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How Much Infrastructure Is Too Much? A New Approach and Evidence from China

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Summary. — This paper extends the Ackerberg–Caves–Frazer approach to a nonparametric aggregate production function to address both the endogeneity and the function misspecification issues in estimating the returns to infrastructure and private capital and thus the optimal allocation between them. Based on Chinese provincial data over 1995–2011, we find that in 1997 most Chinese provinces were under-invested in infrastructure, whereas in 2008 most of the western provinces were over-invested in infrastructure. Such findings suggest that the nationwide large-scale infrastructure investment enacted by the Chinese government after the 1997 and 2008 financial crises may be of different economic efficiency.
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1. INTRODUCTION

Facing the shocks from the 2008 global financial crisis and the potential economic slowdown, the Chinese government once again fell back on infrastructure investment to revive its economy. For example, of the additional investment of Ren Min Bi (RMB)4 trillion enacted by the Chinese government in 2009 and 2010, approximately 53% were invested in infrastructure including, for example, railroads, highways, airports, water conservancy construction, and the upgrading of power grids. This stimulus package triggered the largest infrastructure investment boom in China since 1985. According to the National Bureau of Statistics (NBS henceforth) of China, the total investment in infrastructure in 2009 was RMB6.18 trillion, and this number rose to RMB7.2 trillion in 2010. Compared with 2008, the total infrastructure investment in 2009 and 2010 increased by 45% and 63%, respectively, higher than the two historical records in China since 1985: 36% in 1992 and 37% in 1998.

However, the magnitude of China's investment in infrastructure has raised many concerns and controversy among economists and policy makers. On the one hand, advocates argue that China's infrastructure remains underdeveloped and that the large-scale infrastructure investment can help China to avert the contagion effects of the 2008 global economic slowdown and further speed up China's economic growth in the future. On the other hand, opponents believe that China's current infrastructure stock is already ahead of the real needs of its economy. They are afraid, therefore, that such a large-scale infrastructure investment plan will not only lead to vastly underused infrastructure in the economy, but it will also add to the government's debt burden and expose the government to substantial fiscal risk.

This controversy regarding China's large-scale infrastructure investment following the 2008 global financial crisis actually reflects the debate in the literature on the contribution of infrastructure to the productivity of private factors of production and to aggregate output. Such a debate can be traced back to the very early empirical work by Aschauer (1989, 1990) who, using a production function approach and the United States' time-series data over 1949–85, finds that a 10% rise in the infrastructure stock would raise multifactor

productivity by almost 4%. [1] According to him, therefore, the declining output per capita in the United States over 1970–85 was associated with the decline in infrastructure investment during that period. However, the high return to infrastructure found by Aschauer (1989, 1990) has been questioned by many economists from both the methodological and the econometric perspectives (e.g., Gramlich, 1994; Haughwout, 2002). Issues ranking high on the list of potential problems include the reverse causality from productivity to infrastructure and a spurious correlation due to nonstationarity of the data. The reverse causality from productivity to infrastructure is not limited to time-series studies only. Holtz-Eakin (1994), for example, points out that a more prosperous state is likely to spend more on infrastructure. Such a positive correlation between infrastructure and productivity, however, should not be misunderstood as that greater infrastructure could lead a state to be more productive.

Not taking into consideration the reverse causality from productivity to infrastructure is likely to bias the estimated returns to infrastructure. The literature on the contribution of infrastructure to economic growth, in fact, has suggested various ways of solving this problem. For example, by introducing fixed effects in the specification of the error structure to control for unobserved state characteristics, Holtz-Eakin (1994) finds no contribution of infrastructure on multifactor productivity. However, as admitted by Holtz-Eakin himself, this approach may not work well for a panel of short duration as it ignores the information from cross-state variation in the variables. Duffy-Deno and Eberts (1991) and Cadot, Roller, and Stephan (2006) propose a simultaneous equation estimation method, where the first equation models the aggregate production function and the second models how infrastructure investment is determined. Therefore, the estimated contribution of

infrastructure to economic growth depends on the assumptions imposed on how infrastructure investment is determined under constraints that are primarily political (Drazen, 2000; Grossman & Helpman, 2001; Persson & Tabellini, 2000).

Acknowledging the difficulty of dealing with the reverse causality from productivity to infrastructure in the production function approach, some studies (e.g., Lynde & Richmond, 1992; Morrison & Schwartz, 1996; Nadiri & Mamuneas, 1994) switch to the cost function approach to examine the contribution of infrastructure to aggregate output. The cost function approach uses input prices as explanatory variables, which are more likely to be exogenous than input variables. In the cost function approach, infrastructure is usually assumed to be an unpaid factor of production, and the contribution of infrastructure to aggregate output is measured by its effect on the level of variable cost curves. As it is, this cost function approach is viewed by many economists as a better way to estimate the contribution of infrastructure to aggregate output. However, the need for information on input prices, at least at the industry level, limits the application of this approach in empirical studies.

While issues of reverse causality have received considerable attention in the literature, little research exists to investigate how model misspecification may also bring about biased estimates of returns to infrastructure. In the production function approach, for example, the most frequently used form of the production function is the Cobb–Douglas form, which assumes that the output elasticities of all inputs are exactly the same across locations and/or over time. However, this assumption appears to be too restrictive, as many studies point out that the output elasticities of inputs exhibit large variations, either across locations or over time. Therefore, a trans-log production function is often also used to consider the nonlinear relationships between inputs and output. But it does not work well in practice either, as the form of nonlinearity remains highly restricted. Therefore, Henderson and Kumbhakar (2006) first propose a nonparametric approach that imposes no restrictions on the functional form when estimating the returns to infrastructure and other inputs to aggregate output. Using the U.S. state-level data over the period 1970–86, they find that there exist large differences in the estimates under the Cobb–Douglas, the trans-log, and the nonparametric approaches, and that only under the nonparametric approach is the contribution of infrastructure to economic growth found to be significantly positive. Henderson and Kumbhakar (2006), hence, question the validity of results from studies such as Baltagi and Pinnoi (1995) and Garcia-Mila, McGuire, and Porter (1996), which find no significant or even negative contribution of infrastructure to economic growth based on Cobb–Douglas or trans-log production functions.

With the various approaches devised to overcome the econometric difficulties in estimating the contribution of infrastructure to economic growth, there is an increasing consensus in the empirical literature on the generally positive impact of infrastructure on economic growth. For example, in a critical survey of the infrastructure-growth nexus, Romp and de Hann (2007) note that among 39 Organisation for Economic Co-operation and Development (OECD) countries, 32 of them find a positive effect of infrastructure on economic growth, three of them find inconclusive results, and only four find a negligible or negative effect. Likewise, recent studies that focus on developing countries also find a generally positive, and even larger, impact of infrastructure on economic development and poverty reduction (Démurger, 2001; Fan & Chan-Kang, 2005; Ligthart, 2002; Ramirez, 2004).[2] Given the observed large positive impact, Ramirez (2004) and Gibson and Olivia (2010), therefore, suggest a policy of increasing the supply of infrastructure as a way to stimulate economic growth in developing countries. Such a policy suggestion, although reasonable when infrastructure is the bottleneck of economic development, should not be taken without caution by policy makers. At least, it is very important to evaluate how much more to invest in infrastructure at a particular time point given the budget constraint and the current stock of infrastructure and private capital. It is also worth noting that among the empirical studies that find positive correlation between infrastructure and economic growth, the actual magnitude of the effect of infrastructure on economic growth varies greatly, and much of this variation arises from not carefully navigating the potential empirical and econometric pitfalls, as pointed out by Estache and Fay (2007). It is therefore our goal to address such issues in this paper and offer a more accurate and nuanced interpretation of the contribution of infrastructure to economic growth.

In both developed and developing countries, whether infrastructure is optimally provided is often a key question for policy makers and economists. One strand of the literature tries to answer this question by comparing the return to infrastructure with the marginal cost of raising funds for infrastructure (e.g., Berndt & Hansson, 1992; Conard & Seitz, 1994). The difficulty in approximating the marginal cost of infrastructure, however, impedes the implementation of this approach. Another strand of the literature focuses on the optimal allocation between infrastructure and private capital by examining the relative contribution of these two kinds of capital to aggregate output, as an increase in infrastructure (at the expense of lower investment in private capital) will raise or lower the aggregate output depending on whether the marginal product of infrastructure exceeds, or is exceeded by, the marginal product of private capital. Aschauer (2000) shows that, in an endogenous growth model where an increased investment in infrastructure requires a corresponding increase in tax rates, the maximum long-run growth rate could be achieved when the after-tax marginal product of private capital equals the marginal product of infrastructure. Turnovsky (1997) and Kamps (2005), however, point out that the maximum welfare is still achieved when the marginal product of private capital equals the marginal product of infrastructure.[3]

Based on the theory of optimal allocation between infrastructure and private capital and through our close examination of the relative marginal product of infrastructure to private capital at the provincial level, this study seeks to evaluate the efficiency of infrastructure investment in China, especially the two large-scale infrastructure investment plans enacted by the Chinese government after the 1997 and 2008 financial crises. It is worth noting that in this study we primarily focus on the question whether infrastructure as a whole is under- or over-invested, relative to the private capital stock, in China at the provincial level over the period 1997–2011. Issues such as the impacts of different types of infrastructure, quality *versus* quantity of infrastructure, or new investment in *versus* maintenance of infrastructure are beyond the scope of this paper. Studies that do address these aforementioned issues certainly abound in the literature. Gibson and Olivia (2010), for example, discuss the poor quality of, as well as the limited access to, infrastructure on economic development in rural Indonesia. Fan and Chan-Kang (2005) also compare the returns to express way and lower level roads in China over 1982–99. Agénor (2009) and Kalaitzidakis and Kalyvitis (2004) both discuss the optimal allocation between investment in new infrastructure and the expenditure on the maintenance

of old infrastructure stock. While all such studies do offer important policy implications regarding how to allocate investment efficiently within infrastructure, they still fall short to effectively address the question whether infrastructure as a whole is under- or oversupplied relative to private capital.

