Estimating Productivity of Public Infrastructure Investment*

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Abstract

This paper develops a model of endogenous productivity to examine the impact of public infrastructure investment on output. It matches firm-level production data with province-level infrastructure data to address a set of well-known identification issues in the literature, and employs a structural estimation to distinguish the long-run productivity effect from the short-run Keynesian demand effect of public infrastructure investment. The estimated rates of return of infrastructure are 9.2% and 2.5%, respectively, for revenue-based and quantity-based total factor productivity. The returns almost triple once maximal 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 productive firms to more productive firms.

JEL Classification: O47, H54, D24, C23, F15

Key Words: Public Infrastructure Investment, Productivity, Rate of Return, Resource Reallocation

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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 researches 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 the 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. Dozens of countries have been urged to cut their government spending by the IMF every year.

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 US 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 diversed, ranging from strongly agree to strongly disagree. A large

[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 flatterning in 2013. The Asian Infrastructure Investment Bank established in 2014 states its mission as to contribute to Asian infrastructure development and regional connectivity.

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 NPV 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.”

This paper aims to know more. First, what is the average rate of return of public infrastructure investment? Answer to this question is clearly at the central of the current policy debates. Advocators of public investment, such as Lawrence H. Summers claims that if the investment earns a 6% real return, it really is a free lunch since such investment actually makes it possible to reduce debt burdens of future generations. [3] 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? As pointed out by Michael Spence, productivity gains are vital 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.[4] Third, 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.

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. 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. Using an aggregate production function including public capital as an additional input, the average rate of return can be inferred by estimating the average relationship between public capital and GDP. For example, in his 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 intensively questioned and 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 elas-

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

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

ticity with respect to public capital varies widely, from -1.7 for New Zealand in one research to 2.04 for Australia in another research. In between these extremes, a non-negligible share of the reported estimates 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.

As what will be discussed in detail in Section 2 of this paper, the dispersed empirical findings in the existing literature may be driven by 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. 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. Neither can the homogenous quantitative effect estimated from an aggregate production function shed much light on the exact mechanism through which such investment contributes to aggregate efficiency gains.

This paper tries to address such identification issues using a set of new methodologies. First, instead of estimating an aggregate production function, we estimate a production function using firm-level production data matched with province-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 past infrastructure investment of the province, this identification strategy mitigates the reverse causality problem. Second, inspired by Doraszelski and Jaumandreu (2013), rather than constructing a stock of public infrastructure, we estimate an endogenous productivity model in which public infrastructure investment affects firm productivity through a first-order Markov process. This allows us to avoid the potential measurement errors in the stock of public infrastructure and the associated non-stationarity problem in estimation. Third, under some auxiliary assumptions on the demand system as in De Loecker (2011), we distinguish the quantity total factor productivity (TFPQ) from the revenue total factor productivity (TFPR). The TFPR includes both the Keynesian demand effect and the productivity effect of public infrastructure, while the TFPQ only reflects the effect of public infrastructure on productivity.

We apply this methodology to a panel of Chinese manufacturing firms matched with province-level public infrastructure investment during 1998 to 2007, using the proxy method as in Ackerberg et al. (2006) to control for the simultaneity bias in a production function estimation. In our benchmark specification, the average real annual rates of return of public infrastructure investment are 2.5% and 9.2%, estimated based on TFPQ and TFPR, respectively. 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 increase to 7.2% and 28.3%. This implies that, first, public infrastructure investment does have large and positive returns on average, especially when spillover effects are taken into account. Second, more than two-thirds of the positive effect of such investment on output is indeed via the Keynesian demand effect.

Besides obtaining estimates on the average rate of return, our estimation strategy also has a unique advantage in investigating the underlying mechanism on why public infrastructure investment is productive. One interesting finding from our estimation procedure is that despite of the positive aggregate productivity effect on average, there is substantial heterogeneity in the estimated effects across firms within the same industry. One possible explanation is Melitz (2003). We then further test how public infrastructure investment may affect the exit probability and market share of firms with different productivity levels, according to the two direct implications of the Melitz (2003) model. Our empirical evidences are consistent with the mechanism that aggregate productivity gains stem from resource reallocations from less to more productive firms. Public infrastructure investment thus plays a role as a catalyst for these reallocations by increasing the exposure of an economy to trade, both domestic and international trade.

The rest of the paper is organized as follows. Section 2 introduces the aggregate production that have been widely used in the literature in estimating the productivity effect of public infrastructure. We discuss the identification issues associated with this approach. Our empirical model based on a firm-level production function and endogenous productivity is presented in Section 3. Section 4 explains the data and reports the empirical findings. Section 5 presents additional evidences in support of an increased trade exposure mechanism of resource reallocation promoted by public infrastructure. Section 6 summarizes the findings and discusses the limitations.

2 The Literature and This Paper

2.1 An Aggregate Production Function

Starting with Aschauer's initial paper, the traditional literature expands an aggregate production function with Hicks-neutral productivity A:

$$Q = AF(K, L),$$

where Q is the aggregate output; K and L are private capital and labor force. Assuming that the services provided by the public infrastructure capital B contributes to the total factor productivity A, an augmented three-factor production function becomes the workhorse model of this literature:

$$Q = A_o F(B, K, L),$$

where A_o is the total factor productivity purged of the influence of the public capital stock. As the stock of public infrastructure capital, B evolves according to the law of motion:

$$B_t = (1 - \delta_b)B_{t-1} + G_{t-1}, \tag{1}$$

where G is the flow of investment in public infrastructure and δ_b is the imposed depreciation rate of G. Using Cobb-Douglas form and rewriting the production function in logs yields:

$$\ln Q = \ln A_o + \alpha_b \ln B + \alpha_k \ln K + \alpha_l \ln L.$$

To determine the rate of return of public capital, differentiating the production function gives

$$\alpha_b = \frac{\partial \ln Q}{\partial \ln B} = \frac{\partial Q/Q}{\partial B/B} = \frac{\partial Q}{\partial B}\frac{B}{Q},$$

where $\frac{\partial Q}{\partial B}$ is the marginal product of public capital, or the economic rate of return of public capital. By definition, it is the multiplication of α_b, the output elasticity with respect to public capital, and $\frac{Q}{B}$, the output-to-public capital ratio:

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

Since $\frac{Q}{B}$ is directly observable from the data, inference the rate of return of public capital is equivalent to estimating the elasticity α_b, the parameter of key interest of this literature.

2.2 Identification Challenges

Consider how to estimate α_b in a panel data model:

$$\ln Q_{it} = \alpha_0 + \alpha_b \ln B_{it} + \alpha_k \ln K_{it} + \alpha_l \ln L_{it} + \mu_i + T_t + \varepsilon_{it}, \tag{2}$$

where μ_i denotes the country/region/state/province specific factors; T_t can be used to control for common macroeconomic shocks; and ε_{it} denotes idiosyncratic shocks.

Gramlich (1994) and Calderon et al. (2014) survey a set of identification challenges in this empirical literature. We highlight a few of the points that are most relevant to this paper. The first and also the main challenge is the reverse causality. The equation (2) aims to identify the effect of public infrastructure on output, but the causality could go from output to public infrastructure. In the short run, public spending tends to be cut in slumps and increased in booms. In the long run, 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 both long run and short run causality is bidirectional."

There are various ways to deal with this bi-causality. The first candidate is the instrumental variable (IV) approach. However, under this context it is usually hard to find a convincing external IV without the problem of weak instrument. Meanwhile, researches using internal IVs, for example, Holtz-Eakin (1994), often generate very low returns. The second approach to control simultaneity is the simultaneous equations approach. For example, Roller 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). It finds that when growth in roads changes, productivity growth changes disproportionately in U.S. industries with more vehicles. That vehicle-intensive industries benefit more from road-building suggests that roads are productive. Fernald's logic is intuitive but is hard to apply to other type's infrastructure and the infrastructure as a whole.

Second, when researchers write down equation (2), the idea is to infer the contribution of public infrastructure capital stock to aggregate supply. The observed Q_{it} in this equation is the equilibrium aggregate output. But when public infrastructure investment increases, aggregate demand is what changes in the short-run. 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, due to the Keynesian demand effect, leading to an upward bias in the inference of productivity effect of public infrastructure.

Finally, there are also a set of other econometric problems in estimating equation (2). 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 (2) 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_{it}. [5] In order to construct B_{it} using the perpetual inventory method, one needs information on the initial value and the whole history of the investment flow series $\{G_{i0}, G_{i1}, G_{i2}, \cdots, G_{it}\}$ and assumes a depreciation rate δ_b. This implies that the constructed stock data is very likely to be contaminated with measurement errors. Besides reverse causality and the combined supply and demand effects, there is another form of simultaneity bias in equation (2) due to unobserved factors included in ε_{it}. 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 residuals, rending the OLS estimates biased and inconsistent.

2.3 Methodologies of This Paper

A fundamental difference of this paper from the literature originates from the nature of the data. We use firm-level production data matched with province-level infrastructure investment data. This allows us to apply a set of novel methodologies to address those well-known challenges in the literature.

As discussed above, reverse causality is the main identification challenges in an aggregate production function estimation. Using a firm-level production function can avoid or mitigate this issue by nature. In a firm-level production function, the province-level infrastructure investment may shift firms' output by increasing their productivity. However, when there are a large number of firms in a province, every individual firm's output does not affect province-level infrastructure expenditure. Thus, the reverse

[5] 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.

causality from output to infrastructure is muted in this setup.

Another unique advantage of using a firm-level production function is that it is possible to net out the Keynesian demand effect from the estimated productivity effect of public infrastructure investment. With firm-level data, on 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 the demand shocks. Although in general only sales revenue – the multiplication of equilibrium output and price are observable to econometricians, under certain structural assumptions, following De Loecker (2013), we are able to distinguish the TFPQ from the TFPR. The TFPR includes both the Keynesian demand effect and the productivity effect of public infrastructure, while the TFPQ only reflects the effect of public infrastructure on productivity.

Firm-level data also facilitate us to address other econometric problems by using recently developed techniques in production function estimation with endogenous productivity. Inspired by Doraszelki and Jaumandreu (2013) in modelling R&D, we model the productivity of a firm in year t as a function of infrastructure investment in $t-1$ and productivity in $t-1$. Such approach will only require data on infrastructure investment flows without having to construct the infrastructure capital stock. This leads to a standard firm-level production function with some additional regressors. Thus the proxy approach, such as Ackerber et al. (2006), can be applied to address the simultaneity bias.

