Bridging Micro and Macro Production Functions: The Fiscal Multiplier of Infrastructure Investment*

Minsu Chang† Hanbaek Lee‡

November 11, 2025

Abstract

This paper investigates the fiscal multiplier of infrastructure investment using an estimated heterogeneous-firm general equilibrium model. We theoretically and quantitatively show that the firm-level non-rivalry in infrastructure usage drives a significant discrepancy in the estimated input elasticities between the firm and state levels. Moreover, it microfounds the increasing returns to scale assumption in a representative-agent framework (Baxter and King, 1993). The quantitative findings indicate a fiscal multiplier of approximately 1.15 over a 2-year horizon, suggesting a significantly greater net economic benefit than the representative-agent model prediction. This is due to the low sensitivity of the firm-level investment to the general equilibrium effect, followed by a significantly dampened crowding out.

Keywords: Infrastructure investment, fiscal multiplier, heterogeneous-agent model, non-rivalry.

JEL codes: E23, E60, H54.

*This paper was previously circulated under the title "Public Infrastructure Investment and Corporate Taxations." We are grateful for Kosuke Aoki, Ippei Fujiwara, Chad Jones, David Lagakos, Ponpoje Porapakkarm, B. Ravikumar, José-Víctor Ríos-Rull, Tatsuro Senga, Michael Song, Donghai Zhang, Sarah Zubairy, and participants of the seminar at Federal Reserve Bank of New York, National Graduate Institute for Policies Studies, Seoul National University, American University, Federal Reserve Bank of St. Louis, University of Tokyo, Midwest Macro Meetings, KAEA Macro Workshop, and East Asia Macroeconomics Mini-Conference for their constructive comments and discussions. This work was supported by the Research Grant of the Center for National Competitiveness at the Institute of Economic Research, Seoul National University.

†Seoul National University. Email: minsuchang@snu.ac.kr

‡University of Cambridge. Email: hanbaeklee1@gmail.com

1 Introduction

The economic effects of infrastructure spending have become central to policy discussions, particularly with the Infrastructure Investment and Jobs Act, which allocates over $1.2 trillion to transportation and physical infrastructure projects. Fiscal multipliers are essential tools for evaluating government expenditure's economic impact. This paper examines the fiscal multiplier associated with infrastructure investment, incorporating firm-level investment decisions—an unexplored dimension in the literature.

Our heterogeneous firm model contributes to the literature in three key ways. First, we show that the non-rivalry of public capital leads to a substantial gap between firm-level and state-level elasticities of substitution between private and public capital in a CES production function. Specifically, firm-level gross substitutability translates into gross complementarity at the aggregate level. We also demonstrate that incorporating non-rivalry into a firm-level CES production function implies increasing returns to scale in an aggregate Cobb-Douglas production function, micro-founding the widely used production function in Baxter and King (1993).

This result follows from a simple economic intuition: a marginal increase in public capital raises all firms' marginal product of capital (MPK), amplifying the aggregate benefit beyond a single firm's response. Capturing this amplified benefit requires an additional efficiency-enhancing component in the aggregate production function, which we show manifests as complementarity in a CES function or increasing returns to scale in a Cobb-Douglas function.

Second, we find that the heterogeneous firm model yields a higher output multiplier than the representative firm model. This arises from firm-level convex capital adjustment costs, which discipline investment responses to interest rate changes (Winberry, 2021; Koby and Wolf, 2020). Since heterogeneous firms face higher average adjustment costs, their investment response is muted, mitigating the negative crowding-out effect and increasing the overall output multiplier.

Third, we estimate the heterogeneous firm model in general equilibrium—a computationally challenging task. We introduce a novel estimation procedure that jointly searches for market-clearing prices and model parameters, reducing computational costs. The fiscal multiplier in our model is significantly more sensitive to the elasticity of substitution than in a representative firm model due to the amplifying effect of public capital non-rivalry. This highlights the importance of estimating elasticity parameters in heterogeneous firm models.

Our baseline model features a firm-level CES production function incorporating private capital, public capital, and labor inputs. Public capital enters the production function in a non-rivalrous manner as in Glomm and Ravikumar (1994), but we extend this framework to include firm-level heterogeneity. Firms face idiosyncratic productivity shocks and lumpy investment decisions with both fixed and convex adjustment costs (Cooper and Haltiwanger, 2006; Winberry, 2021). We estimate the micro-level parameters under the general equilibrium by extending the existing simulated method of moments by including market-clearing conditions as additional moments, employing a multi-block Metropolis-Hastings algorithm. This significantly improves computational efficiency compared to conventional methods that solve for market-clearing prices at each parameter guess.

Using our estimated model, we compute fiscal multipliers following a one-time, unexpected infrastructure spending shock equal to 1% of steady-state GDP, financed by a lump-sum tax. While increased public capital boosts output, the resulting rise in interest rates leads to crowding out of private investment. Accounting for these effects, the short-run aggregate fiscal multiplier over two years is 1.149, compared to 1.414 in partial equilibrium, with the discrepancy driven by general equilibrium crowding-out effects. Our estimate exceeds those in the literature (Ramey, 2019, 2020), which abstract from non-rivalry and firm heterogeneity. We show that the firm-level frictional capital adjustment in the extensive margin is one of the key channels to the mitigated crowding-out effect in our heterogeneous-firm model. Also, the sorting between the fiscal infrastructure spending and the region-specific productivity significantly positively contributes to raising the fiscal multiplier.[1]

Related Literature Three strands of literature relate to our work. First, we contribute to studies on fiscal multipliers (Baxter and King, 1993; Leeper et al., 2010; Nakamura and Steinsson, 2014; Sims and Wolff, 2018; Hagedorn et al., 2019; Ramey, 2020; Hasna, 2021). Unlike prior work, we quantify infrastructure spending multipliers in a heterogeneous firm framework incorporating firm-level investment. Our theoretical results also micro-found the widely used macro-level production function in Baxter and King (1993).

