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Infrastructure, Industrial Productivity and Regional Specialization in China

Jie Zhang*

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Infrastructure can affect sectoral productivity and lead to industrial structure changes. Under the framework of Harrigan (1997), this study provides an empirical analysis of the effect of infrastructure on China's industry-level productivity and regional specialization during the period of 1987-2007. We calculate the total factor productivity of 9 manufacturing industries in 28 provinces and study the effects of roads networks, telecommunications, and electric power supply on regional variations in sectoral TFP. We also examine the effect of these infrastructures on the sectoral output share across provinces. By using a structure model of infrastructure accumulation and the 3SLS estimation strategy to control for endogeneity of infrastructure provisions, we find that telecommunications and electric power have positive effects on sectoral TFP performance, while road networks and telecommunications help to explain the regional comparative advantage and production specialization.

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JEL Classification: E22, H54, O18, R53.

Keywords: Infrastructure, Total Factor Productivity, Industrial Specialization.

1 Introduction

Regional disparity has become a serious problem with the rapid economic growth in China. The labor productivity among regions not only consists of large and persistent differences, but recent research also suggests a huge disparity in TFP performance across provinces at the industry level(Jefferson et al, 2008)[1]. Ac-

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[1] Jefferson, Rawski and Zhang(2008) investigate China's industrial TFP performance by using firm level data and suggest that there exist big regional TFP disparity in China: the east coastal area have highest TFP level, but the inland provinces' TFP level have significant catch-up effect to the east provinces.

cording to the neoclassical trade theory, these regional productivity differences will change regional production specialization patterns(Harrigan, 1997).

There are two objectives of this study. First, we aimed to calculate the extent to which differences in total factor productivity(TFP) across provinces at the sectoral level can be attributed to differences in infrastructures. The second goal was to study the effect of infrastructure on regional specialization. Although an affirmative answer to the first question implies an affirmative answer to the second question, the latter is also worth investigating independently because there may be other channels of causation ranging from infrastructure to regional specialization, such as capital mobility(Cai et al, 2005), and the rough measurement of relative productivity could obscure this relationship.

After Ashauer(1989), casual observation suggests that the lack of adequate roads, weak telecommunication systems, and power outages are main obstacles to productivity improvements in most developing countries. Furthermore, recent studies suggest that infrastructure is likely to influence sectoral productivity(Clarida and Findlay, 1992) and is important for facilitating international specialization(Bellak et al, 2009). Yeaple and Golub (2007) provide empirical evidence of Clarida and Findlay(1992)'s model using cross country data that shows that infrastructures help to explain the international production specialization.

The relationships between infrastructure, productivity, and regional specialization are important policy issues. Government may influence both the absolute advantage and comparative advantage through its policies towards infrastructure, for policy plays a decisive role in the infrastructure supply due to the public good and natural monopoly dimensions of infrastructure, either directly through public investment or indirectly through the regulatory environment. Indeed, countries such as China always pledge infrastructure improvements as part of a package of targeted investment incentives. In recent decades, Chinese style fiscal decentralization reform and subsequent local government competition has given local officials strong incentives to invest more in infrastructure in order to absorb FDI and obtain a higher GDP growth rate(Zhang et al, 2007). As a result, the share of government expenditure spent on infrastructure in China is extraordinarily higher than other developing countries. Rapid improvement in infrastructure provisions can alter the relative productivity among regions, which will lead to regional comparative advantage change, and finally affect the industrial structure. Despite the importance of this issue, to the best of our knowledge no previous empirical study has focused on this topic in China at the industry level.

In this study we attempt to fill this gap. We calculate TFP for 9 manufacturing industries located in 28 provinces, and study the effect of road networks, telecommunications, and electric power on regional variations in sectoral TFP as well as on sectoral output shares across provinces. Unlike other empirical studies, we focus on the level of the variables instead of on growth rates. As Hall and Jones (1999) have argued, the investigation of the level may be a more natural research question since differences in the level of productivity or income reflect differences in welfare. Moreover, the endogeneity of infrastructure provision raises difficult problem in identifying the effects of infrastructure on comparative advantages for local governments choose infrastructures based on the characteristics of their provinces. Highly productive provinces can afford higher levels of infrastructure, so the direction of causation runs in both directions. In this study, we use a structural model inspired by Roller and Waverman(2001) and Castells et al(2005), which endogenizes the infrastructure provision by specifying a micromodel of infrastructure investment and then jointly estimated with the TFP determinants equation. Using this approach, we can endogogize infrastructure supply. Finally, we find that increased provision of infrastructure has positive effect on TFP performance in most industries, and a significant effect of infrastructure exists on industry-level productivity differences and comparative advantage. Moreover, changes in the availability of infrastructure alter industrial specialization patterns.

The remainder of this paper is organized into five sections. In the second section we discuss the background and the related empirical literatures. Section 3 presents the theoretical model and the empirical strategy. Section 4 describes the database and the measurement of TFP level. The results of the econometric exercises are reported in section 5, while some summarizing remarks, together with some policy suggestions, are discussed in the final sections.

2 Background

China's market oriented reform in 1978 led to rapid market integration and considerable industrial structure changes across regions. Rapid improvement of infrastructure might be an important determinant of this industrial structure change, for its asymmetric effects on sectoral TFP will finally change regional comparative advantage as well as the industrial structure.

2.1 Fiscal decentralization and infrastructure investment

China's infrastructure development is always regarded as a success story[2], that has important effects on driving China's economic growth(Demurger, 2001). Particularly after the Asian financial crisis in 1998, the urban public investment[3] that was mainly spent on infrastructure construction experienced a high growth period, and its share in total fixed assets investment maintained a high level of approximately 30%. Meanwhile, if we divide the infrastructure into hard and

[2]China implemented many regional development plan in the past two decades, including the Plan of West China Development(from 2000), the Revitalization of the Old Industrial Base of Northeast China(from 2003) and the Plan of Encouraging the Rise of Middle China(from 2006). Moreover, China issued a 600 billion dollars fiscal stimulus package to fight against global financial crisis at the end of 2008. In all these expenditure expansions, public investment especially the infrastructures investment account for biggest share.

[3]Including the fix asset investment in the following public sectors: (1) Production and supply of electricity, gas and water; (2) Transportation, Storage and post; (3) Management of water conservancy, environment and public facilities. And the social services contain: (4) Scientific research, education, health and culture; (5) Public management and social organizations.

Table 1: Growth of urban infrastructure investment in China 1985-2009

Year	Electricity	Transport	Public facilities	Education	Organization
1985	80.6	118.1	53.6	99.4	40.4
	(9.22)	(13.50)	(6.13)	(11.36)	(4.62)
1990	190.1	109.6	58.2	82.5	32.3
	(21.48)	(12.38)	(6.58)	(9.32)	(3.64)
1995	356.9	450.2	186.0	149.2	134.4
	(17.00)	(21.44)	(8.86)	(7.10)	(6.40)
2000	688.9	1011.8	613.5	318.1	244.0
	(18.47)	(27.12)	(16.45)	(8.53)	(6.54)
2005	1891.9	2407.7	1571.3	1042.6	733.0
	(8.51)	(10.83)	(7.07)	(4.69)	(3.30)
2009	3338.0	5775.4	4595.9	2072.9	1095.2
	(6.43)	(11.12)	(8.85)	(3.99)	(2.11)
Annual growth rate	16.78%	17.60%	20.38%	13.49%	14.74%

Note: a) Number in bracket denotes the share of sectoral fixed assets investment in total investment(%); b) Unit: 100 million rmb(price level of 1978); c) Data source: China Statistical Yearbook.

soft infrastructure[4], as in table 1, the hard infrastructure had a much higher growth rate than the soft infrastructure. As for the reason for that, most studies focus on the importance of the role of local government, and particularly the economic and political incentives of local government officials.

The fiscal decentralization reform that started in the 1980s is a key institutional arrangement for China's high growth(Lin and Liu, 2000; Jin, Qian and Weingast, 2005; Zhang and Gong, 2005). From 1978 to 1993, the fiscal contracting system[5] was introduced to replace the highly centralized fiscal system[6] that had been used previously, and in 1994, the central government introduced a tax sharing system reform[7]. After that, local governments gained the power to control fiscal expenditure, and since then the share of local government ex-

[4]The first 3 categories are hard infrastructure and the last two are soft infrastructure.

