Estimating Productivity of Public Infrastructure Investment*

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Abstract

The productivity effect of public infrastructure investment is controversial in the literature using aggregate data, mainly due to reverse causality. To address the identification issue, this paper develops a model of endogenous productivity in a firm-level production function, and matches Chinese firm-level production data with province-level infrastructure investment data. A structural model is employed to further distinguish the long-run productivity effect from the short-run Keynesian demand effect of public investment. The estimated rates of return of public infrastructure investment are 9.2% and 2.5%, respectively before and after controlling for the demand effect. The returns triple once national spillover effects are taken into account. Firm-level evidences are consistent with a mechanism in which public infrastructure investment functions as a catalyst in facilitating resource reallocation from less to more productive firms.

JEL Classification: C23, D24, E22, H54, O40

Key Words: Public Infrastructure Investment, Productivity, Demand Effect, Rate of Return

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1 Introduction

This paper is motived by two important policy debates concerning the current world economy. In developing countries, on the one hand, infrastructure investment[1] has often been advocated as a precursor to economic development by many authorities and international institutions.[2] On the other hand, there is a lack of convincing evidence that infrastructure investment does lead to a higher output and income in the long run (Warner, 2014). Concerns on the efficiency of massive infrastructure investment, especially in China in recent years, often appear in academic papers and media reports (Ansar et al., 2016).

In developed economies, fiscal austerity and economic growth mark probably one of the most pronounced trade-offs facing policy makers. On the one hand, the general idea that public investment will boost economic growth becomes even more appealing when the global economy faces severe demand constraints and high unemployment. On the other hand, the recent European Debt Crisis makes fiscal austerity a golden discipline. Every year dozens of countries have been urged by the IMF to cut their government spending.

This paper investigates three questions.[3] First, what is the average rate of return of public infrastructure investment? Answer to this question is clearly at the centre of the current policy debates. If the investment earns a high enough real return, it is actually possible to reduce debt burdens of future generations.[4] Second, if public infrastructure investment does raise output and income, is it simply because of the Keynesian demand effect or does it indeed enhance productivity of the supply side? Productivity gains are fundamental to long-term growth, because they typically translate into higher incomes, in turn boosting demand. The danger lies in debt-fueled investment that shifts future demand to the present, without stimulating productivity growth.[5] Third,

[1] Infrastructure investment, public investment and public infrastructure investment have often been used interchangeably in the literature, although their exact definitions are not always the same. This paper adopts the terminology "public infrastructure investment" to refer to those investment expenditures that are mainly financed by the government and have the nature of a public good.

[2] African Development Bank called on its members to prioritize the infrastructure investment to stop its growth from flattening in 2013. The Asian Infrastructure Investment Bank established in 2014 states its mission as to contribute to Asian infrastructure development and regional connectivity.

[3] These questions are closely related with a poll on public infrastructure investment conducted by the Initiative on Global Markets Forum of the Booth Business School at the University of Chicago in 2014. Appendix A summarizes the diverse opinions among prominent economists on these questions.

[4] Why public investment really is a free lunch? by Lawrence H. Summers on 6 October 2014 at *Financial Times*.

[5] Why public investment? by Michael Spence on 20 February 2015 at *Project Syndicate*.

if the average rate of return of public infrastructure investment is indeed positive, what are the underlying mechanisms for such investment to promote aggregate productivity? Understanding to this question is vital to the evaluation and planning of large scale infrastructure policies.

To address whether public infrastructure investment enhances the output of the economy at the aggregate level, the existing literature has mainly focused on cross-country or cross-state time series evidences.[6] Using an aggregate production function including public capital as an additional input, the average rate of economic return can be inferred by estimating the average relationship between public capital and GDP. For example, in a seminal work, Aschauer (1989) estimates an output elasticity with respect to public capital to be from 0.38 to 0.56, which implies a rate of return for public infrastructure to be more than 100% in the U.S. during 1949 to 1985. However, this finding has been extensively re-examined by many subsequent studies. As surveyed in Bom and Ligthart (2014), remarkably little consensus has emerged in the literature. The estimated output elasticity with respect to public capital varies widely, from -1.70 to 2.04. In between these extremes, a non-negligible share of the reported estimates of elasticity are statistically not different from zero. In two most recent studies, Warner (2014) finds little growth effect of infrastructure in developing economies while Shi and Huang (2014) report very high returns in China.

The dispersed empirical findings in the existing literature may be the consequence of a set of methodological challenges, for example, poor measurement for the stock of infrastructure capital, non-stationarity in aggregate level variables, and in particular, the reverse causality between output and infrastructure. Higher GDP may lead to higher public infrastructure for various reasons. Thus, a big and positive estimated return (or output elasticity) of public infrastructure could be driven by this reverse causality, which cannot be easily dealt with using aggregate data. Furthermore, the existing aggregate production function estimation framework by nature cannot distinguish the aggregated demand effect from the aggregate productivity effect of public infrastructure investment.

This paper aims to address these identification issues using a set of new methodologies. First, instead of estimating an aggregate production function, we estimate a production function using Chinese firm-level production data matched with province-

[6] For a specific public infrastructure investment project, for example, building an airport, it is straightforward to calculate its financial return, if the benefits and costs of the project are well defined and recorded.

level public infrastructure data. Under the logic that an individual firm's current output benefits from the past infrastructure investment of a province while its current output does not affect the current or past infrastructure investment of the province, the reverse causality problem in the literature using macro data is solved. Second, by modeling a demand system as in De Loecker (2011), we distinguish the revenue-based total factor productivity (TFPR) from the quantity-based total factor productivity (TFPQ). The effect estimated from a TFPR model includes both the Keynesian demand effect and the productivity effect of public infrastructure, while the effect estimated from a TFPQ model only reflects the effect of public infrastructure on productivity. Third, we estimate an endogenous productivity model in which public infrastructure investment affects firm productivity via a first-order Markov process, in the same spirit as in Doraszelski and Jaumandreu (2013). Using the form of a flow, rather than a stock, allows us to avoid the potential measurement errors in the stock of public infrastructure and the associated non-stationarity problem in estimation.

Using a panel of Chinese manufacturing firms matched with province-level public infrastructure investment during 1998 to 2007, we find, that first, there is a 9.2% annual real rate of return of public infrastructure investment in the TFPR model. This implies that public infrastructure investment does have large and positive effects on average. Second, in contrast, the return estimated from the TFPQ model is much smaller, which suggests more than two thirds of the positive effects on output is indeed via the Keynesian demand effect.

We further consider the spillover effects of public infrastructure investment across regions. In a specification where public infrastructure investment is allowed to have national spillover effects on firms locating outside of the province, the estimated rates of return triple.

Finally, using our estimation strategy, substantial heterogeneity in the estimated effects across firms allows us to investigate the underlying mechanism on why public infrastructure investment is productive at the aggregate level. We examine how public infrastructure investment affects the exit probability and market share of firms with different productivity levels. The evidences are consistent with the hypothesis that public infrastructure investment plays a role as a catalyst for resource reallocation from less to more productive firms, similar to the impact of trade on productivity argued by Melitz (2003).

The rest of the paper is organised as follows. Section 2 explains how to estimate the return of public infrastructure using a firm-level production function approach, after discussing the identification issues in the literature using aggregate data. Section 3 describes the data and reports the empirical findings. Section 4 distinguishes the productivity effect from the demand effect. The spillover effect of public infrastructure investment is examined in Section 5. Section 6 presents evidences consistent with a mechanism of resource reallocation promoted by public infrastructure. Section 7 includes various robustness checks. Finally, Section 8 summarises the findings and discusses the limitations.

2 Estimating Return of Public Infrastructure Investment

2.1 Identification Challenges

Starting with Aschauer's (1989) paper, the traditional literature has been working on an augmented aggregate production function in the logarithm form:

$$\ln Q = \alpha_0 + \alpha_b \ln B + \alpha_k \ln K + \alpha_l \ln L + \varepsilon, \tag{1}$$

where Q, K, L are the aggregate output, private capital and labour force, and the public capital stock B is treated as an additional input. The output elasticity α_b is the key parameter of interest, as the economic return, or the marginal revenue product of public capital, $MRPB$, can be inferred using the relationship:

$$MRPB \equiv \frac{\partial Q}{\partial B} = \alpha_b \frac{Q}{B}.$$

Estimating α_b, however, involves a set of identification issues, as surveyed by Gramlich (1994) and Calderon et al. (2014). The first and also the main challenge is reverse causality. The equation (1) aims to identify the causal effect of public infrastructure on output, but the causality could go from output to public infrastructure. Higher GDP may mean greater demand for the amenities provided by public infrastructure; higher GDP may also mean more income for expenditures on public infrastructure. As Canning and Pedroni (2008) conclude, "in general the causality is bidirectional."

There are various ways to deal with the reverse causality. The first candidate is the instrumental variable (IV) approach. However, under this context it is usually hard to find a convincing external instrument without the problem of weak instrument. Meanwhile, researches using internal instruments, for example, Holtz-Eakin (1994), often generate very low returns. The second approach is the simultaneous equations approach. For example, Röller and Waverman (2001) specify a micro-model of supply and demand for telecommunications investment, which is jointly estimated with the macro production function. However, their approach relies on detailed price information of telephone service, which usually is unavailable in other applications. The third candidate is to explore the cross-industry variation in the productivity effect of infrastructure by using disaggregated data such as Fernald (1999).[7] Fernald's logic is intuitive but is hard to apply to other type's infrastructure and infrastructure as a whole.

The second challenge is the demand effect. When researchers write down equation (1), the idea is to infer the contribution of public infrastructure capital stock to aggregate supply. But the observed Q in this equation is the equilibrium aggregate output. When public infrastructure investment increases, aggregate demand is what changes in the short-run due to the Keynesian demand effect. Thus even if the true aggregate supply effect of public infrastructure were zero, a rise in public infrastructure investment would raise aggregate demand and output in the short-run. The estimated effect of public infrastructure using the equilibrium aggregate output could mix both supply-side and demand-side contributions.

Third, there are also a set of other econometric problems in estimating equation (1). Perhaps the most obvious one is the potential spurious correlation due to the non-stationarity of macroeconomic time series variables. A common practice is to use some form of differencing. However, the literature that takes difference of equation (1) tend to get much lower estimates for α_b, often not even positive and always statistically insignificant. One possible explanation is indeed due to the measurement errors in the stock of public infrastructure B.[8] In order to construct B using the perpetual inventory method, one needs information on the initial value and the whole history of the investment flow series and assumes a depreciation rate. This implies that the constructed stock data is very likely to be contaminated with measurement errors.

Finally, besides reverse causality and the combined supply and demand effects, there is another form of simultaneity bias in equation (1) due to unobserved factors

[7] He finds that when growth in roads changes, productivity growth changes disproportionately in U.S. industries with more vehicles. The vehicle-intensive industries benefit more from road-building suggests that roads are productive.

[8] If the serial correlation of the measurement errors is smaller than the serial correlation of the true unobserved explanatory variable, first differencing the data is bound to exacerbate the measurement errors and lead to more severe downward bias than OLS estimation of the levels equation.

included in ε. For example, a technology shock or a change in energy prices might simultaneously affect the aggregate output and the factor inputs. This would set up a correlation between the regressors and the errors, rending the OLS estimates biased and inconsistent.

2.2 A Firm-level Production Function Approach: the TFPR Model

To address these identification issues, this paper adopts a firm-level production function approach with matched data on province-level infrastructure investment. For each industry s, consider a standard sales revenue generating equation in the production function estimation literature:

$$r_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_{it} + \epsilon_{it}, \tag{2}$$

where r_{it} is the real sales revenue of firm i in year t, and l_{it}, k_{it}, m_{it} are the labour, capital and intermediate inputs, all in the logarithm form. ω_{it} represents an unobservable firm-specific revenue-based productivity, and ϵ_{it} denotes the unobservable idiosyncratic shocks to firm's sales revenue.

To model the effect of public investment on productivity, we assume that the productivity process ω_{it} follows a first-order Markov process:

$$\omega_{it} = h_t(\omega_{it-1}, g_{jt-1}) + v_{it}, \tag{3}$$

where g_{jt-1} is the logarithm of public infrastructure investment flow G_{jt-1} in province j where the firm i is located and in year $t-1$ when the public investment is made, and v_{it} is an unobservable firm-specific innovation to the revenue-based productivity. Following the literature, such as Foster et al. (2008), we refer the system of equations (2) and (3) to the TFPR model.

Substituting (3) into (2) gives

$$r_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + h_t(\omega_{it-1}, g_{jt-1}) + v_{it} + \epsilon_{it}. \tag{4}$$

Similar to the aggregate production function approach (1), public investment g_{jt-1} can be regarded as an additional input in the firm-level production function. Different from the aggregate production function approach (1), the effect of g_{jt-1} is operating through the endogenous productivity process (3). The time-to-build assumption implies that it takes time for the infrastructure investment to contribute to a firm's productivity.

The first-order Markov process then models the contribution of previous infrastructure investment flows to ω_{it} through the lagged productivity ω_{it-1}. Here g_{jt-1} is introduced in the same fashion as in De Loecker (2011, 2013) on the productivity effect of trade liberalization, and in Doraszelki and Jaumandreu (2013) studying the productivity impact of R&D investment. By construction, g_{jt-1} is uncorrelated with productivity shock v_{it}.