Second, we contribute to research bridging micro- and macro-level elasticity estimates. Our approach aligns with Oberfield and Raval (2021), which estimates labor-capital substitution elasticities at plant and aggregate levels based on a structural framework. Similar to this paper, we find that the elasticity of substitution between private and public capital at the firm level differs from that at the state level, confirming that micro-level substitutability translates into macro-level complementarity.[2]

[1] The baseline multiplier in our quantitative model lies within the range of estimates reported in previous studies, such as Ramey (2011). A more extensive comparison of our estimates with the literature is in Appendix H. Appendix D includes additional quantitative analysis on the role of time-to-build and the inequality effects of the fiscal spending shock.

[2] We demonstrate this theoretically in Section 2 and quantitatively in Appendix C.

Third, we relate to literature on firm investment, which examines lumpy investment patterns and macroeconomic implications (Caballero and Engel, 1999; Cooper and Haltiwanger, 2006; Abel and Eberly, 2002; Khan and Thomas, 2008; Winberry, 2021). We incorporate convex and fixed capital adjustment costs, estimating parameters to capture firm-level investment dynamics. Our findings show that firm-level heterogeneity under capital adjustment frictions leads to a markedly different fiscal multiplier than the representative firm counterpart.

2 A simple theory on micro and macro production functions

In this section, we theoretically demonstrate that non-rivalry in public capital usage (such as infrastructure) at the firm level leads to a noteworthy disparity between the estimated input elasticities with micro and macro production functions. Specifically, we will use the terms "micro" to denote firm-level and "macro (or aggregate)" to refer to state-level unless otherwise indicated.[3]

Consider a CES production function $F(K, N, L; \lambda, z)$ with constant or decreasing returns to scale (CRS or DRS):

$$F(K, N, L; \lambda, z) = z(\theta K^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}\alpha} L^{\gamma}, \quad \alpha + \gamma \leq 1 \tag{1}$$

where λ is the elasticity of substitution between private and public capital; α is the capital share; γ is the labor share; K is the private capital input; N is the public capital input, L is the labor input; z is the productivity level. $\theta \in (0, 1)$ is the weight parameter between the private and public capital. Then, we consider a static labor

[3] It is essential to note that the theoretical implications presented in this section extend beyond a specific level of aggregation, transcending the state-level focus addressed in this paper.

demand problem: $\max_L \; F(K,N,L;\lambda,z) - wL$, which leads to the labor demand of $L^* = z^{\frac{1}{1-\gamma}} (\gamma/w)^{\frac{1}{1-\gamma}} (\theta K^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}\frac{\alpha}{1-\gamma}}$. We rewrite the production function with the implicit labor demand:

$$F(K,N,L^*;\lambda,z) = f(K,N;\lambda,z) := z^{\frac{1}{1-\gamma}} \left(\frac{\gamma}{w}\right)^{\frac{\gamma}{1-\gamma}} (\theta k^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}\frac{\alpha}{1-\gamma}}. \quad (2)$$

Then, we consider estimation of the elasticity of substitution at the firm level and at the state level using the CES production function as in equation (2). Suppose we use a dataset that contains firm-level observations (k_1, k_2, y_1, y_2, N), where the subscript $i \in \{1,2\}$ represents two different firms in the same state.[4] It is important to note that the state-level capital stock N is shared among all firms in the same state.

In the firm-level estimation, we estimate the firm-level elasticity and the productivity (z,λ) that satisfy

$$f(k_1, N; \lambda, z) = y_1 \quad \text{and} \quad f(k_2, N; \lambda, 1) = y_2, \quad (3)$$

where the second firm's productivity is normalized to be unity.

In the state-level estimation, we estimate the state-level elasticity ξ that satisfies

$$f(k_1 + k_2, N; \xi, 1) = y_1 + y_2. \quad (4)$$

where the state-level productivity is normalized to be unity.

We show that, due to the non-rivalrous nature of public capital, firm-level estimate λ and state-level estimate ξ can be starkly different. Under a set of mild conditions, to be formally outlined later, private and public capital are gross substitutes at the firm level, despite their gross complementary nature at the state level.

[4] Propositions in this section can be *generalized* to 1) $n \geq 2$ firms and 2) a continuum of firms indexed by $i \in [0,1]$. These results are available in Appendix K.