[5]Local government had to contract with central government to meet certain revenue and expenditure targets. The rest can be controlled by local governments. This reform gave the local government more incentives to develop the local economy. However, it also created an incentive for local governments to conceal information about local revenue from the central government, and therefore the revenue share of the central government decreased to approximately 22% in 1993.

[6]All the revenues are collected by the local government but had to be handed in to the central government, then the central government deliver these revenues according to local spending needs.

[7]This reform divided the tax into three parts: central tax, local tax, and sharing tax. The biggest part is the sharing tax, where 75% of the tax from the industrial sector and 60% of the income tax was controlled by the central government, and 95% of the tax from the service sector was assigned to the local government. After this reform, the share of central government in the total fiscal revenue increased to approximately 50% in 1994.

penditure in total fiscal expenditure has increased from 52.6% in 1978 to 80% in 2009. Meanwhile, the centralized political system grants the central government the right to assess sub-level officials based on their jurisdiction's economic performance, and as a result this political incentive encourages local officials to develop the economy and compete with the officials in other provinces for absorbing private capital, which is termed "yardstick competition"(Li et al, 2005; Zhou, 2007). Therefore, the best choice for local leadership is to increase the expenditure on infrastructure investment, such as roads, telecommunications and electric powers, which can help the local government absorb more FDI and obtain higher output level. Due to this situation, the percentage of fiscal expenditure spent on infrastructure construction in China is extraordinarily higher than other developing countries.

Under such circumstances, the infrastructure financing regime has also experienced significant changes. The source of infrastructure funds has transitioned from conventional budgetary funding[8] to a much more diversified system. Besides government money, the share of unconventional financing tools is increasing year by year, and mainly including the domestic bank loans and land transfer fees, which account for almost half of all of these revenues. For example, in 2007 approximately 30% of all revenue came from taxes and fees, 30% was from domestic loans, 20% was from land transfer fees, and the remaining 20% came from public-private partnership financing(Wang, 2010). As a result, the decentralization process induced a de facto rise in inequality between provinces since the capacity to raise funds to finance infrastructure investments mainly depends on local government revenues and/or their ability to negotiate with the central government. Table 2 gives a broad overview of provincial infrastructure endowment disparities. The most pronounced regional difference can be found between coastal and interior provinces, particularly in road network density, which is lower and lower the closer provinces are to the west. This disparity also can be found in telecommunications and energy infrastructures. Therefore, the endogeneity of the infrastructure provision leads to large challenge in assessing the productivity effects of infrastructure stocks.

2.2 The TFP effect of infrastructure

From Arrow and Kurtz(1970), theoretical model suggest that infrastructure provides valuable facilities to private sectors, increasing the availability of resources and contemporaneously improving the productivity of existing ones. Yet, the empirical evidence of this infrastructure-productivity link is controversial. A first body of evidence, showing a substantial positive impact of public capital (see Aschauer, 1989, 1990; Munnell, 1990a,b, among others), has been questioned by Holtz-Eakin (1994) and Garcia-Mila et al(1996), who argued that earlier analyses were plagued by reverse causation from productivity to public capital, spurious correlation due to nonstationarity of the data, and unobserved

[8] The share of budgeted money decreased from 32.6% in 1987 to approximately 10% in 2009.

Table 2: Regional Differences in Infrastructure Availability, 1999-2009 Average

Province	Population density (km2)	Road network density km/1,000km2 Railway	Road	Highway	Telecommunication (set/1,000 persons)b	Electricity production (kWh/ person)
East						
Beijing	918	60	1002	32	1290	1202
Tianjin	888	112	904	45	796	2881
Liaoning	286	26	454	12	616	2013
Shanghai	2104	33	1086	49	1098	3828
Jiangsu	700	11	806	23	567	2152
Zhejiang	457	12	621	17	845	2410
Fujian	282	13	535	9	682	1946
Guangdong	475	11	747	14	846	2223
Middle						
Hebei	362	25	505	11	400	1752
Shanxi	212	17	551	8	404	3357
Neimenggu	21	7	88	1	355	4106
Jilin	142	19	303	3	452	1392
Heilongjiang	84	12	202	2	444	1415
Anhui	446	17	666	10	296	963
Jiangxi	257	14	508	8	294	743
Shandong	585	20	800	19	548	1859
Henan	574	22	798	15	297	1278
Hubei	315	12	638	8	373	1720
Hunan	307	14	539	6	283	862
West						
Guangxi	201	13	298	6	291	918
Sichuang	180	6	279	3	466	724
Guizhou	215	10	408	3	218	614
Yunnan	115	5	458	4	276	1305
Shanxi	180	17	374	6	392	1259
Gansu	64	5	156	2	292	1691
Qinghai	7	2	49	0	397	3566
Ningxia	113	15	285	237	260	4518
Xinjiang	12	2	61	0	460	1433
Average	152	9	281	6	498	1634

Note: a)Data source: China compendium of statistics 1949-2008 and China Statistical Yearbook 2010; b)Including cell phones.

state-specific characteristics. Taking these aspects into account, they found an irrelevant effect of public capital on productivity. However, these results were later challenged by a group of studies who use more extensive country samples and demonstrated positive effect of public capital on productivity after controlling for reverse causation and unobservable characteristics(Canning, 1999; Fernald, 1999; Roller et al, 2001; Canning and Pedroni, 2004). Bronzini et al(2009) use panel cointegration techniques to estimate the long-run relationship between TFP, R&D, human capital and public infrastructure across Italian regions, and find a long-run equilibrium between productivity level and public capital. Hence, the effect of public infrastructure on productivity remains an open question that leaves room for further empirical investigation, but most of the research supports the idea that the productivity effect is significant in developing countries where the saturation point has not been reached.

Regarding the TFP effect of China's infrastructure, Fleisher and Chen (1997) first use transportation route length as explanatory variable for provincial TFP level and growth from 1978 to 1993, but they do not find significant contribution of transport infrastructure to TFP. Fan et al(2004) also find that infrastructure affected productivity through the telecommunication channel and argue that the contribution of roads is much smaller than telecommunication in the agriculture sector, and even insignificant in non-agriculture sectors. However, more recent studies have reexamined the importance of transportation infrastructure. Liu and Hu(2010) apply system GMM technique to provincial panel data in order to specify the spillover effects of infrastructure, the results indicate that transportation infrastructure and information infrastructure have a significant spillover effect on TFP growth. Xue(2011) recently analyzes the TFP growth effect of infrastructure at the industry level, and find that the transport infrastructure has the most significant impact. However, both of these studies ignored the problem of endogeneity of the infrastructure provision.

2.3 Regional specialization development in China

The study of China's regional specialization begins from the debate on the existence of market segmentation, and Young(2000) first argue that regional industrial structure tends to converge because of the extensive regional protectionism caused by fiscal institutional arrangement[9]. However, Cai et.al (2002) studied the regional changes in factor endowment and comparative advantage, and suggest that the regional specialization is strengthening. Furthermore, Bai et al. (2004), Fan(2004), Huang and li(2005) calculate the Krugman Specialization Index in order to measure the specialization level by using industrial level data with more segments and longer time series, and suggest that the regional specialization level has increased substantially since the reform in 1978. Among which eastern China has the lowest specialization level. Wu(2009) explain that the geographic industrial clustering, which is increasing particularly in eastern

[9]In China's economic transition process, local government created many artificial market distortions to protect rent-seeking opportunities, thus exacerbating the domestic market segmentation and regional anti-specialization.

coastal areas, weakened the industrial upgrading in western provinces. While the eastern coast region specializing in those manufacturing industries which are capital and knowledge-intensive, the middle and western regions are more concentrated in low value-added manufacturing industries and the agriculture sector, both of which are more dependent on natural resources and labor supply. Existing research has focused on measuring production specialization; however, no study to date has explored the reasons behind these observations.

What determines regional production pattern? Past researchers always focus on particular industry[10], but ignore the relationship among industries, more recent studies have begun to introduce the general equilibrium method in this issue. According to neoclassical trade theory, productivity differences (Ricardian model) and regional factor endowment differences(Heckscher-Ohlin model) are two sources of comparative advantages. Harrigan (1997) first introduce sectoral technological differences into the Heckscher-Ohlin model and regard it as an important determinant of specialization in OECD countries, which means both the Ricardian and Heckscher-Ohlin models are important for understanding international patterns of production.