As in the aggregate production function approach (1), the key parameter of interest is the firm-specific output elasticity of infrastructure investment, which can now be obtained as

$$e_{it} = \frac{\partial r_{it}}{\partial g_{jt-1}} = \frac{\partial \omega_{it}}{\partial g_{jt-1}} = \frac{\partial h_t}{\partial g_{jt-1}}. \tag{5}$$

The firm-level production function approach consisting of equations (2) and (3) has some unique advantages in addressing the identification challenges long-lasting in the literature. First, using a firm-level production function (2) avoids the reverse causality by nature. The lagged province-level infrastructure investment may shift individual firm's current output by increasing it productivity. However, when there are a large number of firms in a province, each individual firm's current output does not affect lagged province-level infrastructure investment decision.

Second, the endogenous productivity process (3) models the effect of public infrastructure on firm's productivity in the form of a flow. Different from estimating an aggregate production function with a public capital stock, this new approach does not require the whole historical information on public infrastructure investment flows and avoids the measurement errors associated with an arbitrarily imposed depreciation rate.

Furthermore, using a firm-level production function, it is possible to net out the Keynesian demand effect from the long-run productivity effect of public infrastructure investment under some auxiliary assumptions on the demand system. We will elaborate this point in Section 4.

Finally, equation (5) implies that the effect of public infrastructure investment on productivity may vary from firm to firm, depending on ω_{it-1}, the attained productivity level of firm i, and g_{jt-1}, the infrastructure investment of province j. Our approach thus allows us to recover the distribution of the output elasticities and characterise the heterogeneities across firms. This is crucial in exploring the mechanism of how infrastructure investment affects productivity, as investigated in Section 6.

Despite these advantages of using disaggregated data, to obtain a return of public infrastructure investment that is conceptually comparable to the one in the existing literature, two issues should be taken care. The first is how to calculate the average return after obtaining firm-specific output elasticities as in equation (5). To calculate the average output elasticity, we need to aggregate these firm-level output elasticities into an industry average, and then aggregate these industry-level output elasticities into a sector average. The assumptions and procedures on calculating the average return of infrastructure investment are reported in Section 3.

The second issue is the spillover effect of public investment. When the firm-level production data is matched only with the infrastructure investment data of the province where the firm locates, it may understate the infrastructure impacts by ignoring the out-of-province benefits arising from the positive externality of public goods. A model and empirical results with spillover effects will be presented in Section 5.

2.3 Identification and Estimation

The system of equations (2) and (3) leads to a standard endogenous firm-level production function considered by Olley and Pakes (1996), Levinsohn and Petrin (2003) and Ackerberg et al. (2006). The OLS estimates of $\beta's$ in equation (2) is known to be inconsistent due to the correlation between input factors l_{it}, k_{it}, m_{it} and ω_{it}. We follow Ackerberg et al. (2006) to control this simultaneity bias by the proxy method. The fundamental identification assumption is that m is a variable input and k is a dynamic input. Profit maximization thus leads to an optimal intermediate inputs:

$$m_{it} = m_t(l_{it}, k_{it}, \omega_{it}).$$

The strict monotonicity of m_{it} in ω_{it} implies an inverse function:

$$\omega_{it} = \omega_t(l_{it}, k_{it}, m_{it}). \tag{6}$$

Denote $\beta \equiv (\beta_l, \beta_k, \beta_m)'$ and $x_{it} \equiv (l_{it}, k_{it}, m_{it})'$. Inserting equation (6) into the equation (2) yields a reduced-form equation:

$$r_{it} = x_{it}'\beta + \omega_{it} + \epsilon_{it} = \phi_t(x_{it}) + \epsilon_{it},$$

where the nonlinear function $\phi_t(x_{it}) = x_{it}'\beta + \omega_t(x_{it})$. By construction ϵ_{it} has zero mean and is independent of x_{it}. Thus, by proxying ω_{it} using equation(6), the reduced-form equation can be consistently estimated by a nonparametric regression of r_{it} on x_{it}. This process is called the first-stage regression, which provides a fitted value $\hat{\phi}_t(x_{it})$ for r_{it}.

With this fitted value, the second-stage regression provides moment conditions to identify the parameters of interest. To be specific, for a given value of β, the productivity innovation v_{it} can be obtained as the residual of a nonparametric regression of $\omega_{it}(\beta)$ on $\omega_{it-1}(\beta)$ and g_{jt-1}:

$$v_{it}(\beta) = \omega_{it}(\beta) - h_t(\omega_{it-1}(\beta), g_{jt-1})$$

where

$$\omega_{it}(\beta) = \hat{\phi}_t(x_{it}) - x'_{it}\beta \tag{7}$$

and

$$\omega_{it-1}(\beta) = \hat{\phi}_{t-1}(x_{it-1}) - x'_{it-1}\beta.$$

The estimates of β can be obtained by the generalised method of moments estimation under the moment conditions:

$$E\left[(v_{it}(\beta)) \otimes \begin{pmatrix} l_{it-1} \\ k_{it} \\ m_{it-1} \end{pmatrix}\right] = 0. \tag{8}$$

The identification of $\beta_l, \beta_k, \beta_m$ strictly follows the timing assumptions in Ackerberg et al. (2006).[9]

2.4 Calculating the Return

With estimates of β, the firm-specific elasticity e_{it} defined in (5) can be obtained by a nonparametric/polynomial regression, where ω_{it} is obtained by (7). Then, we use sales revenue of each firm as the weight to aggregate these firm-level output elasticities into an industry average, and adjust the ratio between value-added and sales revenue:

$$e_{st} = \left(\sum\nolimits_i e_{it}\frac{R_{ist}}{R_{st}}\right)\frac{dv_s}{dr_s}, \tag{9}$$

where $\frac{R_{ist}}{R_{st}}$ represents firm i's revenue as a share of total revenue in industry s and year t; the ratio $\frac{dv_s}{dr_s}$ is obtained by a fixed-effect regression of log value-added on log sales revenue for industry s. Finally, we use value-added of each industry as the weight to aggregate these industry-level output elasticities into an average for the manufacturing sector:

$$e_t = \sum\nolimits_s e_{st}\frac{V_{st}}{V_t}, \tag{10}$$

where $\frac{V_{st}}{V_t}$ denotes industry s's value-added as a share of total value-added in the manufacturing sector in year t.

[9] We experiment labor as a variable input and a dynamic input, and obtain very similar results.

Our ultimate quantity of interest, the average rate of economic return, or the marginal revenue product of infrastructure investment, $MRPG_t$, can be obtained by multiplying e_t with the corresponding GDP-to-infrastructure investment ratio in year t:

$$MRPG_t = e_t \frac{GDP_t}{G_{t-1}}. \tag{11}$$

Under the assumption that the output elasticity e_t calculated from manufacturing sector are representative for the whole economy, we then obtain the rate of return of infrastructure investment to the whole economy.

3 Empirical Results

3.1 Data and Variables

3.1.1 Firm-Level Production Data

The firm-level data come from the Annual Survey of Industrial Firms conducted by China's National Bureau of Statistics, covering years from 1998 to 2007. The data have been widely used in many researches regarding the productivity of Chinese manufacturing firms, such as Song et al. (2011), Yu (2015), and Hsu et al. (2016), among many others. The survey contains information on firm characteristics, output and input, and balance sheet variables, for all state-owned firms and non-state-owned firms with sales revenue above 5 million Chinese Yuan. In total these firms produce 80% value-added of China's industrial sector. Brandt et al. (2012) provide an excellent introduction and user manual to this survey. We match the annual data into a panel and construct the real capital stock by the perpetuity inventory method strictly following their procedures. Both the output and input data are deflated using the 2-digit industry-wide price indices, which are aggregated over the 4-digit benchmark price indices constructed by Brandt et al. (2012).

Like all existing literature, our production function estimation focuses on the 29 industries in the manufacturing sector. Table 1 lists the industrial code and definition for these industries. Average annual number of observations for the corresponding industry is reported in column (1). On average there are more than 7,000 observations for each industry in every year. Columns (2) and (3) present the median values of the real annual growth rates of labor productivity and capital productivity in each industry. Although the labour and capital productivities have been growing at 6.6% and 10.8% per year for the whole manufacturing sector, there is also substantial variation across industries. Column (4) reports the output deflators for each industry that have been employed to deflate the sales revenue data.[10]

3.1.2 Province-Level Infrastructure Data

The China Statistics Yearbooks and the China Fixed Investment Statistical Yearbooks report total investment in fixed assets by industry and by province. According to Aschauer (1989), the core infrastructure has the highest explanatory power for productivity, where the core infrastructure usually refers to highways, mass transit, airports, electrical and gas facilities, water and sewers in the traditional literature. The more recent literature, such as Röller and Waverman (2001) and Grimes et al. (2012), also includes telecommunications and internet connectivity as an important part of physical infrastructure. Based on the data availability, in this paper we define core infrastructure investment as total investment in fixed assets in the industries of (1) production and supply of electricity, gas and water; (2) transport, storage and post; and (3) information transmission, computer services and software. We also include investment in (4) management of water conservancy, environment, and public facilities in our robustness checks and define the sum of the four categories as the broad infrastructure investment.

Qin (2016) surveys some useful stylised facts on the scale and speed of infrastructure investment in China and the financing mechanism backing such investment. Since the mid-1990s, infrastructure investment has been regarded as a major policy priority by the Chinese central government and has been emphasised throughout the successive Five-Year Plans. Although the financing infrastructure investment is generally shared among the central government, local governments and private sector, the provincial governments have been regarded as the key decision maker for most infrastructure investment.[11] Among many others, Li and Zhou (2005), Zhang et al. (2007) and Xu (2011) argue that the provincial governments in China have a strong incentive

[10] The industries 25 petroleum processing and coking and 33 smelting and pressing of nonferrous metals have witnessed much smaller growth rates. One possible reason is the great output price variation in these two industries over the sample period. As reported in column (4), when on average the output deflator of the manufacturing sector in 2007 is only around 115, the output prices of these two industries have doubled over the decade. In the following analyses, we thus drop the industries 25 and 33, to rule out the possible contamination from high inflation and large price volatility.

[11] For example, in 2005, 12% of total spending on road development was funded by central government grants; 42% was funded by bank loans to province and county-level governments through various special purpose vehicles borrowing against future toll revenues; 28% was funded by provincial government sources such as revenues from the annual road maintenance fees charged to vehicle owners; 15% was funded by local government sources; and 4% was funded by the private sector and state-owned enterprises (Qin, 2016).

in infrastructure investment as a response to the GDP yardstick competition under China's regionally decentralised authoritarian system. Such institutional background explains why almost all existing empirical studies on China's infrastructure investment use the province-level data.

Table 2 provides a description on the infrastructure investment aggregated from the province-level data during our sample period. Investment data are deflated by the price indices of investment in fixed assets by province. Data on industrial and total GDP are collected from the China Statistics Yearbooks and are deflated by the corresponding GDP deflators. According to Table 2, the core infrastructure investment has been steadily increasing throughout 1998 to 2007 at a real annual growth rate of 11.9%. Although the absolute level of investment substantially increased since year 2003,[12] the ratios between such investment to industrial GDP and total GDP have been rather stable across the decade, which are around 21.2% and 8.9%, respectively. This seems to be consistent with the findings in the literature that the causal relationship between infrastructure investment and GDP is bi-directional. Similar patterns on the broad infrastructure investment are also observed in the lower panel of Table 2.

3.2 Estimating Productivity Process

The estimates of β in the sales revenue function (2) are reported in Appendix B. Table 3 presents the polynomial estimates of the endogenous productivity process (3) for the entire manufacturing sector. This serves as a direct illustration for the average impact effect of the infrastructure investment on the revenue-based total factor productivity. First, the productivity process is highly non-linear. This suggests that the productivity process would be misspecified by a simple linear model. Second, both the infrastructure investment itself and its interaction with the lagged productivity are highly significant. This implies that the effect of infrastructure investment on productivity is firm-specific, depending on a firm's attained productivity level. Both the non-linearity of the productivity process and the significance of the interaction term in an endogenous productivity echo those findings in De Loecker (2013), who studies the role of learning by exporting.

Given the heterogeneous impact effect, we calculate elasticity $\omega_{it} = \partial\omega_{it}/\partial g_{jt-1}$, the

[12] There are two possible reasons to the sudden increase in infrastructure investment in year 2003. One is the substantial GDP growth since 2003 caused an increase in both the demand and the supply of infrastructure investment. Another explanation lies in a change in the statistical criteria on infrastructure investment. Before 2003, categories (2) and (3) were combined together as investment in transport, storage, post and telecommunication service, which were divided separately since 2003.

partial derivative of log productivity with respect to log infrastructure investment at the median lagged log productivity level. We obtain an elasticity of 0.023, suggesting that for a firm with median productivity level in the whole manufacturing sector, infrastructure investment does enhance its productivity.

To highlight the degree of heterogeneity, we also calculate the elasticities by industry and report their values at the 25^{th}, 50^{th} and 75^{th} percentiles of the productivity in Table 4. As expected, we see substantial variations along the productivity distribution within each industry, and also across different industries. For all industries, the effects of infrastructure investment on productivity increase with the initial productivity level. While firms at the higher quantiles of the productivity usually benefit from the infrastructure investment, firms at the lower quantiles of the productivity could in fact gain less or suffer from the infrastructure investment.

3.3 Output Elasticities and Rates of Return

Table 5 reports the estimated output elasticities by industry and the average return of public infrastructure investment in China during 1999-2007. The industry-average output elasticities defined in equation (9) are presented in the upper panel for each industry. The sector-level output elasticities defined in equation (10) are reported in the first row of the lower panel.