Intuitively, when a public capital stock increases, all the firms' marginal products of capital increase due to the non-rivalry, of which the sum outweighs a single firm's increase. To capture this amplified gain, an aggregate production function framework needs an extra component that leads to more efficient utilization of the public capital stock than a firm-level production. Therefore, in our paper's context, the state-level estimate supports a substantially stronger complementarity between private and public capital stocks than the firm-level estimate.[5]

Proposition 1. *Suppose we are given the micro-level data set* (k_1, k_2, y_1, y_2, N) *s.t.*

$$\exists i \in \{1, 2\} \text{ s.t. } k_i < N, \quad N \leq k_1 + k_2, \quad \frac{y_1}{k_1} = \frac{y_2}{k_2}.$$

Suppose the micro-level estimates (z, λ) *and the aggregate-level estimate* ξ *are exactly identified by fitting the data with the production functions as follows:*

$$f(k_1, N; \lambda, z) = y_1, \quad f(k_2, N; \lambda, 1) = y_2, \quad \text{and} \quad f(k_1 + k_2, N; \xi, 1) = y_1 + y_2.$$

Then, if the micro-level input elasticity satisfies $\lambda \geq 1$*, the aggregate-level input elasticity satisfies* $\xi < 1$.

Proof. See Appendix J. ■

2.1 Link to the production function of Baxter and King (1993)

In this section, we connect the CES production function in equation (2) with the widely employed production function proposed by Baxter and King (1993). To

[5]The assumptions of $k_i < N$ and $N < k_1 + k_2$ serve to capture a moderate case in which a public capital stock N is not too small to be greater than the smallest firm's capital stock, yet the total private capital in the economy remains larger than the available public capital.

The productivity set at 1 under the aggregate production function (which does not lie between the micro-level productivity 1 and z) is not crucial for our theoretical prediction. A slight change in the assumption allows the proposition to hold. Specifically, the necessary modification is $\forall i \in \{1, 2\}$ such that $k_i < N$. A detailed proof is available upon request.

examine the macroeconomic implications of changes in public capital, Baxter and King (1993) employs the following formulation of a production function:

$$H(K, N, L; \zeta, z) = zK^{\alpha} L^{\gamma} N^{\zeta}, \quad \alpha + \gamma \leq 1, \tag{5}$$

where α is the capital share between the private input factors; ζ is the scale parameter for the public capital stock. By rewriting the production function with the implicit labor demand, we obtain $h(K, N; \zeta, z) = z^{\frac{1}{1-\gamma}} (\gamma/w)^{\frac{\gamma}{1-\gamma}} K^{\frac{\alpha}{1-\gamma}} N^{\frac{\zeta}{1-\gamma}}$.

In Proposition 2, we show that the non-rivalry between the private and public capital stocks in the firm-level production function of (2) and these inputs being gross substitutes lead to the estimate of $\zeta > 0$ in the aggregate Cobb-Douglas production function under mild assumptions.

Proposition 2. *Suppose we are given the micro-level data set (k_1, k_2, y_1, y_2, N) s.t.*

$$\exists i \in \{1, 2\} \text{ s.t. } k_i < N, \quad 1 < N \leq k_1 + k_2, \quad \frac{y_1}{k_1} = \frac{y_2}{k_2}.$$

Suppose the micro-level estimates (z, λ) and the aggregate-level estimate ζ are exactly identified by fitting the data with the production functions as follows:

$$f(k_1, N; \lambda, z) = y_1, \quad f(k_2, N; \lambda, 1) = y_2, \quad \text{and} \quad h(k_1 + k_2, N; \zeta, 1) = y_1 + y_2.$$

Then, if the micro-level input elasticity satisfies $\lambda \geq 1$, the public capital scale parameter satisfies $\zeta > 0$.

Proof. See Appendix J. ■

Proposition 1 and Proposition 2 provide a theoretical connection between the firm-level and the aggregate-level production functions. In particular, the latter shows that the non-rivalrous characteristic of public capital, acting as a gross substitute for private capital within the firm-level CES production function, can potentially lead to the emergence of increasing returns to scale (IRS) Cobb-Douglas production functions, aligning with the framework of Baxter and King (1993). The following corollary summarizes the propositions' economic implications.

Corollary 1. *If the assumptions of Proposition 2 are satisfied, the separately identified* (ξ,ζ) *imply that*

(i) private and public capital are gross complement in aggregate CES production function, and

(ii) under the Cobb-Douglas production function with $\alpha + \gamma = 1$*, the aggregate production function is IRS as in Baxter and King (1993).*

Proof. The proof of this corollary is immediate from the prior propositions. ■

The theoretical results we propose in this section are simple yet powerful in its generic applicability. In Appendix K, we show that the propositions can be generalized in multiple dimensions. First, the results apply to an environment with discretely many firms ($n-$firm), shown in Appendix K.1. Appendix K.2 shows its applicability to the continuum of firms. In Appendix K.3, we show that the theoretical prediction stays unaffected by the inclusion of the congestion effect. Lastly, Appendix K.4. discusses how the assumption on the observed firm-level output-to-capital ratio can be relaxed and provides the specific boundaries for the relaxed inequality condition.