In a perfect world, production patterns would surely best be left for the markets to determine. However, governments typically have preferences over them, either because of technological externalities, social issues, or loose "strategic" considerations. Recent findings suggest that infrastructure has asymmetric TFP effect at the industry level, which means that infrastructure could be an important factor in explaining regional production specialization. Findlay and his co-authors first modeled this effect of infrastructure on comparative advantage (Findlay and Wilson 1987, Clarida and Findlay 1992). Yeaple and Golub(2007) provides empirical evidence of Clarida and Findlay(1992)'s model by using international comparable data including 18 countries and 10 manufacturing industries, and find that infrastructure, particularly the transportation infrastructure has a large effect on industrial TFP growth, moreover, the TFP effects of different infrastructure are asymmetric. Finally, infrastructure help to explain international specialization. Xue(2010) applied Yeaple and Golub(2007)'s model to China's regional data at the industry level, and suggest that roads and telecommunication have no effect on regional comparative advantage, but electric power is important for the improvement of the comparative advantage in those capital-intensive and heavy industries.

3 Methodology

This section use neoclassical trade theory to construct the link between factor endowment, TFP level and industrial structures. Following Harrigan(1997), we draw on a dual approach to general equilibrium theory, namely Gross domestic product(GDP) function framework as developed by Dixit and Norman(1980)

[10]For example, examine the role industry characteristics, labor, credit policy, regulation and trade policy. This method prevailed in the debate about industrial policy in 1980s and the trade policy in 1990s.

and Woodland(1982) and first applied by Kohli(1991) in international trade studies. This method can easily establishes relative factor endowments and productivity difference as determinants of industrial structure. Therefore, if infrastructure has asymmetric effects on TFP level, then we can use this framework to investigate how the infrastructure affects regional production specialization.

3.1 Determinants of sectoral output share in GDP

Considering an economy with fixed factor supplies, constant returns to scale technology and competitive markets, the amount produced in each industry will maximize GDP for the economy, this effect is Adam Smith's "invisible hand" in action. That is, the industry outputs of the competitive economy will be chosen to maximize GDP:

$$R_t\left(p_t, v_t\right) = \max_{y_t}\left\{p_t \cdot y_t \middle| \left(y_t, v_t\right) feasible\right\} \tag{1}$$

where the revenue function $R_t\left(p_t, v_t\right)$ is a representative province's GDP, $\mathbf{p}_t$ is an $n \times 1$ vector of commodity prices, $\mathbf{v}_t$ is an $n \times 1$ vector of factor endowments, and y_t is vector of net output. As in Dixit and Norman(1980), the revenue function has two properties: 1) R(p,v) is homogeneous of degree one in p and v; and 2) by using envelope theorem, we can obtain supply function from the revenue function:

$$\frac{\partial \mathrm{R}\left(p_t, v_t\right)}{\partial \mathrm{p}_{it}} = y_{it}$$

If θ_t is an $n \times n$ diagonal matrix of hicks-neutral province- and sector- specific technology parameters, then a bigger θ_t indicates a hicks-neutral technology progress. According to Dixit and Norman(1980), the revenue function(1) can be expressed as $R_t\left(\theta_t p_t, v_t\right)$, here θ_t has the same effect on revenue function with price level $\mathbf{p}_t$. To relate infrastructure to the observed industrial specialization across provinces, we follow Harrigan(1997), in assuming that the revenue function can be approximated by a second-order translog(a flexible form in which elasticities are not constrained to be constant):

$$\begin{aligned}\ln\mathrm{R}_t\left(\theta_t\mathbf{p}_t,\mathbf{v}_t\right) = \alpha_0 + \sum_j \alpha_j \ln\theta_{jt}p_{jt} + \sum_k \beta_k \ln v_{kt} + \frac{1}{2}\sum_i\sum_j \gamma_{\mathrm{ij}}\ln\theta_{it}p_{it}\ln\theta_{jt}p_{jt} \\ + \frac{1}{2}\sum_k\sum_l \delta_{kl}\ln v_{kt}\ln v_{lt} + \sum_i\sum_k \emptyset_{ik}\ln\theta_{it}p_{it}\ln v_{kt}\end{aligned} \tag{2}$$

Because the GDP function is homogeneous of degree one in prices and factor endowments, which implies the following homogeneity restrictions:

$$\sum_j \alpha_j = \sum_k \beta_k = 1; \sum_i \gamma_{\mathrm{ij}} = \sum_k \delta_{kl} = \sum_i \emptyset_{ik} = \sum_k \emptyset_{ik} = 0 \tag{3}$$

By using property (2) of the revenue function showed above, and differentiating equation(2) with respect to one industry price level p_j, we can obtain the sectoral output shares function:

$$\mathrm{s}_{jt} = \frac{p_{jt}y_{jt}}{R_t} = (\frac{\partial R_t}{\partial p_{jt}})\frac{p_{jt}}{R_t} = \frac{\partial \mathrm{ln} R_t}{\partial ln p_{jt}} = \alpha_j + \sum_i \gamma_{\mathrm{ij}} \mathrm{ln}\theta_{it} p_{it} + \sum_k \emptyset_{jk} \mathrm{ln} v_{kt} \quad (4)$$

where s_{jt} is the output share of industry j in the total final output at time t. An important feature of (4) is that price changes as well as changes in technological ability in one industry have general-equilibrium effects on other industries (captured by γ_{ij}). Now suppose that each province faces the same prices in each period, but provinces differ in their factor endowments and technologies. Choosing one province and one year as a reference point and using c subscripts to denote provinces, and imposing the homogeneity restrictions on equation (3), we have:

$$\mathrm{s}^c_{jt} = \alpha_j + d_{jt} + \sum_{i=2}^{n} \gamma_{\mathrm{ij}} \mathrm{ln} \frac{\theta^c_{it}}{\theta^c_{1t}} + \sum_{k=1}^{m} \emptyset_{jk} \mathrm{ln} v^c_{kt} \quad (5)$$

Here we define $d_{jt} = \sum_{i=2}^{n} \gamma_{\mathrm{ij}} \mathrm{ln} \frac{p_{it}}{p_{1t}}$ as a time-specific effect. This method provides a theoretical framework to introduce technology as an determinant of the regional comparative advantages, and this framework is proved to be effective in Harrigan(1997). If all provinces face the same final goods prices, and there are neutral technology differences across sectors for a particular province, i.e. $\theta^c_{it} = \theta^c_t$, then output share differences across regions and over time depend on relative factor supply differences, and in such a case cross-province technology differences determine the level but not the composition of GDP. If $\theta^c_{it} \neq \theta^c_t$, which means technology differences at the industry level cross provinces do exist, and the output share is determined by technology and factor endowments jointly.

3.2 The role of productive infrastructure

Next we introduce infrastructure into this framework. First, consider the relationship between infrastructure $\mathrm{G_t}$ and observed productivity θ_t. Following Yeaple and Golub(2007), we assume that the productivity elasticity of industry j with respect to infrastructure provision (φ_j) is identical among regions:

$$\mathrm{ln}\theta^c_{jt} = \varphi_j ln G^c_t + ln\omega^c_{jt} + e^c_{jt} \quad (6)$$

According to equation(6), observed TFP level θ^c_{jt} of industry j in time t and province c is a function of infrastructure stock G^c_t, unobserved technological ability ω^c_{jt} and a stochastic measurement error e^c_{jt}. Substituting (6) into (5), we have:

$$\mathrm{s}_{jt}^{c}=\alpha_j+d_{jt}+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}\varphi_i\ln G_t^c+\sum_{k=1}^{m}\emptyset_{jk}\ln v_{kt}^{c}+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}ln\omega_{it}^{c}+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}e_{it}^{c} \quad (7)$$

Infrastructure influences industry-level productivity as captured by φ_i and these changes in productivity in turn have general equilibrium effects through γ_{ij}. For simplicity, following Hulten(2006), we assume ω_{jt}^c satisfies the following process: $\omega_{jt}^c=\omega_{0j}^c e^{\lambda_j t}$, which means the unobserved technological ability ω_{jt}^c has a constant growth rate λ_j. Then, we can rewrite (6) as:

$$\ln\theta_{jt}^c=ln\omega_{0j}^c+\lambda_j t+\varphi_j lnG_t^c+\delta_j X_{jt}^c+e_{jt}^c \quad (8)$$

The vector X represents other control variables, such as the regional human capital stock and FDI amount. So equation (7) can be written as:

$$\mathrm{s}_{jt}^{c}=\alpha_j+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}\varphi_i\ln G_t^c+\sum_{k=1}^{m}\emptyset_{jk}\ln v_{kt}^{c}+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}\lambda_j t+\varepsilon_{jt}^{c} \quad (9)$$

Here, $\varepsilon_{jt}^c=d_{jt}+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}ln\omega_{0i}^c+\sum_{i=1}^{n}\gamma_{\mathrm{ij}}e_{it}^c$ is unobservable. Now, equation (9) establishes a direct link from infrastructure to the evolution of sectoral output shares. However, while estimating equation (8), we will face an identification problem caused by the endogeneity of infrastructure provision: highly productive provinces can afford higher levels of infrastructure. Here, we introduce a structure model of the infrastructure accumulation to fix this endogenous problem.