We list the ratios of industrial GDP-to-infrastructure investment and of total GDP-to-infrastructure investment, respectively in the following rows. Thus the second last row presents the rates of return of infrastructure investment to the industrial sector. Under the assumption that the output elasticities calculated from these 27 manufacturing industries are representative for the whole economy, the last row of Table 5 reports the rates of return of infrastructure investment to the Chinese economy, defined in equation (11). The 9-year average rate of return during 1999-2007 is 9.2%. The yearly returns vary from 8.0% in 1999 and peak to 10.7% in 2003. This finding indicates that public infrastructure investment does generate significantly positive return in China, at least during our sample period.

4 Controlling for Demand Effect: the TFPQ Model

This section illustrates how to net out the Keynesian demand effect from the estimated productivity effect of public infrastructure investment using a firm-level production function approach. With firm-level data, on the one hand, public infrastructure investment enters the production function by enhancing productivity, just as in an aggregate production function. On the other hand, one may explicitly write down a demand function where infrastructure investment shifts firm's demand. Although in general only sales revenue – the multiplication of equilibrium output and price is observable to econometricians, under certain structural assumptions, following De Loecker (2011), we are able to distinguish the TFPQ from the TFPR by controlling the demand effect of public infrastructure investment. In this sense, the effect estimated from a TFPR model includes both the Keynesian demand effect and the productivity effect of public infrastructure, while the effect estimated from a TFPQ model only reflects the effect of public infrastructure on productivity.

4.1 Production and Demand

Consider a firm i that actively produces and sells in industry s, province j and year t. It employs labour L_{it}, capital K_{it} and intermediate inputs M_{it} to produce physical output Q_{it} according to a Cobb-Douglas production function:

$$Q_{it} = L_{it}^{\alpha_L} K_{it}^{\alpha_K} M_{it}^{\alpha_M} \exp(\omega_{it}^q + \epsilon_{it}^q), \tag{12}$$

where α_L, α_K,and α_M are the corresponding output elasticities. ω_{it}^q represents an unobservable firm-specific quantity-based productivity, and ϵ_{it}^q denotes the unobservable idiosyncratic shocks to firm's physical output. Similar to the revenue-based productivity process (3), the quantity-based productivity process ω_{it}^q follows a first-order Markov process:

$$\omega_{it}^q = h_t^q(\omega_{it-1}^q, g_{jt-1}) + v_{it}^q, \tag{13}$$

where v_{it}^q is an unobservable firm-specific innovation to the quantity-based productivity.

As in De Loecker (2011), we assume the firm faces a constant elasticity of substitution (CES) demand system:

$$Q_{it} = Q_{sjt}(\frac{P_{it}}{P_{st}})^{-\sigma_s} \exp(\xi_{it}), \tag{14}$$

where P_{it} is the price of goods sold by firm i; and P_{st} is the average price of the goods in industry s. ξ_{it} is a firm-specific demand shifter; and Q_{sjt} is an aggregate demand shifter in industry s and province j. The parameter σ_s is the elasticity of substitution for industry s, where $1 < \sigma_s < \infty$.

To model the effect of public investment on demand, we decompose the firm-specific demand shifter ξ_{it} into two parts:

$$\xi_{it} = \tau g_{jt} + \widetilde{\xi}_{it}, \tag{15}$$

where g_{jt} is the logarithm of province j's infrastructure investment flow in year t; and $\widetilde{\xi}_{it}$ denotes the unobservable firm-specific demand shocks. Different from the time-to-build assumption on the effect of infrastructure investment on productivity (13), equation (15) implies that the effect of infrastructure investment on demand is instantaneous.

4.2 Estimation Equation

Rewriting the production and demand equations in the logarithm form leads to the following equations:

$$\ln Q_{it} \equiv q_{it} = \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \omega_{it}^q + \epsilon_{it}^q. \tag{16}$$

and

$$\ln P_{it} - \ln P_{st} = -\frac{1}{\sigma_s}\left(\ln Q_{it} - \ln Q_{sjt}\right) + \frac{1}{\sigma_s}\xi_{it}. \tag{17}$$

Notice that in most applications both the physical output Q_{it} and the firm-level price P_{it} are not observed to econometricians. Sales revenue $P_{it}Q_{it}$ is usually taken as a proxy for output in practice. To control the change in price and get a real firm-level sales revenue, $P_{it}Q_{it}$ is often deflated by an industry-wide producer price index P_{st}. Adding $(\ln P_{it} - \ln P_{st})$ on both sides of equation (16) yields the following equation:

$$\ln \frac{P_{it}Q_{it}}{P_{st}} = \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + (\ln P_{it} - \ln P_{st}) + \omega_{it}^q + \epsilon_{it}^q. \tag{18}$$

Replace the unobservable $(\ln P_{it} - \ln P_{st})$ using the CES demand system (17):

$$\ln \frac{P_{it}Q_{it}}{P_{st}} = \left(1 - \frac{1}{\sigma_s}\right)\ln Q_{it} + \frac{1}{\sigma_s}\ln Q_{sjt} + \frac{1}{\sigma_s}\xi_{it}, \tag{19}$$

and substitute $\ln Q_{it}$ and ξ_{it} in equation (19) using (16) and (15):

$$\begin{aligned} \ln \frac{P_{it}Q_{it}}{P_{st}} &= \left(1 - \frac{1}{\sigma_s}\right)(\alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it}) \\ &\quad + \left(1 - \frac{1}{\sigma_s}\right)(\omega_{it}^q + \epsilon_{it}^q) + \frac{1}{\sigma_s}\ln Q_{sjt} + \frac{1}{\sigma_s}\left(\tau g_{jt} + \widetilde{\xi}_{it}\right). \end{aligned}$$

Reparameterization leads to an estimation equation for the revenue generating production function:

$$r_{it} = \beta_l^* l_{it} + \beta_k^* k_{it} + \beta_m^* m_{it} + \beta_s^* q_{sjt} + \beta_g^* g_{jt} + \omega_{it}^* + \epsilon_{it}^*, \tag{20}$$

where $r_{it} = \ln \frac{P_{it}Q_{it}}{P_{st}}$, is the logarithm of deflated real sales revenue. $q_{sjt} = \ln Q_{sjt}$, is the logarithm of the aggregate demand shifter. $\beta_h^* = \left(1 - \frac{1}{\sigma_s}\right)\alpha_h$ for $h = \{l, m, k\}$; $\beta_s^* =$

$\frac{1}{\sigma_s}$; $\beta_g^* = \frac{\tau}{\sigma_s}$, represent the set of parameters, which can be used to recover the structural parameters $\{\alpha_L, \alpha_K, \alpha_M, \sigma_s, \tau\}$. The transformed productivity $\omega_{it}^* = \left(1 - \frac{1}{\sigma_s}\right)\omega_{it}^q = (1-\beta_s^*)\,\omega_{it}^q$, is simply a linear scale of the original quantity-based productivity ω_{it}^q. The combined error term $\epsilon_{it}^* = \left(1 - \frac{1}{\sigma_s}\right)\epsilon_{it}^q + \frac{1}{\sigma_s}\widetilde{\xi}_{it} = (1-\beta_s^*)\,\epsilon_{it}^q + \beta_s^*\widetilde{\xi}_{it}$ is a linear combination of those unobservable idiosyncratic shocks to production and demand. Thus, by construction ϵ_{it}^* is uncorrelated with any of the regressors.

4.3 TFPQ, TFPR, and the Output Elasticities

Consider the productivity effect of public infrastructure investment as in equation (16). Our key parameter of interest is the output elasticity with respect to the public infrastructure investment through the productivity channel:

$$e_{it}^q = \frac{\partial q_{it}}{\partial g_{jt-1}} = \frac{\partial \omega_{it}^q}{\partial g_{jt-1}}. \tag{21}$$

Note that ω_{it}^q contributes to the quantity of output and is thus known as the TFPQ.

Equation (16) is not estimatable but equation (20) is:

$$r_{it} = \beta_l^* l_{it} + \beta_k^* k_{it} + \beta_m^* m_{it} + \beta_s^* q_{sjt} + \beta_g^* g_{jt} + \omega_{it}^* + \epsilon_{it}^*.$$

The relationship between ω_{it}^q and ω_{it}^* implies that estimating elasticity e_{it}^q is equivalent to estimating equation (20):

$$e_{it}^q = \frac{\partial \omega_{it}^q}{\partial g_{jt-1}} = \frac{1}{(1-\beta_s^*)}\frac{\partial \omega_{it}^*}{\partial g_{jt-1}}.$$

In this sense, we call the system of equations (20) and (13) the TFPQ model.

Compared with the firm-level production function (2) considered in Section 2, equation (20) includes additional variables q_{sjt} and g_{jt} to control for the demand effects. In contrast, ω_{it} in (2) also absorbs the demand shocks on the sales revenue and is thus known as TFPR. That is why we refer the system of equations (2) and (3) to the TFPR model. Consequently, the elasticities and returns calculated in Section 2 are revenue-based, contrasting with the quantity-based elasticities and returns here.

Same as estimating equation (2), we apply the proxy method by Ackerberg et al. (2006) to equation (20) with two additional variables q_{sjt} and g_{jt}. Now in the first-stage regression, $\phi_t^q(x_{it}^*) = x_{it}^{*\prime}\beta^* + \omega_t^*(x_{it}^*)$, where $\beta^* \equiv (\beta_l^*, \beta_k^*, \beta_m^*, \beta_s^*, \beta_g^*)'$ and $x_{it}^* \equiv (l_{it}, k_{it}, m_{it}, q_{sjt}, g_{jt})'$, so that $r_{it} = \phi_t^q(x_{it}^*) + \epsilon_{it}^*$. Similar to $\omega_t(x_{it})$ in equation (6), here $\omega_t^*(x_{it}^*)$ is the proxy function for ω_{it}^* due to monotonicity of $m_{it} = m_t(x_{it}^*)$.

The moment conditions for identification in the second-stage now become

$$E\left[(v_{it}^{q}(\beta_l^*, \beta_k^*, \beta_m^*, \beta_s^*, \beta_g^*)) \otimes \begin{pmatrix} l_{it-1} \\ k_{it} \\ m_{it-1} \\ q_{sjt-1} \\ g_{jt} \end{pmatrix}\right] = 0. \tag{22}$$

The identification of $(\beta_l^*, \beta_k^*, \beta_m^*)$ is based on the timing assumption of l, k and m, the same as in the TFPR model in Section 2. The additional parameters (β_s^*, β_g^*) are identified by the assumption that shocks to productivity (v_{it}^q) are uncorrelated with lagged industry-province aggregate output (q_{sjt-1}) and province-level infrastructure investment (g_{jt}).

4.4 Empirical Results

Appendix B reports the estimation results for equation (20). A highly non-linear productivity process and heterogeneous output elasticities across firms with different productivity level as in Table 3 and 4 are also observed for the quantity-based productivity. For the sake of space, we only summarise the output elasticities across industry and the average rates of return in Table 6. A comparison between Table 5 and 6 highlights an important finding that, after netting out the demand effect, the quantity-based output elasticities become much smaller than those revenue-based. For example, the average output elasticities for industry 13 (food processing) and for the whole manufacturing sector during 1999-2007 are -0.045 and 0.002, compared with -0.002 and 0.007 in Table 5. Consequently, lower rates of return are observed after controlling for the demand effect. The last row of Table 6 shows that the economy-wide rate of return based on quantity productivity is 2.5% averaging across years from 1999 to 2007, which is less than one-third of that based on revenue productivity. This indicates that much of the contribution of infrastructure investment to output is indeed via the Keynesian demand effect.

5 Spillover Effects

The baseline specifications in equation (3) of Section 2 and equations (13), (14) and (15) of Section 4 have explicitly assumed that the effects of public infrastructure investment only take place on firms that locate within the province. However, firm i's productivity may benefit not only from those public infrastructure in its location province j, but also from the public infrastructure in the rest of the country. Similarly, firm i's demand – both aggregate and firm-specific demand – may be shifted not only by those public infrastructure in its location j, but also by the public infrastructure in the rest of the country.

The argument of interregional spillover effects has indeed been used to explain why larger output elasticities of public infrastructure are typically found for time-series studies using aggregated data. To account for the spillover effects of public infrastructure, studies using regional data, for example, Holtz-Eakin and Schwartz (1995), employ so-called "effective" public infrastructure, which includes the public infrastructure of neighboring regions in addition to the regional data. Using aggregate and regional-level data from Spain, Pereira and Roca-Sagales (2003) argue that aggregate effects of public infrastructure cannot be captured in their entirety by the direct effects in the region itself. They find that the aggregate effects are due in equal parts to the direct and spillover effects of public infrastructure.

Following this literature, we generalise our model by replacing the province-level data with a distance-weighted national-level data of public infrastructure investment in our benchmark model. We also experiment by replacing the province-level data with the regional neighboring-level data for robustness check. These exercises turn out to be quantitatively important in inferring the return and qualitatively crucial in evaluating the efficiency of public infrastructure investment.