2.4 Additional Contribution

Compared with existing literature that use aggregated macroeconomic data, there is one disadvantage and one advantage in using firm-level data. The disadvantage lies in that when the firm-level production data is matched only with the infrastructure investment data of the province where the firms locate, it may understate the infrastructure impacts by ignoring the out-of-province benefits arising from the positive spillover effects of public goods. Indeed, the spillover argument has been used to explain why larger output elasticities of public capital are typically found for time-series studies using more aggregated data. To account for the spillover effects, studies using regional data, for example, Holtz-Eakin and Schwartz (1995), employ so-called "effective" public capital, which includes public infrastructure of neighboring regions. Using aggregate and regional-level data from Spain, Pereira and Roca-Sagales (2003) argue that aggregate effects of public capital cannot be captured in their entirety by the direct effects for each region from public capital installed in the region itself and they find that the aggregate effects are due in almost equal parts to the direct and spillover effects of public capital.

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

The unique advantage of using firm-level data comes from the possibility to investigate the underlying mechanisms. 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, reduction in transportation and transaction costs, spatial spillovers and network externalities. It is thus not surprising that the number of studies estimating the returns significantly dwarft those exploring the specific mechanisms of the positive effect.[6] 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, 1989), 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 emphasize 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

[6]A few exceptions include Shirley and Winston (2004) and Li and Li (2013). Using U.S. and Chinese firm-level data, respectively, they find with a more reliable transportation network, firms are able to save on inventory holding costs by cutting their inventory stock, leading to improvement in individual firms' productivity.

the impact of roads and railways on the decentralization of Chinese cities in terms of population and industrial GDP.

As pointed out by Munnell (1992), much more work is required to spell out the specifics of the link between public capital and economic performance. The great variation in the estimated effects of infrastructure investment across heterogeneous firms, allows us to characterize and test a possible mechanism through which infrastructure investment affects aggregate productivity. Similar to the recent literature on transport infrastructure based on county- or city-level data, we also emphasize the heterogenous 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.

3 A Model with Endogenous Productivity and Public Infrastructure Investment

3.1 Production and Demand

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

$$Q_{it} = L_{it}^{\alpha_L} K_{it}^{\alpha_K} M_{it}^{\alpha_M} \exp(\omega_{it} + u_{it}), \tag{3}$$

where α_L, α_K,and α_M are the corresponding output elasticities. ω_{it} represents an unobservable firm-specific productivity in logarithm, and u_{it} denotes the unobservable idiosyncratic shocks to production or measurement error in the output data.

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

$$Q_{it} = Q_{sjt}(\frac{P_{it}}{P_{st}})^{-\sigma_s} \exp(\xi_{it}), \tag{4}$$

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 $1 < \sigma_s < \infty$.

3.2 Productivity, Demand and Public Infrastructure Investment

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

$$\omega_{it} = h_t(\omega_{it-1}, g_{jt-1}) + v_{it}, \tag{5}$$

where g_{jt-1} is the logarithm of province j's infrastructure investment flow in year $t-1$; and v_{it} is an unobservable firm-specific productivity innovation. This specification is similar to the one in Doraszelski and Jaumandreu (2013) who study the productivity impact of R&D investment. Different from the capital accumulation equation (1), it is the instantaneous investment flow G_{jt-1}, instead of capital stock B_{jt}, that contributes to the current productivity ω_{it}. 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 through the lagged productivity ω_{it-1}.

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

$$\xi_{it} = \tau g_{jt} + \widetilde{\xi}_{it}, \tag{6}$$

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, equation (6) implies that the effect of infrastructure investment on demand is instantaneous.

3.3 Log Deflated Sales Revenue and Estimating Equation

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

$$\ln Q_{it} \equiv q_{it} = \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \omega_{it} + u_{it}. \tag{7}$$

and

$$\ln P_{it} - \ln P_{st} = -\frac{1}{\sigma_s}\left(\ln Q_{it} - \ln Q_{sjt}\right) + \frac{1}{\sigma_s}\xi_{it}. \tag{8}$$

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 (7) yields the following equation:

$$\ln \frac{P_{it}Q_{it}}{P_{st}} = \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + (\ln P_{it} - \ln P_{st}) + \omega_{it} + u_{it}. \tag{9}$$

The left-hand side of equation (9) is the logarithm deflated real sales revenue, the dependent variable used in most empirical studies for production function estimation. The right-hand side of equation (9) now has an additional term $(\ln P_{it} - \ln P_{st})$ in contrast to that of equation (7). This term is unobservable and and negatively correlated with inputs. If one estimates equation (9) without taking care of the correlation between this term and the inputs, the estimates for the output elasticities are known to have an omitted price variable bias in the literature (Kletter and Griliches, 1996).

An important contribution of De Loecker (2011) is to replace the unobservable price error $(\ln P_{it} - \ln P_{st})$ using the CES demand system (8):

$$\ln \frac{P_{it}Q_{it}}{P_{st}} = \left(1 - \frac{1}{\sigma_s}\right) \ln Q_{it} + \frac{1}{\sigma_s} \ln Q_{sjt} + \frac{1}{\sigma_s} \xi_{it}. \tag{10}$$

Substitute $\ln Q_{it}$ and ξ_{it} in equation (10) using (7) and (6):

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

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

$$r_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_s q_{sjt} + \beta_g g_{jt} + \omega^*_{it} + \epsilon_{it}, \tag{11}$$

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 of interest, which can be used to recover the structural parameters $\{\alpha_L, \alpha_K, \alpha_M, \sigma_s, \tau\}$. The transformed productivity $\omega^*_{it} = \left(1 - \frac{1}{\sigma_s}\right) \omega_{it} = (1 - \beta_s)\, \omega_{it}$, is simply a linear scale of the original productivity ω_{it}. The combined error term $\epsilon_{it} = \left(1 - \frac{1}{\sigma_s}\right) u_{it} + \frac{1}{\sigma_s} \widetilde{\xi}_{it} = (1 - \beta_s)\, u_{it} + \beta_s \widetilde{\xi}_{it}$ 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.

3.4 TFPQ, TFPR, and the Output Elasticities

Consider the productivity effect of public infrastructure investment as in equation (7):

$$q_{it} = \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \omega_{it} + u_{it}.$$

Our key parameter of interest is the output elasticity with respect to the public infrastructure investment through the productivity channel:

$$e_{it}^{TFPQ} = \frac{\partial q_{it}}{\partial g_{jt-1}} = \frac{\partial \omega_{it}}{\partial g_{jt-1}}. \tag{12}$$

Note that ω_{it} contributes to the quantity of output and is thus known as the quantity total factor productivity (TFPQ).

Equation (7) is not estimatable but equation (11) is:

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

And the relationship between ω_{it} and ω_{it}^* implies that estimating elasticity e_{ig}^{TFPQ} is equivalent to estimating equation (11):

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

In almost all empirical applications without controlling for the unobserved price error and thus the demand shocks, the standard solution is to proxy the physical output using the log deflated sales revenue and to specify an empirical version for equation (7) as:

$$r_{it} = \theta_l l_{it} + \theta_k k_{it} + \theta_m m_{it} + z_{it} + e_{it}. \tag{13}$$

Note that z_{it} contributes to the revenue of output and is thus known as the revenue total factor productivity (TFPQ). In an empirical exercise that does not distinguish TFPR and TFPQ, $(\theta_l, \theta_k, \theta_m)$ are often interpreted as $(\alpha_l, \alpha_k, \alpha_m)$. However, under our model specifications the measured productivity z_{it} in fact contains not only the productivity effect of infrastructure investment via ω_{it}, but also the demand effect via q_{sjt} and g_{jt}:

$$z_{it} = z\left(q_{sjt}, g_{jt}, \omega_{it}\right).$$

As a direct comparison to equation (5), if z_{it} is also assumed to follow a first-order Markov process as ω_{it}:

$$z_{it} = h_t'(z_{it-1}, g_{jt-1}) + v_{it}', \tag{14}$$

the output elasticity with respect to infrastructure investment obtained from equation (13) will then reflect the contribution of infrastructure investment through both the productivity channel and the demand channel:

$$e_{it}^{TFPR} = \frac{\partial r_{it}}{\partial g_{jt-1}} = \frac{\partial z_{it}}{\partial g_{jt-1}}. \tag{15}$$

The specifications (5) and (14) imply that the output elasticities e_{it}^{TFPQ} and e_{it}^{TFPR} may vary from firm to firm, depending on the attained productivity level of firm i and the infrastructure investment of province g. Our model thus allows us to to recover the distribution of the elasticities and characterize the heterogeneity across firms, which is crucial in exploring the mechanism of how infrastructure investment affects productivity.

3.5 Identification and Estimation

The OLS estimates for βs in equation (11) is known for suffering from the simultaneity bias, 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 l and k are dynamic inputs. Profit maximization thus leads to an optimal intermediate inputs:

$$m_{it} = m_t(l_{it}, k_{it}, q_{sjt}, g_{jt}, \omega_{it}^*).$$

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

$$\omega_{it}^* = \omega_t(l_{it}, k_{it}, m_{it}, q_{sjt}, g_{jt}), \tag{16}$$

which is called the control function in the proxy approach.

Denote

$$\begin{aligned} \beta &\equiv (\beta_l, \beta_k, \beta_m, \beta_s, \beta_g)', \\ x_{it} &\equiv (l_{it}, k_{it}, m_{it}, q_{sjt}, g_{jt})'. \end{aligned}$$

Inserting equation (16) into the structural equation (11) 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 this equation can be consistently estimated by a polynomial regression of r_{it} on x_{it}. This process is called the first-stage regression, which gets rid of the error term ϵ_{it} and provides a fitted value $\hat{\phi}_t(x_{it})$ for log deflated sales revenue 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 by 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

$$\omega_{it}(\beta) = \frac{\omega^*_{it}}{1-\beta_s} = \frac{\hat{\phi}_t(x_{it}) - x'_{it}\beta}{1-\beta_s}$$

and

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

The parameters β are obtained by the generalized method of moments under the moment conditions:

$$E[v_{it}(\beta)|I_{t-1}] = 0,$$

which implies that

$$E\left[(v_{it}(\beta_l, \beta_k, \beta_m, \beta_s, \beta_g)) \otimes \begin{pmatrix} l_{it} \\ k_{it} \\ m_{it-1} \\ q_{sjt-1} \\ g_{jt-1} \end{pmatrix}\right] = 0. \tag{17}$$

The identification for $(\beta_l, \beta_k, \beta_m)$ strictly follows the timing assumption as in Ackerberg et al. (2006). The additional parameters (β_s, β_g) are identified by the assumption that shocks to productivity are uncorrelated with lagged industry-province aggregate output and lagged province-level infrastructure investment.