3 Model

3.1 Household

Time is discrete and lasts forever. We consider the standard representative household with temporal utility u_t, of which the arguments are consumption c_t and region-specific per-capita labor supply L_{jt}, $j \in \{G, P\}$:

$$u_t = u(c_t, L_{Gt}, L_{Pt}) = log(c_t) - \sum_{j \in \{G,P\}} \omega_j \frac{\eta}{1+\frac{1}{\chi}} L_{jt}^{1+\frac{1}{\chi}} \tag{6}$$

where χ is the Frisch labor supply elasticity parameter, and η is the labor disutility parameter. ω_j is the exogenously determined portion of the labor force in region j such that $\omega_G + \omega_P = 1$. L_{jt} is the per-capita labor supply at region j, and $\omega_j L_{jt}$ is the region-specific total labor supply.[6] The temporal utility in the future periods is discounted by the discount factor β. The household is subject to the following budget constraint:

$$c_t + \frac{a_{t+1}}{1+r_t} + \frac{B_{t+1}}{1+r_t^B} = \sum_j \omega_j (w_{jt}\mathcal{E}_t + w_{jt}L_{jt})(1-\tau^h) + D_t(1-\tau^h) + (a_t - D_t) + T_t + B_t \tag{7}$$

where a_{t+1} and a_t are the wealth based on equity holding. D_t is the dividend from the equity holding. r_t is the market interest rate to be determined in the competitive market, and r_t^B is the interest rate of the government bond. L_{jt} is labor supply of region j, $\mathcal{E}_t$ is an exogenously determined portion of public employment out of the total labor force.[7] B_t is savings in government bonds, and T_t is the lump-sum subsidy. w_{jt} is the region-specific wage to be determined at each region's competitive labor market.[8] τ^h is the income tax rate that symmetrically applies to both labor and capital income. The household maximizes the sum of the discounted

[6] In the calibration, the aggregate employment is one of the target moments. The aggregate employment L_t is determined as follows:

$$L_t = \omega_G L_{Gt} + \omega_P L_{Pt}.$$

[7] We assume the public sector's wage follows the competitive level at the private market.

[8] In our working paper version, we considered a single competitive labor market shared by two regions. The main results are not strongly affected by different labor market setups. The results of the single labor market are available upon request.

expected temporal utilities through the choice of $\{c_t, L_{Gt}, L_{Pt}, a_{t+1}, B_{t+1}\}_{t=0}^{\infty}$ based on the rational expectation.

3.2 Production technology

A measure one of ex-ante homogenous firms are considered. Each firm owns capital. It produces a unit of goods from the inputs of labor and capital. The production technology of a firm i located at a region j follows a CES form as specified below:[9]

$$y_{it} = z_{it}x_{jt}\mathcal{C}(Y_{jt})f(k_{it}, l_{it}, \mathcal{N}_{jt}) = z_{it}x_{jt}\mathcal{C}(Y_{jt})\left(\theta(k_{it})^{\frac{\lambda-1}{\lambda}} + (1-\theta)\mathcal{N}_{jt}^{\frac{\lambda-1}{\lambda}}\right)^{\frac{\lambda}{\lambda-1}\alpha} l_{it}^{\gamma} \quad (8)$$

where y_{it} is output, k_{it} is capital input, l_{it} is labor input, and $\mathcal{N}_{jt}$ is a region-specific infrastructure stock. z_{it} is idiosyncratic productivity and x_{jt} is a region-specific productivity. $\theta \in (0,1)$ is the weight parameter between the private and public capital. α is capital share, and γ is labor share such that $\alpha + \gamma < 1$.[10] $\mathcal{C}(Y_{jt}) = \left(\frac{\overline{Y}}{Y_{jt}}\right)^{\iota}$ is region-specific congestion effect following Glomm and Ravikumar (1994). $\overline{Y}$ is the normalizer for the congestion effect, Y_{jt} is the regional aggregate output, and ι is the congestion elasticity parameter. In our quantitative analysis, we set the normalizer at the steady-state regional aggregate output of region P, $\overline{Y} = Y_P^{ss}$.

Idiosyncratic productivity z_{it} follows a log $AR(1)$ process, where ρ_z and σ_z are persistence and standard deviation of independent and identically distributed (*iid*) innovation in the process. The idiosyncratic shock process is discretized using the Tauchen method for computation.[11]

[9]In the baseline specification, we normalize the aggregate productivity as unity, as our estimation and the fiscal multiplier analysis are based on the stationary recursive competitive equilibrium. The extension of including the stochastic aggregate productivity process would allow the state-dependent fiscal multiplier analysis, which we leave for future research.

[10]It is worth noting that Proposition 1 applies to a production function with decreasing returns to scale.

[11]The specific form is as follows: $ln(z_{i,t+1}) = \rho_z ln(z_{it}) + \epsilon_{z,i,t+1}, \quad \epsilon_{z,i,t+1} \sim_{iid} N(0, \sigma_z^2)$.

In the economy, there are two regions $j \in \{G, P\}$ of which infrastructure levels and productivity levels are different from each other. We denote the poor infrastructure region as P and the good infrastructure region as G: $N_G > N_P$. Firms switch from one group to the other following an exogenous Markov process, which reflects the observed state-level productivity fluctuations.[12] Using the production function, firms at a regional group j earn operating profit in each period by solving the following problem:

$$\pi(z_{it}, k_{it}, j; Y_{jt}, \mathcal{N}_{jt}, w_t) = \max_{l_{it}} z_{it} x_{jt} \mathcal{C}(Y_{jt}) f(k_{it}, l_{it}, \mathcal{N}_{jt}) - w_{jt} l_{it} \tag{9}$$

where w_{jt} is the region-specific real wage that will be endogenously determined in the competitive market of each region.