Our research, therefore, serves as an attempt to complement these studies and contribute to the current literature in this area. First, we propose in this study a new econometric method that extends the proxy approach developed by Ackerberg, Caves, and Frazer (2006) (ACF approach henceforth) to a nonparametric aggregate production function and therefore addresses the potential issues of both model misspecification and reverse causality. Unlike the simultaneous equation estimation method, the ACF approach in this study imposes no assumptions on how infrastructure investment is decided; instead, it only requires a variable that does not appear in the production function but increases monotonically with total factor productivity (TFP henceforth).[4] Using such a variable as a proxy to invert out the unobserved TFP, we can isolate the reverse causality from TFP to inputs and thus consistently estimate the contributions of all the inputs to aggregate output. Moreover, as the reverse causality remains unsolved in Henderson and Kumbhakar (2006), our consideration of reverse causality under the nonparametric model addresses simultaneously the issues of model misspecification and reversal causality, which in turn contributes to the current literature of aggregate production function estimation.

In addition, when we calculate the stock of infrastructure and private capital and compare the marginal products of infrastructure and private capital, our study also takes into consideration the fact that the price of infrastructure increased much faster than that of private capital in the past two decades in China. To our knowledge, this is the first time in the infrastructure literature that such a relative price change has been considered. In the meantime, the spatial spillover effects of economic growth from neighboring regions are also controlled when we estimate the contribution of infrastructure and private capital to aggregate output. Such improvements in both data quality and econometric method, hence, can help us to more accurately estimate the relative marginal product of infrastructure to private capital at the provincial level, which in turn enables us to more precisely evaluate the efficiency of infrastructure investment in China.

Using Chinese provincial data over the period 1995–2011, our empirical results show that the output elasticity of infrastructure fluctuates around 0.255, and that of private capital around 0.277. Based on the estimated output elasticities of infrastructure and private capital, we identify a noticeable shortage in infrastructure for most provinces in China in 1997, as the extra output from the investment of one more RMB in infrastructure was higher than that from the investment of one more RMB in private capital. And China's gross domestic product (GDP) loss due to the misallocation between infrastructure and private capital in 1997 was 2.58%. In 2008, although some eastern and central provinces still exhibited a relative shortage in infrastructure, most of the western provinces were already over-invested in infrastructure relative to their private capital stock. We show that, due to such differences, the nationwide large-scale infrastructure investment enacted by the Chinese government after the 1997 and 2008 financial crises are of different economic efficiency.

The rest of the paper proceeds as follows. In Section 2, we define investment efficiency and discuss its relation to the misallocation between infrastructure and private capital. In Section 3, we discuss in detail the various econometric issues in estimating the contributions of infrastructure and private capital, and

present a new method that addresses such issues. Section 4 describes how we prepare the data for our empirical study. Section 5 presents our main results and discusses them in relation to the Chinese government's policy decisions in different periods. The last section concludes with relevant policy implications.

2. DEFINITION OF INVESTMENT EFFICIENCY

How much infrastructure is too much? From the perspective of welfare maximization, the investment of one more RMB in infrastructure should be able to generate as much extra output as the investment of one more RMB in private capital. If one more RMB invested in infrastructure can generate much more extra output than one more RMB invested in private capital, then there is an obvious shortage in infrastructure; otherwise, we can say that there is too much infrastructure in the economy. Symbolically, we can define the investment efficiency as the price-adjusted relative marginal product between infrastructure and private capital, which can be expressed as:

$$E = \frac{\partial Y}{\partial K_i} \bigg/ \left(P \cdot \frac{\partial Y}{\partial K_p} \right), \tag{1}$$

where Y denotes GDP, K_i denotes the stock of infrastructure, K_p denotes the stock of private capital, and P denotes the relative price of infrastructure to private capital. Throughout this paper, we use the subscript i to denote infrastructure and the subscript p to denote private capital.

3. ECONOMETRIC ISSUES AND THE ACF APPROACH

To more accurately measure the investment efficiency defined in Eqn. (1), we need to be able to consistently estimate the marginal contributions of both infrastructure and private capital to aggregate output. However, even among the economists who argue that infrastructure contributes positively to output, there is little agreement on what is a reasonable rate of return for infrastructure. The difficulty in identifying the marginal contribution of infrastructure to aggregate output is due to well-documented econometric challenges such as model misspecification (Henderson & Kumbhakar, 2006), nonstationarity (Tatom, 1993), endogeneity (Berndt & Hansson, 1992), and spillover of growth effect (Conley & Ligon, 2002). In the following subsections (3a–3e), we discuss in detail all these issues and the methods that fix them.

(a) *Misspecification of functional form*

The most frequently used form of the production function in the productivity literature is the Cobb–Douglas form. When the aggregate production function exhibits constant returns to scale with respect to all the inputs, the relationship between inputs and output takes the following form:

$$\ln y_{st} = \beta_i \cdot \ln k_{i,st} + \beta_p \cdot \ln k_{p,st} + \ln A_{st}, \tag{2}$$

where the lower-case letters y, k_i, and k_p denote GDP per working resident, infrastructure per working resident, and private capital per working resident, respectively; the uppercase letter A denotes TFP; the subscripts s and t denote location and time, respectively; and β_i and β_p measure the output elasticities of infrastructure and private capital, respectively. In this particular production form, we assume that the

output elasticities of inputs do not vary across locations or over time.

Several versions of the trans-log production function are often also used to accommodate the possible nonlinearity between inputs and output. For example, one may assume:

$$\ln y_{st} = \sum_{n=i,p} \beta_n \cdot \ln k_{n,st} + \sum_{\substack{n=i,p \\ m=i,p}} \beta_{nm} \cdot \ln k_{n,st} \cdot \ln k_{m,st} + \ln A_{st}. \tag{3}$$

Although a trans-log production function considers the non-linearity between inputs and outputs, the consistency of estimates depends on whether the trans-log production function correctly specifies the nonlinearity.

We may also consider the possible nonlinearities between inputs and output without imposing a specific form:

$$\ln y_{st} = f(\ln k_{i,st}, \ln k_{p,st}) + \ln A_{st}. \tag{4}$$

There are various methods of estimating the production function f as well as its partial derivatives nonparametrically. The nonparametrically estimated partial derivatives, which measure the output elasticities of inputs, vary across locations and over time. But as we will soon discuss, a direct estimation of Eqn. (4) may suffer from the spurious correlation between variables of aggregate output and capital inputs. Consequently, we take the first-order difference for all the regressions in this study. The varying output elasticities are, hence, estimated based on the first-order differenced version of Eqn. (4), which will be discussed in greater detail in the next section.

(b) *Spurious correlation*

The issue of spurious regression arises if all the variables in the estimation of aggregate production function are not stationary and show similar growing trends. Such a problem will generate inconsistent estimates of the production function. If the production function is assumed to be in the Cobb–Douglas form, the spurious regression problem can be solved simply by taking the first-order difference:

$$d \ln y_{st} = \beta_i \cdot d \ln k_{i,st} + \beta_p \cdot d \ln k_{p,st} + d \ln A_{st}, \tag{5}$$

where $d \ln x_{st} = \ln x_{st} - \ln x_{s,t-1}$.

Similarly, we can also solve this problem in the nonparametric setting. According to the mean value theorem, if a function g is continuously differentiable everywhere, there exists a $\theta \in (0,1)$ such that:

$$g(x_t) - g(x_{t-1}) = \frac{\partial g}{\partial x}(x_{t-1} + \theta dx_t) \cdot dx_t,$$

where x_t may be a vector. Therefore, function (4) can also be rewritten in its first-order differenced form:

$$d \ln y_{st} = \beta_{i,st} \cdot d \ln k_{i,st} + \beta_{p,st} \cdot d \ln k_{p,st} + d \ln A_{st}, \tag{6}$$

where $\beta_{n,st} = \frac{\partial f}{\partial k_n}(k_{i,st-1} + \theta dk_{i,st}, k_{p,st-1} + \theta dk_{p,st})$, $\theta \in (0,1)$, $n = i, p$, measures the contributions of infrastructure and private capital to aggregate output in location s at time t. Given the nature of our research question, it is reasonable to assume that $\beta_{i,st}$ and $\beta_{p,st}$ vary with $z_{st} = k_{i,st}/k_{p,st}$. Eqn. (6) can thus be written as the following varying coefficient model:

$$d \ln y_{st} = \beta_i(z_{st}) \cdot d \ln k_{i,st} + \beta_p(z_{st}) \cdot d \ln k_{p,st} + d \ln A_{st}. \tag{7}$$

Note that the key difference between Eqns. (5) and (7) is that the output elasticities in Eqn. (5) are constant, whereas we allow the output elasticities of both infrastructure and private

capital to vary with the ratio of infrastructure to private capital in Eqn. (7).