The identification and estimation for equation (13) follows a similar two-stage procedure, except that we do not include the demand effect terms q_{sjt} and g_{jt}, so that the first-stage regression for the reduced-from equation becomes

$$r_{it} = \phi'_t(l_{it}, k_{it}, m_{it}) + \epsilon'_{it}.$$

The moment conditions for the second-stage regression are

$$E\left[(v'_{it}(\theta_l, \theta_k, \theta_m)) \otimes \begin{pmatrix} l_{it} \\ k_{it} \\ m_{it-1} \end{pmatrix}\right] = 0,$$

where

$$v'_{it}(\theta) = z_{it}(\theta) - h'_t(z_{it-1}(\theta), g_{jt-1}).$$

3.6 Spillover Effects

The benchmark specification has 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 the public investment in its location province j, but also from the public investment in the rest of the country, though the effect from the latter might be smaller. Similarly, firm i's demand – both aggregate and firm-specific demand – may be shifted not only by the public investment in its location j, but also by the public investment in the rest of the country, though the shift by the latter might be smaller.

To address the concern that interregional spillover effects cannot be fully captured by studies looking at small geographical units, we revise productivity equation (5) into:

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

revise the aggregate demand shifter equation (4) into:

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

and revise the firm-specific demand shifter equation (6) into:

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

Here $\overline{g}_{jt-1}$ is the logarithm of $\overline{G}_{jt}$, and $\overline{G}_{jt}$ is the weighted-average of G_{kt}:

$$\overline{G}_{jt} = \sum w_{jk} * G_{kt}. \tag{18}$$

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

$$\overline{Q}_{sjt} = \sum w_{jk} * Q_{skt}, \tag{19}$$

where j is the province where the firm i locates and $k! = j$ represents the rest of other provinces of the country. The weighting matrix w_{jk} is constructed and normalized as in Ertur & Koch (2007):

$$\begin{aligned} w_{jk} &= \frac{\frac{1}{d_{jk}}}{\sum_{k!=j} \frac{1}{d_{jk}}}, \\ w_{jj} &= 1. \end{aligned}$$

It implies the public infrastructure investment of a province has a direct impact on the productivity and demand of the firms locating within the province. However, it also has an impact on those firms locating outside of the province, where the effects of the impact diminish with the distance between the out-of-province firm and the province.

4 Empirical Results

4.1 Data and Variables

4.1.1 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 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 basic firm characteristics, output and input data, and balance sheet information, for all state-owned firms and non-state-owned firms with sales revenue above 5 million RMB. In total these firms produce 80% value-added of the 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 procedure. 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 estimations focus on the 29 industries in the manufacturing sector. Table 2 lists the industrial code and definition for these industries. Average annual number of observations for the corresponding industry is reported in the third column. On average there are more than 7000 observations for each industry in every year. The next two columns present the median values for the real annual growth rate of labor productivity and capital productivity across firms in each industry. Although both the labor and capital productivities have been growing around 10% per year for the whole manufacturing sector, there is also substantial variation across different industries. In particular, the industries 25 petroleum processing and coking and 33 smelting and pressing of nonferrous metals have witnessed a significant productivity drop. One possible reason is the great output price variation in these two industries over the sample period. As reported in the last column of Table 2, 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.

4.1.2 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 Roller 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 stylized 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 emphasized throughout the successive Five-Year Plans. Although the burden of financing infrastructure investment is generally shared between the central government, local governments and private sector, the governments at the province level have been regarded as the key decision maker for most infrastructure investment.[7] Among many others, Li and Zhou (2005), Zhang et al. (2007) and Xu (2011) argue that the province governments in China have a strong incentive in infrastructure investment as a response to the GDP yardstick com-

[7]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)

petition under the regionally decentralized authoritarian system. Such institutional background explains why almost all existing empirical studies on China's infrastructure investment has been using the data at the province level.

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, core infrastructure investment has been steadily increasing throughout 1998 to 2007 at a real annual growth rate of 12%. Although the absolute level of investment substantially increased since year 2003,[8] the ratios between such investment to industrial GDP and total GDP have been rather stable across the decade, which are around 21% and 9%, respectively. This seems to be consistent with the findings in the literature that the causal relationship between infrastructure investment and GDP are bi-directional. Similar patterns on the broad infrastructure investment can also be observed from the lower panel of Table 2.

4.2 Baseline Results

4.2.1 Estimates For the Revenue Equations

Table 3 presents the estimates of the coefficients for the revenue equation (11) and (13) in Panel A and B respectively. The estimation procedure follows what is described in Section 3.5 and is applied on a 2-digit industry level for the 27 manufacturing 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 functions $\phi_t(\cdot)$ and $\phi_t'(\cdot)$. In the second stage regression, the productivity processes $h_t(\cdot)$ and $h_t'(\cdot)$ are also proxied by a fourth-order polynomial function with interaction terms. We also experiment with lower-order polynomial functions in our robustness checks.

In an application without controlling for the omitted price variable bias, the estimates for equation (13) will be interpreted as the production function coefficients. Thus our estimates in Panel B are comparable with the literature that apply the proxy approach to control for the simultaneity bias in estimating production func-

[8] 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 seperately since 2003.

tion. Compared with for example, Pavcnik (2002), Panel B shows a larger coefficient on intermediate inputs and smaller coefficients for labor and capital. 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. Notice a few industries in Panel B 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 A1, where all the coefficients are positive and significant.

The coefficients in Panel A 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. Notice that by definition β_s should all be positive but Panel A reports 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 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 A2 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. 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.

4.2.2 Estimates for the Endogenous Productivity Processes

Table 4 presents the nonparametric estimates for the endogenous productivity process (5) and (14) for the entire manufacturing sector. This serves as a direct illustration for the average impact effect of the infrastructure investment on the total factor productivity. There are two important common findings, both for the TFPQ and for the TFPR models. First, the productivity processes are highly non-linear. This suggests that using a simple linear model to characterize the processes would be mis-specified. 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.

Given the heterogenous impact effect, we calculate the partial derivative of log productivity with respect to log infrastructure investment at the median lagged log productivity level. We obtain an elasticity of 0.0094 for the TFPQ and 0.0225 for the TFPR. This means that for a firm with median productivity level in the whole manufacturing sector, infrastructure investment does enhance its productivity. This effect is positive, not only for the revenue productivity, but also for the quantity productivity. The magnitude on the revenue productivity is more than twice of that on the quantity productivity. This confirms the conjecture that the infrastructure investment may bring in more output, not only through the productivity channel, but also through the demand channel. And the latter turns out to be quantitatively important.

To highlight the degree of the heterogeneity, we also calculate the elasticities by industry and report the effects at the 25th, 50th and 75th percentiles of the productivity in Table 5. As expected, we see substantial variation across industries and along the productivity distribution, both for the TFPQ and for the TFPR models. However, there are also two consistent patterns. First, for all the industries, the effects of infrastructure investment on productivity – both revenue productivity and quantity productivity – increase with the initial productivity level. Firms at the lower quantiles of the productivity could in fact suffer from the infrastructure investment. Firms at the higher quantiles of the productivity usually benefit from the infrastructure investment. Second, for most of the industries, the elasticities from the TFPR are larger than those from the TFPQ, conditional on the productivity distribution. This once again suggests the importance to distinguish the quantity productivity from the revenue productivity.

4.2.3 Output Elasticities and Rates of Return

Now we are ready to report the average rate of return of public infrastructure investment, the central research question of this paper. First, we calculate the firm-level output elasticities e_{it}^{TFPQ} and e_{it}^{TFPR} for each firm in each year by each industry according to equation (12) and (15).

Second, 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:

$$\begin{aligned} e_{st}^{TFPQ} &= \frac{dv_{st}^{TFPQ}}{dg_{t-1}} = \frac{dv_s}{dr_s}\left(\sum\nolimits_i e_{it}^{TFPQ}\frac{R_{ist}}{R_{st}}\right), \\ e_{st}^{TFPR} &= \frac{dv_{st}^{TFPR}}{dg_{t-1}} = \frac{dv_s}{dr_s}\left(\sum\nolimits_i e_{it}^{TFPR}\frac{R_{ist}}{R_{st}}\right), \end{aligned}$$

where $\frac{R_{ist}}{R_{st}}$ represents firm i's revenue as a share of total revenue in industry s; the ratio $\frac{dv_s}{dr_s}$ is obtained by a fixed-effect regression on log value-added over log sales revenue for industry s. These weighted-average industry-level value-added-based output elasticities are presented in the top rows of Table 6 for each industry.

Third, we use value-added of each industry as the weight to aggregate these industry-level output elasticities into a sector average for the manufacturing sector:

$$\begin{aligned} e_{t}^{TFPQ} &= \sum\nolimits_s e_{st}^{TFPQ}\frac{V_{st}}{V_t}, \\ e_{t}^{TFPR} &= \sum\nolimits_s e_{st}^{TFPR}\frac{V_{st}}{V_t}, \end{aligned}$$

where $\frac{V_{st}}{V_t}$ denotes industry s's value-added as a share of total value-added in the manufacturing sector. These weighted-average sector-level value-added-based output elasticities are reported in the fifth last row of Table 6.

Finally, our ultimate quantities of interest, that is, the average economic rates of return of infrastructures investment can be obtained by multiplying the output elasticities with the corresponding GDP-to-infrastructure investment ratios in different years:

$$\begin{aligned} r_{t}^{TFPQ} &= e_{t}^{TFPQ}\frac{GDP_t}{G_{t-1}}, \\ r_{t}^{TFPR} &= e_{t}^{TFPR}\frac{GDP_t}{G_{t-1}}. \end{aligned}$$

In the fourth and third last rows of Table 6, we list the ratios of industrial GDP-to-infrastructure investment and of total GDP-to-infrastructure investment, respectively.

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 6 reports the rates of return of infrastructure investment to the Chinese economy.

As observed in Panel A, the economy-wide rate of return based on quantity productivity is 2.5% averaging across year 1999 to 2007. It varies from zero in 2007 to the peak of 4.5% in 2004. In Panel B, the average rate of return based on revenue productivity is 9.2%, which varies from 8.0% in 1999 and peaks to 10.7% in 2003. These findings have two important implications. First, the average rate of return of infrastructure investment in China is positive, at least during our sample period. As far as we know, this is the first paper that confirms a positive rate of return of infrastructure investment using firm-level data and addressing a set of identification issues long-lasting in the literature. Second, the rates of return based on revenue productivity are more than twice of those based on quantity productivity. This is consistent with the concern that much of the contribution of infrastructure investment to output is indeed via the Keynesian demand effect.

4.3 Results with Spillover Effects

To investigate the potential out-of-province benefits arising from the spillover effects of public goods, we re-estimate the model using the same procedure but replacing the infrastructure investment and aggregate demand shifter with their corresponding weighted-average (18) and (19). Table 7 reports the output elasticities across industries and the average rates of return for the industrial sector and the economy under such specifications. In our robustness checks, we present another set of results with alternative measure of spillover effects.