3.3 Firm-level investment

Firms make an investment decision as in Khan and Thomas (2008). A small-scale capital adjustment is specified as $\Omega(k_{it}) := [-\nu k_{it}, \nu k_{it}]$. When they make a large-scale capital adjustment, $I_{it} \notin \Omega(k_{it})$, they need to pay a fixed adjustment cost ξ_{it}, where $\xi_{it} \sim_{iid} Uniform[0, \overline{\xi}]$. This cost is regarded as a labor overhead cost, so the actual cost is $w_t \xi_{it}$. If a firm makes a small-scale capital adjustment, $I_{it} \in \Omega(k_{it})$, it does not need to pay a fixed adjustment cost.[13]

Following Cooper and Haltiwanger (2006) and Winberry (2021), we assume all

[12] Specifically, firms' physical location is fixed, while states can move around the regional groups. We assume the following transition matrix:

$$\begin{bmatrix} p_{t+1}^P \\ p_{t+1}^G \end{bmatrix} = \begin{bmatrix} \pi_{PP} & \pi_{PG} \\ \pi_{GP} & \pi_{GG} \end{bmatrix}' \begin{bmatrix} p_t^P \\ p_t^G \end{bmatrix}.$$

[13] By allowing the fixed cost ξ to be uniformly distributed *iid* shock, the value function becomes smooth without a kink. As in Khan and Thomas (2008), the optimal extensive-margin investment decision follows a threshold rule $\xi_t^* \in [0, \overline{\xi}]$ such that if $\xi < \xi_t^*$, a firm makes a large-scale investment. For the brevity, we omit the detailed description.

investments are subject to a convex adjustment cost, $C(I_{it}, k_{it}) = \frac{\mu}{2}\left(\frac{I_{it}}{k_{it}}\right)^2 k_{it}$. The convex adjustment cost plays an essential role in this paper, as it helps to capture the realistic sensitivity of aggregate investment in response to the exogenous shocks (Zwick and Mahon, 2017; Koby and Wolf, 2020; Lee, 2025).

3.4 Government

The government collects income tax from households at the rate of τ^h and corporate tax at τ^c. Household income is the sum of labor income $\sum_{j\in\{G,P\}} \omega_j w_{jt} l_{jt}$ and dividend income D_t. The tax rates are exogenously determined. Government issues a bond B_{t+1} which matures in one period and is discounted by the gross bond return, $1 + r_t^B$ and pays back the maturing bond, B_t. Using the revenue $\mathcal{R}_t$ financed from the taxation and the net debt issuance, the government spends through three channels: infrastructure investment $\mathcal{F}_t$, public employment $\sum_{j\in\{G,P\}} \omega_j w_{jt} \mathcal{E}_t$, and lump-sum subsidy T_t:

$$\tau^h\left(\sum_{j\in\{G,P\}} \omega_j w_{jt} l_{jt} + D_t\right) + \tau^c \int (\pi_t - \delta k_t) d\Phi_t + \frac{B_{t+1}}{1 + r_t^B} - B_t = \mathcal{F}_t + \sum_{j\in\{G,P\}} \omega_j w_{jt} \mathcal{E}_t + T_t \tag{10}$$

The public employment $\sum_{j\in\{G,P\}} \omega_j \mathcal{E}_t = \mathcal{E}_t = \mathcal{E}$ is exogenously determined. The split between the lump-sum subsidy and the infrastructure investment is determined exogenously by φ. To be specific, for $\varphi > 0$, $\mathcal{F}_t = \varphi(\mathcal{R}_t - \sum_{j\in\{G,P\}} \omega_j w_{jt} \mathcal{E}_t)$, and $T_t = (1 - \varphi)(\mathcal{R}_t - \sum_{j\in\{G,P\}} \omega_j w_{jt} \mathcal{E}_t)$.

The country-level infrastructure $\mathcal{N}_{At}$ and state-level infrastructure $\mathcal{N}_{jt}$ ($j \in \{G, P\}$) evolve according to the following law of motion:[14]

[14]There are two fixed points for the stationary infrastructure stock. We focus only on the greater one, which is a stable fixed point. Specifically,

$$\mathcal{N}_A^{ss} = \frac{1 + \sqrt{1 - 2\mu\delta_{\mathcal{N}}}}{2\delta_N} \mathcal{F}^{ss}, \qquad \mathcal{N}_j^{ss} = \zeta_j \mathcal{N}_A^{ss} \quad \text{for } j \in \{P, G\}.$$

$$\mathcal{N}_{A,t+s} = \mathcal{N}_{A,t+s-1}(1-\delta_{\mathcal{N}}) + \mathcal{F}_t - \frac{\mu}{2}\left(\frac{\mathcal{F}_t}{\mathcal{N}_{A,t+s-1}}\right)^2 \mathcal{N}_{A,t+s-1},\ \mathcal{N}_{jt} = \zeta_j \mathcal{N}_{At},\ \text{for } j \in \{G, P\}, \tag{11}$$

where the aggregate infrastructure $\mathcal{N}_{At}$ satisfies $\mathcal{N}_{At} = \mathcal{N}_{Pt} + \mathcal{N}_{Gt}$. The split between the poor infrastructure region and the good infrastructure region is exogenously determined by ζ_j, which is calibrated to match the distribution of infrastructures described in Table 1. A positive integer s represents time to build for the infrastructure investment. Infrastructure investment is subject to the same convex capital adjustment cost as private investment.