3.3 Endogeneity: formation of infrastructure stock

First we consider the case of local government investment. Following Berhman and Craig (1987) and Catells et.al(2005), we assume that China's infrastructure investment is spending as if there were a constrained maximization of the local government's social welfare function, i.e. the maximization of output level(Zhang et al, 2007), which can be expressed as

$$Max\ \mathrm{W}_t^c=\mathrm{Y}_t^c$$

where Y_t^c is aggregate output of region c in year t. The problem for the government is to choose spending on infrastructure investment that maximizes the aggregate output level, taking into account the effect of infrastructure capital on output, and the exogenous budget constraint such as:

$$I_{gt}^c\le R_t^c$$

I_{gt}^c is the infrastructure investment in region c and R_t^c are the resource available for investing in infrastructure in given year t. We then obtain the following first order condition:

$$\zeta_t^c = \frac{\partial \mathrm{W}_t^c}{\partial I_{gt}^c} = \frac{\partial \mathrm{W}_t^c}{\partial \mathrm{Y}_t^c}\frac{\partial \mathrm{Y}_t^c}{\partial G_t^c}\frac{\partial G_t^c}{\partial I_{gt}^c} \tag{10}$$

where ζ_t^c is the marginal cost of public revenues, which we allow to change from year to year. By taking logs on (10) and assuming $\partial G_t^c/\partial I_{gt}^c = 1$, we obtain the following expression for the desired stock of infrastructures for each region ($\ln \mathrm{G}_t^{c*}$)

$$\ln \mathrm{G}_t^{c*} = ln\gamma^c + ln\mathrm{Y}_t^c - ln\zeta_t^c \tag{11}$$

here γ^c is the output elasticity of infrastructure stock in region c which can be regarded as an individual effect. Expression (11) can be interpreted as the capital stock that the government plans for a region, which depends on the public investment efficiency and the financial constraint.

To develop a model that can be estimated based on expression (11), we assume that it is difficult for the government to instantaneously adapt the allocation of investment to a region after a change occurs in its characteristics, which means that adjusting the capital stock to its long-term value entails significant costs. We assume that the infrastructure stock will be the previous period stock (i.e.,$\ln G_{t-1}^c$) plus a portion (ρ) of the difference between previous stock and the desired stock ($\ln \mathrm{G}_{t-1}^{c*}$):

$$\ln G_t^c = lnG_{t-1}^c + \rho(lnG_{t-1}^{c*} - lnG_{t-1}^c)$$

From this we obtain the local public capital accumulation function:

$$\ln G_t^c = (1-\rho)\, lnG_{t-1}^c + \rho\left(ln\gamma + ln\mathrm{Y}_{t-1}^c - ln\zeta_{t-1}^c\right) + \varepsilon_t^c \tag{12}$$

Meanwhile, although 80% of China's infrastructure construction is complemented by the local government, the central government investment is still very important for two reasons: 1) most of the central investment is earmarked for specific regions, such as the west provinces; and 2) if the amount of infrastructure project exceeds 30 million dollars, then the local governments must obtain approval from the central government[11]. Therefore, the central government can reduce regional inequity, which means the aversion to regional infrastructure inequality still exists in China. The allocation of central government infrastructure investment is modeled in the Appendix, and the most important difference between them is the introduction of the consideration of inequity aversion for the central government. However, the available database unfortunately does not provide sufficient information on infrastructure investment by the different levels of government. For simplicity, we assume here that the total infrastructure stock formation satisfies the following process:

[11]Details can be seen from 'Decision of the State Council on Reforming the Investment System' (No.20 [2004] of the State Council, issued on 16th July, 2004).

$$\ln G_t^c = f^c + f_t + \eta ln G_{t-1}^c + \varphi ln\gamma + \sum_{k=1}^{m} \xi_k \ln v_{kt-1}^c + \varsigma ln\zeta_{t-1}^c + \omega \ln \mathrm{y}_{t-1}^c + LC_{t-1}^c + u_t^c \tag{13}$$

where G_t^c is the sum of infrastructure stock invested by local and central government in region c, and y_{t-1}^c is per capita income at time t-1. If $\omega = 0$, then the government's single consideration is the public investment efficiency and this situation is identical with the case of local government investment. LC_{t-1}^c denotes the extent of local government competition. As shown in section 2,there are evidences argue that the local governments are competing for higher economic growth by investing more in productive infrastructure to absorbing more FDI. Thus, we use real FDI per capita to denote the degree of local government competition[12]. ζ_{t-1}^c is the shallow price of fiscal revenue. f^c and f_t are individual and time effect respectively. We can then estimate equation (8) and (13) simultaneously to alleviate the endogeneity stated above.

3.4 Econometric strategy

While we mainly rely on a structure model to identify the effect of infrastructure on observed TFP and industrial specialization, the panel nature of our data allows us to control for common unobservable. First, to control for technology shocks by industry which are common across provinces, we add time-industry fixed effects to (8). To control for unobserved changes in prices, and government policies that might also be correlated with infrastructure provisions across provinces, we add province-industry-specific intercepts and industry-specific time effects to equation (9).

Therefore, equation (13), (8) and (9) can be used to estimate the following relations: (a)infrastructure stock accumulation; (b)infrastructure and observed TFP level, and (c)infrastructure and regional production specialization. Given the high correlation of unobservables across the TFP, we estimate (13) and (8) for all industries as a system using three-stage least squares.

4 Data and Measurement

To conduct the econometric analysis, we need three database: the production data of manufacturing industries which is used to measure the TFP level, the infrastructure stock data, and the data of other control variables. All data used here are based on the official published statistical data.

4.1 Input and output data of 9 manufacturing industries

To calculate the TFP level at the industry level across 28 provinces, we need the input and output data, including the industrial value added, labor input, and

[12]Fu et al(2007) use foreign company's real tax rate to denote local government competition, however, there is no data about this tax rate before 1993, so we us FDI as proxy index.

Table 3: Industry Classification

28 Provinces:
Beijing, Tianjin, Hebei, Shanxi, Neimenggu, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan,Guizhou,Yunnan, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang.

Product classification system: 9 categories of the Industrial Classification for National Economic ActivitiesGB/T4754-2002and their two-digit constituent part are listed below.

Food	C13	Processing industry of agricultural and subsidiary food
	C14	Food manufacturing
	C15	Beverage industries
	C16	Tobacco manufactures
Apparel	C17	Manufacture of textile
	C18	Manufacture of wearing apparel, footwear and headwear
Paper	C22	Manufacture of pulp, paper, paperboard and articles of paper and paperboard
	C23	Printing and reproduction of recorded media
Chemicals	C25	Processing of crude oil, coking and nuclear fuel
	C26	Chemical raw materials and manufacture of other basic chemical raw materials
	C27	Manufacture of pharmaceuticals
	C28	Manufacture of chemical fibers
Metals	C31	Manufacture of non-metal products
	C32	Manufacture and casting of ferrous metals
	C33	Manufacture and casting of non-ferrous metals
	C34	Manufacture of metal products
Equipments	C35	Universal equipment manufacturing
	C36	Manufacture of special equipment
Transportation Equipments	C37	Transportation equipment
Electric Machines	C39	Manufacture of electric machines and equipment
Info and Telecommunications	C40	Manufacture of Telecommunication Equipments, Computers and Other Electric Equipments
	C41	Manufacture of Instruments and Appliances, Culture-related and Office Machinery

capital stock. China's official statistic data at the province level are available starting in 1987, but after 2007, the government stopped reporting the industry value added data. Therefore, the sample period for this study is from 1987 to 2007.