(c) *Reverse causality*

The issue of reverse causality has already been widely discussed in the productivity literature. For instance, Holtz-Eakin (1994) discusses the impacts of including dummy variables for time and location into estimation. A dummy variable for location is used as a proxy for the omitted factors in production that do not vary over time, including for example land area, location, the endowments of raw materials, and other factors that result in differential productivity across locations. A dummy variable for time is used primarily to control for the output effect of business cycles that are common to all locations. If we assume:

$$\ln A_{st} = \gamma_s + \delta_t + \varepsilon_{st}, \tag{8}$$

$d \ln A_{st}$ in the first-differenced form of the production function (5) or (7) can then be written as:

$$d \ln A_{st} = \delta_t + d\varepsilon_{st}. \tag{9}$$

That is, the dummy variable for location can be eliminated in our estimation of Eqns. (5) and (7). However, it is also very likely that $d \ln A_{st}$, the growth of TFP, could be affected by factors, such as institutional quality and financial development, which vary only slightly, if at all, in a short period. Therefore, in our empirical study, we still include a dummy variable for location:

$$d \ln A_{st} = \gamma_s + \delta_t + d\varepsilon_{st}. \tag{10}$$

A key point of this study, hence, is to examine whether $d\varepsilon_{st}$, the residual after excluding both the time fixed effect δ_t and the provincial fixed effects γ_s from $d \ln A_{st}$, is mean independent of $d \ln k_{i,st}$ and $d \ln k_{p,st}$. If the answer is no, the direct estimates based on Eqns. (5) or (7) will be inconsistent. Unfortunately, the mean dependence issue is very likely to exist in our data because the Chinese government tends to use infrastructure investment as a choice for reviving its economy when it expects a large negative TFP shock $d\varepsilon_{st}$. The negative correlation between $d\varepsilon_{st}$ and $d \ln k_{i,st}$ will bias downward the direct estimates of the output elasticity of infrastructure in Eqns. (5) or (7). Therefore, a new econometric approach is required to deal with the reverse causality in our estimation of Eqns. (5) and (7).

(d) *ACF approach*

Here, we discuss in detail how the ACF approach works to address the potential reverse causality in our model. First, we can always decompose the term $d\varepsilon_{st}$ into two components:

$$d\varepsilon_{st} = d\varpi_{st} + d\mu_{st}, \tag{11}$$

where $d\varpi_{st}$ is the part of the TFP shock anticipated in advance, which affects $d \ln k_{i,st}$ and $d \ln k_{p,st}$. The component $d\mu_{st}$ is the part of the TFP shock unanticipated in advance, which thus is uncorrelated with $d \ln k_{i,st}$ or $d \ln k_{p,st}$.

When extending the ACF approach to our estimation of the aggregate production function, a key point is to find a valid proxy variable for $d\varpi_{st}$. This proxy variable must meet the following two conditions: (1) it is not an input that contributes to the aggregate output; (2) it increases monotonically with $d\varpi_{st}$. In the case of the aggregate production function, the growth rate of private consumption per working resident will be a natural and ideal candidate. Specifically, we assume that:

$$d \ln c_{st} = \phi(d\varpi_{st}, \ d\ln k_{i,st}, \ d \ln k_{p,st}), \quad (12)$$

where the functional form of ϕ is not restricted, except that it must satisfy the property that $\partial (d \ln c_{st})/\partial (d\varpi_{st}) > 0$. Therefore, $d\varpi_{st}$ can be expressed as:

$$d\varpi_{st} = \phi^{-1}(d \ln c_{st}, \ d \ln k_{i,st}, \ d \ln k_{p,st}). \quad (13)$$

The Cobb–Douglas form of aggregate production in Eqn. (5) can be rewritten as:

$$d \ln y_{st} = \beta_i \cdot d \ln k_{i,st} + \beta_p \cdot d \ln k_{p,st}$$
$$+ \phi^{-1}(d \ln c_{st}, \ d \ln k_{i,st}, \ d \ln k_{p,st}) + \gamma_s + \delta_t + d\mu_t. \quad (14)$$

The ACF approach has two stages. In the first stage, we can obtain a consistent estimate of $dy_{st}, d\hat{y}_{st}$, by treating ϕ^{-1} as a nonparametric function.[5] Note that the coefficients β_i and β_p cannot be identified in the first stage, as $d \ln k_{i,st}$ and $d \ln k_{p,st}$ also show up in the function ϕ^{-1}; but δ_t and γ_s can be consistently estimated in the first stage. Hence, $d\varpi_{st}$ can be inverted out as:

$$d\widehat{\varpi}_{st} = d \ln \hat{y}_{st} - \beta_i \cdot d \ln k_{i,st} - \beta_p \cdot d \ln k_{p,st} - \widehat{\gamma}_s - \widehat{\delta}_t. \quad (15)$$

In the second stage, under the assumption that $d\varpi_{st}$ follows a first-order Markov process, we can estimate β_i and β_p by minimizing the following objective:

$$\sum_{1\leqslant s\leqslant S, \ 2\leqslant t\leqslant T} [d \ln y_{st} - \widehat{\gamma}_s - \widehat{\delta}_t - \beta_i \cdot d \ln k_{i,st} - \beta_p$$
$$\cdot d \ln k_{p,st} - \rho(d\widehat{\varpi}_{st-1})]^2, \quad (16)$$

where the function ρ governs the first-order Markov process of $d\varpi_{st}$. Note that the first-order Markov process for $d\varpi_{st}$ is also a key assumption that distinguishes the ACF approach from the ordinary least squares (OLS) one, in which we simply assume $d\varpi_{st} = d\varpi_{st-1}$.

For the nonparametric form of aggregate production expressed in Eqn. (7), the entire process of the ACF approach differs slightly. First, we can rewrite the production function in the following form:

$$d \ln y_{st} = \beta_i(z_{st}) \cdot d \ln k_{i,st} + \beta_p(z_{st}) \cdot d \ln k_{p,st}$$
$$+ \rho(d\varpi_{st-1}) + \gamma_s + \delta_t + d\mu_{st}, \quad (17)$$

as we assume that $d\varpi_{st}$ follows a first-order Markov process. Given Eqn. (13), we can then rewrite Eqn. (17) in the following varying coefficient form:

$$d \ln y_{st} = \sum_{n=i,p} \beta_n(z_{st}) \cdot d \ln k_{n,st}$$
$$+ \varphi(d \ln c_{st-1}, \ d \ln k_{i,st-1}, \ d \ln k_{p,st-1}) + \gamma_s$$
$$+ \delta_t + d\mu_{st}, \quad (18)$$

where the function φ is the composition of ρ and ϕ^{-1}. To avoid the curse of dimensionality, we can simply assume that the function φ also takes the varying coefficient form. With this assumption and without the dummies for time and provinces, we can estimate Eqn. (18) using the local constant least-squares method, which delivers the estimates of $\beta(z_{st})$ as:

$$\widehat{\beta}(z_{st}) = \left[\sum X_{st} \cdot X'_{st} \cdot K(z_{st})\right]^{-1} \left[\sum X_{st} \cdot d \ln y_{st} \cdot K(z_{st})\right], \quad (19)$$

where $X_{st} = (1, \ d \ln k_{i,st}, \ d \ln k_{p,st}, \ d \ln c_{st-1}, \ d \ln k_{i,st-1}, \ d \ln k_{p,st-1})'$. We choose the kernel function $K(z_{st})$ as Gaussian:

$$K(z_{st}) = \frac{1}{\sqrt{2\pi}h} \exp\left(-\frac{[(z_{st}-z)/h]^2}{2}\right), \quad (20)$$

where the bandwidth h is fixed.[6]

With the dummies for time and province in Eqn. (18), the whole estimation process will take three steps as suggested by Li and Racine (2007). In the first step, we run the local constant least-squares regression of $d \ln y_{st}, \delta_t$ and γ_s, respectively, on the dependent variables X_{st}. In the second step, we can regress the residual of $d \ln y_{st}$ from the first step on the residuals of δ_t and γ_s using OLS method, which delivers us the consistent estimates of time and provincial dummies, $\widehat{\delta}_t$ and $\widehat{\gamma}_s$. In the third step, we regress $d \ln y_{st} - \widehat{\gamma}_s - \widehat{\delta}_t$ on X_{st} again using the local constant least-squares method to obtain $\widehat{\beta}(z_{st})$.[7]

(e) *Spillover effects from neighboring regions*

The economic interdependence of neighboring regions has been widely discussed in the literature of economic growth and development (e.g., Ades & Chua, 1997; Cohen & Paul, 2004; Moreno & Trehan, 1997). In particular, Conley and Ligon (2002) investigate the relationship between economic distance and the magnitude of cross-country spillovers and find that these spillovers turn out to be quite important. In the present study, as we are using a panel data at the provincial level, it is also important for us to take into consideration the spillover effects from neighboring regions. In fact, there seems to be a clear spatial pattern within China: provinces of high growth rates tend to neighbor each other. Such a spatial autocorrelation might arise because of either certain unobserved common factors among neighboring regions (e.g., climates, topography, location, institutional quality, and financial development) or the interaction between neighboring regions through cross-border flows of goods or some shared use of key factors.