To summarize the state variables, the individual state variables are idiosyncratic productivity shock, z_{it}, and individual capital stock, k_{it}. The aggregate state variables are the tuple of each region's infrastructure stocks, $\mathcal{N}_t = (\mathcal{N}_{Pt}, \mathcal{N}_{Gt})$, infrastructure spending history and plan, $\mathbb{F}_t = (\mathcal{F}_{t+\tilde{s}})_{\tilde{s}=-s}^{\infty}$, the government bond holdings, B_t, and the distribution of individual state variables, Φ_t.[15]

3.5 Competitive equilibrium

In this section, we define the competitive equilibrium. Our main analyses are based on 1) the stationary recursive competitive equilibrium, where we estimate our model, and 2) the transitional competitive equilibrium, where we analyze the fiscal multiplier after a fiscal spending shock. For the latter, we consider the perfect foresight impulse response to unexpected fiscal spending shocks. We define competitive equilibrium with time subscript to nest both stationary and transitional competitive equilibrium.[16]

[15]Given these aggregate states, the regional aggregate output vector for the congestion effect is also known.

[16]The value functions of households and heterogeneous firms are available in Appendix B.

Definition 1 (Competitive equilibrium)**.**

Given $\{\mathcal{N}_t, \mathbb{F}_t\}_{t=0}^{\infty}$ *and* (B_0, Φ_0)*, a set of functions*

$\{\widehat{c}_t, \widehat{a}_{t+1}, \widehat{L}_{Gt}, \widehat{L}_{Pt}, \widehat{B}_{t+1}, \widehat{V}_t, \widehat{I}_t, \widehat{I}^c_t, \widehat{l}_t, \widehat{\xi}^*_t, \widehat{J}_t, \widehat{Y}_{Gt}, \widehat{Y}_{Pt}, \widehat{\Phi}_{t+1}, \widehat{D}_t, \widehat{T}_t, \widehat{\mathcal{R}}_t, \widehat{w}_{Pt}, \widehat{w}_{Gt}, \widehat{r}_t, \widehat{r}^B_t\}_{t=0}^{\infty}$ *is competitive equilibrium if*

1. $\{\widehat{c}_t, \widehat{a}_{t+1}, \widehat{L}_{Gt}, \widehat{L}_{Pt}, \widehat{B}_{t+1}, \widehat{V}_t\}$ *solves the household's problem.*
2. $\{\widehat{I}_t, \widehat{I}^c_t, \widehat{l}_t, \widehat{\xi}^*_t \widehat{J}_t\}$ *solves the firms' problem.*
3. $\widehat{w}_{Pt}$*,* $\widehat{w}_{Gt}$ *and* $\widehat{r}_t$ *are determined at the levels where labor and equity markets are cleared for* $\forall t \in \{0, 1, 2, \dots\}$

$$[\textit{Labor market}]: \quad \omega_j \widehat{L}_{jt} = \int \left(\widehat{l}_t + \frac{(\widehat{\xi}^*_t)^2}{2\overline{\xi}} \right) d\Phi_{jt}, \quad \textit{for } j \in \{G, P\}$$

where Φ_{jt} *is the* j *region's firm distribution.*

$$[\textit{Equity market}]: \quad \widehat{a}_t = \int \widehat{J}_t d\Phi_t, \quad \widehat{a}_0 = a_0.$$

4. *Aggregate dividend satisfies the following identity:*

$$\widehat{D}_t = \int \left(\pi_t(1-\tau^c) + \tau^c \delta k_t - \left(\widehat{I}_t + C(\widehat{I}_t, k_t) + \widehat{w}_t \frac{\widehat{\xi}^*_t}{2} \right) \frac{\widehat{\xi}^*_t}{\overline{\xi}} - \left(\widehat{I}^c_t + C(\widehat{I}^c_t, k_t) \right) \left(1 - \frac{\widehat{\xi}^*_t}{\overline{\xi}} \right) \right) d\Phi_t$$

where $\widehat{w}_t$ *is a function that takes* $\widehat{w}_{jt}$ *for* j *region's firm.*

5. *Government budget is balanced* (10)*.*
6. *There is no arbitrage between the wealth return and the bond return:* $\widehat{r}_t = \widehat{r}^B_t$
7. *The firm-level optimal investments are consistent with the law of motion of the firm distribution* Φ_t*.*

4 Estimation

We first externally calibrate non-central parameters based on estimates from the existing literature.[17] The core parameters are estimated based on the extended simulated method of moments (SMM), where the key identifying variations come from regional heterogeneity. Specifically, we define two regions P and G, based on the infrastructure ranking and geographical proximity, as illustrated in Figure 1. The brown areas represent poor-infrastructure regions, primarily in the West, while the green areas indicate good-infrastructure regions. The infrastructure ranking is considered to capture properly the sorting between the fiscal spending and the region-specific productivity observed in the U.S., which we show has a significant impact on the fiscal multiplier in Section 5.4.[18] The geographical proximity is considered to minimize the cross-group spillover effect, which we do not explicitly include in the model.[19] Table 1 presents summary statistics comparing poor- and good-infrastructure regions, with data sourced from Bennett et al. (2020).[20]

The transition probabilities are set to be persistent ($\pi_{PP} = 0.90, \pi_{GG} = 0.98$).[21] The infrastructure portion for group G, ζ_G, is set at 0.81, and the Poor's portion ζ_P is 0.19.[22]

[17] These parameters are listed in Table C.2 in the Online Appendix. We keep it in the Appendix due to space constraints, though several of these parameters are important for understanding our quantitative results.

[18] In Appendix L, we also present theoretical results demonstrating that grouping affects fiscal multipliers in the presence of sorting. We clarify that our grouping strategy is both theoretically justified and empirically grounded to capture the observed sorting patterns.