When analyzing the official statistic data of the Chinese industry, it is important to note that there was a structure change in the statistical caliber of industrial statistics in 1998. The statistical respondents before 1998 were indices and gross output value of 'rural industry, town cooperative industry and individual industry', which were changed to 'industrial enterprises above designated size' after 1998[13]. The inconsistency in these data make the intertemporal analysis of China's manufacturing industries very difficult. Therefore in this study, we divided our sample period into two parts: 1987-1997 and 1999-2007 (there are no official data reported in 1998). Moreover, the industry classification system changed in 1993. In order to compare data before and after 1993, following Chen (2011), we ignored industries that did not have consistent data available for the period of 1987-1992[14] , which resulted in a total of 9 industries list in the table above.

4.1.1 Industrial value added

China began to report the industrial value added data in 1993. Before that, only 'Net Industrial Output' data were available. Therefore, we have to transform these data before 1993 to industrial value added data. The method we used is as follows: Value added = Net industrial output + Depreciation in this year[15]. The depreciation data D_t can be obtained by using the following equations[16]:

$$D_t = AD_t - AD_{t-1}$$
$$AD_t = CF_t - NF_t$$

Where AD_t is accumulated depreciation, CF_t is the fixed assets minus cost, and NF_t is the net value of fixed assets. Missing data are calculated by using linear interpolation. We use PPI to denominate all output to the price level of year 1987[17]. The output data are obtained from the 'China Industry Economy Statistical Yearbook' and PPI data is obtained from the 'China Urban Life and Price Yearbook 2009'.

[13]China revised up the statistical threshold of "large-scale" industrial enterprises to measure only those with an annual business income above 5 million renminbi yuan.

[14]Including: 1) the industries that relied on region characters such as city public services providers(utilities), mining industry; 2) data missing in plastics and rubber industries;3)scale is very small such as feather & leather, wood processing, furnitures manufacturing, cultural educational and sports goods manufacturing.

[15]According to the second national industrial censuses in 1986(page 21 of 'Zhongguo Gongye Jingji Tongji Ziliao', 1987), the data fits these 3 equations.

[16]CCER(2002) used the same method to transfer the net output data to value added data.

[17]Because the Value-added of Industry is defined as total output minus Intermediate Input, so it is ought to be denominated by both the PPI and 'PPI of Raw Material, Fuel and Power' to diminish the impact of output and input price changes. However, existing statistic data still using PPI to denominate the industrial value added.

4.1.2 Capital stock

Capital stock $\mathrm{K_t}$ is calculated using the Permanent Inventory Method(PIM):

$$\mathrm{K_t} = \mathrm{I_t} + (1-\delta)\mathrm{K_{t-1}}$$

where $\mathrm{I_t}$ is the fixed capital investment in period t, and δ is the depreciation rate. The initial capital stock in year 1987 is obtained through capitalization of 1987's fixed asset investment: $\mathrm{K_{1987}} = \mathrm{I_{1987}}/10\%$

Following Chen(2011), we define fixed asset investment $\mathrm{I_t}$ as the difference of CF_t[18], and we use an identical price index of fixed assets investment as the deflator index for all industries. The base year is 1987. Data after 1990 are obtained from the 'China Industry Economy Statistical Yearbook' and 'China Statistical Yearbook', and the data before that is from Zhang et al(2003)[19].

When calculating the depreciation rate, most existing related studies use a fixed depreciation rate. However, as suggested by Chen and Li(2006), there are obvious difference in asset structure between different industries. Thus, we try to conduct a varying depreciation rate for different sectors. The 'China Industry Economy Statistical Yearbook, 1992' provides the depreciation rate for different industries from 1987-1991. The depreciation rate after 1992 can be calculated by using $\delta_{\mathrm{t}}^{\mathrm{c}} = D_t/CF_t$, and the data of D_t can be obtained from the part just mentioned above.

4.1.3 Labor inputs

The 'China Industry Economy Statistical Yearbook' provides the labor input data at the industry level from 1987-2007(the data from 1995 and 1998 are missing), and there are many different measurements[20] used for the labor input data during different periods. Although the definition changed, all these measurements denoted the real labor input level at that time. Therefore, we can combine the data series from the 'Formal Employees of Industry' before 1998 and the 'Annual Average Employed Persons' after 1998 to obtain a time-comparable labor input panel data.

4.1.4 Total factor productivity

The comparison of TFP between two provinces b and c asks the the question: how much output could province b produce using province c's inputs? Here we

[18] From 1997, the start point of fixed asset investment including in the statistics increases from 50,000 to 0.5 million RMB Yuan. As a result, we need to make adjustment about the data corresponding to this statistical caliber changes. However, according to table 6-2 in 'China Statistical Yearbook 2007', the Total Investment in Fixed Assets data based on new method and old method are very closed, so we do not make this adjustment.

[19] Jefferson et al(1996) calculate the price index of investment in fixed assets from 1979-1992, using the method consistent with the index in 'China Statistical Yearbook'. Zhang et al(2003) also this data series.

[20] In 'China Industry Economy Statistical Yearbook', before 1998Formal Employees of Industry1993-1997annual average of Formal Employees of Industryafter 1998Annual Average Employed Persons.

calculate the relative TFP level for 9 industries and 28 provinces over the years 1987-2007. Following most of the literature on productivity comparisons, we use a TFP index proposed by Caves et al (1982), which is defined as:

$$\ln \omega_{jt}^{c} = \left(\ln X_{jt}^{c} - \ln\overline{X_{jt}}\right) - \sigma_{jt}^{c}\left(\ln L_{jt}^{c} - \ln\overline{L_{jt}}\right) - (1-\sigma_{jt}^{c})\left(\ln K_{jt}^{c} - \ln\overline{K_{jt}}\right) \quad (14)$$

where X is industrial value added, L is sectoral labor input, and K is capital stock. In each of the parentheses, there are individual province variables relative to the mean value of this variable across provinces in the sample. Finally, $\sigma_{jt}^{c} = (q_{jt}^{c} + \overline{q_{jt}})/2$ is an average of the labor cost share in province c and the cross-province average, and the labor cost share data were computed as the ratio of payment for labor in total value added. This TFP index is widely used because it is superlative in the sense that it is exact for a translog functional form, and it is transitive so that the choice of the base province (here a geometric average of sample provinces) is not important.

We can then compute the TFP at the industry level by using equation(14). As in table 3, the industrial TFP experienced high growth in almost all sectors, particularly for the high value added industries such as telecommunication manufacturing industry, which has an annual TFP growth rate that exceeds 5%. Meanwhile, there is also obvious regional disparity in TFP performance. Although the TFP growth rate gap among districts has not increased in recent years, the original technology level in the east provinces is much higher than in the west provinces, so the eastern regions still obtain the highest productivity level compared to other areas.

4.2 Infrastructures

We considered three kinds of productive infrastructure in this study: road networks, telecommunication, and energy infrastructure. We used three measurements to indicate these infrastructures: total length of the road network in miles, number of telephone lines in use, and electrical power generating capacity, respectively. All three measures were taken from the 'China compendium of statistics 1949-2008'. Considering the regional heterogeneity in population density, we normalized these three infrastructures to the area of each province in order to make these indices much more comparable[21].

However, it can be argued that while roads are pure public goods, telecommunications and electric power are mostly private, albeit subject to increasing returns in some areas. Nonetheless, the natural monopoly characteristic of some telecommunications and electricity services, combined with their importance as shared inputs in all sectors, has entailed a critical role for government policy in determining their supply, both directly and through regulation of private utilities. Therefore, we decided to include all three measures of infrastructure. Ideally, our measures of all three infrastructure variables would capture some element of quality. However, such data do not exist in the necessary panel

[21] Road infrastructure normalized to both population and geography areas.