5.1 Specifications for the Spillover Effects

To address the concern that interregional spillover effects cannot be fully captured by studies looking at small geographical units, we replace the province-level g_{jt-1} in the productivity processes (3) and (13) with an interregional measure of infrastructure investment:

$$\omega_{it} = h_t(\omega_{it-1}, \overline{g}_{jt-1}) + v_{it}, \tag{23}$$

and

$$\omega^q_{it} = h^q_t(\omega^q_{it-1}, \overline{g}_{jt-1}) + v^q_{it}, \tag{24}$$

where $\overline{g}_{jt-1} = \log(\overline{G}_{jt-1})$, and $\overline{G}_{jt}$ is the weighted average of G_{kt}:

$$\overline{G}_{jt} = \sum\nolimits_k w_{jk} \cdot G_{kt}. \tag{25}$$

The weighting matrix w_{jk} is constructed and normalised as in Ertur and Koch (2007):

$$w_{jk} = \frac{\frac{1}{d_{jk}}}{\sum_{k \neq j} \frac{1}{d_{jk}}} \text{ for } k \neq j, w_{jj} = 1.$$

Here, j is the province where the firm i locates. $k \neq j$ represents the rest of other provinces of the country, and d_{jk} is the distance between capital cities of provinces j and k. It implies the public infrastructure investment of a province also has an impact on those firms locating outside of the province, where the magnitude of the impact diminishes with the distance.

In the TFPQ model, to capture the spillover effect on demand side, we also modify the aggregate demand shifter equation (14) into:

$$Q_{it} = \overline{Q}_{sjt}(\frac{P_{it}}{P_{st}})^{-\sigma_s} \exp(\xi_{it}), \tag{26}$$

with a modified firm-specific demand shifter equation (15):

$$\xi_{it} = \tau \overline{g}_{jt} + \widetilde{\xi}_{it}. \tag{27}$$

Similarly, $\overline{Q}_{sjt}$ is the weighted-average of Q_{skt}:

$$\overline{Q}_{sjt} = \sum_k w_{jk} \cdot Q_{skt}, \tag{28}$$

5.2 Results with Spillover Effects

Tables 7 and 8 report the corresponding output elasticities and the average rates of return in models of TFPR and TFPQ with spillover effects, respectively. They can be considered as the counterparts of Tables 5 and 6 with the spillover specifications (23), (24), (26) and (27). Although these tables display assuring patterns that are qualitatively similar, they also show a quantitatively important difference that highlights the significance of the spillover effects. The 9-year average rate of return in the TFPR model now increases from 9.2% to 28.3%. Similarly, Tables 8 and 6 show that the 9-year average rate of return in the TFPQ model now increases from 2.5% to 7.2%.

Our finding is therefore consistent with a general pattern documented in the literature, for example, the survey by Pereira and Andraz (2013), that the return rate of public investment at the regional level is usually smaller than the return at the national level. Note that in our empirical exercises, the returns obtained from a specification with spillover effects triple those without spillover effects. This suggests that, the positive externality and the economy of scale from infrastructure investment might be particularly relevant in an economy with a large size and many regions such as China. This echoes the point made in Li and Li (2013), who find a non-trivial spillover effect of road networks on firms in neighboring provinces, which accounts for around two-thirds of all the inventory reduction due to road investment in China.

Tables 7 and 8 resemble two interesting patterns that we have witnessed from Tables 5 and 6. First, the rates of return in the TFPR model are much larger than those in the TFPQ model. This implies that the Keynesian demand effect also operates in models with spillover effects. Second, over the time the rates of return with spillover effects also display an inverted-U shape which peaks around 2003 and 2004. Hence the public infrastructure investment seems to be most productive in the middle of our sample period.

5.3 An Evaluation on the Rates of Return

So far our empirical exercises now provide 4 estimates of returns of infrastructure investment in 4 models: TFPR, TFPQ, TFPR with spillover effects and TFPQ with spillover effects, presented in Tables 5 to 8. The average rates of return during 1999-2007 are 9.2%, 2.5%, 28.3% and 7.2%, respectively, as summarised in Figure 1a. A natural question may arise at this point: do such rates of return make economic sense? The fact that the literature has estimated very dispersed rates of return from various econometric analyses makes a direct comparison difficult. Instead, we look at some alternative benchmarks in turn.

In the U.S. one most convincing and acceptable calculation of the real rates of return of infrastructure investment comes from project-specific survey evidences and cost-benefit analyses. The Congressional Budget Office surveys and analyzes those cases for various types of highway expenditures done in the early 1980s. It reports an average real rate of return to new urban highway construction of 15% and to projects to maintain current highway conditions of 35% (Gramlich, 1994). Hence our estimates on the rates of return based on TFPR model (9.2% and 28.3%) seem to be in the ballpark of this benchmark, although such estimates are based on a more general category of infrastructure, for a different country and from a different sample period.

In China, according to the Ministry of Housing and Urban-Rural Development, cost-benefit analysis should be undertaken in the feasibility study before the implementation of each infrastructure project. The recommended discount rate is 8%. Of course, the cost-benefit analysis has primarily served as a threshold for project selection. The sequencing and prioritization of infrastructure projects is also driven by the local demand and incentives (Qin, 2016). If we take 8% as the required rate of return in principle when a province makes a project evaluation without considering its out-of-province benefits, the average rate of return estimated from the TFPR model without spillover effects (9.2%) just passes this threshold.

The real rate of return of private investment estimated from our empirical exercises serves as another and probably more natural benchmark. First, it is a direct measure for the opportunity cost of public investment. Second, it comes from the same model, data and econometric approach thus is internally comparable with our estimates on the rates of return of infrastructure investment. Table 9 lists the weighted average rates of return of private investment in each industry, and the whole manufacturing sector, using the revenue-based output elasticity with respect to private capital estimated from equation (2), and the weights of sales revenue.

Table 9 highlights two important patterns. First, the rates of return of private investment vary substantially across industries, where industry 40 (electronic and telecommunications equipment), 16 (Tobacco processing) and 27 (medical and pharmaceutical products) are at the top of the rank; and industry 28 (chemical fiber), 32 (smelting and pressing of ferrous metals), and 17 (textile) are at the bottom of the rank. On average, the manufacturing sector has a rate of return of private investment at 27.3% over our sample period.[13] Second, the rates of return of private investment have been steadily rising over the sample period. This implies an increasing investment efficiency in the Chinese manufacturing sector, a stylised fact well-documented and explained in the literature, such as Hsieh and Klenow (2009), Brandt et al. (2014) and Song and Wu (2015), among many others.

If we compare the returns to infrastructure investment with returns to private investment in the manufacturing sector, there are two interesting messages. First, without considering the spillover effects, the returns to infrastructure investment are clearly lower than the returns to private investment. Taking into account the spillover effects, infrastructure investment offers a slightly higher rate of return than private investment, at least during our sample period. Nevertheless, one should also bear in mind the second point: manufacturing is usually the most productive sector in a

[13] Doraszelki and Jaumandreu (2013), who estimate the rate of return of R&D, also report their estimates for the rates of return of physical investment across nine Spanish manufacturing industries. Net of depreciation, their rates of return of physical investment vary from 7.2% to 31.1% with a sector average at 18.9%. Consider that we have used a 9% depreciation rate to construct capital stock, the two sets of estimation on the returns are very close to each other.

fast-growing economy like China; and the Annual Survey of Industrial Firms itself is a selected sample. It only includes those successful continuing firms, which are either large or productive or both large and productive, and new entries, which are usually highly productive.

Another useful benchmark we consider is from Bai and Zhang (2014), who estimate the rates of return to physical investment – both private and public – in China from 1978 to 2013, using aggregate data and capital income share in GDP, equipped with an accounting framework. According to their estimation, the returns to investment in China during 1999 to 2007 vary from 20.1% to 24.3% with an average of 22.3%, where the peak also appears around 2003 and 2004. Thus the rates of return from this benchmark happen to lie in between our revenue-based returns to public infrastructure with and without spillover effects, as illustrated in Figure 1b.

6 Mechanism

Understanding the specific links between public infrastructure and economic performance is probably equally pertinent as estimating the returns. After all, the mechanisms leading to a positive return of infrastructure investment are often so intuitive that have sometimes been taken for granted in the early literature. Possible channels mentioned include economy of scale in production (Aschauer, 1989), reduction in transportation costs (Fernald, 1999) and transaction costs (Yang and Ng, 1993), spatial spillover (Holtz-Eakin and Schwartz, 1995) and network externalities (Röller and Waverman, 2001). An overall negative return to infrastructure investment could also be legitimate and meaningful. The possible explanation offered by the literature include tax distortion in financing public investment (Barro, 1990), crowding-out effect on private investment due to higher interest rates or tighter credit constraints (Cavallo and Daude, 2011), and inefficiency and corruption during the process of building the infrastructure (Keefer and Knack, 2007).

A recent empirical literature on transport infrastructure in China emphasises that public infrastructure could impact the distribution of economic activities. For example, Banerjee et al. (2012) find that proximity to transportation networks has a moderately positive causal effect on per capital GDP levels across sectors, but it has no effect on per capital GDP growth. Faber (2014) shows that the National Trunk Highway System can lead to a reduction in industrial and total output growth among connected peripheral counties relative to non-connected ones. Baum-Snow et al. (2015) study the impact of roads and railways on the decentralization of Chinese cities in terms of population and industrial GDP.

Similar to the recent literature on transport infrastructure based on county- or city-level data, we also emphasise the heterogeneous impact effects of infrastructure investment. However, we move one more step forward by providing firm-level evidences that are consistent with the catalyst role of public infrastructure investment in facilitating resource reallocation. This paper thus further contributes to the infrastructure literature by filling in a gap from microeconomic foundation to macroeconomic implications.

6.1 A Possible Channel: Resource Reallocation

Two important findings can be established from our empirical exercises so far. First, at the aggregate level, public infrastructure investment contributes to the productivity positively, both in the TFPR and TFPQ models and both with and without the spillover effects. Second, and probably more interesting, at the firm-level, public infrastructure investment has a heterogeneous effect across different firms, depending on the attained productivity level of the firm. The findings of an aggregate positive effect and a heterogeneous individual effect seems to be consistent with the theme advocated by a recent literature on misallocation and productivity, see, for example, the survey by Restuccia and Rogerson (2013). In an economy with heterogeneous firms, when resources are reallocated from less productive firms to more productive ones, the aggregate productivity of the economy increases.

The public infrastructure may play an important role as the catalyst in facilitating such resource reallocation. A specific mechanism could be the one characterised in Melitz (2003). In a dynamic industry model with heterogeneous firms, a trade liberalization – via an increase in the number of trading partners, a decrease in the variable trade cost, or a decrease in the fixed market entry cost – in all cases, will force the least productive firms to exit and will reallocate market shares from less productive to more productive firms. Both the exit of the least productive firms and the additional market shares gained by the more productive firms contribute to an aggregate productivity increase.

It is well known that before the 2000s China has been largely excluded from the international goods market and subject to widespread local protectionism (Young, 2000; Bai et al., 2004; Poncet, 2005). Tombe and Zhu (2015), who recently study on how misallocation due to goods- and labour-market frictions affects aggregate productivity in China, find that reductions in international and in particular internal trade costs account for two fifths of aggregate productivity growth in China between 2000 and 2005. Besides various policy and institutional reforms, one particular contribution to the reduction in trade costs could come from the public infrastructure investment.

6.2 Linking Output Elasticity with Firm Characteristics

To examine this possible channel, we first provide some evidence on which firms are benefiting or benefiting more from public infrastructure investment. Since both productivity and elasticity *per se* are not directly observable, Table 10 further links output elasticity, the impact of infrastructure investment on productivity, with observable firm characteristics. Estimated output elasticities from various specifications in Section 3, 4 and 5 are regressed on firm age, size, ownership, exporting status and geographic location.

A common finding arises across all specifications, that all else being equal, a firm that is younger, smaller, non-state-owned, exporting and locating in the eastern region has a larger output elasticity than its counterpart. Since firms with such characteristics are well-known to be more productive firms in China, this finding therefore suggests that infrastructure investment tends to benefit firms with high productivity more than those with low productivity, consistent with the resource reallocation mechanism.

6.3 Testing the Hypothesis

To formally test the hypothesis that public infrastructure investment facilities resource reallocation by reducing trade costs and increasing firm's exposure to trade, we then examine two specific predictions derived from the Melitz (2003) model. First, all else being equal, public infrastructure investment increases the probability of exit of the less productive firms. Second, all else being equal, public infrastructure investment increases the market shares of the more productive firms. Following the literature, such as Olley and Pakes (2001), Pavcnik (2003) and De Loecker (2011), the productivity measure in these exercises is obtained as the Solow residual, from both TFPR and TFPQ models, with and without spillover effects, in respective specifications of Table 11 and Table 12.

Table 11 presents Probit regressions of exit probability. A firm i is defined as exit in year $t+1$ if it is observed in year t but not in year $t+1$ in the dataset. On average, the exit probability is around 11%. In column (1) of the regressions, we start with a baseline specification with productivity and capital stock only. Both are negative, significant and of a similar magnitude as that in Olley and Pakes (2001) and Pavcnik (2003). In column (2), the corresponding public infrastructure investment measure is added in the regression in each model. Overall, public infrastructure investment itself reduces the probability of exit. However, in column (3), we interact public infrastructure investment with a dummy variable, which has a value one if a firm's productivity in year t is below the median value of productivity. This interaction term is significantly positive, implying that the impact of public infrastructure investment on firm's exit depends on firm's productivity. A low productivity firm is indeed more likely to exit with more public infrastructure investment.

Table 12 has a similar structure as Table 11, but the dependent variable changes into market share of each firm in year t. In column (1), lagged productivity and capital stock have positive and significant prediction power on the market share of a firm in the next year. When public infrastructure investment is added into the regressions as in column (2), it also contributes positively and significantly to the market share. What is the most relevant is again column (3), where we interact public infrastructure investment with a dummy variable for high productivity. Consistent with our expectation, this additional term is significantly positive, implying that the impact of public infrastructure investment on firm's market share depends on firm's productivity. This verifies the hypothesis that public infrastructure investment facilitates to reallocate the market share towards more productive firms.