[19] We thank an anonymous referee for suggesting considering the geographical proximity. Regarding spillover effect, we acknowledge that our model is limited in capturing cross-group spillovers, which would require an explicit modeling framework beyond the current setup.

[20] Details on the state-level data sources and variable construction are presented in Appendix A.

[21] Transition probabilities are constructed using the state-level data in Table A.1 in Appendix A. Specifically, we use the two moments: 1) the transition probability from the Good to Poor region and 2) the ratio of the number of firms between the two regions. We check the robustness of our main results over a different specification of the transition probability in Appendix I.

[22] If we standardize the infrastructure capital stock of the poor and good groups by their respec-

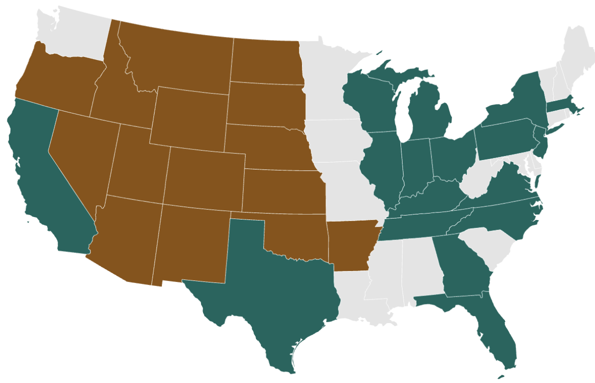

Figure 1: Regions with good vs. poor infrastructure

Notes: Brown areas indicate poor infrastructure, while green areas represent good infrastructure.

Table 1: Comparison of two states: regions with good vs. poor infrastructure

	Poor infrastructure	Good infrastructure
Infrastructure portion	0.190 (0.001)	0.810 (0.001)
Establishment (#) portion	0.161 (0.004)	0.839 (0.002)
Firm (#) portion	0.160 (0.004)	0.840 (0.002)
GDP ($) portion	0.135 (0.004)	0.865 (0.004)
Employment (#) portion	0.147 (0.005)	0.853 (0.003)

Notes: Standard errors are in parentheses. # stands for the number of observations.

4.1 Estimation method

In order to make the estimation procedure computationally feasible, we extend the SMM method by augmenting data moments with market clearing conditions.[23] In other words, we treat market clearing prices as parameters to be estimated where the associated moments in the estimation procedure are market clearing conditions. As we estimate the stationary recursive competitive equilibrium, we omit the time subscript in this section for brevity.

With the standard estimation with general equilibrium models, the computa-

tive population sizes, we find that $\zeta_G = 0.84$, which is close to the value of 0.81 used in our analysis.

[23] The challenges of estimating a general equilibrium model with the existing SMM are elaborated in Appendix C.1.

tional bottleneck lies in that we need to satisfy market clearing conditions for each candidate parameter vector. Instead, our suggested method treats market clearing conditions as additional moments: $(p - 1/c, w_G - \omega_G \eta L_G^{\frac{1}{\chi}} c/(1-\tau^h), w_P - \omega_P \eta L_P^{\frac{1}{\chi}} c/(1-\tau^h))$.

We implement our estimation method in a Bayesian way as in Fernández-Villaverde et al. (2016) and use the multiple-block Metropolis-Hastings where we break the parameter space into two blocks, one for the price block and the other for the other model parameters. We include more details on the algorithm in Appendix C.

4.2 Estimation results

As is common in the literature, the proportion of firms making lumpy investments disciplines the upper bound for fixed cost $\bar{\xi}$. The average investment-to-capital ratio informs the convex adjustment cost parameter μ, while its standard deviation governs parameter ν, which characterizes the constrained investment region. Total working hours determine the labor disutility parameter η. The productivity x is related to the output share of the good-infrastructure region, while the government spending level G is associated with the government spending-to-output ratio. θ is disciplined by the private-to-infrastructure capital ratio.

Our paper includes the difference in private capital stocks between states with high and low infrastructure levels as an informative moment for the firm-level elasticity of substitution parameter λ. However, clean identification of a parameter is inherently challenging, as changes in it affect multiple moments simultaneously. Consequently, no single moment exclusively identifies λ; instead, our estimation relies on the joint fit of multiple moments.[24]

[24] We assess the sensitivity of the selected moment targets to illustrate the usefulness of incorpo-

Table 2 reports the posterior means and the 90% credible intervals of parameters from our estimation. The firm-level elasticity of substitution λ is estimated to be 1.076, which supports the Cobb-Douglas production function as a reasonable specification.[25] The productivity of the Good region is approximately double that of the Poor region. Table 3 shows the model fit for the targeted moments. The model-generated moments fit the empirical targets reasonably well.[26]

Table 2: Estimation results

		Posterior		Uniform Prior
Parameter	Description	Mean	90% interval	[Min, Max]
$\bar{\xi}$	fixed cost upper bound	0.637	[0.561,0.695]	[0.001,1.900]
μ	convex adjustment cost	3.028	[2.819,3.258]	[0.200,3.500]
ν	constrained investment	0.044	[0.040,0.047]	[0.001,0.080]
θ	private capital share	0.693	[0.674,0.730]	[0.500,0.999]
λ	elasticity of substitution	1.076	[1.039,1.143]	[0.300,2.500]
x	productivity of good region	1.936	[1.913,1.963]	[0.500,2.500]
G	government spending level	0.105	[0.090,0.114]	[0.010,0.400]
η	labor disutility	2.813	[2.771,2.845]	[2.100,3.500]

5 Analyses of fiscal multipliers

We analyze the fiscal multipliers of infrastructure investment based on our estimated structural model. We define the fiscal multiplier as follows:

$$\text{Fiscal Multiplier} = \frac{\sum_{t=1}^{T} \text{Present value of } \Delta x_t}{\sum_{t=1}^{T} \text{Present value of } \Delta \mathcal{G}_t} \tag{12}$$

rating the Good region's private capital share in inferring λ in Appendix C.6.