Table 7 resembles two interesting patterns that we have seen from Table 6. First, the rates of return based on revenue productivity are much larger than those based on quantity productivity. This implies that the Keynesian demand effect also operates in a model with spillover effects. Second, over the time the rates of return with spillover effects also display an inverted-U shape which peaks around year 2003 and 2004. Hence the public infrastructure investment seems to be most productive in the middle of our sample period.

Although Table 7 and Table 6 display assuring patterns that are qualitatively similar, they also show a quantitatively important difference that highlights the significance of the spillover effects. The average rate of return based on TFPQ now increases from 2.5% to 7.2%; and the average rate of return based on TFPR now increases from 9.2% to 28.3%. 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 number found in the researches which study at the national level. Note that in our empirical exercises, the returns obtained from a specification with spillover effects triple those from a specification 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.

4.4 An Evaluation on the Rates of Return

Our empirical exercises now provide two sets of estimates on the rates of return of infrastructure investment: one is based on the assumption that a firm's productivity and demand only depend on the infrastructure made by the province where it locates; the other assumes that its productivity and demand could be affected by a weighted-average infrastructure investment of the whole nation. Thus one may think these two sets of estimates provide a lower bound and an upper bound on the rates of return with no and maximal spillover effects. A natural question may arise at this point: do such rates of return make economic sense or are they high or low? 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.

4.4.1 Alternative Benchmarks

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% ~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% for infrastructure projects. 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 8 lists r_{st}, the weighted-average rates of return of private investment in each industry, and r_t, the weighted-average rates of return of private investment for the manufacturing sector:

$$\begin{aligned} r_{st} &= \theta_k^s \left(\sum\nolimits_i \frac{R_{ist}}{K_{ist}} \frac{R_{ist}}{R_{st}} \right), \\ r_t &= \sum\nolimits_s r_{st} \frac{R_{st}}{R_t}, \end{aligned}$$

where θ_k^s is the revenue-based output elasticity with respect to capital for industry s reported in Panel B of Table 3; $\frac{R_{ist}}{K_{ist}}$ stands for firm i's revenue-to-capital ratio; $\frac{R_{ist}}{R_{st}}$ represents firm i's revenue as a share of total revenue in industry s; and $\frac{R_{st}}{R_t}$ denotes industry s's revenue as a share of total revenue in the manufacturing sector. There are two interesting patterns observed in Table 8. 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.[9] 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 stylized fact well-documented and explained in the literature, such as Hsieh and Klenow (2009), Brandt et al. (2014) and Song and Wu (2016), 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 that first, manufacturing is usually the most productive sector in a fast-growing economy like China; and second, 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. Therefore, 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 during the year of 2003 and 2004. Thus the rates of return from this benchmark happen to lie in between our estimated returns to infrastructure investment with and without spillover effects.

4.4.2 Summary of the Pattern

Figure 1 summarizes six series for the rates of return. Four of them are returns to infrastructure investment, estimated with and without spillover effects, based on TFPQ and TFPR models, respectively. The fifth of them is the returns of private investment estimated from our empirical exercises. And the sixth is cited from Bai and Zhang (2014). Our evaluation on the rates of return leads to several important conclusions. First, our estimated rates of return of infrastructure investment are positive in all

[9] Doraszelki and Jaumandreu (2013), who estimate the rate of return of R&D, also report their estimates for the rates of return of phycial 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.

specifications and in almost every year of our sample period. However, the magnitude of the returns is much smaller than that found in the early literature using aggregate level data and subject to a set of identification issues. Second, the returns to infrastructure investment are higher than those to private investment, only if we take into account the positive spillover effects of public goods. Third, the returns estimated from a TFPQ model are only about one-third of those from a TFPR model, suggesting much of the positive contribution of infrastructure investment to output is through the short-run demand effect. Finally, year of 2003 and 2004 seems to witness the highest rates of return to investment over our sample period.

4.5 Robustness Checks

We consider three sets of robustness checks in turn. The corresponding output elasticities and rates of return are summarized in Table 9, while Table 6 and 7 serve as our benchmark results. First, we change our definition for G_{jt} from core infrastructure into broad infrastructure by adding on investment expenditure on management of water conservancy, environment, and public facilities. 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 9.1 with those in Table 6. The average rate of return now decreases from 2.5% to 0.9% in the TFPQ model, and from 9.2% to 7.8% in the TFPR model, although both of sets of returns are positive and show a hump-shape over the sample period. Thus our estimations are consistent with the expectation and have a robust time pattern.

In the second robustness check, we experiment with the linear, quadratic and third-order polynomials to proxy the functions $\phi_t(\cdot)$, $\phi_t'(\cdot)$, $h_t(\cdot)$ and $h_t'(\cdot)$. A linear functional form leads to very different results from Table 6. In particular, the returns from the TFPR model will inflate a lot and from the TFPR model will become negative. Results from the quadratic functional form are somewhere in between those specifications with a linear and a third-order polynomial. When we further increase the order of polynomials, the returns tend to stabilize. Table 9.2 presents the findings for a third-order polynomial. Now the average rates of return are 3% and 6.5% from the TFPQ and TFPR model, respectively. These are quite close to the benchmark results, where we employ a fourth-order polynomial. 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 will only affect 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}, a 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 Table 6 but smaller than those in Table 7. This is consistent with the pattern one may observe from Table 9.3, Table 6 and Table 7. Under this alternative specification of spillover effects, the average rate of return is 3.0% from the TFPQ model, in between of 2.5% and 7.2%; and is 18.6% from the TFPR model, in between of 9.2% and 28.3%.

5 A Possible Mechanism

5.1 Aggregate Gains and Heterogenous Effects

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. Despite the variation in the magnitude from different specifications, this common finding is established, not only for the TFPR model, but also for the TFPQ model, both for the case with and without spillover effects. Second, and probably more interesting, at the firm-level, public infrastructure investment has a heterogeneous effect across different firms. In particular, such heterogenous effect is dependent on the productivity itself. In Table 4 and Table A4, the endogenous productivity processes show that the impact of infrastructure investment on a firm's productivity depends significantly and positively on the attained productivity of the firm. In Table 5 and Table A5, the output elasticities with respect to infrastructure investment monotonically increase with the productivity quantiles.

Since both productivity and elasticity *per se* are not directly observable, Table 10 further links the impact of infrastructure investment on observable firm characteristics.

That is we run regressions of estimated output elasticities from various specifications over firm age, size, ownership, exporting status and geographic location. A common finding turns out to arise across all specifications, that all else being equal, a firm that is younger, smaller, non-state-owned, exporting and locating in the eastern area has a larger output elasticity than its counterpart. Since firms with such characteristics are well-known as more productive firms, this finding once again confirms the property that infrastructure investment tends to benefit firms with high productivity more than those with low productivity.

5.2 Channel at Work: Resource Reallocation

Understanding the exact mechanisms via which public infrastructure investment affects the aggregate productivity is probably equally pertinent as estimating the returns of such investment. 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 heterogenous 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 characterized in Melitz (2003). In the analyses of Melitz (2003), 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 2000s China has been largely excluded from the international goods market and subject to widespread local protectionism (Young, 2000; Bai et al., 2004; Poncet). Tombe and Zhu (2015), a recent study on how misallocation due to goods- and labour-market frictions affect aggregate productivity in China, finds that reductions in international and in particular internal trade costs accounts 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.

5.3 Testing the Hypothesis

To test the hypothesis that public infrastructure investment facilities resource reallocation by reducing trade costs and increasing firm's exposure to trade, we 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; and second, all else being equal, public infrastructure investment increases the market shares of the more productive firms.

Table 11 presents the Probit models of exit probabilities, using the estimates on productivities from both TFPQ and TFPR models, with and without externalities, respectively. 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 of which are negative, significant and have a similar magnitude as that found in Olley and Pakes (2001) and Pavcnik (2003). In column (2), we add the corresponding public infrastructure investment measure for each model. Overall, more 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. This interaction term turns out to be significantly positive. This implies that 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 market share 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 turns to significantly contribute to the market share. What is 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. This verifies the hypothesis that public infrastructure investment facilitates to reallocate the market share towards more productive firms.

The empirical evidences, both at the extensive and at the intensive margins thus turn out to support our hypothesis. This finding echoes the recent literature on how transport infrastructure affects the distribution of economic activities, such as Faber (2014), and challenges one the original intentions of public infrastructure investment in reducing regional disparity.

6 Conclusion

This paper addresses three 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 novel structural estimation on the productivity 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 on output is via the short-run Keynesian demand effect, although the long-run quantity total factor of productivity also benefits from such investment. Third, firm-level evidences on exit and market share 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 important 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 sectors 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 overinvested 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 SOE reforms and entered the WTO so that the role of catalyst of infrastructure investment is maximized. Further investment could be subject to the diminishing returns to capital. On the other hand, spatial spillovers 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 the institutions and incentives from political economy.

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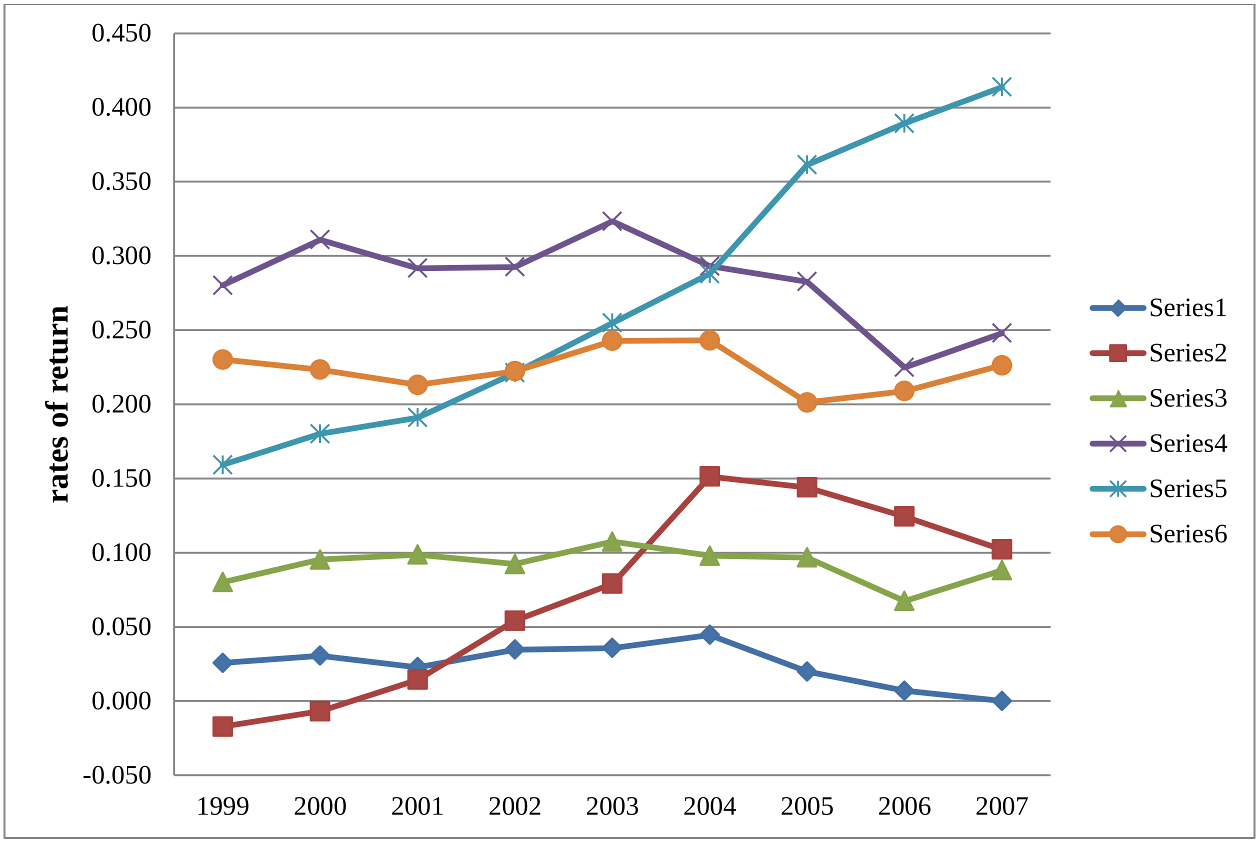