The empirical evidences, both from the extensive and from the intensive margins therefore are consistent with our hypothesis on resource reallocation. This finding echoes the recent literature on how transport infrastructure affects the distribution of economic activities, such as Faber (2014), and also challenges one of the original intentions of public infrastructure investment in reducing regional disparity.

7 Robustness Checks

This section presents three sets of robustness checks in turn. The corresponding output elasticities and rates of return are summarised in Table 13, while Tables 5 to 8 serve as our benchmark results. First, we change our definition for G_{jt} from core infrastructure into broad infrastructure by adding the investment expenditure on management of water conservancy, environment, and public facilities to the core infrastructure.

Considering that this category of infrastructure mainly aims on enhancing residents welfare from improved amenities, one may expect a lower rate of return of the broad infrastructure investment than of the core infrastructure investment. This is indeed the finding when we compare the returns from Table 13.a with those in Tables 5 and 6. The average rate of return now decreases from 9.2% to 7.8% in the TFPR model, and from 2.5% to 0.9% in the TFPQ model, although both sets of the returns are positive and show a hump-shape over the sample period. Thus our estimates are consistent with the expectation and have a robust time pattern.

In the second robustness check, we experiment with third-order polynomials to proxy the functions $\phi_t(\cdot)$, $\phi_t^q(\cdot)$, $h_t(\cdot)$ and $h_t^q(\cdot)$, with results presented in Table 13.b. Now the average rates of return are 6.5% and 3% from the TFPR and TFPQ models, respectively. These are quite close to the benchmark results, where we employ a fourth-order polynomial for all the nonparametric regressions. When we further increase the order of polynomials, there is virtually no further change in our empirical findings.

The final robustness check is on the specification of the spillover effects. In the benchmark case, we assume that the positive externality of public investment can spill over across the whole nation. In this robustness check, we consider a more conservative assumption that the public investment of a province only affects the productivity and demand of firms locating within this province and its neighboring provinces. That is, we now add infrastructure investment of the neighboring provinces into G_{jt}, and industrial output of the neighboring provinces into Q_{sjt}, another common practice in the literature studying the regional effect of infrastructure investment. If public investment does have a positive spillover effect, and if such effect does go beyond the neighboring provinces, we should expect the returns from this robustness check to be larger than those in Tables 5 and 6 but smaller than those in Tables 7 and 8. This is consistent with the pattern one may observe from Table 13.c. Under this alternative specification of spillover effects, the average rate of return in the TFPR model is 18.6%, in between of 9.2% without spillover (in Table 5) and 28.3% with national spillover (in Table 7). Similarly, the average rate of return in the TFPQ model is 3.0%, in between of 2.5% without spillover (in Table 6) and 7.2% with national spillover (in Table 8).

8 Conclusion

This paper addresses three important, controversial and long-lasting research questions on public infrastructure investment. We deal with a set of identification challenges in the literature, by matching a panel of Chinese manufacturing firm-level data from 1998 to 2007 with the corresponding province-level infrastructure investment data and providing a novel structural estimation method on the productivity effect of infrastructure investment. The main findings are as follows. First, there are strong and robust evidences on the productivity effect of public infrastructure investment. The average rate of return of private investment lies in between the returns of public infrastructure investment with and without spillover effects. Second, more than two-thirds of the contribution of public infrastructure investment to output is via the short-run Keynesian demand effect, although the long-run quantity-based total factor of productivity also benefits from such investment. Third, firm-level evidences on firm characteristics and dynamics are consistent with the hypothesis that public infrastructure investment contributes to aggregate productivity by facilitating resource reallocation from less productive firms to more productive firms.

The answers to these research questions clearly have significant policy implications. There are, however, also some other questions that go beyond the limit of this paper. First, the overall efficiency of public infrastructure investment does not rule out the possibility that some type of infrastructure investment could be unproductive or inefficient in some industries and in some regions, even during our sample period. Second, beyond our sample period, we have to be very cautious on concluding whether China has over-invested or under-invested in infrastructure investment. On the one hand, the rates of return of infrastructure investment seem to peak during 2003 and 2004, a period when China just completed the reforms of state-owned firms and entered the WTO so that the catalyst role of infrastructure investment in resource reallocation is maximised. Further investment could be subject to the diminishing returns to capital. On the other hand, spatial spillover and network externalities do not rule out the possibility of economy of scale and increasing returns. Finally, what has been identified in this paper can be regarded as the benefits of public infrastructure investment. We briefly discuss the efficiency of such investment using the rates of return to private investment as a measure of its opportunity cost. A more complete evaluation requires studies on the schemes and designs of public finance, and on the institutions and incentives from a perspective of political economy.

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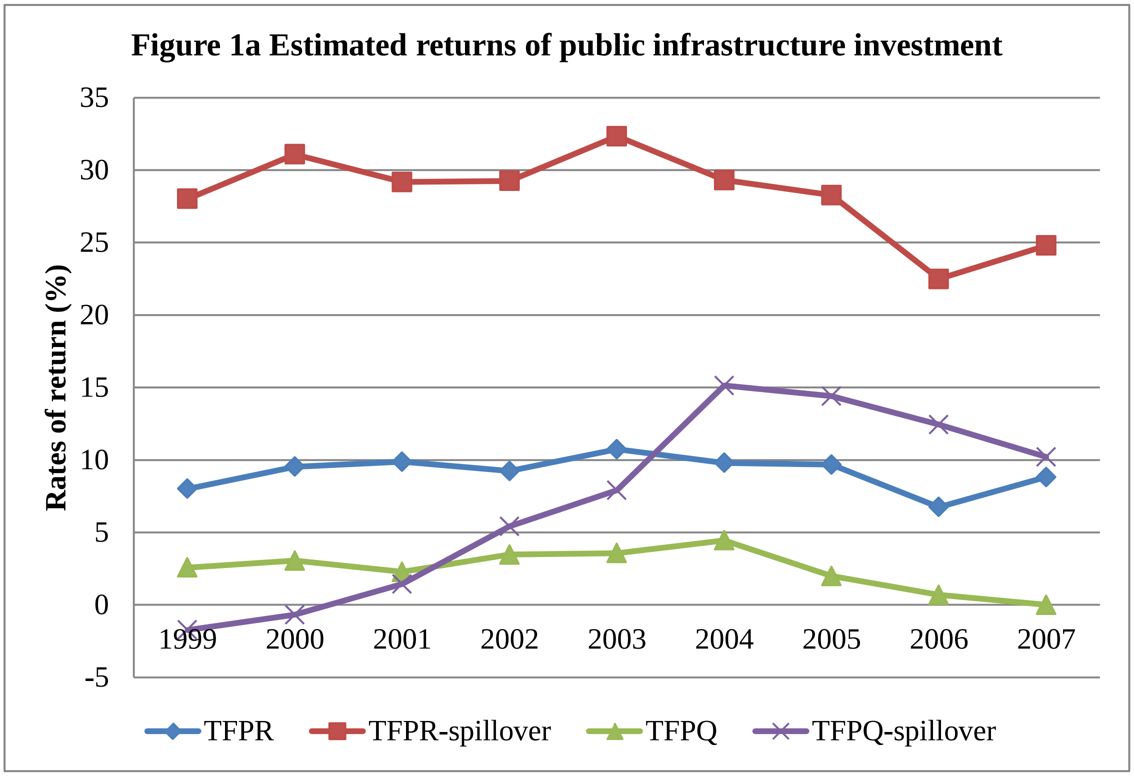
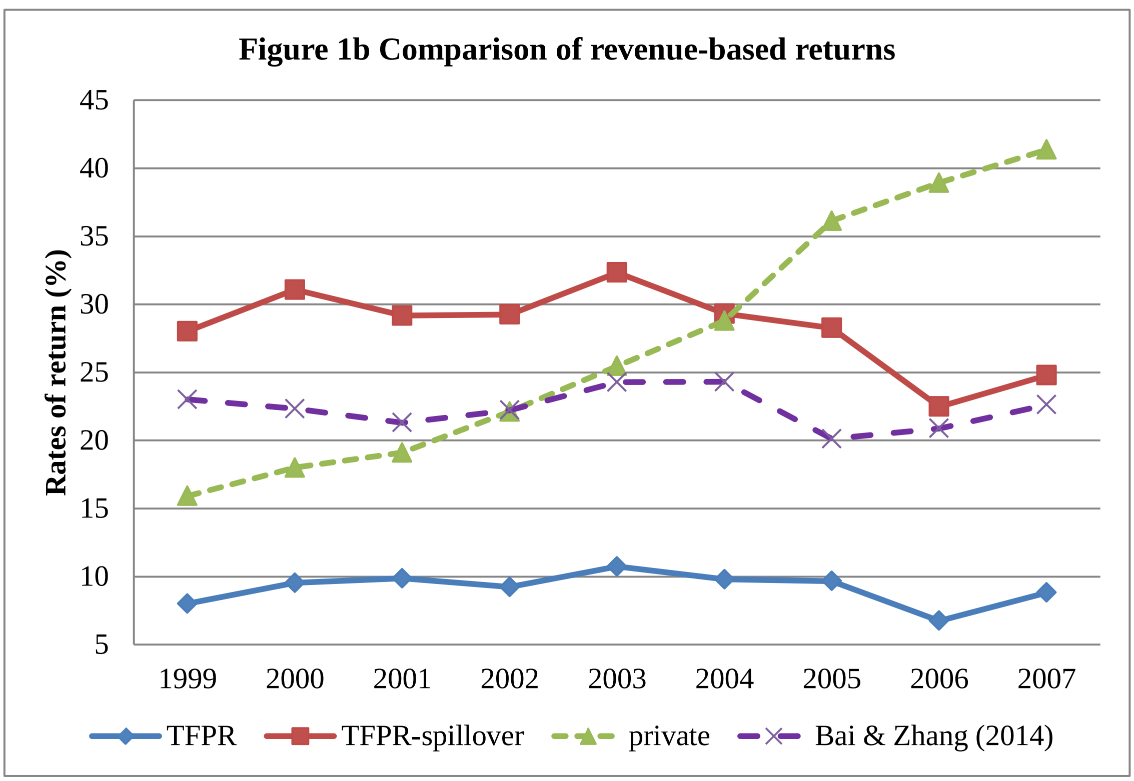


Note:

This figure reports the returns of public infrastructure investment over 1999-2007 in 4 models: TFPR, TFPR with spillover effects, TFPQ and TFPQ with spillover effects, respectively.



Note:

This figure compares the returns of public infrastructure investment in two models: TFPR, TFPR with spillover effects, with our estimated returns of private capital and the returns of physical investment from Bai and Zhang (2014).

Table 1 Firm-level data description

industry	definition	(1)	(2)	(3)	(4)
13	Food processing	13,029	6.9	11.2	126.72
14	Food manufacturing	5,246	6.7	10.6	106.94
15	Beverage manufacturing	3,590	8.2	11.1	102.26
16	Tobacco processing	264	6.4	9.0	121.75
17	Textile industry	17,562	7.0	12.0	109.13
18	Garments & other fiber products	9,725	5.6	9.9	103.03
19	Leather, furs, down & related products	4,861	6.7	9.8	109.42
20	Timber processing, bamboo, cane, palm fiber	4,453	11.0	15.3	108.26
21	Furniture manufacturing	2,365	7.2	11.1	104.87
22	Papermaking & paper products	6,124	7.4	10.7	105.03
23	Printing industry	4,361	4.5	7.1	93.40
24	Cultural, educational & sports goods	2,658	4.8	9.8	107.00
25	*Petroleum processing & coking*	*1,802*	*1.6*	*8.5*	*201.03*
26	Raw chemical materials & chemical products	14,970	7.5	12.1	122.16
27	Medical & pharmaceutical products	4,303	8.4	13.1	96.49
28	Chemical fiber	1,031	6.6	9.2	122.58
29	Rubber products	2,427	7.3	10.4	111.31
30	Plastic products	9,446	5.4	8.6	114.49
31	Nonmetal mineral products	17,594	10.3	13.2	106.08
32	Smelting & pressing of ferrous metals	4,948	8.8	15.3	133.74
33	*Smelting & pressing of nonferrous metals*	*3,643*	*1.8*	*6.1*	*196.66*
34	Metal products	11,018	6.1	10.8	114.41
35	Ordinary machinery	15,358	8.7	13.7	105.55
36	Special purpose equipment	8,606	7.2	12.4	106.39
37	Transport equipment	9,896	7.4	12.3	96.11
39	Electric equipment & machinery	12,025	4.7	9.9	117.62
40	Electronic & telecommunications equipment	6,766	7.5	11.9	83.49
41	Instruments, meters, cultural & office equipment	2,907	6.3	11.0	92.19
42	Other manufacturing	3,952	2.4	8.5	117.17
	average	7,067	6.6	10.8	115.01

Note:

(1): # of observations per year: (number of total firms for each industry during 1998-2007)/10

(2): labor productivity growth (%): median real growth rate of value-added/employees

(3): capital productivity growth (%): median real growth rate of value-added/capital stock

(4): output deflator of 2007 (1998 = 100): from Brandt et al. (2012)

Table 2 Data description on infrastructure investment

	average	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
core infrastructure investment											
volume (billion Yuan, 1998 price)	1184.1	729.4	778.0	845.9	884.6	891.9	1058.9	1284.6	1559.1	1847.6	1961.5
real growth rate (%)	11.9	NA	6.7	8.7	4.6	0.8	18.7	21.3	21.4	18.5	6.2
investment/industrial GDP (%)	21.2	21.5	21.1	20.9	20.1	18.5	19.4	21.1	23.0	24.2	22.3
investment/total GDP (%)	8.9	8.6	8.5	8.5	8.2	7.6	8.2	9.1	9.9	10.4	9.7
broad infrastructure investment											
volume (billion Yuan, 1998 price)	1619.5	929.1	1022.4	1120.5	1194.5	1272.8	1472.2	1734.5	2106.5	2545.0	2797.9
real growth rate (%)	13.2	NA	10.0	9.6	6.6	6.6	15.7	17.8	21.4	20.8	9.9
investment/industrial GDP (%)	28.8	27.4	27.8	27.7	27.2	26.3	27.0	28.6	31.1	33.3	31.8
investment/total GDP (%)	12.1	10.9	11.2	11.3	11.1	10.9	11.4	12.2	13.3	14.3	13.8

Note:

1. Data are from China Statistics Yearbooks and China Fixed Investment Statistical Yearbooks.
2. Infrastructure investment data are deflated by the price indices of investment in fixed assets by province.
3. Industrial GDP and total GDP data are deflated by the corresponding GDP deflators.
4. For the definitions of core and broad infrastructure investment, see Section 3.1.2.