Table 4: Relative TFP Growth Rates, Average Annual, 1987-2007

Province	Food	Text	Pape	Chem	Meta	Mach	Tran	Elec	Comm
East									
Beijing	1.4	2.6	0.7	0.4	-0.7	2.4	1.3	3.3	5.1
Tianjin	0.7	2	0.9	0.3	1.2	1.6	2.5	1.1	5.1
Liaoning	1.9	3.1	2.7	-0.6	1	3.2	2.6	1.9	5.9
Shanghai	1.8	1.7	-0.8	-0.6	0.8	1.3	2.1	1.3	3.2
Jiangsu	2.7	1.8	0.9	1.3	2.3	2.4	2.3	2.5	4.1
Zhejiang	1.9	0.8	-0.6	0.9	1.1	1.5	1.5	1.2	3.2
Fujian	3.4	2.5	1.8	1.6	2.6	3.7	2.9	3.4	4.8
Guangdong	3.1	2	1.2	1	2.1	2.5	3.7	2.1	5.5
Middle									
Hebei	2.1	3.1	2.2	0.7	1.3	3.7	4.2	2.8	4.9
Shanxi	1.6	2.4	2.7	0.4	0.6	3.1	2.6	2.9	6
Neimenggu	2.5	2.4	3.7	3.1	1.8	4.2	2.3	4.6	4.2
Jilin	1.5	3.9	0.3	1.9	1.9	4.2	3.5	3.8	5.2
Heilongjiang	2.5	3.3	0.7	-1.2	1.9	4	2.2	3.7	6.4
Anhui	1.6	2.5	2	1.7	2.3	3.7	3.5	3.7	5.7
Jiangxi	2.5	2.9	2.4	2.4	1.2	3.1	2.2	0.9	5.6
Shandong	1.3	2.4	1.7	1.1	2.6	3.7	3.8	3.2	5.6
Henan	0.6	2.5	2.8	1.9	2.4	4	3.8	3.1	5.1
Hubei	1.4	2.4	2.2	1	0.7	2.9	2.5	2.2	4.5
Hunan	3.6	4.4	3.9	3.3	3.4	5.7	4.4	4.8	6.8
West									
Guangxi	1.6	3.9	0.5	2.8	1.4	4.2	4.2	3.7	4.5
Sichuang	3.4	3.5	2.2	3.1	2.7	4.3	4.1	3.3	6.5
Guizhou	2.6	0.6	0.2	3.1	1.7	3.5	4	4.9	5.1
Yunnan	2.5	1	1.7	2.4	1	3.9	3.9	2.9	6.4
Shanxi	2.4	3.4	3.5	2.8	4	4.3	5.7	4.1	6
Gansu	2.6	2.9	3.4	-0.4	1.9	4.2	5.6	6.2	4.8
Qinghai	4	2	-3.1	3.4	0.9	4.1	3.9	3.7	4.4
Ningxia	3.5	4.9	1.2	3.1	1.9	3.9	3.9	5.2	4.7
Xinjiang	1.8	0.3	1.7	-0.6	1.6	3.5	2.4	5.8	2.6

Note: calculated by author.

format, and therefore we are forced to use quantity measures unadjusted for quality. Road network length, number of telephone lines, and electrical power generating capacity are each normalized by the size of the labor force.

4.3 Other control variables

Here we use real FDI per capita to measure the local government competition, which can be calculated by transforming the real FDI amount of each province priced by dollars to the amount priced by RMB. The data of the average exchange rate of the current year are from 'China compendium of statistics 1949-2008'. For simplicity, the human capital is calculated by using average schooling years:

$$HR = Prim \times 6 + Midd \times 9 + High \times 12 + Univ \times 16$$

Here, $Prim$, $Midd$, $High$ and $Univ$ indicate the percentage of people who received education in primary, middle school, high school and university respectively (6 years of age and older). The source of these data is 'China compendium of statistics 1949- 2008'.

Moreover, approximately 50% of infrastructure financing comes from non-government funds, such as bank loans, so we use Savings Deposit of Urban and Rural Households per capita to indicate the financial constraint facing the local government. The data were obtained from the 'Almanac of China's Finance and Banking'.

Finally, the labor input is classified according to education level: (1) low skilled workers with at most a primary education; (2) middle skilled workers with at most a secondary education; and (3) high-skilled workers with at least some higher education. These data were obtained from the 'China Population & Employment Statistics Yearbook'(1990-2008).

5 Estimation Results

This part reports the estimation results for equations (8), (9), and (13): the accumulation of infrastructure stock, the effects of infrastructure on productivity and comparative advantage as measured by output shares. In contrast to Yeaple and Golub (2007), we performed the estimation in levels in order to save more useful information lost in regression in the first difference. We first estimate equation (13) for each infrastructure using System GMM because there is lagged dependent variables on the right side of the regression equations[22]. We

[22]The dynamic structure of the model (13) makes the OLS estimator upwards biased and inconsistent, since the lagged export share is correlated with the error term. A possible solution is represented by Blundell and Bond (1997) who propose the System GMM which derived from the estimation of a system of two simultaneous equations, one in levels (with lagged first differences as instruments) and the other in first differences (with lagged levels as instruments). In multivariate dynamic panel models, the System-GMM estimator is shown to perform better than OLS and difference GMM (Blundell et al. 2000).

Table 5: Determinants of allocation of infrastructure investment

	Road networks	Telecommunication	Electric Powers
Lagged infrastructure			
Roads	0.72***		
Telecommunication		0.86***	
Electric Powers			0.92***
Lagged Endowments			
Capital stock	0.18**	-0.09***	-0.04
Lows kill labor	0.10*	0.24***	-0.04**
Middles kill labor	-0.45***	-0.20**	0.01
Highs kill labor	0.11**	0.12***	0.07***
Local competition	0.01*	0.02	-0.01
GDP per capita	0.04	0.18**	-0.10**
Savings deposits	0.06**	0.16***	0.03**
Arellano-Bond test			
AR(1)	0.00	0.01	0.01
AR(2)	0.42	0.58	0.45
Sargan Test	0.38	0.43	0.51
No. observations	601	601	602

Note: a) standard error indicated in parenthese; b) ***,** and * indicate statistically significant at 1%, 5%, and 10% levels respectively..

also used Sargan tests to assess our assumption that lagged endowments and infrastructure endowments are appropriate instruments.

5.1 Determinants of local infrastructure investment

The estimation results of equation (13) are shown in Table 5. Each column corresponds to an infrastructure type and each row corresponds to an independent variable. All of the estimates include regional- and time-fixed effects. The second-order test indicates no second-order autocorrelation in the residuals. Moreover, the Sargan test fails to reject the null hypothesis that the instruments are valid. These two tests suggest the reasonableness of model specification and the validity of instrument variables.

Table 5 reveals that infrastructure stock per worker is closely related to lagged factor endowments and infrastructure measures, particularly their own lagged terms. Interestingly, there appear to be significant differences in the types of lagged endowments of relevance, with Capital particularly important for roads, but not for telecommunications and electric power. Highly skilled labor is important for all three infrastructures, middle skilled labor correlates with electric power, and low skilled labor correlates with road and telecommunications.

As expected, local government competition has a significant positive effect on road infrastructure, but not for telecommunications and electric power, which means that local competition drives the local government to increase investments in road networks. This observation is most likely because the telecommunications industry has been conducting market-oriented reform for approximately 20 years, and thus investments in this sector are less likely to be determined by the local government alone. Moreover, the generation of electric power is heavily dependent on natural resources, so it is not likely to be affected by the local officials.

Interestingly, regional equity consideration indicated by the index of GDP per capita only holds true in the energy infrastructure, and is even positive for telecommunications, but not significant for roads. There are several reasons for this observation. First, with the gradual equalization of basic public services and electric power in China, allocations of energy investment are beginning to consider the importance of reducing regional inequality. Second, electric power is heavily dependent on local resources such as coal and water resources, which are mainly located in western provinces. Finally, as expected, the local savings are very important for all three infrastructures, which is consistent with the fact that approximately 50% of infrastructure financing comes from market financing, such as bank loans. Therefore, the rapid development of China's infrastructure construction owns a lot to the help of regional savings.

5.2 TFP effect of infrastructure

The estimates of equation (8), which relate industry TFP level to infrastructure stocks, are shown in Table 6. The table is organized with each row corresponding to an industry (dependent variable) and each column corresponding to an infrastructure measure (independent variable). Standard errors for the coefficient estimates are shown in parentheses. Finally, the last two rows show the chi-squared values and their corresponding p-values for two types of tests of cross-equation coefficient restrictions on that column's infrastructure variable. The first is the test of the null hypothesis to assess if the coefficients on changes in infrastructure are jointly zero, while the second is the test of the hypothesis that the coefficients are the same across equations.