In our Cobb–Douglas model, the spillover effects from neighboring regions can be modeled as:

$$d \ln y_{st} = \sum_{n=i,p} \beta_n \cdot d \ln k_{n,st}$$
$$+ \phi^{-1}(d \ln c_{st}, \ d \ln k_{i,st}, \ d \ln k_{p,st}) + \sum_{n=i,p} \theta_n$$
$$\cdot W \cdot d \ln k_{nt} + \gamma_s + \delta_t + d\mu_{st}, \quad (21)$$

with $d\mu_t = \theta_\mu \cdot W \cdot d\mu_t + v_t$, where $d \ln k_{nt} = (d \ln k_{n,1t}, \ldots, d \ln k_{n,st})'$, $d\mu_t = (d\mu_{1t}, \ldots, d\mu_{st})'$, and W is a known $S \times S$ spatial weight matrix whose diagonal elements are zero.[8] v_{st} is independent over time and across regions. θ_i and θ_p denote the spillover effects that one region has on its economic growth from its neighboring regions' infrastructure and private capital growth, respectively; while θ_μ captures the spatial autocorrelation in the data.

In our nonparametric model in the varying coefficient form, the spillover effects from neighboring regions can be similarly modeled as:

$$d \ln y_{st} = X_{st} \cdot \beta(z_{st}) + \sum_{n=i,p} \theta_n \cdot W \cdot d \ln k_{nt} + \gamma_s + \delta_t + d\mu_{st}, \quad (22)$$

with the same assumptions on $d\mu_t$ and v_{st}. $d \ln k_{nt}$ and $d\mu_t$ are the same as defined in Eqn. (21). X_{st} and z_{st} are the same as defined in Eqn. (19).

Although a parametric model with spatial autocorrelation can be estimated with some standard procedure (LeSage & Pace, 2009), a nonparametric model with spatial autocorrelation remains a challenge to us. And even for a parametric model, it is still difficult to find an effective econometric tool that can simultaneously address issues of spatial

autocorrelation and reversal causality. To solve this problem, we first estimate Eqns. (21) and (22) by imposing the assumption that θ_μ is equal to 0. Note that in both Eqns. (21) and (22), θ_i and θ_p can be estimated using the same method for estimating δ_t and γ_s, because $W \cdot d \ln k_{it}$ and $W \cdot d \ln k_{pt}$ are exogenous. In such regressions, therefore, both the reverse causality and the spillover effects from neighboring regions' infrastructure and private capital are controlled. We can thus use the methods proposed by Baltagi, Song, and Koh (2003) to examine if there is spatial autocorrelation in the residuals.[9] If the tests find no evidence of spatial autocorrelation in the residuals from our regression, our estimates above under the null hypothesis that θ_μ is equal to 0 are then appropriate.

4. DATA

Data used in our study are China's provincial panel data spanning the period 1995–2011. Compared with data at the level of the entire economy, a provincial panel may provide more variations in the data. More importantly, because provinces in China exhibit large variations in economic development and structure, it is of our special interest to examine differences in investment efficiency at the provincial level. That is, we are interested not only in determining whether China as a whole economy is over-invested in infrastructure but also in knowing which provinces are over-invested and which underinvested in infrastructure.

In constructing the variable of GDP per working resident, we need the data for real GDP, resident population, and the ratio of working resident (defined as the ratio of the resident population between ages 15 and 64 to the whole resident population) for each province. Each province's real GDP data can be obtained from the *China Statistical Yearbooks* released by NBS. The resident population in this study is derived by dividing reported provincial nominal GDP by reported provincial nominal GDP per capita released by NBS in 2012 in the statistical yearbooks for each province, as suggested by Li and Gibson (2013).[10] The ratio of working resident for each province is obtained from *China Population Statistical Yearbooks* 1995–2006 and *China Population and Employment Statistical Yearbooks* 2007–12. Li and Gibson (2013) document the difference between residence and *hukou* registered population at the provincial level in China, but did not take into consideration the significant difference in the ratio of working residence across provinces due to labor migration.[11] In this study, we define GDP per capita by dividing each province's GDP by its working resident.

The data for capital stock are not officially reported by NBS. Hence, we need to construct each province's stock of infrastructure and private capital using the annually reported data of investment in various types of capital from *China Fixed Investment Statistical Yearbooks* 1985–2010. To distinguish infrastructure from private capital, the total investment will be broken down into four types. The first type, investment in infrastructure, includes the following: (1) production and supply of electricity, gas, and water; (2) transport, storage, and post; (3) information, transmission, computer service, and software; and (4) management of water conservancy, environment, and public facilities.[12] The second type is residential investment. The third type, defined as investment in human capital, includes investment in education and public health. The fourth type, defined here as investment in private capital, is simply total investment minus the other three types of investment mentioned above. We start our calculation of the capital stock from 1985.

In this study, we adopt the perpetual inventory method in the calculation of the capital stock. Symbolically, for the stock of infrastructure, this technique can be expressed as:

$$K_{i,st} = (1 - \delta_i) K_{i,st-1} + I_{i,st}, \qquad (23)$$

where $I_{i,st}$ denotes investment in infrastructure and δ_i denotes the depreciation rate of infrastructure. In this study, we follow Bai, Hsieh, and Qian (2006) to set δ_i to 0.08.

It is important to note that the price of goods invested in infrastructure increased much more rapidly than the price of goods invested in private capital in China since 1991. Following Greenwood, Hercowitz, and Krusell (1997) and Krusell, Ohanian, Rios-Rull, and Violante (2002), we can interpret this relative price change as the technological change specific to producing private capital. However, this relative price change has long been neglected in the literature when calculating the stock of private capital in China. To address this problem, we adopt the following equation when calculating the stock for private capital:

$$K_{p,st} = (1 - \delta_p) K_{p,st-1} + P_t \cdot I_{p,st}, \qquad (24)$$
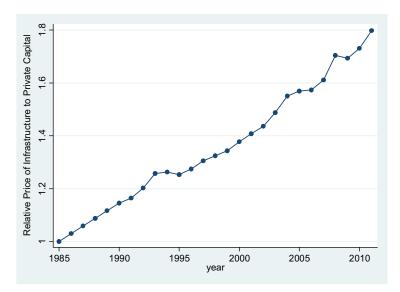
where $I_{p,st}$ denotes investment in the private capital stock, and δ_p denotes the depreciation rate of private capital. P_t is the price of infrastructure relative to private capital. That is, the value of investment in private capital in our study is adjusted by the relative price change between private capital and infrastructure. To our knowledge, this is the first time that this relative price change has been considered in estimating China's private capital stock.

It is worth pointing out that only the price indices of structures and machines/equipment are officially reported by NBS since 1991. As infrastructure is composed almost purely of structures, we can simply use the price index of structures as the proxy for the price of investment in infrastructure. The private capital, however, comprises nearly half structures and half machines/equipment. Hence, we construct the price index of private capital as the average of the price indices of structures and machines/equipment. δ_p in this study is set to 0.16, the average of the depreciation rate of structures and that of machines/equipment as reported in Bai *et al.* (2006). Figure 1 shows a clear increasing trend of the relative price of infrastructure to private capital in China since 1991.

The quality of China's provincial GDP data has been criticized by many researchers, mainly because the sum of provincial GDP is always larger than the one reported by NBS of China. This discrepancy, however, sometimes only reflects the methodological problems in constructing GDP data at both the provincial and the national levels in China. For example, based on the 2004 economic census, the GDP figures of the whole country before 2004 are in fact found to be seriously under-counted due to the under-counted value added in the tertiary sector, and the revised GDP figures were rather close to pre-economic census provincial GDP data (Holz, 2008). Although some scholars argue that China's GDP data are suspicious in some years, they also admit that there is no hard evidence of data falsification (Holz, 2003; Rawski, 2001). Chow (2006) also claims that the GDP growth figures in China are by and large reliable. In fact, China's GDP growth data have been widely used in various studies to understand the Chinese economy. The results in this study, hence, will at least be comparable to the findings in those studies.

Table 1 presents the summary statistics of the ratio of infrastructure to private capital, the ratio of infrastructure to GDP, and the ratio of private capital to GDP in China's 28 provinces over the period 1995–2011.[13] China classified its provinces into three groups (eastern, central, and western) offi-

Note: NBS starts to report the price indices for structures and machines/equipment since 1991. Therefore, we can only construct our price indices for infrastructure and private capital directly since 1991, too. The relative prices of infrastructure to private capital over 1985-1990 are approximated by the averagegrowth rate of this relative price over 1991-2011. Such a treatment has little impact on our estimate of private capital stock because we start our calculation of private capital stock from 1985 and only use the data from 1995 in our econometric analysis. A large proportion of the bias, if there is any, will disappeardue to the depreciation of private capital.