Table 3 Productivity process: TFPR model

Depedent variable: $\omega_{i,t}$

	Estimate	Standard error
$\omega_{i,t-1}$	-0.809 ***	0.017
$\omega^2_{i,t-1}$	-0.022 ***	0.002
$\omega^3_{i,t-1}$	0.000 ***	0.001
$\omega^4_{i,t-1}$	0.000 ***	0.000
$g_{j,t-1}$	-0.027 ***	0.001
$\omega_{i,t-1} * g_{j,t-1}$	0.088 ***	0.001
$e_{it} = \partial\omega_{i,t} / \partial g_{j,t-1}$ at median $\omega_{i,t-1}$:		0.023
# of observations:		1,347,547
R-squared:		0.770

Note:

1. Industrial dummies are included.

2. *** p<0.01, ** p<0.05, * p<0.1

Table 4 Output elasticities by productivity percentile: TFPR model

industry	25th percentile	50th percentile	75th percentile
13	-0.003	-0.002	0.000
14	0.021	0.021	0.021
15	-0.001	0.004	0.008
16	0.033	0.035	0.039
17	-0.001	0.005	0.014
18	0.026	0.026	0.027
19	0.002	0.006	0.014
20	-0.011	0.004	0.020
21	-0.015	0.000	0.020
22	0.013	0.016	0.020
23	0.040	0.043	0.046
24	0.012	0.021	0.030
26	0.001	0.002	0.003
27	0.017	0.024	0.033
28	0.005	0.015	0.024
29	-0.023	0.005	0.015
30	-0.003	0.001	0.002
31	0.014	0.021	0.028
32	-0.006	-0.004	-0.002
34	-0.015	-0.008	-0.002
35	0.009	0.018	0.022
36	0.003	0.009	0.013
37	0.002	0.008	0.013
39	-0.027	-0.025	-0.024
40	0.020	0.020	0.020
41	-0.024	-0.008	0.017
42	-0.001	0.001	0.003
average	0.003	0.009	0.016

Note:

This table reports the output elasticities at the 25th, 50th and 75th percentiles of $\omega_{i,t-1}$.

Table 5 Output elasticities and average rates of return: TFPR model

industry	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
13	-0.002	0.000	0.000	-0.001	-0.001	-0.002	-0.003	-0.003	-0.004	-0.004
14	0.017	0.018	0.018	0.018	0.017	0.018	0.017	0.016	0.017	0.017
15	0.005	0.000	0.002	0.004	0.004	0.007	0.004	0.006	0.007	0.010
16	0.025	0.024	0.025	0.024	0.024	0.024	0.025	0.026	0.026	0.025
17	0.007	0.016	0.013	0.013	0.012	0.010	0.007	0.005	-0.020	0.005
18	0.022	0.023	0.023	0.022	0.022	0.022	0.022	0.021	0.021	0.021
19	0.009	0.014	0.016	0.013	0.013	0.012	0.007	0.004	0.002	0.002
20	0.014	0.035	0.030	0.020	0.022	0.022	0.014	0.005	-0.005	-0.011
21	0.009	0.022	0.023	0.019	0.018	0.016	0.010	0.002	-0.011	-0.017
22	0.016	0.011	0.012	0.013	0.013	0.014	0.015	0.018	0.021	0.022
23	0.036	0.034	0.034	0.035	0.035	0.035	0.036	0.037	0.038	0.039
24	0.019	0.026	0.027	0.024	0.025	0.024	0.020	0.012	0.008	0.006
26	0.001	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.000	0.000
27	0.026	0.020	0.019	0.022	0.022	0.024	0.025	0.032	0.034	0.038
28	0.014	0.011	0.023	0.018	0.017	0.005	0.022	0.024	0.012	-0.006
29	-0.004	-0.021	-0.020	-0.015	-0.014	-0.011	0.002	0.012	0.017	0.018
30	0.000	-0.003	-0.003	-0.002	-0.002	-0.002	0.000	0.002	0.002	0.003
31	0.016	0.011	0.010	0.012	0.012	0.012	0.015	0.020	0.023	0.026
32	-0.002	-0.006	-0.005	0.007	0.003	0.006	0.000	-0.011	-0.010	-0.004
34	-0.002	0.004	0.005	0.001	0.001	0.000	-0.004	-0.008	-0.008	-0.010
35	0.016	0.004	0.017	0.014	0.008	0.014	0.018	0.020	0.017	0.028
36	0.007	0.003	0.003	0.004	0.004	0.005	0.006	0.010	0.012	0.013
37	0.004	-0.001	0.000	0.001	0.001	0.002	0.004	0.008	0.010	0.012
39	-0.024	-0.027	-0.025	-0.027	-0.028	-0.027	-0.026	-0.011	-0.018	-0.028
40	0.018	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018
41	0.002	0.027	0.023	0.017	0.011	0.005	-0.003	-0.013	-0.024	-0.028
42	0.001	-0.002	-0.001	0.000	0.000	0.001	0.002	0.003	0.003	0.004
sector average elasticity	0.007	0.006	0.007	0.008	0.007	0.007	0.007	0.008	0.006	0.008
industrial GDP/G	5.298	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to industry (%)	3.8	3.2	3.9	4.0	3.8	4.5	4.2	4.2	2.9	3.8
return to economy (%)	9.2	8.0	9.5	9.9	9.2	10.7	9.8	9.7	6.7	8.8

Note:

1. The numbers in the upper panel are the industry weighted average elasticities and their 9-year averages.
2. Sector average elasticity denotes the weighted average elasticity of the manufacturing sector.
3. Return to industry is the product of sector average elasticity and industrial GDP/G.
4. Return to economy is the product of sector average elasticity and total GDP/G.

Table 6 Output elasticities and average rates of return: TFPQ model

industry	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
13	-0.045	-0.045	-0.045	-0.045	-0.045	-0.045	-0.044	-0.044	-0.044	-0.044
14	-0.010	-0.017	-0.017	-0.013	-0.010	-0.014	-0.009	-0.005	-0.004	-0.003
15	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.048	0.048
16	0.022	0.023	0.022	0.023	0.023	0.022	0.022	0.021	0.022	0.022
17	0.014	0.007	0.008	0.010	0.009	0.011	0.016	0.015	0.024	0.022
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001
19	0.022	0.024	0.025	0.024	0.023	0.022	0.022	0.019	0.019	0.018
20	-0.020	-0.006	-0.011	-0.023	-0.017	-0.015	-0.020	-0.021	-0.028	-0.033
21	0.000	0.006	0.005	0.004	0.004	0.004	0.000	-0.003	-0.009	-0.011
22	0.013	0.006	0.008	0.010	0.010	0.011	0.013	0.018	0.021	0.024
23	0.003	-0.003	-0.003	-0.001	-0.001	0.000	0.001	0.007	0.011	0.013
24	0.033	0.044	0.047	0.041	0.041	0.040	0.035	0.023	0.016	0.013
26	-0.012	-0.008	-0.009	-0.011	-0.011	-0.012	-0.014	-0.013	-0.012	-0.014
27	-0.009	-0.008	-0.008	-0.009	-0.008	-0.009	-0.009	-0.010	-0.010	-0.011
28	0.031	0.033	0.028	0.037	0.039	0.031	0.031	0.031	0.028	0.024
29	-0.011	-0.007	-0.008	-0.009	-0.009	-0.011	-0.013	-0.013	-0.014	-0.014
30	-0.005	0.004	0.003	0.002	0.001	0.001	-0.009	-0.013	-0.016	-0.018
31	0.015	0.016	0.017	0.016	0.016	0.017	0.015	0.013	0.012	0.011
32	0.020	0.018	0.020	0.021	0.020	0.021	0.021	0.017	0.018	0.023
34	-0.013	-0.010	-0.009	-0.012	-0.012	-0.012	-0.015	-0.016	-0.016	-0.016
35	-0.002	-0.008	-0.008	-0.004	-0.004	-0.003	0.000	0.002	0.004	0.006
36	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	0.000
37	-0.004	-0.006	-0.005	-0.004	-0.004	-0.006	-0.003	-0.003	-0.001	-0.001
39	-0.043	-0.042	-0.042	-0.044	-0.043	-0.043	-0.044	-0.044	-0.043	-0.042
40	0.023	0.027	0.029	0.022	0.032	0.030	0.031	0.024	0.010	0.002
41	0.000	-0.005	-0.004	-0.003	-0.002	0.000	0.002	0.003	0.005	0.006
42	0.003	-0.006	-0.007	-0.001	-0.003	0.000	0.007	0.009	0.013	0.018
sector average elasticity	0.002	0.002	0.002	0.002	0.003	0.002	0.003	0.002	0.001	0.000
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	2.5	2.6	3.1	2.3	3.5	3.6	4.5	2.0	0.7	0.0

Note: See Table 5.

Table 7 Output elasticities and average rates of return: TFPR with spillover

industry	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
13	-0.001	0.015	0.012	0.007	0.005	0.001	-0.010	-0.006	-0.015	-0.016
14	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.049	0.049	0.049
15	0.037	0.027	0.030	0.034	0.035	0.041	0.036	0.040	0.042	0.049
16	0.054	0.056	0.055	0.055	0.055	0.055	0.054	0.053	0.053	0.054
17	0.027	0.039	0.035	0.034	0.033	0.030	0.026	0.024	-0.006	0.023
18	0.052	0.058	0.059	0.055	0.054	0.056	0.053	0.045	0.042	0.042
19	0.026	0.037	0.040	0.034	0.033	0.031	0.023	0.015	0.012	0.011
20	0.042	0.079	0.070	0.051	0.055	0.055	0.041	0.025	0.007	-0.004
21	0.033	0.057	0.057	0.049	0.048	0.045	0.033	0.019	-0.002	-0.013
22	0.044	0.039	0.040	0.041	0.041	0.043	0.044	0.047	0.051	0.052
23	0.069	0.063	0.062	0.066	0.063	0.065	0.070	0.073	0.076	0.079
24	0.052	0.067	0.069	0.063	0.064	0.062	0.054	0.038	0.027	0.024
26	0.014	0.017	0.017	0.016	0.015	0.015	0.013	0.013	0.012	0.011
27	0.014	0.010	0.009	0.010	0.010	0.011	0.013	0.020	0.022	0.025
28	0.042	0.041	0.055	0.047	0.046	0.030	0.052	0.054	0.037	0.013
29	-0.032	-0.067	-0.066	-0.054	-0.053	-0.049	-0.023	0.002	0.011	0.014
30	0.008	0.011	0.011	0.010	0.010	0.010	0.007	0.006	0.005	0.004
31	0.042	0.039	0.039	0.040	0.040	0.040	0.041	0.044	0.045	0.047
32	0.002	-0.001	0.000	0.007	0.005	0.006	0.002	-0.004	-0.003	0.000
34	-0.002	0.005	0.006	0.002	0.001	0.000	-0.004	-0.008	-0.009	-0.010
35	0.046	0.017	0.047	0.040	0.028	0.041	0.053	0.056	0.051	0.077
36	0.015	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.015
37	0.022	0.010	0.013	0.014	0.015	0.018	0.021	0.031	0.036	0.040
39	-0.038	-0.041	-0.038	-0.040	-0.043	-0.041	-0.040	-0.022	-0.030	-0.043
40	0.043	0.050	0.049	0.047	0.047	0.044	0.041	0.038	0.034	0.032
41	0.033	0.027	0.027	0.029	0.030	0.033	0.035	0.037	0.040	0.041
42	0.007	0.002	0.003	0.005	0.005	0.006	0.008	0.009	0.010	0.011
sector average elasticity	0.022	0.022	0.024	0.023	0.022	0.022	0.022	0.023	0.020	0.023
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	28.3	28.0	31.1	29.2	29.3	32.3	29.3	28.3	22.5	24.8

Note: See Table 5.

