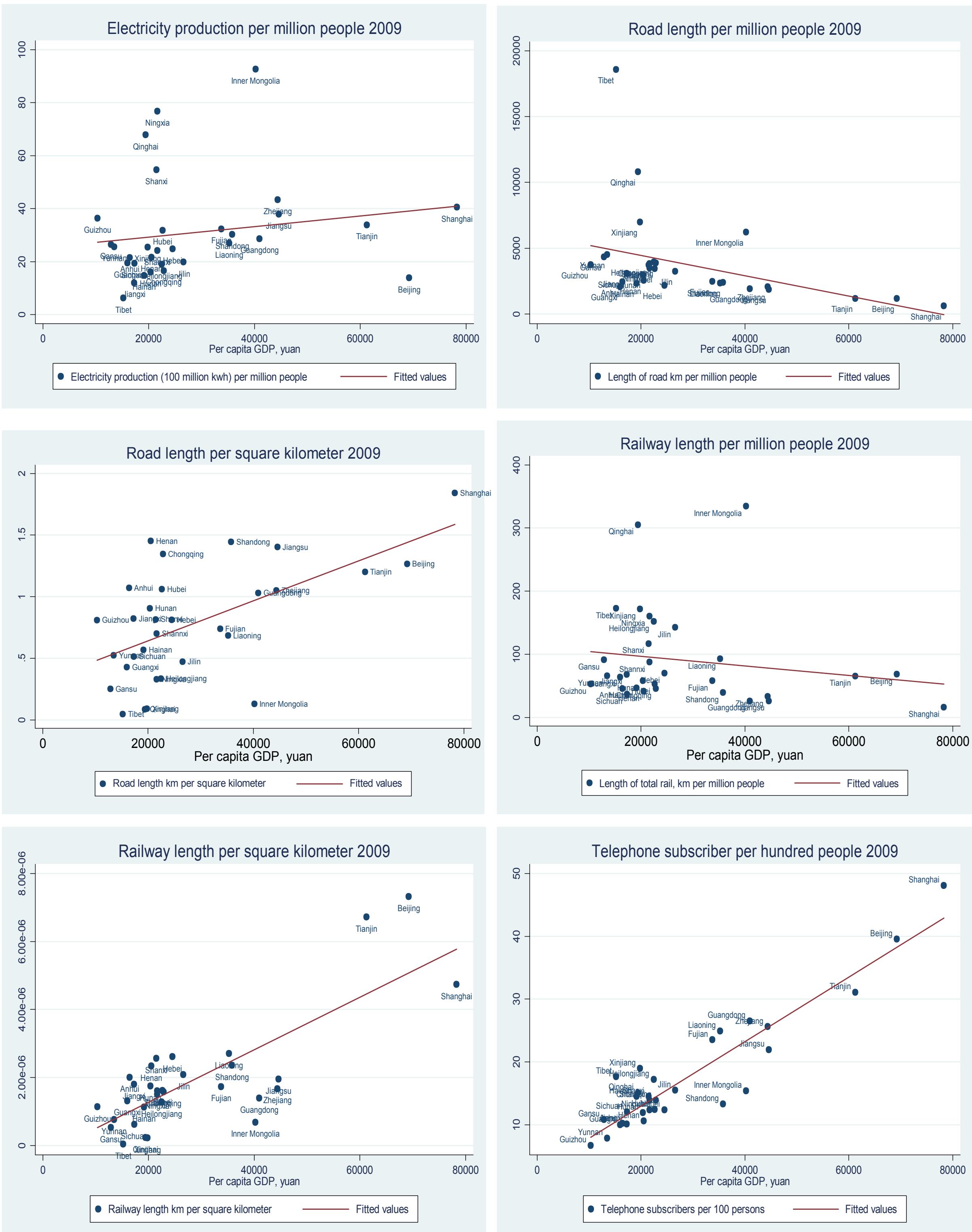

Table 9 Average effect of infrastructure capital on real per capita economic growth

(Dependent variable: Log(three year forward moving average of RGDPPC $_{t+1\_t+3}$/RGDPPC$_{t-1}$); Method: fixed or random effects with robust standard errors)

	RE Eq.(3)	FE Eq.(4)
Ln(RGDPPC$_{t-1}$)	-0.125**** (-3.51)	-0.578**** (-6.84)
ΔLn (ELECPDMP)	0.139** (2.39)	0.0836* (2.02)
ΔLn(HWMP)	-1.375* (-1.90)	-0.564*** (-3.47)
Ln(RWLENMP)	-0.0377** (-2.39)	-0.00311 (-0.11)
Ln(TELESUBHP)	0.0621*** (2.78)	0.0388* (1.77)
Ln(RFDICYPC)	0.0237*** (3.27)	0.0371*** (3.06)
Ln(RSPINV)	-0.0112 (-0.50)	-0.0333 (-1.25)
Ln(GRADS)	0.0533*** (2.58)	0.00734 (0.34)
Ln(ngd)	-0.185**** (-3.93)	
ΔLn(RDEP)	-0.487 (-1.33)	-0.0565 (-1.16)
Ln(LAND)	0.0163*** (2.78)	
t	-0.00571 (-1.01)	0.0422**** (4.87)
1993-1997(p1)	-0.255**** (-3.36)	
2003-2009(p3)	-0.582*** (-2.60)	
Ln(RGDPPC$_{t-1}$)*p3	0.147*** (2.62)	
Ln(RGDPPC$_{t-1}$)*Central	-0.0496** (-2.46)	
ΔLn (ELECPDMP)*Central	0.264** (2.49)	
ΔLn (ELECPDMP)*Western	-0.119 (-1.55)	-0.0378 (-0.55)
ΔLn (ELECPDMP)*Northeastern	-0.202**** (-3.36)	-0.186** (-2.68)