Figure 1. *The relative price of infrastructure to private capital over 1985–2011.*

Table 1. *Summary Statistics*

Province	Ratio of $k_{i,st}$ to $k_{p,st}$				Ratio of $k_{i,st}$ to y_{st}				Ratio of $k_{p,st}$ to y_{st}			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Beijing (E)	0.44	0.60	0.51	0.05	0.26	0.32	0.29	0.02	0.50	0.64	0.57	0.04
Fujian (E)	0.51	0.66	0.59	0.05	0.18	0.37	0.27	0.05	0.35	0.72	0.46	0.11
Guangdong (E)	0.51	0.75	0.62	0.08	0.21	0.25	0.23	0.01	0.31	0.44	0.37	0.04
Hebei (E)	0.30	0.44	0.37	0.05	0.16	0.33	0.24	0.05	0.47	1.07	0.68	0.18
Jiangsu (E)	0.23	0.43	0.33	0.06	0.12	0.19	0.16	0.03	0.40	0.79	0.50	0.12
Liaoning (E)	0.28	0.54	0.41	0.09	0.19	0.28	0.22	0.02	0.41	1.00	0.58	0.17
Shandong (E)	0.18	0.35	0.26	0.06	0.14	0.18	0.15	0.01	0.47	1.00	0.62	0.19
Shanghai (E)	0.37	0.65	0.51	0.09	0.25	0.31	0.28	0.02	0.46	0.73	0.56	0.09
Tianjin (E)	0.41	0.51	0.47	0.03	0.28	0.37	0.31	0.02	0.57	0.91	0.65	0.08
Zhejiang (E)	0.28	0.57	0.44	0.09	0.13	0.32	0.24	0.07	0.44	0.76	0.55	0.11
Anhui (C)	0.28	0.55	0.42	0.08	0.12	0.27	0.18	0.05	0.32	0.96	0.46	0.19
Heilongjiang (C)	0.39	0.59	0.50	0.06	0.24	0.37	0.29	0.03	0.52	0.84	0.59	0.08
Henan (C)	0.25	0.57	0.43	0.10	0.15	0.33	0.25	0.06	0.44	1.32	0.62	0.27
Hubei (C)	0.44	0.74	0.61	0.10	0.21	0.36	0.31	0.05	0.40	0.81	0.52	0.10
Hunan (C)	0.44	0.84	0.61	0.14	0.16	0.30	0.23	0.04	0.28	0.69	0.40	0.12
Jiangxi (C)	0.29	0.80	0.57	0.16	0.14	0.35	0.24	0.08	0.25	1.21	0.47	0.28
Jilin (C)	0.27	0.42	0.35	0.05	0.17	0.35	0.22	0.05	0.49	1.31	0.66	0.25
Shanxi (C)	0.53	0.83	0.64	0.11	0.28	0.52	0.37	0.07	0.44	0.94	0.59	0.16
Gangsu (W)	0.45	0.75	0.61	0.10	0.19	0.39	0.30	0.06	0.40	0.77	0.49	0.10
Guangxi (W)	0.44	1.06	0.75	0.22	0.20	0.58	0.37	0.11	0.37	1.07	0.52	0.20
Guizhou (W)	0.43	1.13	0.83	0.24	0.20	0.65	0.45	0.18	0.44	0.77	0.53	0.10
Inner Mongolia (W)	0.52	0.81	0.67	0.11	0.30	0.72	0.45	0.15	0.46	1.34	0.69	0.28
Ningxia (W)	0.53	0.97	0.73	0.14	0.19	0.38	0.29	0.06	0.29	0.69	0.40	0.12
Qinghai (W)	0.62	0.95	0.80	0.10	0.55	0.83	0.74	0.11	0.74	1.25	0.93	0.15
Shaanxi (W)	0.43	0.78	0.64	0.12	0.21	0.44	0.31	0.07	0.41	0.88	0.50	0.13
Sichuan (W)	0.40	0.69	0.60	0.10	0.26	0.79	0.52	0.17	0.65	1.42	0.87	0.23
Xinjiang (W)	0.32	0.53	0.45	0.07	0.31	0.55	0.44	0.08	0.90	1.15	0.97	0.07
Yunnan (W)	0.47	1.17	0.83	0.25	0.25	0.72	0.45	0.15	0.48	0.73	0.54	0.07

Note: Hainan and Tibet are excluded from our sample due the lack of data. E, C, and W in parentheses denote the eastern, central, and western groups, respectively.

cially in 1986 according to their economic development at that particular point. [14] In 2000, China enacted a so called "Western Development" plan to help develop their economy in the western provinces. Guangxi and Inner Mongolia, although originally classified as central provinces, were also included in this development plan. Hence, in this study, we label Guangxi and Inner Mongolia as western provinces.

We observe from Table 1 that both the ratio of infrastructure to private capital and the ratio of infrastructure to GDP in the western provinces, on average, are much higher than those in the other two groups. Meanwhile, the ratio of private capital to GDP in the western provinces, on average, is only slightly higher than that in the other two groups. Therefore, Table 1 shows us at least three facts: (1) the western provinces in China are in fact relatively more abundant in infrastructure; (2) the unit contribution of infrastructure to GDP in the western provinces is smaller than that in the other two groups; and (3) the relative abundance of infrastructure in the western provinces does not help to increase the unit contribution of its private capital to GDP.

5. EMPIRICAL RESULTS

(a) Estimation of the aggregate production function

To demonstrate how the reverse causality can bias the estimates, we report in Table 2 the estimated output elasticities of infrastructure and private capital using both the OLS approach and the ACF approach based on the Cobb–Douglas production functional form. Note that in the OLS approach for the Cobb–Douglas production function, $\phi^{-1}(d \ln c_{st}, d \ln k_{i,st}, d \ln k_{p,st})$ is simply set to 0 in Eqn. (21).

For the nonparametric model, if the reverse causality is not taken into consideration, the coefficients of the variables $d \ln c_{st-1}$, $d \ln k_{i,st-1}$, and $d \ln k_{p,st-1}$ are all 0 in Eqn. (22), which we call the direct approach. The estimates for the nonparametric production function, under both the direct and the ACF approaches, are presented in Table 3. Note that the estimated output elasticities of infrastructure and private capital based on a nonparametric production function can vary both across location and over time. In this study, they are assumed to vary with the ratio of infrastructure to private capital. In

Table 3, we report the estimates of β_i and β_p for the averaged ratio of infrastructure to private capital.

To show how the time and provincial dummies can affect our estimation results, we also report all the regression results without any dummies, with only time dummies, and with both time and provincial dummies. In all the regressions, we include the spillover effects from neighboring regions' growth of infrastructure and private capital but not spatial autocorrelation due to the econometric difficulty discussed above. For each regression, hence, we test if spatial autocorrelation really exists using the LM test proposed by Baltagi et al. (2003).

Tables 2 and 3 present many similar results. First, the estimates of β_i are all smaller in the OLS/direct approach than in the ACF approach, confirming our initial hypothesis that a negative correlation between the observed TFP growth and infrastructure growth will make the OLS estimate of β_i bias downward. In the OLS/direct approach, the estimates of β_p are also biased downward, suggesting that there is also a negative correlation between the observed TFP growth and private capital growth. Second, the estimated β_i with time dummies tends to be larger than that without time dummies, whereas the estimated β_p with time dummies tends to be smaller than that without time dummies. Third, only when both the time and the provincial dummies are included, do the LM tests for spatial autocorrelation fail to reject the null hypothesis of no spatial autocorrelation. In other words, it will be appropriate not to include spatial autocorrelation in regression in this empirical study when both the time and the provincial dummies are included. Last, when both the time and the provincial dummies are included, we find a significantly positive spillover effect from neighboring regions' growth in private capital but not in infrastructure.

Of course, results in Tables 2 and 3 also show some differences. First, under the ACF approach, the nonparametric model outperforms the Cobb–Douglas model in terms of model fit, especially when both time and provincial dummies are included. This is consistent with the large variation that we find in the estimated output elasticities of infrastructure and private capital in our nonparametric model with both time and provincial dummies under the ACF approach: $\beta_i \in [0.248, 0.330]$ and $\beta_p \in [0.222, 0.295]$. Much of the variation comes from the fact that the ratio of infrastructure to private capital itself varies significantly both over time and across

Table 2. *The Output Elasticities of Infrastructure and Private Capital—Based on the Cobb–Douglas Production Functional Form*

Variables	OLS approach			ACF approach		
Infrastructure	0.152***	0.174***	0.198***	0.269***	0.278***	0.289***
	[0.024]	[0.023]	[0.025]	[0.022]	[0.021]	[0.020]
Private capital	0.194***	0.188***	0.164***	0.318***	0.273***	0.252***
	[0.019]	[0.019]	[0.020]	[0.022]	[0.020]	[0.019]
Spillover of infrastructure	−0.004*	−0.003	−0.001	−0.001	−0.003	−0.002
	[0.002]	[0.002]	[0.004]	[0.002]	[0.003]	[0.003]
Spillover of private capital	0.005**	0.004	0.005*	0.003	0.005*	0.006**
	[0.002]	[0.003]	[0.003]	[0.002]	[0.003]	[0.002]
Time fixed effect	No	Yes	Yes	No	Yes	Yes
Provincial fixed effect	No	No	Yes	No	No	Yes
LM test for spatial autocorrelation	5.568	9.815	0.365	9.639	13.375	3.010
R^2	0.551	0.662	0.702	0.680	0.708	0.745
Observations	448	448	448	420	420	420