Table 8 Output elasticities and average rates of return: TFPQ with spillover

industry	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
13	-0.102	-0.102	-0.102	-0.103	-0.103	-0.103	-0.104	-0.102	-0.102	-0.102
14	-0.019	-0.018	-0.020	-0.017	-0.014	-0.022	-0.020	-0.020	-0.022	-0.022
15	0.001	-0.002	-0.002	-0.002	-0.002	0.002	-0.002	0.004	0.008	0.007
16	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.005
17	0.035	0.031	0.032	0.033	0.033	0.035	0.036	0.037	0.039	0.041
18	0.049	0.045	0.043	0.046	0.046	0.046	0.048	0.053	0.057	0.060
19	0.063	0.069	0.070	0.068	0.065	0.063	0.061	0.058	0.057	0.055
20	-0.024	-0.002	-0.009	-0.032	-0.021	-0.019	-0.026	-0.027	-0.037	-0.046
21	-0.013	-0.014	-0.014	-0.013	-0.011	-0.011	-0.011	-0.009	-0.016	-0.016
22	0.016	0.017	0.017	0.018	0.018	0.017	0.017	0.014	0.013	0.011
23	-0.006	0.005	-0.001	-0.002	-0.011	-0.014	-0.017	-0.009	-0.003	-0.002
24	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.091
26	-0.019	-0.017	-0.017	-0.018	-0.018	-0.019	-0.020	-0.020	-0.019	-0.020
27	-0.044	-0.045	-0.045	-0.044	-0.044	-0.044	-0.043	-0.044	-0.043	-0.043
28	0.049	0.055	0.040	0.060	0.065	0.046	0.044	0.049	0.044	0.034
29	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032
30	-0.013	-0.010	-0.009	-0.009	-0.009	-0.009	-0.016	-0.017	-0.018	-0.018
31	0.029	0.024	0.020	0.024	0.020	0.018	0.025	0.038	0.044	0.049
32	0.053	0.052	0.053	0.053	0.053	0.054	0.054	0.051	0.053	0.056
34	-0.016	-0.014	-0.012	-0.015	-0.014	-0.015	-0.017	-0.018	-0.018	-0.018
35	-0.005	-0.007	-0.012	-0.004	-0.009	-0.008	-0.004	-0.001	0.001	0.002
36	-0.005	-0.004	-0.005	-0.005	-0.005	-0.006	-0.005	-0.003	-0.003	-0.003
37	-0.010	-0.006	-0.009	-0.008	-0.008	-0.011	-0.010	-0.013	-0.012	-0.014
39	-0.080	-0.080	-0.080	-0.081	-0.081	-0.081	-0.082	-0.081	-0.080	-0.077
40	0.076	0.019	0.041	0.047	0.078	0.088	0.117	0.112	0.094	0.090
41	0.021	0.013	0.014	0.015	0.016	0.019	0.024	0.026	0.030	0.030
42	0.026	0.012	0.008	0.017	0.016	0.022	0.031	0.036	0.042	0.049
sector average elasticity	0.006	-0.001	-0.001	0.001	0.004	0.005	0.011	0.012	0.011	0.009
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	7.2	-1.7	-0.7	1.4	5.4	7.9	15.1	14.4	12.4	10.2

Note: See Table 5.

Table 9 Rates of return of private investment (%)

industry	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
13	22.8	14.6	15.6	17.8	20.9	24.5	25.2	28.3	28.9	29.3
14	20.2	12.2	13.5	14.6	16.8	19.6	21.3	25.4	27.4	30.8
15	16.4	10.4	10.9	11.1	13.0	14.4	16.5	19.9	24.4	26.8
16	52.5	43.1	43.5	45.4	50.0	50.3	53.3	57.7	61.7	67.9
17	5.3	3.3	3.7	4.0	4.6	5.0	5.3	7.0	7.2	7.9
18	15.6	11.3	12.1	12.7	14.1	15.3	15.2	18.4	20.0	21.1
19	11.9	8.2	8.8	9.6	11.2	12.3	12.4	14.0	14.6	16.1
20	11.5	7.9	8.3	8.8	10.4	10.4	10.7	14.4	15.5	17.0
21	15.6	10.3	10.7	11.3	13.8	15.9	16.2	18.8	20.5	23.0
22	24.0	15.6	17.2	17.9	20.2	22.8	23.9	29.0	31.8	37.7
23	28.2	19.6	19.9	20.4	24.0	26.4	26.6	33.8	38.1	45.0
24	38.4	31.4	33.7	32.6	34.6	38.0	36.8	45.2	44.2	48.8
26	12.5	8.0	8.5	9.3	10.8	12.7	12.8	15.5	16.8	18.3
27	48.0	36.5	40.4	41.7	43.6	45.6	45.4	54.8	57.0	66.7
28	4.9	2.6	3.0	3.4	4.0	5.1	4.6	6.7	7.2	7.8
29	15.1	11.0	11.3	11.6	12.7	14.0	15.4	18.4	19.4	22.3
30	26.1	18.5	19.4	20.8	23.3	26.7	25.2	30.4	33.5	37.3
31	33.3	20.1	21.9	22.9	27.1	30.8	32.4	41.8	47.4	55.7
32	4.9	2.6	3.0	3.4	4.3	5.3	5.5	6.0	7.0	7.2
34	5.8	3.7	4.3	4.2	5.2	5.9	6.5	7.2	7.5	8.1
35	19.9	10.6	11.5	12.6	15.4	19.2	21.5	26.9	29.8	31.4
36	26.2	14.2	15.6	16.0	20.9	25.1	28.0	35.0	37.8	43.1
37	19.4	11.2	11.1	12.4	16.5	20.3	22.7	23.1	27.1	30.3
39	20.6	12.9	14.5	15.0	17.2	20.6	23.1	26.1	27.3	28.9
40	90.1	51.4	60.6	63.5	70.2	84.0	92.5	124.5	129.7	134.7
41	21.0	13.2	14.0	16.1	17.1	18.8	23.3	28.6	28.4	29.8
42	32.4	27.6	28.4	29.1	30.7	33.6	34.3	35.2	35.7	36.5
sector average return	27.3	15.9	18.0	19.1	22.1	25.5	28.8	36.1	38.9	41.4

Note:

1. The numbers in the matrix are the industry weighted average returns of private capital and their 9-year averages.
2. Sector average return denotes the weighted average of returns of private capital for the whole manufacturing sector.

Table 10 Linking output elasticity with firm characteristics

Dependant variable: output elasticity*1000

model	TFPR	TFPQ	TFPR-spillover	TFPQ-spillover
age	-0.002***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.001)
lnemp	-0.090***	-0.190***	-0.202***	-0.221***
	(0.019)	(0.014)	(0.041)	(0.032)
NSOE	1.223***	1.657***	0.605***	0.665***
	(0.078)	(0.057)	(0.160)	(0.128)
EXPORT	0.725***	0.476***	0.668***	1.572***
	(0.027)	(0.027)	(0.049)	(0.059)
EASTERN	0.480***	1.968***	0.163***	0.876***
	(0.029)	(0.028)	(0.063)	(0.060)
observations	1,346,897	1,346,897	1,346,897	1,346,897
R-squared	0.49	0.774	0.48	0.774

Note:

1. age: firm's age
2. lnemp: log of number of employees
3. NSOE: non-SOE dummy, non-SOEs = 1, SOEs = 0
4. EXPORT: exporter dummy, exporters = 1, nonexporters = 0
5. EASTERN: location dummy, eastern provinces = 1, noneastern provinces = 0
6. Industry dummies and year dummies are included in all regressions.
7. Robust standard errors are reported in parentheses.
8. *** p<0.01, ** p<0.05, * p<0.1

Table 11 Probit regressions of exit probability

Dependent variable: firm *i* 's exit in year *t* +1

model	TFPR			TFPR-spillover		
	(1)	(2)	(3)	(1)	(2)	(3)
Productivity	-0.142***	-0.140***	-0.0958***	-0.143***	-0.140***	-0.091***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)
Capital	-0.137***	-0.136***	-0.138***	-0.136***	-0.136***	-0.137***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Infrastructure		-0.088***	-0.091***		-0.172***	-0.178***
		(0.003)	(0.003)		(0.006)	(0.006)
Infrastructure*Low			0.005***			0.005***
			(0.000)			(0.000)
# of obs.	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116
predicted prob	0.112	0.112	0.111	0.112	0.112	0.111

model	TFPQ			TFPQ-spillover		
	(1)	(2)	(3)	(1)	(2)	(3)
Productivity	-0.148***	-0.159***	-0.112***	-0.141***	-0.151***	-0.104***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)
Capital	-0.136***	-0.135***	-0.136***	-0.136***	-0.135***	-0.135***
	(0.001)	(0.001)	-(0.001)	(0.001)	(0.001)	(0.001)
Infrastructure		-0.106***	-0.120***		-0.205***	-0.233***
		(0.003)	(0.003)		(0.006)	(0.006)
Infrastructure*Low			0.005***			0.005***
			(0.000)			(0.000)
# of obs.	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116
predicted prob	0.112	0.111	0.111	0.112	0.111	0.111

Note:

1. Industry dummies and year dummies are included in all regressions.
2. LOW: dummy variable, LOW_{it} = 1 (0) if productivity is below (beyond) median.
3. *** p<0.01, ** p<0.05, * p<0.1

Table 12 Regressions of market share

Dependent variable: firm *i* 's market share in year *t*

model	TFPR			TFPR-spillover		
	(1)	(2)	(3)	(1)	(2)	(3)
Productivity	0.532***	0.534***	0.380***	0.517***	0.520***	0.363***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)
Capital	0.566***	0.566***	0.572***	0.564***	0.565***	0.569***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Infrastructure		0.312***	0.311***		0.604***	0.621***
		(0.002)	(0.002)		(0.003)	(0.003)
Infrastructure*High			0.0260***			0.027***
			(0.000)			(0.000)
# of obs.	1,346,842	1,346,842	1,346,842	1,346,842	1,346,842	1,346,842
R-squared	0.554	0.565	0.586	0.552	0.564	0.588

model	TFPQ			TFPQ-spillover		
	(1)	(2)	(3)	(1)	(2)	(3)
Productivity	0.461***	0.529***	0.362***	0.430***	0.497***	0.332***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Capital	0.562***	0.563***	0.562***	0.561***	0.562***	0.559***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Infrastructure		0.378***	0.439***		0.721***	0.863***
		(0.002)	(0.002)		(0.004)	(0.004)
Infrastructure*High			0.0268***			0.027***
			(0.000)			(0.000)
# of obs.	1,346,842	1,346,842	1,346,842	1,346,842	1,346,842	1,346,842
R-squared	0.551	0.567	0.589	0.550	0.566	0.590

Note:

1. Industry dummies and year dummies are included in all regressions.
2. HIGH: dummy variable, $HIGH_{it-1}$ = 1 (0) if productivity is below (beyond) median.
3. Lagged values of explanatory variables are used in regressions.
4. *** p<0.01, ** p<0.05, * p<0.1

Table 13 Robustness checks

Panel a) Broad infrastructure investment

	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
					TFPR model					
sector average elasticity	0.008	0.007	0.008	0.009	0.008	0.008	0.008	0.009	0.008	0.009
total GDP/BG	9.351	9.832	9.689	9.574	9.798	10.116	9.627	9.098	8.442	7.980
return to economy (%)	7.8	7.1	8.2	8.3	7.7	8.5	8.1	8.4	6.4	7.5
					TFPQ model					
sector average elasticity	0.001	0.000	0.000	0.000	0.001	0.001	0.003	0.002	0.001	0.000
total GDP/BG	9.351	9.832	9.689	9.574	9.798	10.116	9.627	9.098	8.442	7.980
return to economy (%)	0.9	-0.2	0.3	0.1	1.2	1.4	2.7	1.5	0.7	0.1

Panel b) Third-order polynomials

	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
					TFPR model					
sector average elasticity	0.005	0.004	0.004	0.005	0.005	0.004	0.005	0.006	0.007	0.007
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	6.5	5.1	5.7	5.8	6.2	6.4	7.0	8.0	7.5	7.1
					TFPQ model					
sector average elasticity	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.001
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	3.0	2.2	2.9	2.6	3.9	4.4	4.5	3.7	2.0	0.9

Panel c) Spillover effects from neighbouring provinces

	9-year average	1999	2000	2001	2002	2003	2004	2005	2006	2007
					TFPR model					
sector average elasticity	0.015	0.015	0.017	0.015	0.014	0.014	0.014	0.015	0.012	0.016
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	18.6	19.2	21.3	18.6	19.1	20.7	18.9	18.2	13.8	17.6
					TFPQ model					
sector average elasticity	0.002	-0.004	-0.002	-0.001	0.001	0.002	0.006	0.006	0.006	0.007
total GDP/G	12.630	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992
return to economy (%)	3.0	-4.5	-2.8	-1.6	1.6	3.4	8.2	7.1	7.3	8.0

Note:

1. Sector average elasticity denotes the weighted average elasticity of the manufacturing sector.

2. Return to economy is the product of sector average elasticity and GDP/BG in panel a) (and GDP/G in panels b) and c)).

Appendix (not for publication)

A. Poll on Public Infrastructure Investment

The Initiative on Global Markets Forum of the Booth Business School at the University of Chicago conducted a poll on public infrastructure investment in 2014. Forty-four prominent economists from top U.S. universities have been asked to comment on the following two questions. Question A says: "Because the U.S. has underspent on new projects, maintenance, or both, the federal government has an opportunity to increase average incomes by spending more on roads, railways, bridges and airports." More than 80% of the respondents agreed or strongly agreed with this statement, while some replied uncertain. For example, Abhijit Banerjee asked: "Uncertain. Investment will probably raise incomes for Keynesian reasons but will it promote growth?"