We begin with several observations on the general features of the results. First, as indicated by the chi-squared test and corresponding p-values reported in the second row from the bottom in Table 6, the test that all coefficients are equal to zero across industries can be rejected at standard levels for all three types of infrastructure. Second, of the three infrastructure types, telecommunications appears to have the most pervasive effect across industries. An increase in the number of telephone lines and electrical generating capacity per worker is associated with a statistically significant increase in TFP in 5-6 of the 9 industries, while the length of the road network per worker is associated with a statistically significant increase in only chemical, equipment, and telecommunication manufacturing.

Table 6: TFP level as a function of infrastructure endowments

Industry	Road networks		Telecommunication		Electric Powers		Human Capital		FDI	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Food	0.02	-0.38	0.08	0.03	0.23**	-0.19	1.44***	-0.41	0.01	0.04*
Apparel	-0.13	0.2	0.52**	0.08	-0.09	1.09***	-0.07	-0.35	0.18**	0.06**
Paper	0.02	-0.18	0.12	0.06	0.05	-0.12	-0.04	-0.43	-0.17**	0.03
Chemicals	0.02*	-0.18**	0.23**	0.11	0.41***	0.12*	-1.19**	-1.35**	0.08***	-0.03
Metals	0	-0.33	-0.1	0.01	0.12*	0.48***	-0.71*	-0.96**	-0.02	0.08***
Equipments	0.24*	0.19**	0.29	0.08	0.11*	-0.40**	-0.15	-1.44**	0.02*	0.06**
Transportation Eq.	-0.19	-0.01	0.55***	0.16**	0.66**	-0.08	1.74*	-0.89*	0.26***	0.03**
Electric Machines	0.03	-0.48*	0.76***	0.08*	0.63	0.36**	-0.28	-1.02**	0.42***	0.01
Telecommunication	0.35*	0.18	0.40*	0.41***	-0.04	-0.28	-0.54	-0.49	0.04*	-0.04
Test-coeff. Jointly Zero	15.01	21.3	41.05	26.66	31.8	73.22				
(p-value)	-0.01	-0.01	0 0	0	0					
Test-coeff. Equal	14.96	19.81	41.04	21.54	50.69	72.23				
(p-value)	-0.06	-0.01	0	-0.01	0	0				

Note: a); The results of model (1) are based on the period of 1999-2007, and the results of model (2) are based on the period 1987-1997; b) 3SLS estimation including individual and time effects; c) ***,** and * indicate statistically significant at 1%, 5%, and 10% levels respectively..

Taken together, these results are suggestive of a positive link between infrastructure provision, particularly with respect to telecommunications infrastructures and industrial productivity, which is slightly different from the results of Stephan and Golub (2007). This phenomenon may reflect the increasing importance of information and telecommunications in China. Moreover, compared with the period of 1987-1997, the telecommunication infrastructure has a much larger TFP effect in the period after 1999, which means that the TFP effects increase as the telecommunication network becomes more complex.

We now turn to the implications of our results for the hypothesis that infrastructure affects comparative advantage through its variable impact on sectoral TFP. While the coefficients estimated across industries vary from industry to industry in terms of both magnitude and statistical significance, the standard errors of the coefficients are large relative to their differences across industries. The last row in the table reports the chi-squared statistic and its corresponding p-value for the test of the hypothesis that the coefficients are the same across industries. The results of these tests indicate that the hypothesis that the effect of all three infrastructures is uniform across industries can be rejected at a 5% level of significance. The results suggest all them might be a source of comparative advantage within manufacturing. For example, telecommunication infrastructure have larger TFP effects on high tech and value added industries, such as transportation equipment, electrical, and telecommunication industries, while electric power is more important for high energy intensive industries, such as chemical and metal industries. However, the TFP effects are not significant in more than half of all these manufacturing industries. Notably, this may reflect in large part the relatively imprecise estimates of our coefficients, which is due in part to the small sample size used. Furthermore, the low TFP effect of roads may come from the measurement inaccuracy of the road infrastructure, because the comprehensiveness of the road network and transport flow on the road is much more important than the total length of the road network.

We found that FDI also has a positive effect on the TFP level in six industries, which is consistent with findings in other studies from China. However, the effect of human capital is not significant in most of the industries, and is even negative in the chemical and metal industries, indicating that the measurement of human capital is not sufficient[23].

5.3 Output share effects of infrastructure endowments

We now turn to the relationship between infrastructure and industrial specialization.

Table 7 is organized in the same fashion as Table 6 with each row corresponding to an industry equation and each column corresponding to an independent variable. The last three columns are our three infrastructure measures and the

[23]This result is consistent with Vandenbussche, Aghion and Meghir(2006), which suggest that in OECD countries, only the human capital who received high education have positive TFP effect, while the average human capital have negative effect on TFP. Peng(2007) also get this conclusion by using a Chinese panel data from 1982-2004.

first four columns correspond to net factor endowments. To better understand the effect of infrastructure (and primary factor endowments) on industrial specialization, we included both the agricultural sector (tenth row) and the service sector (the eleventh row).

Finally, the last two rows report chi-squared and p-values for tests of joint hypotheses across equations. The second row from the bottom corresponds to the chi-squared test and corresponding p-value for the test that all the coefficients for the appropriate input are zero, while the last row corresponds to the chi-squared test and corresponding p-value for test that all of the coefficients for the tradable goods industries (with the exception of services) are the same.

Several general observations are in order regarding the coefficients on primary factor endowments. First, an increase in capital stock has a different effect on the output share of manufacturing industries in the two time periods of our samples, demonstrating a positive effect in the latter period, which is consistent with Harrigan (1997), and has a negative effect on the increase of the share of tertiary industries. However, the results from the first time period are opposite. The likely reason for this is that during the structural reform of China's industry after 1998 and the access to WTO in 2001, capital intensive industries, such as chemicals, metals, and equipment industrie, began to replace labor intensive industries such as apparels and papers industries. Therefore, the increase of total capital stock will help in the development of manufacturing industries. Second, an increase of low skilled workers is associated with greater agricultural output as well as an increase in the output of several labor intensive manufacturing industries, such as apparels, papers, and chemical industries, while also reducing the output of telecommunication manufacturing.

Finally, all factor endowment variables are statistically significant in the sense that a joint test assessing if they are collectively zero is resoundingly rejected for each endowment type. Moreover, the hypothesis that the coefficients on factor endowments for manufacturing sectors are the same is sharply rejected for each endowment variable.

We now turn to the estimated effect of our three infrastructure variables on the structure of industrial production. The output shares of nine industries appear to be influenced by the availability of at least one type of infrastructure. Furthermore, all three infrastructure types are found to be statistically different from zero and to be statistically different from each other as indicated by the Chi-squared values shown in the second-to-last row of Table 7.

Table 7: Industrial specialization as a function of infrastructure and factor endowments

Industry	Capital stock		Low Skill labor		Middle skill		High skill		Roads		Telecomm.		Electric Powers	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Food	6.90***	0.35	-1.40*	3.43**	-4.60**	-0.67	-1.25**	-0.75	1.04*	5.50**	0.12	0.28	1.33	-4.39**
Apparel	0.40	-5.42**	1.05**	3.98**	-0.63	-0.63	0.22	0.78	0.04	0.16	-0.81**	-0.19	3.25**	2.57**
Paper	0.45**	-0.87**	-0.06	1.50**	0.10	-0.77**	-0.13*	0.20	0.24**	1.21**	-0.20**	-0.11	0.26*	0.37
Chemicals	2.62	-4.53**	0.34	8.60**	-1.95	-5.01**	0.12	1.21	1.04	2.41	0.89	-0.67	4.91**	-1.56
Metals	13.63**	-3.68**	-4.86**	5.94**	-6.38**	-2.93	0.10	0.35	1.59	9.93***	-0.36	-1.28**	0.99	1.26
Equipments	2.81**	-3.22**	-2.20**	3.95**	0.32	-0.34	-0.96*	0.26	0.57*	3.65***	-1.96**	0.11	0.25*	1.75**
Transport.	2.79**	0.94	-2.40**	-2.70**	-0.60	2.21*	-0.58	-0.94	-0.53	3.28**	-1.91**	0.49	-0.63	-1.45
Electric Mach.	0.90*	-1.02**	-0.81	2.16**	0.56	-0.52	0.29	0.38	0.72**	1.20	-1.10**	-0.04	-0.38	1.24**
Telecomm.	-0.64	1.73**	-1.81	-2.87**	2.98*	2.01**	0.92	-0.17	2.52***	0.33	-2.69**	0.73**	1.59	-0.34
Agriculture	-8.28**	-0.29	0.49*	-14.27	4.64	-1.59	0.98	2.16	0.09	3.59	-5.12**	-2.64**	-5.85**	-11.66**
Tertiary	-13.78**	17.80**	8.55**	-19.40**	0.58	7.44**	0.94	-3.76**	0.03*	0.88	-3.17	-1.17	-5.28*	-7.20**
Coeff. jointly	118.37	119.96	41.10	137.85	44.86	23.96	35.23	10.44	24.62	42.90	76.29	27.12	95.14	52.67
Zero (p-value)	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.49	-0.01	0.00	0.00	0.00	0.00	0.00
Coeff. equal	119.96	114.45	41.03	136.55	41.19	23.19	32.83	9.94	19.39	26.53	63.63	26.00	94.75	52.47
(p-value)	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.45	-0.04	0.00	0.00	0.00	0.00	0.00

Note: a) Panel SUR estimation including individual and time effects; b) standard error is indicated inn parentheses; c) ***,** and * indicate statistically significant at 1%, 5%, and 10% levels respectively..