Figure 1 Summary for various rates of return

Note:
Series 1: for infrastructure investment, estimated based on TFPQ model without spillover effects
Series 2: for infrastructure investment, estimated based on TFPQ model with spillover effects
Series 3: for infrastructure investment, estimated based on TFPR model without spillover effects
Series 4: for infrastructure investment, estimated based on TFPR model with spillover effects
Series 5: for private investment, estimated based on TFPR model without spillover effects
Series 6: for physical investment, using aggregate data, cited from Bai and Zhang (2014)

Table 1 Firm-level data description

code	industry definition	col (1)	col (2)	col (3)	col (4)
13	Food processing	13029	7.63	2.59	126.72
14	Food manufacturing	5246	12.35	8.07	106.94
15	Beverage manufacturing	3590	13.28	9.88	102.26
16	Tobacco processing	264	7.55	4.35	121.75
17	Textile industry	17562	16.87	10.50	109.13
18	Garments & other fiber products	9725	14.70	9.19	103.03
19	Leather, furs, down & related products	4861	11.62	7.49	109.42
20	Timber processing, bamboo, cane, palm fiber	4453	25.97	21.65	108.26
21	Furniture manufacturing	2365	22.37	17.96	104.87
22	Papermaking & paper products	6124	19.08	15.81	105.03
23	Printing industry	4361	15.06	12.02	93.40
24	Cultural, educational & sports goods	2658	17.05	10.99	107.00
25	*Petroleum processing & coking*	*1802*	*-4.85*	*-11.39*	*201.03*
26	Raw chemical materials & chemical products	14970	12.19	7.28	122.16
27	Medical & pharmaceutical products	4303	19.51	15.02	96.49
28	Chemical fiber	1031	12.82	9.81	122.58
29	Rubber products	2427	14.86	11.17	111.31
30	Plastic products	9446	19.64	15.95	114.49
31	Nonmetal mineral products	17594	23.60	19.64	106.08
32	Smelting & pressing of ferrous metals	4948	12.64	5.86	133.74
33	*Smelting & pressing of nonferrous metals*	*3643*	*-6.56*	*-11.78*	*196.66*
34	Metal products	11018	13.50	7.50	114.41
35	Ordinary machinery	15358	17.71	11.40	105.55
36	Special purpose equipment	8606	18.06	11.78	106.39
37	Transport equipment	9896	16.49	10.90	96.11
39	Electric equipment & machinery	12025	-1.13	-6.79	117.62
40	Electronic & telecommunications equipment	6766	25.36	20.60	83.49
41	Instruments, meters, cultural & office equipment	2907	18.58	13.31	92.19
42	Other manufacturing	3952	9.22	2.78	117.17
	average	7067	13.97	9.09	115.01

Note:

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

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

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

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

Table 2 Data description on infrastructure investment

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
core infrastructure investment [1]	729.37	777.96	845.93	884.64	891.88	1058.89	1284.58	1559.15	1847.64	1961.46	1184.15
core infrastructure investment real growth rate [2]	..	6.66	8.74	4.58	0.82	18.73	21.31	21.37	18.50	6.16	11.87
core infrastructure investment/industrial GDP [2]	21.49	21.13	20.93	20.14	18.46	19.44	21.15	23.01	24.15	22.31	21.22
core infrastructure investment/total GDP [2]	8.59	8.52	8.54	8.25	7.62	8.22	9.06	9.88	10.39	9.66	8.87
broad infrastructure investment [1]	929.12	1022.36	1120.51	1194.46	1272.79	1472.22	1734.53	2106.49	2545.03	2797.93	1619.54
broad infrastructure investment real growth rate [2]	..	10.04	9.60	6.60	6.56	15.67	17.82	21.44	20.82	9.94	13.16
broad infrastructure investment/industrial GDP [2]	27.38	27.77	27.72	27.19	26.35	27.03	28.56	31.08	33.27	31.83	28.82
broad infrastructure investment/total GDP [2]	10.95	11.19	11.31	11.13	10.88	11.43	12.24	13.35	14.31	13.78	12.06

Note:

1. unit: billion Yuan, 1998 price
2. unit: %
3. Data are from China Statistics Yearbooks and China Fixed Investment Statistical Yearbooks.
4. Infrastructure investment data are deflated by the price indices of investment in fixed assets by province.
5. Industrial GDP and total GDP data are deflated by the corresponding GDP deflators.

Table 3 Estimates for the revenue equations

Panel A: TFPQ

code	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 3 Estimates for the revenue equations

Panel B: TFPR

code	θ_l	$s.e.(\theta_l)$	θ_k	$s.e.(\theta_k)$	θ_m	$s.e.(\theta_m)$
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 4 Nonparametric estimates of the productivity processes

Panel A: TFPQ					Panel B: TFPR		
	Estimate		Standard error		Estimate		Standard error
$\omega_{i,t-1}$	0.3320	***	0.0174	$z_{i,t-1}$	-0.8090	***	0.1870
$\omega^2_{i,t-1}$	-0.0164	***	0.0016	$z^2_{i,t-1}$	-0.0224	***	0.0051
$\omega^3_{i,t-1}$	-0.0010	*	0.0005	$z^3_{i,t-1}$	0.0001	***	0.0000
$\omega^4_{i,t-1}$	0.0000	*	0.0000	$z^4_{i,t-1}$	0.0000	***	0.0000
$g_{j,t-1}$	0.0202	***	0.0012	$g_{j,t-1}$	-0.0266	***	0.0050
$\omega_{i,t-1} g_{j,t-1}$	0.0209	***	0.0011	$z_{i,t-1} g_{j,t-1}$	0.0876	***	0.0098
$\partial\omega_{i,t}/\partial g_{j,t-1}$ at median $\omega_{i,t-1}$	0.0094			$\partial z_{i,t}/\partial g_{j,t-1}$ at median $z_{i,t-1}$	0.0225		
Number of observations	1,347,547			Number of observations	1,347,547		
R-squared	0.991			R-squared	0.770		

Note:
1. Industrial dummies are included.
2. *** p<0.01, ** p<0.05, * p<0.1

Table 5 Nonparametric estimates of the output elasticities

Panel A: TFPQ				Panel B: TFPR			
industry	25th pct	50th pct	75th pct	industry	25th pct	50th pct	75th pct
13	-0.058	-0.058	-0.057	13	-0.003	-0.002	0.000
14	-0.027	-0.017	-0.006	14	0.021	0.021	0.021
15	0.056	0.057	0.058	15	-0.001	0.004	0.008
16	0.030	0.032	0.034	16	0.033	0.035	0.039
17	0.011	0.017	0.021	17	-0.001	0.005	0.014
18	-0.001	-0.001	0.000	18	0.026	0.026	0.027
19	0.023	0.026	0.029	19	0.002	0.006	0.014
20	-0.030	-0.016	-0.003	20	-0.011	0.004	0.020
21	-0.004	0.007	0.016	21	-0.015	0.000	0.020
22	0.002	0.008	0.016	22	0.013	0.016	0.020
23	-0.009	0.002	0.013	23	0.040	0.043	0.046
24	0.020	0.035	0.049	24	0.012	0.021	0.030
26	-0.014	-0.012	-0.010	26	0.001	0.002	0.003
27	-0.012	-0.010	-0.007	27	0.017	0.024	0.033
28	0.032	0.036	0.041	28	0.005	0.015	0.024
29	-0.011	-0.004	0.001	29	-0.023	0.005	0.015
30	-0.016	-0.006	0.003	30	-0.003	0.001	0.002
31	0.013	0.017	0.020	31	0.014	0.021	0.028
32	0.015	0.018	0.020	32	-0.006	-0.004	-0.002
34	-0.020	-0.015	-0.011	34	-0.015	-0.008	-0.002
35	-0.009	-0.004	0.002	35	0.009	0.018	0.022
36	-0.003	-0.002	0.000	36	0.003	0.009	0.013
37	-0.013	-0.009	-0.004	37	0.002	0.008	0.013
39	-0.049	-0.047	-0.045	39	-0.027	-0.025	-0.024
40	0.009	0.032	0.053	40	0.020	0.020	0.020
41	-0.013	-0.008	-0.002	41	-0.024	-0.008	0.017
42	-0.013	-0.003	0.009	42	-0.001	0.001	0.003
average	-0.003	0.003	0.009	average	0.003	0.009	0.016