Question B states: "Past experience of public spending and political economy suggests that if the government spent more on roads, railways, bridges and airports, many of the projects would have low or negative returns." The opinion to this question was much more diverse, ranging from strongly agree to strongly disagree. A large proportion of the replies concentrated on "uncertain" or "agree". For example, Daron Acemoglu commented: "Uncertain. Past evidence suggests that there will be waste and corruption. But this does not imply that average net present value is negative." And Abhijit Banerjee commented: "Agree. Many does not have to mean most, and on average returns may be quite positive. We just don't know enough right now."

B. Additional Estimation Results

Table A1 presents the estimates of the coefficients for the sales revenue equation (2). The estimation procedure follows what is described in Section 2.3 and is applied on a 2-digit industry level for the 27 industries listed in Table 1. In the first stage regressions, year dummies are added to control for common aggregate shocks. A fourth-order polynomial function with interaction terms is employed to approximate the nonlinear function $\phi_t(\cdot)$. In the second stage regression, the productivity process $h_t(\cdot)$ is also approximated by a fourth-order polynomial function with interaction terms.

Notice that without netting out the demand effect, these estimates are comparable with the large literature that apply the proxy approach to control for the simultaneity bias in estimating a production function. Compared with for example, Pavcnik (2002), Table A1 shows a larger coefficient on intermediate inputs and a smaller coefficient for labor and capital for most industries. However, such pattern is consistent with the findings in Yu (2015), who uses a subset of the firms from the same dataset as ours.

Dai et al. (2016) emphasize the importance of export processing in explaining the low value-added in China's manufacturing sector.

There are a few industries in Panel B that witness negative though not significant coefficients. One possible explanation is that some of the state-owned firms were not profit-maximizers in the early period of our sample. Since the reform for the state-owned firms largely completely in 2002, we re-estimate the model using a subsample from 2003 to 2007 only. The results are reported in Table A2, where all the coefficients are positive and significant.

The coefficients in Table A2 are reduced-form parameters of the production function and the demand system. These estimates thus control for both the simultaneity bias and the omitted price variable bias. The estimates on β_s^* and β_g^* are of particular interest, which back out the structural parameters σ_s – the elasticity of substitution and τ – the elasticity of the firm-specific demand shifter with respect to province infrastructure investment. β_g^* is a direct indicator on how infrastructure investment affects the firm-specific demand. 22 out of 27 industries show a positive coefficient, which highlights the importance to control for the demand effect of infrastructure investment on the measured productivity.

Notice that by definition β_s^* should all be positive but there are 7 out of 27 industries with negative estimates for β_s^*. This might imply a model misspecification in using the CES functional form to describe the demand structure of these industries, or a poor measure for the aggregate demand shifter Q_{sjt}. For a manufacturing industry s open to international trade, a proper measure for Q_{sjt} should be the sum of output produced and sold in province j and imports from the rest of the world to province j. However, much of the output produced in province j may not be sold in this province but exported to the rest of world. We don't have imports information with province destination but we are able to identify exporters in our dataset. Table A4 presents the estimates for the same model but only using a subsample with non-exporters, which successfully reduces the number of industries with negative β_s^* as expected.

Table A5 estimates the quantity-based productivity process (13). Table A6 reports the output elasticities (21) at the 25^{th}, 50^{th} and 75^{th} percentiles of the attained productivity. These two tables are the counterparts of Table 3 and Table 4 for the revenue-based productivity process. Despite the quantitative differences, a model controlling for the demand effect also displays a non-linear productivity process and produces heterogenous output elasticities across firms with different productivity level.

Detailed estimation results for the production function, productivity process, and output elasticities by percentile and by industry with spillover effects and under various robustness checks are not presented for saving the space but are available upon request.

Table A1 Estimates for the sales revenue equation (2)

industry	β_l	$s.e.(\beta_l)$	β_k	$s.e.(\beta_k)$	β_m	$s.e.(\beta_m)$
13	0.042	0.006	0.035	0.003	0.912	0.005
14	0.023	0.019	0.052	0.006	0.922	0.011
15	-0.054	0.099	0.057	0.040	0.988	0.123
16	0.458	1.219	0.193	0.118	0.692	0.576
17	0.012	0.059	0.014	0.015	0.971	0.088
18	0.213	0.091	-0.002	0.008	0.813	0.083
19	0.064	0.033	0.014	0.014	0.934	0.050
20	0.132	0.026	-0.032	0.019	0.989	0.034
21	0.066	0.045	0.025	0.036	0.918	0.049
22	0.062	0.013	0.071	0.015	0.842	0.026
23	0.295	0.082	0.123	0.039	0.652	0.083
24	0.065	0.042	0.058	0.021	0.859	0.066
26	0.018	0.013	0.032	0.003	0.937	0.011
27	0.077	0.038	0.152	0.051	0.747	0.073
28	0.014	0.012	0.020	0.008	0.949	0.013
29	0.052	0.073	0.043	0.037	0.896	0.090
30	0.060	0.010	0.063	0.015	0.857	0.018
31	0.082	0.004	0.117	0.013	0.843	0.005
32	0.048	0.012	0.014	0.008	0.948	0.012
34	0.103	0.034	0.010	0.026	0.935	0.044
35	0.000	0.007	0.043	0.005	0.934	0.010
36	0.062	0.022	0.061	0.025	0.864	0.036
37	0.171	0.045	-0.011	0.040	0.893	0.030
39	0.049	0.007	0.032	0.003	0.913	0.006
40	0.094	0.015	0.117	0.019	0.809	0.025
41	0.086	0.039	0.031	0.031	0.895	0.059
42	0.084	0.039	0.039	0.004	0.864	0.039

Note: All standard errors are bootstrapped using 1000 replications.

Table A2 Re-estimating Table A1 using 2003-2007 subsample

industry	β_l	β_k	β_m
13	0.038	0.022	0.928
14	0.035	0.027	0.936
15	0.062	0.025	0.931
16	0.154	0.145	0.836
17	0.036	0.005	0.965
18	0.093	0.021	0.887
19	0.062	0.026	0.919
20	0.050	0.020	0.916
21	0.049	0.025	0.915
22	0.030	0.017	0.953
23	0.068	0.064	0.872
24	0.089	0.039	0.871
26	0.015	0.030	0.947
27	0.042	0.026	0.950
28	0.022	0.020	0.947
29	0.051	0.028	0.920
30	0.059	0.022	0.934
31	0.038	0.018	0.937
32	0.035	0.012	0.958
34	0.274	0.063	0.694
35	0.025	0.027	0.950
36	0.029	0.035	0.928
37	0.047	0.043	0.899
39	0.048	0.022	0.931
40	0.092	0.031	0.892
41	0.061	0.040	0.879
42	0.089	0.022	0.903

Table A3 Estimates for the sales revenue equation (20)

industry	β_l*	*s.e.* (β_l*)	β_k*	*s.e.* (β_k*)	β_m*	*s.e.* (β_m*)	β_s*	*s.e.* (β_s*)	β_g*	*s.e.* (β_g*)
13	0.046	0.005	0.032	0.003	0.911	0.005	0.027	0.002	0.129	0.019
14	0.087	0.031	0.046	0.019	0.874	0.029	0.072	0.011	0.043	0.009
15	0.277	0.050	-0.037	0.035	0.799	0.041	-0.837	0.031	0.170	0.017
16	0.690	0.492	0.233	0.230	0.535	0.255	-0.128	0.054	0.108	0.105
17	0.017	0.006	0.013	0.003	0.960	0.008	-0.006	0.002	0.008	0.009
18	0.066	0.083	0.008	0.012	0.943	0.074	0.001	0.006	0.070	0.009
19	0.186	0.035	0.023	0.012	0.799	0.032	-0.075	0.014	0.062	0.021
20	-0.091	0.045	0.131	0.032	0.786	0.043	0.125	0.015	0.243	0.026
21	-0.009	0.054	0.118	0.056	0.785	0.075	0.095	0.023	0.112	0.048
22	0.059	0.023	0.092	0.022	0.791	0.027	0.060	0.019	0.069	0.020
23	0.270	0.052	0.061	0.063	0.748	0.049	0.105	0.022	0.073	0.023
24	0.118	0.077	0.034	0.016	0.861	0.091	-0.038	0.017	0.018	0.021
26	0.020	0.029	0.031	0.005	0.935	0.023	0.014	0.010	0.017	0.011
27	0.144	0.039	0.093	0.066	0.784	0.027	0.173	0.020	0.089	0.042
28	0.021	0.010	0.027	0.006	0.937	0.010	-0.012	0.006	-0.010	0.021
29	0.172	0.083	0.132	0.082	0.622	0.088	0.153	0.026	0.037	0.038
30	0.050	0.018	0.063	0.073	0.860	0.034	0.046	0.029	0.095	0.062
31	0.112	0.049	0.052	0.116	0.846	0.026	0.153	0.044	0.081	0.014
32	0.045	0.005	0.021	0.003	0.936	0.005	0.015	0.002	-0.041	0.020
34	0.019	0.072	0.031	0.013	0.943	0.054	0.023	0.011	0.023	0.014
35	0.217	0.038	0.036	0.028	0.772	0.034	0.066	0.011	-0.008	0.006
36	-0.110	0.055	0.062	0.045	1.005	0.046	0.017	0.018	0.026	0.015
37	0.052	0.025	0.058	0.040	0.876	0.025	0.097	0.013	0.028	0.021
39	0.078	0.069	0.028	0.011	0.893	0.064	0.045	0.006	-0.022	0.013
40	0.138	0.040	0.006	0.045	0.877	0.019	0.127	0.025	0.037	0.073
41	0.106	0.049	0.102	0.055	0.718	0.060	0.099	0.014	-0.022	0.024
42	0.196	0.057	0.028	0.007	0.778	0.049	-0.001	0.006	0.043	0.017

Note: All standard errors are bootstrapped using 1000 replications.

Table A4 Re-estimating Table A3 using non-exporters subsample

industry	β_l*	β_k*	β_m*	β_s*	β_g*
13	0.047	0.032	0.910	0.021	0.142
14	0.000	0.051	0.928	0.061	0.055
15	0.017	0.047	0.944	0.001	0.139
16	-0.306	0.265	0.987	-0.058	0.229
17	-0.011	0.014	0.983	0.012	-0.004
18	0.107	0.002	0.891	0.047	0.021
19	0.081	0.016	0.914	0.030	0.045
20	-0.100	0.171	0.685	0.194	0.220
21	0.000	0.087	0.821	0.061	0.116
22	0.078	0.083	0.788	0.066	0.064
23	0.271	0.073	0.733	0.127	0.080
24	0.023	0.050	0.912	0.001	0.005
26	0.019	0.029	0.929	0.021	0.019
27	0.184	0.043	0.832	0.173	0.114
28	0.006	0.024	0.946	-0.004	-0.014
29	0.002	0.014	0.984	0.017	0.085
30	0.061	0.054	0.867	0.027	0.089
31	0.134	0.036	0.851	0.211	0.102
32	0.045	0.018	0.933	0.004	-0.029
34	0.007	0.033	0.936	0.038	0.029
35	0.268	0.051	0.660	0.149	-0.023
36	0.160	0.040	0.768	0.155	0.016
37	0.085	0.055	0.844	0.115	0.032
39	0.044	0.027	0.908	0.037	-0.009
40	0.210	-0.008	0.939	-0.198	-0.008
41	0.042	0.094	0.728	0.144	0.027
42	0.042	0.049	0.887	0.008	0.096

Table A5 Productivity process: TFPQ model

Depedent Variable: $\omega^{q}_{i,t}$

	Estimate	Standard error
$\omega^{q}_{i,t-1}$	0.332 ***	0.017
$\omega^{q\,2}_{i,t-1}$	-0.016 ***	0.002
$\omega^{q\,3}_{i,t-1}$	-0.001 ***	0.001
$\omega^{q\,4}_{i,t-1}$	0.000 ***	0.000
$g_{j,t-1}$	0.020 ***	0.001
$\omega^{q}_{i,t-1} * g_{j,t-1}$	0.021 ***	0.001
$e^{q}_{it} = \partial\omega^{q}_{i,t} / \partial g_{j,t-1}$ at median $\omega^{q}_{i,t-1}$:		0.009
# of observations:		1,347,547
R-squared:		0.991

Note:

1. Industrial dummies are included.

2. *** p<0.01, ** p<0.05, * p<0.1

Table A6 Output elasticities by productivity percentile: TFPQ model

industry	25th percentile	50th percentile	75th percentile
13	-0.058	-0.058	-0.057
14	-0.027	-0.017	-0.006
15	0.056	0.057	0.058
16	0.030	0.032	0.034
17	0.011	0.017	0.021
18	-0.001	-0.001	0.000
19	0.023	0.026	0.029
20	-0.030	-0.016	-0.003
21	-0.004	0.007	0.016
22	0.002	0.008	0.016
23	-0.009	0.002	0.013
24	0.020	0.035	0.049
26	-0.014	-0.012	-0.010
27	-0.012	-0.010	-0.007
28	0.032	0.036	0.041
29	-0.011	-0.004	0.001
30	-0.016	-0.006	0.003
31	0.013	0.017	0.020
32	0.015	0.018	0.020
34	-0.020	-0.015	-0.011
35	-0.009	-0.004	0.002
36	-0.003	-0.002	0.000
37	-0.013	-0.009	-0.004
39	-0.049	-0.047	-0.045
40	0.009	0.032	0.053
41	-0.013	-0.008	-0.002
42	-0.013	-0.003	0.009
average	-0.003	0.003	0.009