Note: Standard errors in brackets.
The critical values of LM test for spatial autocorrelation at p-values 0.01, 0.05, and 0.1 are 7.289, 4.321, and 2.952, respectively.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 3. *The Output Elasticities of Infrastructure and Private Capital—Based on the Nonparametric Production Functional Form*

Variables	Direct approach			ACF approach		
Infrastructure	0.127[***]	0.168[***]	0.190[***]	0.223[***]	0.259[***]	0.255[***]
	[0.025]	[0.025]	[0.028]	[0.029]	[0.031]	[0.031]
Private capital	0.205[***]	0.188[***]	0.177[***]	0.320[***]	0.282[***]	0.277[***]
	[0.014]	[0.019]	[0.022]	[0.024]	[0.027]	[0.025]
Spillover of infrastructure	−0.003	−0.002	0.000	−0.004	−0.003	0.001
	[0.003]	[0.003]	[0.004]	[0.002]	[0.002]	[0.003]
Spillover of private capital	0.003	0.003	0.005[*]	0.004	0.004[*]	0.008[***]
	[0.003]	[0.003]	[0.003]	[0.002]	[0.002]	[0.002]
Time fixed effect	No	Yes	Yes	No	Yes	Yes
Provincial fixed effect	No	No	Yes	No	No	Yes
LM test for spatial autocorrelation	8.571	14.609	0.982	5.807	11.624	0.209
R^2	0.573	0.663	0.708	0.693	0.757	0.805
Observations	448	448	448	420	420	420

Note: The elasticities of infrastructure and private capital are reported for the averaged ratio of infrastructure to private capital. Standard errors in brackets.
The critical values of LM test for spatial autocorrelation at *p*-values 0.01, 0.05, and 0.1 are 7.289, 4.321, and 2.952, respectively.
[*] $p < 0.1$.
[***] $p < 0.01$.

provinces in China. For example, the minimum ratio is 0.178 in Shandong in 2011, whereas the maximum ratio is 1.171 in Yunnan province in 2007. Second, the estimated output elasticity of infrastructure in the Cobb–Douglas model tends to be larger than the averaged output elasticity of infrastructure in the nonparametric model, whereas the estimated output elasticity of private capital in the Cobb–Douglas model tends to be smaller than the averaged output elasticity of private capital in the nonparametric model. Based on these differences, we choose the estimates in our nonparametric model under the ACF approach with both time and provincial dummies, i.e., Eqn. (22), as our benchmark.

It is worth pointing out that, in our nonparametric model under the ACF approach with both time and provincial dummies, the sum of our estimated β_i and β_p at the averaged ratio of infrastructure to private capital is 0.532. This number is very close to the income share of capital found by Bai *et al.* (2006) over 1990–2005 in China. [15] We also find that although the estimated β_i and β_p will vary with the depreciation rates that we set for infrastructure and private capital, the sum of them never deviate to an unreasonable extent from the income share of capital in China.

(b) *Investment efficiency*

In Figure 2, we present our measured investment efficiency, here defined as the price-adjusted relative marginal product of infrastructure to private capital. We observe that in 1997, the price-adjusted relative marginal product of infrastructure to private capital was above one for most provinces (with Qinghai as the only exception), which indicates that China was experiencing a nationwide shortage in infrastructure at that particular point. Also, this price-adjusted relative marginal product, in general, was higher in the eastern and central provinces than it was in the western provinces.
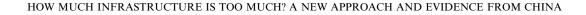
In Table 4, we present the percentages of possible GDP increases for individual provinces and the whole country, i.e., the difference between the current GDP and the maximum GDP, over 1997–2011. Each province's maximum GDP is obtained by dividing its total value of capital stock (the value of infrastructure stock plus the value of private capital stock) between infrastructure and private capital in an optimal way so that the price-adjusted relative marginal product of

infrastructure to private capital is equal to 1. And the whole country's maximum GDP is simply obtained by adding up each province's maximum GDP.

As mentioned earlier, in 1997 the Chinese government enacted a large-scale investment package in infrastructure to avert the contagion effects of the East Asian financial crisis. Despite this large-scale infrastructure investment, we observed a very low willingness to invest in private capital in China during 1998–2001. Compared with 1997, the real investment in private capital over 1998–2001 increased only by 0%, 2%, 12%, and 38%, respectively, whereas the real investment in infrastructure increased by 35%, 43%, 57%, and 66%, respectively. Such a large-scale infrastructure investment package effectively improved the allocation between infrastructure and private capital, which is actually reflected in Figure 2 as a downward trend for the price-adjusted relative marginal product to approach one over the period 1998–2001 for most provinces in China. Correspondingly, in Table 4, we observe that the GDP loss due to the misallocation between infrastructure and private capital declined from 2.58% in 1997 to 0.71% in 2001. Therefore, from the perspective of our production approach, the large-scale infrastructure investment package following the 1997 East Asian financial crisis stimulated China's GDP growth not only by increasing infrastructure stock but also by reducing the misallocation between infrastructure and private capital. And this reduction in misallocation contributed an additional 0.47% to China's GDP growth annually over 1997–2001.

It is also interesting to note that since 2001, the price-adjusted relative marginal product of infrastructure to private capital in the western provinces (except Xinjiang) was persistently below one, indicating a relative oversupply of infrastructure. Such a relative oversupply of infrastructure is likely to be associated with the "Western Development" plan launched by the Chinese government in 2001. In fact, infrastructure development is indeed an important policy instrument in this plan. For every year during 2001–11, the total real GDP of the western provinces accounted for about 15% of the GDP of the whole country, as shown in Figure 3. However, in the same period, the percentages of the real infrastructure invested in the western provinces increased from 25% to 33%. Meanwhile, the percentages of the real private capital invested in the western provinces
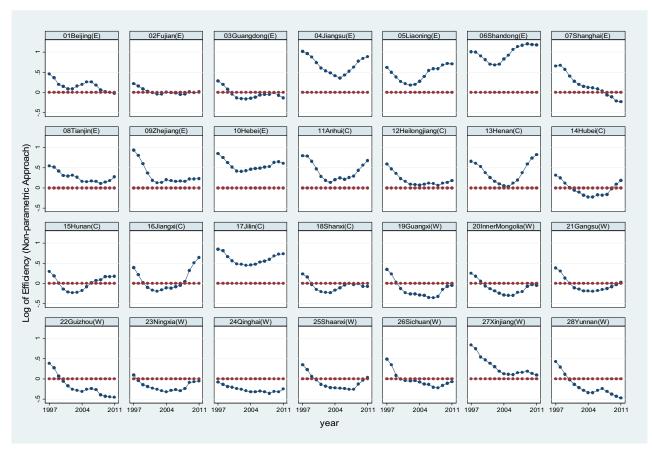
Figure 2. *The investment efficiency based on the nonparametric model with both time and provincial fixed effects.*

only increased from 19% to 21%. What all this indicates is that during 2001–11, although infrastructure investment was used as an important policy instrument to stimulate economic growth in the western provinces, the crowding-in effect of infrastructure on private capital was very limited. The relatively greater infrastructure investment in the western provinces and its limited crowding-in effect on private capital, hence, led to underused infrastructure and caused GDP loss.

In 2008, when faced with the shocks from the global financial crisis, the Chinese government once again fell back on infrastructure investment to revive its economy. Compared with 2008, the total infrastructure investment in 2009 and 2010 increased by 45% and 63%, respectively. However, the Chinese economy in 2008 exhibited some different features when compared with the year 1997. First, it did not exhibit a nationwide relative shortage in infrastructure, as shown in Figure 2. In fact, the infrastructure in the western provinces was already underused. Second, we did not observe a low willingness to invest in private capital following the 2008 global financial crisis. Compared with 2008, the real investment in private capital in 2009 and 2010 increased by 32% and 62%, respectively. Therefore, the nationwide large-scale infrastructure investment following the 2008 global financial crisis did not seem to have improved the allocation between infrastructure and private capital, as did the previous infrastructure investment following the 1997 East Asian financial crisis. Particularly, in some eastern and central provinces (e.g., Jiangsu, Liaoning, Shandong, Hebei, Anhui, Henan, and Jilin) which already exhibited a relative shortage in infrastructure in 2008, the misallocation between infrastructure and private

capital further deteriorated, as depicted in Figure 2, due to their large-scale investment in private capital. And the GDP loss due to this misallocation between infrastructure and private capital increased from 1.31% in 2008 to 1.85% in 2011, as shown in Table 4.
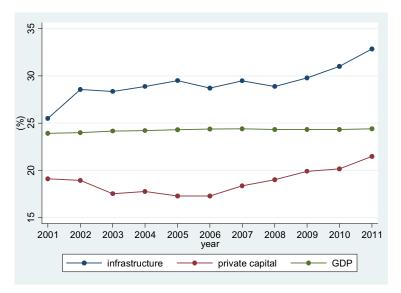
(c) *Discussion and robustness check*

In this study, we focus on evaluating whether infrastructure is under- or oversupplied relative to private capital in China as opposed to whether China is over-invested in capital. However, interpreting the results from our study in relation to those from studies that do address the question whether China is over-invested in capital can offer us valuable policy implications. For example, Bai (2013) finds that the large-scale investment and the low growth rate of TFP after 2008 have caused the overall return to capital in China to decline drastically from above 10% before 2008 to around 5% after that. And in an earlier study of Bai *et al.* (2006), the returns to capital in the western provinces are also found to be smaller than that in the other provinces. These two facts, hence, call for attention from both economists and policy makers to evaluate not only the GDP loss but also the government's fiscal risk due to the relative oversupply of infrastructure in the western provinces in China, especially when we know that a very large proportion of China's infrastructure investment in 2009 and 2010 was financed through local government debt. Such a fiscal risk evaluation, although important, is hard to carry out as detailed information about the financial structure of infrastructure investment is not available.