Table 6 Output elasticities and average rates of return

Panel A: TFPQ

code	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
13	-0.045	-0.045	-0.045	-0.045	-0.045	-0.044	-0.044	-0.044	-0.044	-0.045
14	-0.017	-0.017	-0.013	-0.010	-0.014	-0.009	-0.005	-0.004	-0.003	-0.010
15	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.048	0.048	0.047
16	0.023	0.022	0.023	0.023	0.022	0.022	0.021	0.022	0.022	0.022
17	0.007	0.008	0.010	0.009	0.011	0.016	0.015	0.024	0.022	0.014
18	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	0.000
19	0.024	0.025	0.024	0.023	0.022	0.022	0.019	0.019	0.018	0.022
20	-0.006	-0.011	-0.023	-0.017	-0.015	-0.020	-0.021	-0.028	-0.033	-0.020
21	0.006	0.005	0.004	0.004	0.004	0.000	-0.003	-0.009	-0.011	0.000
22	0.006	0.008	0.010	0.010	0.011	0.013	0.018	0.021	0.024	0.013
23	-0.003	-0.003	-0.001	-0.001	0.000	0.001	0.007	0.011	0.013	0.003
24	0.044	0.047	0.041	0.041	0.040	0.035	0.023	0.016	0.013	0.033
26	-0.008	-0.009	-0.011	-0.011	-0.012	-0.014	-0.013	-0.012	-0.014	-0.012
27	-0.008	-0.008	-0.009	-0.008	-0.009	-0.009	-0.010	-0.010	-0.011	-0.009
28	0.033	0.028	0.037	0.039	0.031	0.031	0.031	0.028	0.024	0.031
29	-0.007	-0.008	-0.009	-0.009	-0.011	-0.013	-0.013	-0.014	-0.014	-0.011
30	0.004	0.003	0.002	0.001	0.001	-0.009	-0.013	-0.016	-0.018	-0.005
31	0.016	0.017	0.016	0.016	0.017	0.015	0.013	0.012	0.011	0.015
32	0.018	0.020	0.021	0.020	0.021	0.021	0.017	0.018	0.023	0.020
34	-0.010	-0.009	-0.012	-0.012	-0.012	-0.015	-0.016	-0.016	-0.016	-0.013
35	-0.008	-0.008	-0.004	-0.004	-0.003	0.000	0.002	0.004	0.006	-0.002
36	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	0.000	-0.002
37	-0.006	-0.005	-0.004	-0.004	-0.006	-0.003	-0.003	-0.001	-0.001	-0.004
39	-0.042	-0.042	-0.044	-0.043	-0.043	-0.044	-0.044	-0.043	-0.042	-0.043
40	0.027	0.029	0.022	0.032	0.030	0.031	0.024	0.010	0.002	0.023
41	-0.005	-0.004	-0.003	-0.002	0.000	0.002	0.003	0.005	0.006	0.000
42	-0.006	-0.007	-0.001	-0.003	0.000	0.007	0.009	0.013	0.018	0.003
average elasticity	0.002	0.002	0.002	0.003	0.002	0.003	0.002	0.001	0.000	0.002
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.010	0.012	0.009	0.014	0.015	0.019	0.009	0.003	0.000	0.010
return to economy	0.026	0.031	0.023	0.035	0.036	0.045	0.020	0.007	0.000	0.025

Table 6 Output elasticities and average rates of return

Panel B: TFPR

code	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
13	0.000	0.000	-0.001	-0.001	-0.002	-0.003	-0.003	-0.004	-0.004	-0.002
14	0.018	0.018	0.018	0.017	0.018	0.017	0.016	0.017	0.017	0.017
15	0.000	0.002	0.004	0.004	0.007	0.004	0.006	0.007	0.010	0.005
16	0.024	0.025	0.024	0.024	0.024	0.025	0.026	0.026	0.025	0.025
17	0.016	0.013	0.013	0.012	0.010	0.007	0.005	-0.020	0.005	0.007
18	0.023	0.023	0.022	0.022	0.022	0.022	0.021	0.021	0.021	0.022
19	0.014	0.016	0.013	0.013	0.012	0.007	0.004	0.002	0.002	0.009
20	0.035	0.030	0.020	0.022	0.022	0.014	0.005	-0.005	-0.011	0.014
21	0.022	0.023	0.019	0.018	0.016	0.010	0.002	-0.011	-0.017	0.009
22	0.011	0.012	0.013	0.013	0.014	0.015	0.018	0.021	0.022	0.016
23	0.034	0.034	0.035	0.035	0.035	0.036	0.037	0.038	0.039	0.036
24	0.026	0.027	0.024	0.025	0.024	0.020	0.012	0.008	0.006	0.019
26	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.000	0.000	0.001
27	0.020	0.019	0.022	0.022	0.024	0.025	0.032	0.034	0.038	0.026
28	0.011	0.023	0.018	0.017	0.005	0.022	0.024	0.012	-0.006	0.014
29	-0.021	-0.020	-0.015	-0.014	-0.011	0.002	0.012	0.017	0.018	-0.004
30	-0.003	-0.003	-0.002	-0.002	-0.002	0.000	0.002	0.002	0.003	0.000
31	0.011	0.010	0.012	0.012	0.012	0.015	0.020	0.023	0.026	0.016
32	-0.006	-0.005	0.007	0.003	0.006	0.000	-0.011	-0.010	-0.004	-0.002
34	0.004	0.005	0.001	0.001	0.000	-0.004	-0.008	-0.008	-0.010	-0.002
35	0.004	0.017	0.014	0.008	0.014	0.018	0.020	0.017	0.028	0.016
36	0.003	0.003	0.004	0.004	0.005	0.006	0.010	0.012	0.013	0.007
37	-0.001	0.000	0.001	0.001	0.002	0.004	0.008	0.010	0.012	0.004
39	-0.027	-0.025	-0.027	-0.028	-0.027	-0.026	-0.011	-0.018	-0.028	-0.024
40	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
41	0.027	0.023	0.017	0.011	0.005	-0.003	-0.013	-0.024	-0.028	0.002
42	-0.002	-0.001	0.000	0.000	0.001	0.002	0.003	0.003	0.004	0.001
average elasticity	0.006	0.007	0.008	0.007	0.007	0.007	0.008	0.006	0.008	0.007
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.032	0.039	0.040	0.038	0.045	0.042	0.042	0.029	0.038	0.038
return to economy	0.080	0.095	0.099	0.092	0.107	0.098	0.097	0.067	0.088	0.092

Table 7 Output elasticities and average rates of return with spillover effects

Panel A: TFPQ

code	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
13	-0.102	-0.102	-0.103	-0.103	-0.103	-0.104	-0.102	-0.102	-0.102	-0.102
14	-0.018	-0.020	-0.017	-0.014	-0.022	-0.020	-0.020	-0.022	-0.022	-0.019
15	-0.002	-0.002	-0.002	-0.002	0.002	-0.002	0.004	0.008	0.007	0.001
16	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.005	0.004
17	0.031	0.032	0.033	0.033	0.035	0.036	0.037	0.039	0.041	0.035
18	0.045	0.043	0.046	0.046	0.046	0.048	0.053	0.057	0.060	0.049
19	0.069	0.070	0.068	0.065	0.063	0.061	0.058	0.057	0.055	0.063
20	-0.002	-0.009	-0.032	-0.021	-0.019	-0.026	-0.027	-0.037	-0.046	-0.024
21	-0.014	-0.014	-0.013	-0.011	-0.011	-0.011	-0.009	-0.016	-0.016	-0.013
22	0.017	0.017	0.018	0.018	0.017	0.017	0.014	0.013	0.011	0.016
23	0.005	-0.001	-0.002	-0.011	-0.014	-0.017	-0.009	-0.003	-0.002	-0.006
24	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.091	0.092
26	-0.017	-0.017	-0.018	-0.018	-0.019	-0.020	-0.020	-0.019	-0.020	-0.019
27	-0.045	-0.045	-0.044	-0.044	-0.044	-0.043	-0.044	-0.043	-0.043	-0.044
28	0.055	0.040	0.060	0.065	0.046	0.044	0.049	0.044	0.034	0.049
29	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032	-0.032
30	-0.010	-0.009	-0.009	-0.009	-0.009	-0.016	-0.017	-0.018	-0.018	-0.013
31	0.024	0.020	0.024	0.020	0.018	0.025	0.038	0.044	0.049	0.029
32	0.052	0.053	0.053	0.053	0.054	0.054	0.051	0.053	0.056	0.053
34	-0.014	-0.012	-0.015	-0.014	-0.015	-0.017	-0.018	-0.018	-0.018	-0.016
35	-0.007	-0.012	-0.004	-0.009	-0.008	-0.004	-0.001	0.001	0.002	-0.005
36	-0.004	-0.005	-0.005	-0.005	-0.006	-0.005	-0.003	-0.003	-0.003	-0.005
37	-0.006	-0.009	-0.008	-0.008	-0.011	-0.010	-0.013	-0.012	-0.014	-0.010
39	-0.080	-0.080	-0.081	-0.081	-0.081	-0.082	-0.081	-0.080	-0.077	-0.080
40	0.019	0.041	0.047	0.078	0.088	0.117	0.112	0.094	0.090	0.076
41	0.013	0.014	0.015	0.016	0.019	0.024	0.026	0.030	0.030	0.021
42	0.012	0.008	0.017	0.016	0.022	0.031	0.036	0.042	0.049	0.026
average elasticity	-0.001	-0.001	0.001	0.004	0.005	0.011	0.012	0.011	0.009	0.006
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	-0.007	-0.003	0.006	0.022	0.033	0.065	0.062	0.054	0.044	0.031
return to economy	-0.017	-0.007	0.014	0.054	0.079	0.151	0.144	0.124	0.102	0.072

Table 7 Output elasticities and average rates of return with spillover effects

Panel B: TFPR

code	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
13	0.015	0.012	0.007	0.005	0.001	-0.010	-0.006	-0.015	-0.016	-0.001
14	0.050	0.050	0.050	0.050	0.050	0.050	0.049	0.049	0.049	0.050
15	0.027	0.030	0.034	0.035	0.041	0.036	0.040	0.042	0.049	0.037
16	0.056	0.055	0.055	0.055	0.055	0.054	0.053	0.053	0.054	0.054
17	0.039	0.035	0.034	0.033	0.030	0.026	0.024	-0.006	0.023	0.027
18	0.058	0.059	0.055	0.054	0.056	0.053	0.045	0.042	0.042	0.052
19	0.037	0.040	0.034	0.033	0.031	0.023	0.015	0.012	0.011	0.026
20	0.079	0.070	0.051	0.055	0.055	0.041	0.025	0.007	-0.004	0.042
21	0.057	0.057	0.049	0.048	0.045	0.033	0.019	-0.002	-0.013	0.033
22	0.039	0.040	0.041	0.041	0.043	0.044	0.047	0.051	0.052	0.044
23	0.063	0.062	0.066	0.063	0.065	0.070	0.073	0.076	0.079	0.069
24	0.067	0.069	0.063	0.064	0.062	0.054	0.038	0.027	0.024	0.052
26	0.017	0.017	0.016	0.015	0.015	0.013	0.013	0.012	0.011	0.014
27	0.010	0.009	0.010	0.010	0.011	0.013	0.020	0.022	0.025	0.014
28	0.041	0.055	0.047	0.046	0.030	0.052	0.054	0.037	0.013	0.042
29	-0.067	-0.066	-0.054	-0.053	-0.049	-0.023	0.002	0.011	0.014	-0.032
30	0.011	0.011	0.010	0.010	0.010	0.007	0.006	0.005	0.004	0.008
31	0.039	0.039	0.040	0.040	0.040	0.041	0.044	0.045	0.047	0.042
32	-0.001	0.000	0.007	0.005	0.006	0.002	-0.004	-0.003	0.000	0.002
34	0.005	0.006	0.002	0.001	0.000	-0.004	-0.008	-0.009	-0.010	-0.002
35	0.017	0.047	0.040	0.028	0.041	0.053	0.056	0.051	0.077	0.046
36	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.015	0.015
37	0.010	0.013	0.014	0.015	0.018	0.021	0.031	0.036	0.040	0.022
39	-0.041	-0.038	-0.040	-0.043	-0.041	-0.040	-0.022	-0.030	-0.043	-0.038
40	0.050	0.049	0.047	0.047	0.044	0.041	0.038	0.034	0.032	0.043
41	0.027	0.027	0.029	0.030	0.033	0.035	0.037	0.040	0.041	0.033
42	0.002	0.003	0.005	0.005	0.006	0.008	0.009	0.010	0.011	0.007
average elasticity	0.022	0.024	0.023	0.022	0.022	0.022	0.023	0.020	0.023	0.022
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.113	0.127	0.119	0.121	0.137	0.126	0.121	0.097	0.107	0.119
return to economy	0.280	0.311	0.292	0.293	0.323	0.293	0.283	0.225	0.248	0.283