ΔLn(HWMP)*p1	1.377*	
	(1.89)	
ΔLn(HWMP)*p2	1.317*	0.525***
	(1.83)	(3.10)
ΔLn(HWMP)*p3	1.342*	0.588***
	(1.88)	(3.40)
Ln(RWLENMP)*p2	-0.212****	0.0574***
	(-5.99)	(3.03)
Ln(RWLENMP)*p3	0.0598**	0.102****
	(2.51)	(3.67)
Ln(RWLENMP)^2*p2	0.0344****	
	(5.83)	
Ln(RWLENMP)*Central	0.0603***	0.0922**
	(3.28)	(2.36)
Ln(RWLENMP)*Northeastern	-0.0247****	-0.586****
	(-6.13)	(-4.35)
Ln(TELESUBHP)*p2	0.0369	
	(1.63)	
Ln(TELESUBHP)*p3	-0.178****	-0.0848****
	(-3.78)	(-4.28)
Ln(TELESUBHP)*Central	-0.0427*	
	(-1.69)	
Ln(TELESUBHP)*Northeastern		-0.0622****
		(-3.82)
Ln(RFDICYPC)*p1	-0.0358**	
	(-2.53)	
Ln(RFDICYPC)*p2	-0.0249**	
	(-2.24)	
Ln(RFDICYPC)*Central		-0.0241**
		(-2.08)
Ln(RFDICYPC)*Western		-0.0202
		(-1.26)
Ln(RSPINV)*p1		0.0159**
		(2.49)
Ln(RSPINV)*p2		0.0468**
		(2.11)
Ln(RSPINV)*Central	0.0781***	
	(3.26)	
Ln(RSPINV)*Western	0.0393****	
	(4.89)	
Ln(GRADS)*p2		0.0564***
		(3.53)
Ln(GRADS)*p3		0.0830***

		(2.95)
ΔLn(RDEP)*p1	0.616*	
	(1.66)	
ΔLn(RDEP)*p2	0.606*	
	(1.67)	
ΔLn(RDEP)*p3	0.534	
	(1.47)	
ΔLn(RDEP)*Central		0.130
		(1.67)
ΔLn(RDEP)*Western		0.149**
		(2.32)
ΔLn(RDEP)*Northeastern	-0.245****	
	(-4.12)	
Central*p1	0.122****	0.0604**
	(3.85)	(2.48)
Central*p2	0.147***	
	(2.77)	
Central*p3	0.198***	
	(3.06)	
Western*p3	0.130****	
	(4.13)	
Northeastern*p2	-0.0515	
	(-1.50)	
Northeastern*p3	0.0994**	
	(2.23)	
Constant term	0.539**	2.606****
	(2.02)	(8.37)
No. of Obs.	457	457
No. of Provinces	31	31

t statistics in parentheses
$^{*}p<0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$, $^{****}p < 0.001$

Table 10 Road classifications and cell phone coverage

(Dependent variable: Ln(three year forward moving average of RGDPPC $_{t+1\_t+3}$/RGDPPC$_{t-1}$); Method: fixed effects with robust standard errors)

	Average effect Eq.(5.1)	Average effect across regions Eq.(5.2)
Ln(RGDPPC$_{t-1}$)	-0.750**** (-8.63)	-0.760**** (-9.48)
ΔLn (ELECPDMP)	0.0244 (0.72)	0.0236 (0.72)
Ln(RDEXPMP)	0.0120 (1.58)	-0.0197 (-1.08)
Ln(RDCLIMP)	0.00131 (0.10)	-0.00539 (-0.38)
Ln(RDCLIIMP)	0.0588 (1.69)	0.0512 (1.47)
ΔLn(RDCLIIIMP)	-0.0213 (-0.72)	-0.00787 (-0.31)
Ln(RDCLIVMP)	-0.0000270 (-0.00)	-0.00476 (-0.24)
ΔLn(RDUCMP)	0.00337 (0.81)	0.00160 (0.44)
Ln(RWLENMP)	0.0357 (1.25)	0.0452 (1.62)
Ln(TELESUBHP)	-0.0146 (-0.46)	0.00455 (0.15)
Ln(CELLHP)	0.0436*** (3.59)	0.0272 (1.70)
Ln(RFDICYPC)	0.00804 (0.88)	0.0151 (1.66)
Ln(RSPINV)	0.0621*** (3.33)	0.0687*** (3.15)
Ln(GRADS)	0.159**** (5.81)	0.123**** (5.00)
ΔLn(RDEP)	0.00485 (0.15)	-0.0139 (-0.42)
t	0.0130 (1.02)	0.0254* (1.88)
Ln(RDEXPMP)*Western		0.0395** (2.40)
Ln(RDEXPMP)*Northeastern		-0.0677*** (-3.60)
Ln(RDCLIMP)*Northeastern		0.0898** (2.61)

Ln(RDCLIIMP)*Northeastern		0.163*
		(1.91)
Ln(CELLHP)*Central		0.0262*
		(2.03)
Ln(CELLHP)*Northeastern		-0.0955***
		(-3.34)
Constant	3.489****	3.363****
	(8.81)	(8.02)
No. of Obs.	227	227
No of Provinces	30	30

t statistics in parentheses
* $p<0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$

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