Table 4. *The Potential Gains in GDP after Removing the Misallocation between Infrastructure and Private Capital—Based on the Nonparametric Model*

Province	1997	1999	2001	2003	2005	2007	2008	2009	2011
Beijing (E)	1.20	0.25	0.06	0.15	0.35	0.17	0.02	0.00	0.01
Fujian (E)	0.29	0.05	0.00	0.01	0.00	0.02	0.02	0.00	0.00
Guangdong (E)	0.51	0.05	0.11	0.16	0.07	0.02	0.02	0.00	0.13
Hebei (E)	3.95	2.15	1.01	0.98	1.21	1.40	1.39	2.05	1.82
Jiangsu (E)	5.68	4.19	2.02	1.25	0.66	1.45	2.00	3.09	4.02
Liaoning (E)	2.11	0.85	0.27	0.22	0.80	1.80	1.79	2.34	2.48
Shandong (E)	5.57	4.46	2.61	2.62	4.43	6.76	7.16	7.68	7.28
Shanghai (E)	2.36	1.84	0.45	0.14	0.07	0.01	0.03	0.07	0.34
Tianjin (E)	1.68	1.02	0.50	0.39	0.13	0.13	0.05	0.10	0.36
Zhejiang (E)	4.85	2.02	0.22	0.10	0.17	0.14	0.13	0.24	0.25
Anhui (C)	3.51	2.45	0.48	0.10	0.33	0.34	0.44	0.97	2.30
Heilongjiang (C)	1.99	0.73	0.15	0.04	0.04	0.06	0.02	0.06	0.14
Henan (C)	2.45	1.55	0.39	0.06	0.01	0.21	0.69	1.76	3.43
Hubei (C)	0.60	0.10	0.02	0.21	0.31	0.19	0.16	0.00	0.16
Hunan (C)	0.52	0.00	0.44	0.38	0.03	0.03	0.03	0.14	0.15
Jiangxi (C)	0.92	0.00	0.23	0.16	0.07	0.01	0.01	0.52	2.08
Jilin (C)	4.00	2.40	1.28	1.09	1.17	1.58	1.81	2.36	2.74
Shanxi (C)	0.34	0.00	0.36	0.40	0.07	0.00	0.01	0.00	0.04
Gangsu (W)	0.89	0.13	0.07	0.24	0.25	0.14	0.09	0.04	0.00
Guangxi (W)	0.73	0.01	0.70	1.82	2.36	1.18	0.67	0.14	0.02
Guizhou (W)	0.89	0.04	0.21	1.44	2.69	3.06	2.96	2.13	1.67
Inner Mongolia (W)	0.38	0.03	0.13	0.45	0.68	0.30	0.26	0.03	0.02
Ningxia (W)	0.07	0.19	0.69	1.33	0.59	0.59	0.37	0.05	0.03
Qinghai (W)	0.04	0.43	0.79	1.15	0.89	0.79	0.90	0.65	0.38
Shaanxi (W)	0.73	0.03	0.11	0.34	0.35	0.42	0.42	0.10	0.00
Sichuan (W)	1.41	0.06	0.01	0.01	0.09	0.25	0.31	0.15	0.04
Xinjiang (W)	3.91	1.69	0.82	0.21	0.07	0.11	0.13	0.17	0.04
Yunnan (W)	1.07	0.10	0.12	0.89	1.94	3.44	3.79	2.97	2.91
All	2.58	1.52	0.71	0.64	0.82	1.19	1.31	1.60	1.85

Note: Hainan and Tibet are excluded from our sample due to the lack of data. E, C and W in parentheses denote the eastern, central, and western groups, respectively. We take the output elasticities of infrastructure and private capital at the averaged ratio of infrastructure to private capital in calculating the potential GDP loss.

Note: Calculations are based on the real value of each province's infrastructure investment, private capital investment and GDP.

Figure 3. *The percentages of infrastructure and private capital invested in and the percentages of GDP contributed by the western provinces over 2001–11.*

Note that the GDP loss reported in this study is due to the misallocation between infrastructure and private capital within each province. We do not take into consideration the GDP loss due to the central government's inefficient distribution of infrastructure investment from the other provinces to the western ones. The GDP loss due to the misallocation between

provinces can be evaluated based on some standard static models, such as the one developed by Hsieh and Klenow (2009). The results, however, depend crucially on the assumptions and the parameter values for the models. Hence, such an approach is often criticized by political economists and policy makers for not taking into consideration the crowding-in effect of infrastructure and other objectives in policy making, such as reduction in the inequality of economic development among provinces. Our empirical study in the case of China finds that the crowding-in effect of infrastructure on private capital was very limited during China's "Western Development." This limited crowding-in effect of infrastructure on private capital may actually reflect the fact that the bottleneck of economic development in the western provinces is not infrastructure but some other intangible factors, such as institutional quality, the degree of marketization, or innovation capacity, as discussed by Wang and Fan (2004). And such bottlenecks may actually prevent, or at least retard, the crowding-in effect of infrastructure on private capital as they will lower the return to private capital. Many researchers, such as Zhang, Gao, Fu, and Zhang (2007), Fu and Zhang (2007) and Chen (2010), also discuss why China could develop its infrastructure stock quickly within the framework of political economy. Our study here complements these political-economy analyses from another perspective by pointing out that infrastructure in most of the western provinces is, in fact, relatively oversupplied after 2001, and that substantial GDP loss has been caused in these provinces due to the within-province misallocation between infrastructure and private capital.

To further check the robustness of our findings, we present the investment efficiency based on the Cobb–Douglas

functional form of aggregate output in Figure 4. And in Table 5, we present the potential GDP gains for each province that result from removing the misallocation between infrastructure and private capital based on the Cobb–Douglas model. We can see that most of our findings are robust under the Cobb–Douglas functional form of aggregate output. For instance, results under the Cobb–Douglas model also show that in 1997 all the provinces in China were in an obvious shortage of infrastructure. Therefore, the large-scale infrastructure investment plan following the 1997 East Asian financial crisis was economically efficient, as it reduced the misallocation between infrastructure and private capital. Compared with the extent of misallocation based on our nonparametric functional form of aggregate output, the one measured under the Cobb–Douglas functional form was even worse. Additionally, Table 5 also shows a larger benefit from the large-scale infrastructure investment plan following the 1997 East Asian financial crisis: the reduction of misallocation between infrastructure and private capital contributed an additional 0.80% to China's GDP growth annually over 1997–2001.

Meanwhile, results also show that under the Cobb–Douglas functional form of aggregate output, the relative oversupply of infrastructure in the western provinces due to the "Western Development" plan is not as obvious as it is under our nonparametric functional form. In 2008, for example, only Guizhou and Yunnan still exhibited a clear oversupply of infrastructure relative to private capital. For the other western provinces, the price-adjust relative marginal product of infrastructure to private capital was close to 1, indicating an efficient allocation between infrastructure and private capital.
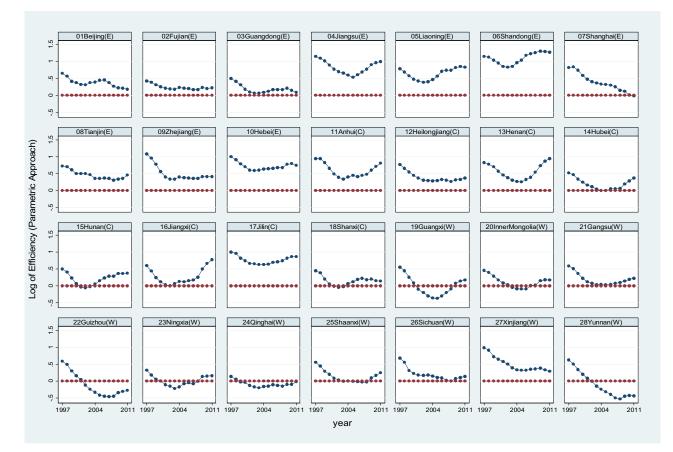

Figure 4. *The investment efficiency based on the Cobb–Douglas model with both time and provincial fixed effects.*

Table 5. *The Potential Gains in GDP after Removing the Misallocation between Infrastructure and Private Capital—Based on the Cobb–Douglas Model*