Table 8 Rates of return of private investment by industry

industry	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
13	0.146	0.156	0.178	0.209	0.245	0.252	0.283	0.289	0.293	0.228
14	0.122	0.135	0.146	0.168	0.196	0.213	0.254	0.274	0.308	0.202
15	0.104	0.109	0.111	0.130	0.144	0.165	0.199	0.244	0.268	0.164
16	0.431	0.435	0.454	0.500	0.503	0.533	0.577	0.617	0.679	0.525
17	0.033	0.037	0.040	0.046	0.050	0.053	0.070	0.072	0.079	0.053
18	0.113	0.121	0.127	0.141	0.153	0.152	0.184	0.200	0.211	0.156
19	0.082	0.088	0.096	0.112	0.123	0.124	0.140	0.146	0.161	0.119
20	0.079	0.083	0.088	0.104	0.104	0.107	0.144	0.155	0.170	0.115
21	0.103	0.107	0.113	0.138	0.159	0.162	0.188	0.205	0.230	0.156
22	0.156	0.172	0.179	0.202	0.228	0.239	0.290	0.318	0.377	0.240
23	0.196	0.199	0.204	0.240	0.264	0.266	0.338	0.381	0.450	0.282
24	0.314	0.337	0.326	0.346	0.380	0.368	0.452	0.442	0.488	0.384
26	0.080	0.085	0.093	0.108	0.127	0.128	0.155	0.168	0.183	0.125
27	0.365	0.404	0.417	0.436	0.456	0.454	0.548	0.570	0.667	0.480
28	0.026	0.030	0.034	0.040	0.051	0.046	0.067	0.072	0.078	0.049
29	0.110	0.113	0.116	0.127	0.140	0.154	0.184	0.194	0.223	0.151
30	0.185	0.194	0.208	0.233	0.267	0.252	0.304	0.335	0.373	0.261
31	0.201	0.219	0.229	0.271	0.308	0.324	0.418	0.474	0.557	0.333
32	0.026	0.030	0.034	0.043	0.053	0.055	0.060	0.070	0.072	0.049
34	0.037	0.043	0.042	0.052	0.059	0.065	0.072	0.075	0.081	0.058
35	0.106	0.115	0.126	0.154	0.192	0.215	0.269	0.298	0.314	0.199
36	0.142	0.156	0.160	0.209	0.251	0.280	0.350	0.378	0.431	0.262
37	0.112	0.111	0.124	0.165	0.203	0.227	0.231	0.271	0.303	0.194
39	0.129	0.145	0.150	0.172	0.206	0.231	0.261	0.273	0.289	0.206
40	0.514	0.606	0.635	0.702	0.840	0.925	1.245	1.297	1.347	0.901
41	0.132	0.140	0.161	0.171	0.188	0.233	0.286	0.284	0.298	0.210
42	0.276	0.284	0.291	0.307	0.336	0.343	0.352	0.357	0.365	0.324
average	0.159	0.180	0.191	0.221	0.255	0.288	0.361	0.389	0.414	0.273

Table 9 Output elasticities and average rates of return from robustness checks

Table 9.1 Broad infrastructure investment

Panel A: TFPQ

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	0.000	0.000	0.000	0.001	0.001	0.003	0.002	0.001	0.000	0.001
industrial GDP/BG	3.963	3.954	3.921	4.045	4.280	4.126	3.907	3.632	3.454	3.920
total GDP/BG	9.832	9.689	9.574	9.798	10.116	9.627	9.098	8.442	7.980	9.351
return to industry	-0.001	0.001	0.000	0.005	0.006	0.012	0.006	0.003	0.000	0.004
return to economy	-0.002	0.003	0.001	0.012	0.014	0.027	0.015	0.007	0.001	0.009

Panel B: TFPR

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	0.007	0.008	0.009	0.008	0.008	0.008	0.009	0.008	0.009	0.008
industrial GDP/G	3.963	3.954	3.921	4.045	4.280	4.126	3.907	3.632	3.454	3.920
total GDP/G	9.832	9.689	9.574	9.798	10.116	9.627	9.098	8.442	7.980	9.351
return to industry	0.029	0.033	0.034	0.032	0.036	0.035	0.036	0.027	0.033	0.033
return to economy	0.071	0.082	0.083	0.077	0.085	0.081	0.084	0.064	0.075	0.078

Table 9.2 Third-order polynomial

Panel A: TFPQ

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.001	0.002
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.009	0.012	0.011	0.016	0.019	0.019	0.016	0.009	0.004	0.013
return to economy	0.022	0.029	0.026	0.039	0.044	0.045	0.037	0.020	0.009	0.030

Panel B: TFPR

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	0.004	0.004	0.005	0.005	0.004	0.005	0.006	0.007	0.007	0.005
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.021	0.023	0.024	0.026	0.027	0.030	0.034	0.032	0.031	0.027
return to economy	0.051	0.057	0.058	0.062	0.064	0.070	0.080	0.075	0.071	0.065

Table 9.3 Spillover effects from neighbouring provinces

Panel A: TFPQ

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	-0.004	-0.002	-0.001	0.001	0.002	0.006	0.006	0.006	0.007	0.002
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	-0.018	-0.011	-0.006	0.007	0.014	0.035	0.031	0.031	0.035	0.013
return to economy	-0.045	-0.028	-0.016	0.016	0.034	0.082	0.071	0.073	0.080	0.030

Panel B: TFPR

year	1999	2000	2001	2002	2003	2004	2005	2006	2007	average
average elasticity	0.015	0.017	0.015	0.014	0.014	0.014	0.015	0.012	0.016	0.015
industrial GDP/G	5.048	5.196	5.193	5.461	6.107	5.736	5.276	4.906	4.757	5.298
total GDP/G	12.525	12.733	12.682	13.229	14.437	13.385	12.285	11.406	10.992	12.630
return to industry	0.077	0.087	0.076	0.079	0.087	0.081	0.078	0.059	0.076	0.078
return to economy	0.192	0.213	0.186	0.191	0.207	0.189	0.182	0.138	0.176	0.186

Table 10 Output elasticities and firm characteristics

Dependant variable: output elasticities

model	TFPQ	TFPR	TFPQ with spillover	TFPR with spillover
lnage	-0.000379***	-0.000131***	-0.000506***	-0.000233***
	(1.69e-05)	(1.88e-05)	(3.88e-05)	(4.20e-05)
lnemp	-0.000148***	-7.74e-05***	-0.000162***	-0.000177***
	(1.48e-05)	(1.91e-05)	(3.39e-05)	(4.12e-05)
NSOE	0.00136***	0.00113***	0.000240*	0.000430***
	(5.91e-05)	(7.94e-05)	(0.000134)	(0.000167)
EXPORT	0.000477***	0.000725***	0.00157***	0.000669***
	(2.69e-05)	(2.65e-05)	(5.88e-05)	(4.91e-05)
EASTERN	0.00197***	0.000482***	0.000876***	0.000165***
	(2.78e-05)	(2.95e-05)	(5.99e-05)	(6.32e-05)
observations	1,346,897	1,346,897	1,346,897	1,346,897
R-squared	0.774	0.490	0.774	0.480

Note:

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

Table 11 Probit models of exit probabilities

Panel A: TFPQ

Dependent variable: firm i exit in year t+1

model	TFPQ			TFPQ with spillover effects		
	col (1)	col (2)	col (3)	col (1)	col (2)	col (3)
ω_{it}	-0.148***	-0.159***	-0.112***	-0.141***	-0.151***	-0.104***
	(0.00404)	(0.00402)	(0.00469)	(0.00397)	(0.00395)	(0.00457)
k_{it}	-0.136***	-0.135***	-0.136***	-0.136***	-0.135***	-0.135***
	(0.00107)	(0.00107)	(0.00107)	(0.00107)	(0.00107)	(0.00107)
g_{jt}		-0.106***	-0.120***		-0.205***	-0.233***
		(0.00304)	(0.00310)		(0.00575)	(0.00586)
$g_{jt} * LOW_{it}$			0.00518***			0.00527***
			(0.000219)			(0.000212)
observations	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116
predicted prob	0.1116	0.1114	0.1111	0.1117	0.1114	0.1111

Panel B: TFPR

Dependent variable: firm i exit in year t+1

model	TFPR			TFPR with spillover effects		
	col (1)	col (2)	col (3)	col (1)	col (2)	col (3)
z_{it}	-0.142***	-0.140***	-0.0958***	-0.143***	-0.140***	-0.0908***
	(0.00432)	(0.00426)	(0.00488)	(0.00438)	(0.00431)	(0.00490)
k_{it}	-0.137***	-0.136***	-0.138***	-0.136***	-0.136***	-0.137***
	(0.00107)	(0.00107)	(0.00107)	(0.00107)	(0.00107)	(0.00107)
g_{jt}		-0.0877***	-0.0914***		-0.172***	-0.178***
		(0.00303)	(0.00303)		(0.00574)	(0.00574)
$g_{jt} * LOW_{it}$			0.00474***			0.00515***
			(0.000209)			(0.000201)
observations	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116	1,106,116
predicted prob	0.1118	0.1116	0.1113	0.1118	0.1115	0.1113

Note:

1. Industry dummies and year dummies are included in all regressions.

2. LOW: dummy variable, LOW_{it} = 1 (0) if $productivity_{it}$ is below (beyond) median.

Table 12 Regression models of market shares

Panel A: TFPQ

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

model	TFPQ			TFPQ with spillover effects		
	col (1)	col (2)	col (3)	col (1)	col (2)	col (3)
ω_{it-1}	0.461***	0.529***	0.362***	0.430***	0.497***	0.332***
	(0.00391)	(0.00399)	(0.00385)	(0.00387)	(0.00395)	(0.00377)
k_{it-1}	0.562***	0.563***	0.562***	0.561***	0.562***	0.559***
	(0.000686)	(0.000677)	(0.000658)	(0.000688)	(0.000678)	(0.000659)
g_{jt-1}		0.378***	0.439***		0.721***	0.863***
		(0.00192)	(0.00191)		(0.00355)	(0.00354)
$g_{jt-1} * HIGH_{it-1}$			0.0268***			0.0271***
			(0.000109)			(0.000105)
observations	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

Panel B: TFPR

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

model	TFPR			TFPR with spillover effects		
	col (1)	col (2)	col (3)	col (1)	col (2)	col (3)
z_{it-1}	0.532***	0.534***	0.380***	0.517***	0.520***	0.363***
	(0.00446)	(0.00434)	(0.00417)	(0.00451)	(0.00438)	(0.00418)
k_{it-1}	0.566***	0.566***	0.572***	0.564***	0.565***	0.569***
	(0.000687)	(0.000681)	(0.000665)	(0.000687)	(0.000681)	(0.000661)
g_{jt-1}		0.312***	0.311***		0.604***	0.621***
		(0.00185)	(0.00182)		(0.00344)	(0.00336)
$g_{jt-1} * HIGH_{it-1}$			0.0260***			0.0266***
			(0.000102)			(9.80e-05)
observations	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

Note:

1. Industry dummies and year dummies are included in all regressions.
2. HIGH: dummy variable, $HIGH_{it-1}$ = 1 (0) if $productivity_{it-1}$ is below (beyond) median.

Table A1 Re-estimating Table 3 Panel B using 2003-2007 subsample

code	θ_l	θ_k	θ_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 A2 Re-estimating Table 3 Panel A using non-exporters subsample

code	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 A3 Estimates for the revenue equations with spillover effects

Panel A: TFPQ

code	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	0.042	0.020	0.031	0.004	0.913	0.019	0.036	0.007	0.274	0.071
14	0.128	0.027	0.040	0.021	0.842	0.028	0.147	0.017	0.113	0.015
15	-0.029	0.029	0.052	0.029	0.969	0.019	-0.021	0.025	0.155	0.022
16	0.622	0.499	0.190	0.282	0.615	0.302	0.036	0.041	0.308	0.194
17	0.160	0.047	0.033	0.022	0.780	0.070	-0.015	0.037	0.038	0.027
18	0.198	0.036	0.009	0.004	0.806	0.031	-0.083	0.008	0.153	0.016
19	0.192	0.012	0.032	0.007	0.781	0.024	-0.248	0.010	0.153	0.020
20	-0.080	0.072	0.061	0.049	0.937	0.077	0.021	0.028	0.619	0.054
21	0.017	0.074	0.074	0.073	0.826	0.100	0.167	0.026	0.213	0.064
22	-0.029	0.036	0.000	0.041	1.038	0.055	-0.024	0.030	0.162	0.038
23	-0.054	0.035	0.111	0.066	0.889	0.038	0.134	0.016	0.207	0.023
24	0.297	0.029	0.033	0.007	0.679	0.038	-0.219	0.015	0.150	0.024
26	0.029	0.036	0.035	0.008	0.919	0.028	0.027	0.021	0.052	0.015
27	0.032	0.038	0.057	0.060	0.916	0.032	0.235	0.016	0.201	0.027
28	0.033	0.009	0.029	0.005	0.923	0.011	-0.025	0.008	0.014	0.037
29	0.046	0.084	0.034	0.062	0.914	0.060	0.078	0.021	0.156	0.025
30	0.045	0.100	0.052	0.107	0.874	0.177	0.126	0.020	0.220	0.104
31	0.144	0.013	-0.003	0.035	0.891	0.011	0.100	0.011	0.231	0.017
32	0.046	0.006	0.019	0.003	0.937	0.006	0.018	0.004	-0.103	0.080
34	0.023	0.062	0.034	0.016	0.931	0.053	0.025	0.017	0.055	0.010
35	0.016	0.043	0.039	0.012	0.928	0.043	0.034	0.025	0.068	0.016
36	0.017	0.104	0.068	0.051	0.873	0.073	0.151	0.038	0.075	0.032
37	0.204	0.026	0.058	0.047	0.755	0.030	0.260	0.018	0.045	0.020
39	0.061	0.087	0.027	0.013	0.905	0.085	0.077	0.010	-0.019	0.033
40	0.114	0.034	-0.008	0.035	0.930	0.016	0.231	0.012	0.183	0.020
41	0.044	0.069	0.128	0.094	0.721	0.109	0.167	0.034	-0.038	0.041
42	0.250	0.076	0.035	0.014	0.708	0.070	-0.011	0.014	0.102	0.020

Note: All standard errors are bootstrapped using 1000 replications.

Table A3 Estimates for the revenue equations with spillover effects

Panel B: TFPR

code	θ_l	$s.e.(\theta_l)$	θ_k	$s.e.(\theta_k)$	θ_m	$s.e.(\theta_m)$
13	0.041	0.005	0.034	0.003	0.915	0.004
14	0.043	0.017	0.052	0.005	0.905	0.010
15	0.003	0.038	0.057	0.011	0.943	0.035
16	0.444	0.764	0.187	0.100	0.699	0.425
17	0.038	0.010	0.019	0.003	0.936	0.013
18	0.142	0.048	0.017	0.004	0.847	0.044
19	0.062	0.020	0.022	0.008	0.919	0.030
20	0.101	0.058	-0.012	0.045	0.980	0.074
21	0.037	0.036	0.047	0.024	0.896	0.036
22	0.064	0.030	0.062	0.027	0.848	0.036
23	0.092	0.167	0.113	0.020	0.798	0.119
24	0.080	0.069	0.059	0.012	0.838	0.088
26	0.026	0.007	0.034	0.003	0.927	0.007
27	0.118	0.031	-0.003	0.041	0.994	0.072
28	0.028	0.012	0.024	0.008	0.935	0.014
29	0.051	0.061	0.011	0.030	0.951	0.072
30	0.061	0.012	0.058	0.019	0.861	0.025
31	0.090	0.008	0.061	0.022	0.864	0.005
32	0.052	0.013	0.014	0.008	0.945	0.012
34	0.093	0.034	0.014	0.023	0.935	0.045
35	0.017	0.006	0.045	0.005	0.914	0.009
36	0.064	0.021	0.037	0.022	0.912	0.032
37	0.125	0.037	0.027	0.020	0.874	0.028
39	0.045	0.007	0.031	0.004	0.917	0.008
40	0.129	0.026	0.080	0.023	0.820	0.027
41	0.094	0.058	0.114	0.039	0.727	0.092
42	0.087	0.035	0.039	0.004	0.859	0.035

Note: All standard errors are bootstrapped using 1000 replications.

Table A4 Nonparametric estimates of the productivity processes with spillover effects

Panel A: TFPQ					Panel B: TFPR		
	Estimate		Standard error			Estimate		Standard error
$\omega_{i,t-1}$	0.3370	***	0.0155	$z_{i,t-1}$	-1.4870	***	0.2505
$\omega^2_{i,t-1}$	-0.0239	***	0.0014	$z^2_{i,t-1}$	-0.0205	***	0.0049
$\omega^3_{i,t-1}$	-0.0008	***	0.0001	$z^3_{i,t-1}$	0.0001	***	0.0000
$\omega^4_{i,t-1}$	0.0000	***	0.0000	$z^4_{i,t-1}$	0.0000	***	0.0000
$g_{j,t-1}$	0.0379	***	0.0012	$g_{j,t-1}$	-0.0100		0.0065
$\omega_{i,t-1}g_{j,t-1}$	0.0124	***	0.0004	$z_{i,t-1}g_{j,t-1}$	0.1185	***	0.0129
$\partial\omega_{i,t}/\partial g_{j,t-1}$ at median $\omega_{i,t-1}$				$\partial z_{i,t}/\partial g_{j,t-1}$ at median $z_{i,t-1}$			
	0.0196				0.0572		
Number of observations				Number of observations			
	1,347,547				1,347,547		
R-squared				R-squared			
	0.997				0.783		

Note:
1. Industrial dummies are included.
2. *** p<0.01, ** p<0.05, * p<0.1

Table A5 Nonparametric estimates of the output elasticities with spillover effects

Panel A: TFPQ				Panel B: TFPR			
industry	25th pct	50th pct	75th pct	industry	25th pct	50th pct	75th pct
13	-0.132	-0.130	-0.129	13	-0.007	0.003	0.017
14	-0.046	-0.034	-0.022	14	0.060	0.061	0.061
15	-0.015	-0.005	0.006	15	0.030	0.039	0.050
16	0.002	0.005	0.008	16	0.075	0.078	0.081
17	0.037	0.041	0.044	17	0.021	0.030	0.040
18	0.051	0.058	0.065	18	0.053	0.060	0.069
19	0.067	0.071	0.079	19	0.016	0.023	0.039
20	-0.051	-0.031	-0.009	20	-0.001	0.026	0.055
21	-0.017	-0.006	0.007	21	-0.002	0.025	0.058
22	0.013	0.016	0.019	22	0.044	0.048	0.053
23	-0.039	-0.017	0.006	23	0.072	0.080	0.090
24	0.102	0.103	0.103	24	0.041	0.060	0.080
26	-0.022	-0.020	-0.019	26	0.015	0.017	0.019
27	-0.053	-0.051	-0.049	27	0.016	0.024	0.032
28	0.049	0.059	0.071	28	0.030	0.044	0.057
29	-0.038	-0.038	-0.038	29	-0.061	-0.007	0.022
30	-0.022	-0.012	-0.005	30	0.006	0.008	0.012
31	0.019	0.036	0.053	31	0.046	0.049	0.053
32	0.056	0.058	0.060	32	0.000	0.001	0.002
34	-0.021	-0.017	-0.013	34	-0.015	-0.008	-0.001
35	-0.018	-0.011	-0.002	35	0.029	0.051	0.061
36	-0.014	-0.010	-0.006	36	0.017	0.018	0.018
37	-0.041	-0.030	-0.018	37	0.014	0.026	0.036
39	-0.091	-0.089	-0.087	39	-0.042	-0.040	-0.038
40	0.001	0.078	0.156	40	0.042	0.049	0.057
41	-0.012	0.000	0.013	41	0.025	0.031	0.036
42	-0.012	0.008	0.035	42	0.005	0.008	0.010
average	-0.009	0.001	0.012	average	0.020	0.030	0.040