Focusing first on roads, we find that an increase in roads is associated with a shift in output out of manufacturing and tertiary industries, but not agriculture. In the period of 1987-1997, increasing road length was associated with an increase in food, papers, metals, equipment, and transportation equipment industries. However, this positive effect shifts to the electrical and telecommunication industries, and this effect becomes much smaller during 1999-2007. As indicated by the chi-squared test and the corresponding p-values shown in the last row of Table 7, the hypothesis that the coefficients on roads across the eleven tradable-goods industries are the same is sharply rejected, and the provision of road networks appears to be associated with comparative advantage in this specification.

The results for telephone lines per worker are very different from those of roads, and in general it has a positive effect on manufacturing industries, which is in contrast to the previous results showing that the telecommunication infrastructure has a large TFP effect on manufacturing. This is most likely because telecommunication infrastructure has other channels that affect production specialization, except the TFP channel, such as the mobility of factor endowment. Moreover, while the coefficient on this variable is statistically significant in seven of eleven industries, it is not statistically different from zero in the test of joint significance. Similarly, the coefficients are also found to be different across industries within the manufacturing sector. These results suggest that telecommunications also appears to be a significant source of comparative advantage.

Finally, electric power is shown in the last column of Table 7. The coefficients on power are statistically different from zero across industries as indicated by the test statistic in the second to last row. An increase in electrical generating capacity appears to be associated with the larger output share of energy intensive industries, such as chemicals, metals, and equipment as well as low value added industries, and smaller output share of high value added industries, such as transportation equipment, electrical, and telecommunication industries. Meanwhile, there are substantial differences in the coefficients within manufacturing, and the chi-squared values reported in the last row strongly suggests that the coefficients are not identical across traded goods industries. Hence, the availability of electrical generating capacity also appears to be associated with comparative advantage.

6 Conclusion and suggestions

Infrastructure investment is a very important policy issue concerning the economic development in developing countries because it is one of the main candidates for explaining disparities of productivity between regions. Moreover, it could be a source of comparative advantage. Therefore, China's local governments always regard infrastructure provisions as effective tools to compete for FDI and industrial upgrading. In this study, we calculated TFP for 28 provinces and 9 manufacturing industries of China, and studied the effects of the supplies of road networks, telecommunications, and electric power on regional variations in sectoral TFP. The analysis is complicated by the endogeneity of infrastructure provisions. Thus, this study focused considerable attention on addressing identification through the use of a three-stage least-squares estimation procedure.

As expected, increased provision of infrastructure tends to raise TFP in many industries, with telecommunications having a particularly strong effect on TFP, and this effect becomes larger as the telecommunication network becomes much complex. However, generally speaking, the TFP effects of infrastructure are not very large and the effects on industry were not as large as expected. In particular, we could not find evidence of the TFP effect of road network, which was very large in the study by Yeaple and Golub (2007). We also found that the effect of infrastructure on TFP varied considerably across sectors, as suggested by the Clarida-Findlay (1992) model, confirming infrastructure as a source of comparative advantage. This conclusion is reinforced by our finding that changes in the availability of infrastructure alter industrial specialization, although our results here are less robust.

Further research should seek to refine the measures of infrastructure to include quality as well as quantity indicators. Improved indicators might help to improve the results for roads and electric power, which were less successful than for telecommunications. Meanwhile, the result of low TFP effect of road infrastructure may change if we consider the spatial effects of infrastructure. Finally, the sources of the different results for eastern and western provinces should also be explored further.

7 Appendix: The allocation of central government infrastructure investment

Following Catells et.al(2005), we assume that infrastructure investment is distributed among provinces as if there is a constrained maximization of the central government's social welfare function, defined over the distribution of output among all the regions. As Behrman and Craig (1987), we use a CES social welfare function that allows varying degrees of relative regional inequality aversion and unequal treatment of regions with the same output levels. This function can be expressed as

$$\text{Max W}_t = (\sum_c N_t^c (\frac{Y_t^c}{N_t^c})^{\phi})^{\frac{1}{\phi}}$$

where N_t^c and $\frac{Y_t^c}{N_t^c}$ are population and GDP per capita respectively of region c in year t. The parameter ϕ quantifies the aversion to regional output inequality, and its range of variation goes from $-\infty$ to one. As becomes more negative, inequality aversion increases. The problem for the central government is to choose a regional distribution of infrastructure investment that maximizes function, taking into account the effect of infrastructure on output as well as an exogenous budget constraint such as

$$\sum_i I_{gt}^c \leq R_t$$

where I_{gt}^c is infrastructure investment in region i and year t and R_t are resources available to invest in infrastructure in given year t. We take R_{it} as given and constant across regions. Thus, we obtain the following first-order condition:

$$\zeta_{it} = \frac{\partial W_{it}}{\partial I_{gt}^c} = \frac{1}{\phi}\left(\sum_i N_t^c \left(\frac{Y_t^c}{N_t^c}\right)^{\phi}\right)^{\frac{1}{\phi}-1} \cdot N_t^c \phi \frac{1}{N_t^c}\left(\frac{Y_t^c}{N_t^c}\right)^{\phi-1} \frac{\partial Y_t^c}{\partial I_{gt}^c} \tag{15}$$

where ζ_{it} is the marginal cost of public revenues, that we allow to change from year to year. By taking logs in (15) and assuming $\partial \mathrm{G}_t^c / \partial I_{gt}^c = 1$, we are able to obtain the following expression for the desired stock of infrastructures for each region ($\ln \mathrm{G}_t^{c*}$):

$$\ln \mathrm{G}_t^{c*} = B_0 + ln\gamma + lnY_t^c + (\emptyset - 1)\ln\left(\frac{Y_t^c}{N_t^c}\right) \tag{16}$$

where $B_0 = (1-\emptyset)\, lnW_t - ln\zeta_{it}$ is a constant within a period. Expression (16) can be interpreted as follows. The capital stock that the government plans for a region depends on the efficiency-equity trade-off, which is implicit in the linear combination of output and population.

To develop a model that can be estimated based on expression (16), we assume that it is difficult for the government to instantaneously adapt the allocation of investment to a region after a change in its characteristics, which means that the adjusting the capital stock to its long-run value entails significant costs. We assume that the infrastructure stock will be the previous period stock (i.e.,$\ln \mathrm{G}_{t-1}^c$) plus a portion (ρ) of the difference between the previous stock and the desired stock ($\ln \mathrm{G}_{t-1}^{c*}$):

$$\ln \mathrm{G}_t^c = ln\mathrm{G}_t^c + \rho(lnG_{t-1}^{c*} - ln\mathrm{G}_{t-1}^c)$$

then we have

$$\ln \mathrm{G}_t^c = (1-\rho)\, ln\mathrm{G}_t^c + \rho\left(B_0 + ln\gamma + lnY_{t-1}^c + (\emptyset - 1)\ln\left(\frac{Y_{t-1}^c}{N_{t-1}^c}\right)\right) \tag{17}$$

In the case of local government, the $\emptyset = 1$, and equation (16) will reduced to a pure efficiency case. Y_{t-1}^c is determined by local factor endowments v_{kt-1}^c and the technology level.

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