Province	1997	1999	2001	2003	2005	2007	2008	2009	2011
Beijing (E)	2.85	1.16	0.67	0.92	1.38	0.97	0.49	0.34	0.23
Fujian (E)	1.26	0.65	0.32	0.22	0.31	0.19	0.19	0.36	0.33
Guangdong (E)	1.69	0.64	0.06	0.03	0.09	0.19	0.19	0.29	0.05
Hebei (E)	6.79	4.27	2.54	2.49	2.87	3.16	3.15	4.13	3.79
Jiangsu (E)	9.11	7.12	4.08	2.93	1.96	3.23	4.06	5.61	6.88
Liaoning (E)	4.23	2.28	1.21	1.10	2.19	3.77	3.75	4.55	4.75
Shandong (E)	8.97	7.48	4.93	4.95	7.44	10.52	11.05	11.72	11.20
Shanghai (E)	4.58	3.82	1.57	0.91	0.71	0.43	0.16	0.10	0.00
Tianjin (E)	3.59	2.56	1.67	1.46	0.88	0.88	0.64	0.80	1.40
Zhejiang (E)	8.01	4.09	1.10	0.80	0.97	0.91	0.86	1.14	1.16
Anhui (C)	6.19	4.71	1.63	0.79	1.34	1.36	1.55	2.48	4.49
Heilongjiang (C)	4.04	2.08	0.94	0.61	0.61	0.66	0.50	0.68	0.92
Henan (C)	4.71	3.39	1.45	0.66	0.44	1.07	2.01	3.71	6.09
Hubei (C)	1.85	0.79	0.18	0.01	0.00	0.02	0.03	0.25	0.95
Hunan (C)	1.70	0.38	0.01	0.00	0.15	0.54	0.56	0.89	0.93
Jiangxi (C)	2.40	0.40	0.01	0.03	0.09	0.21	0.43	1.69	4.17
Jilin (C)	6.86	4.63	2.97	2.67	2.80	3.43	3.78	4.58	5.12
Shanxi (C)	1.36	0.28	0.00	0.00	0.09	0.33	0.23	0.28	0.13
Gangsu (W)	2.34	0.87	0.09	0.01	0.00	0.04	0.07	0.14	0.35
Guangxi (W)	2.07	0.44	0.07	0.61	0.93	0.27	0.06	0.04	0.19
Guizhou (W)	2.34	0.61	0.01	0.40	1.15	1.39	1.33	0.80	0.52
Inner Mongolia (W)	1.44	0.55	0.04	0.01	0.07	0.00	0.00	0.15	0.20
Ningxia (W)	0.71	0.02	0.07	0.34	0.04	0.04	0.00	0.12	0.16
Qinghai (W)	0.13	0.01	0.10	0.26	0.14	0.10	0.15	0.06	0.00
Shaanxi (W)	2.08	0.57	0.06	0.00	0.00	0.01	0.01	0.06	0.39
Sichuan (W)	3.18	0.66	0.22	0.22	0.07	0.00	0.00	0.03	0.14
Xinjiang (W)	6.74	3.60	2.23	1.07	0.70	0.83	0.88	0.98	0.58
Yunnan (W)	2.64	0.80	0.05	0.14	0.68	1.65	1.89	1.33	1.29
All	4.74	3.06	1.56	1.29	1.56	2.14	2.31	2.85	3.20

Note: Hainan and Tibet are excluded from our sample due to the lack of data. E, C, and W in parentheses denote the eastern, central, and western groups, respectively.

However, regarding the economic efficiency of the large-scale infrastructure investment package following the 2008 global financial crisis, the Cobb–Douglas approach and the nonparametric one again deliver very similar results. For example, we also observe under the Cobb–Douglas approach that in some eastern and central provinces (e.g., Jiangsu, Liaoning, Shandong, Hebei, Anhui, Henan, and Jilin) that already exhibited a relative shortage in infrastructure in 2008, the misallocation between infrastructure and private capital further deteriorated after 2008. Table 5 shows that China's GDP loss due to the misallocation between infrastructure and private capital within-province increased from 2.31% in 2008 to 3.20% in 2011.

Furthermore, in order to check whether our conclusion about the relative oversupply of infrastructure in the western provinces since 2001 may have been tinted by the higher depreciation rate for private capital, we also construct our stock of private capital using some lower depreciation rates. All the main results discussed above hold robustly for various depreciation rates of the private capital.

6. CONCLUSIONS

In this study, we examine if infrastructure has been under- or oversupplied relative to private capital at the provincial level in China over 1997–2011. To do so, we first develop a new method to more accurately estimate the output elasticities of infrastructure and private capital. Specifically, we extend the ACF approach to a nonparametric aggregate production function to address the issues of reverse causality as well as

functional misspecification. Moreover, the possible spillover effects from neighboring regions are also taken into consideration in our econometric models.

Our estimation results show that the output elasticity of infrastructure fluctuates in the range [0.248, 0.330] and that the output elasticity of private capital fluctuates within [0.222, 0.295]. Based on our estimates for the output elasticities of infrastructure and private capital, we find that the large-scale infrastructure investment in China following the 1997 East Asian financial crisis was efficient as most of the provinces in China exhibited a clear shortage of infrastructure at that time. However, in 2008, most of the western provinces already exhibited an oversupply of infrastructure relative to private capital due to the "Western Development" plan, whereas some eastern and central provinces still showed a clear shortage of infrastructure. Probably also due to the large-scale investment in private capital, the nationwide large-scale infrastructure investment package following the 2008 global financial crisis did not effectively reduce the misallocation between infrastructure and private capital in China after 2008.

Our findings on the investment efficiency in infrastructure and private capital may be of interest to not only economists but also policy makers. For example, results from our study suggest that the government must be cautious not to over-rely on infrastructure investment as a means to revive its economy or narrow the gap between its developed and undeveloped regions. As a very large proportion of China's infrastructure investment in 2009 and 2010 was financed through government debt, it would also be important to evaluate the fiscal risks that the current stimulus package may bring to the local

governments in future research. Also, given the relative shortage of infrastructure in some eastern and central provinces, the government may want to consider allowing the private sector to invest in and operate some of the infrastructure in those regions.

NOTES

1. In the literature on the relationship between output and public spending, the definitions of public capital and infrastructure are both frequently used. Public capital is a broader concept that includes infrastructure as its most important component. In this study, we use the term "infrastructure" throughout to avoid confusion.

2. Some studies, such as Devarajan, Swaroop, and Zou (1996), Milbourne, Otto, and Voss (2003), and Agénor, Nabli, and Yousef (2005), also find an insignificant or even negative impact of infrastructure on economic growth in developing countries. However, as Estache and Fay (2007) point out, such results should be taken with caution, as these studies rely on public spending data, which may lead to imprecise measures of investment in infrastructure.

3. The distortion associated with taxation discourages the accumulation of private capital. As a result, the infrastructure to private capital ratio with growth maximization is higher than that in the first-best optimum. Maximizing the growth rate involves a consumption loss and, thereby, lowers welfare.

4. Wooldridge (2009) similarly shows how to use proxy variables to control for unobservables and proposes a one-stage generalized method of moments (GMM) estimation procedure. His one-stage procedure, when compared with the two-stage procedure proposed by Ackerberg et al. (2006), is more efficient and allows standard errors to be computed using standard GMM formulas, but it requires a nonanalytic search over a much larger set of parameters.

5. In real application, one can usually approximate the function ϕ^{-1} using a polynomial function.

6. It is well known that estimates of nonparametric models can be sensitive to the bandwidth values. Basically, a larger value of bandwidth that is chosen leads to the increased smoothing of the nonparametric results. In our empirical study, we select the bandwidth values using the least-squares cross-validation method, the most popular one in real application.

7. For a more detailed discussion on the estimation of a varying coefficient model, please refer to Chapter Nine in Li and Racine (2007).

8. In real application, the spatial weight matrix W often takes two forms. In the first form, we assume that only contiguous regions can influence each other. Hence $W(i, j) = 1$ if region i has a border with region j; otherwise $W(i, j) = 0$. In the second form, we assume that $W(i, j) = h(d_{ij})$ where d_{ij} measures the distance between regions i and j. In this study, we use the first form but adjust $W(i, j)$ by multiplying it with the relative economic size between the two regions, as we believe the spillover effect from a big region to a small region will be larger than that from a small region to a big region.

9. Baltagi et al. (2003) proposed several tests for the null hypothesis of no spatial autocorrelation ($\theta_\mu = 0$) and no regional random effects. In this study, we only report the one-sided joint LM test for no spatial autocorrelation and no regional random effects. The other tests, in fact, give very similar results.

10. The population denominator used for GDP per capita switched from a registered to a resident population basis around 2000 for most provinces. In 2011, based on the results from the 2010 census, NBS revised each province's GDP per capita with resident population as the denominator in order to smooth out discrepancies in the time series of resident population.

11. The regions with large migrant in-flows, such as Shanghai, Beijing, and Tianjin, tend to have higher ratios of working residents than the regions with large migrant out-flows, such as Sichuan, Anhui, and Jiangxi, do.

12. Cai and Treisman (2005) define infrastructure investment as "any costly action governments take to increase the productivity of capital in their units." Therefore, they include physical infrastructure, education, public health, and a system of well-enforced property rights and legal protections on the list of infrastructure. In contrast to their approach, we simply define infrastructure in this paper as the physical portion of their list.

13. Hainan and Tibet are excluded from our sample due to the lack of data. Chongqing was separated out from Sichuan as an independent municipality in 1997. In this study, we still include Chongqing as a part of Sichuan in the whole sample period 1995–2011.

14. The eastern group includes Beijing, Fujian, Guangdong, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin, Zhejiang, Hebei, and Hainan. The central group includes Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin, Shanxi, Guangxi, and Inner Mongolia. The western group includes Gangsu, Guizhou, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, and Yunnan.

15. Bai et al. (2006) calculated the income share of capital in China using the provincial data, and found that it varied between 47% and 58% over 1990–2005.

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