[25] Our estimates for λ implies gross substitutability between private and public capital at the firm level. At the state level, aggregating firm behaviors from our model yields an elasticity of 0.482, closely matching the empirical estimate obtained from U.S. state-level data. This finding supports our theoretical prediction that public and private capital are gross substitutes at the firm level but gross complements at the state level. More details can be found in Appendix C.7.

[26] In addition, the market clearing prices are tightly pinned down. Given the posterior mean estimates, the market clearing conditions are satisfied with the numerical accuracy of e^{-7}.

Table 3: Model fit

Targeted moment	Model	Data	Source
Lumpy investment portion	0.125	0.140	Zwick and Mahon (2017)
Average of (i/k)	0.100	0.100	Zwick and Mahon (2017)
Standard deviation of (i/k)	0.158	0.160	Zwick and Mahon (2017)
Private-to-public capital ratio	0.713	0.750	Bureau of Economic Analysis
Good region's private k portion	0.859	0.840	Census Business Dynamics Statistics
Good region's output y portion	0.954	0.865	Bennett et al. (2020)
Spending G to output ratio	0.170	0.150	World Bank Database
Total working hours	0.336	0.330	Current Employment Statistics

Notes: Good region refers to the state with high infrastructure capital stock.

where Δx_t is the deviation at period t of the equilibrium allocation of interest from the steady-state level; $\Delta \mathcal{G}_t$ is the fiscal spending shock at period t. We assume $T = 2$ and the magnitude of the one-time shock is assumed at 1% of the steady-state output level, following Ramey (2020).[27] In this section, we focus on the impact of a sudden shock in fiscal spending specifically through infrastructure investment $\mathcal{F}_t$. We assume the fiscal spending shock is a one-time unexpected shock (MIT shock) without any persistence.[28]

5.1 Baseline analysis

Figure 2 plots the impulse responses of the fiscal policy shock. The impulse response is obtained from the perfect-foresight transition path after the one-time fiscal spending shock. The dashed line in each panel shows the government expenditure changes from the steady-state level in percent of the steady-state output. The

[27]Results for $T = 5$ are reported in Appendix D.2 and D.3.

[28]We assume that all the fiscal policy shock is financed by a lump-sum tax. The lump-sum tax imposes symmetric proportional wealth effects in both regions, resulting in greater wealth effects in level terms for the Good region than for the Poor region. In Appendix D, we also consider changes in corporate tax policy and region-specific tax policies on top of the lump-sum taxation for fiscal financing.

solid line is the impulse response of the equilibrium allocations.[29]

The private investment contemporaneously decreases, which is the outcome of two countervailing forces: 1) increase in the investment incentive with increased infrastructure stock and 2) adjustment in the interest rate that dampens investment (general equilibrium effect; GE effect hereafter). The increase in the investment incentive comes from the imperfect substitution between public and private capital stock. We analytically characterize the countervailing channels in detail in Appendix F.

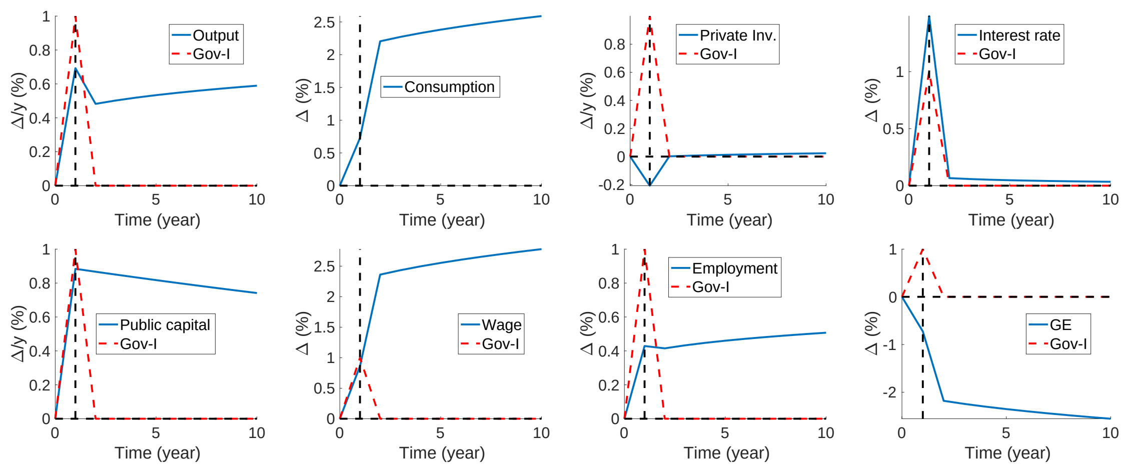

Figure 2: The impulse responses to the infrastructure spending shock

However, a fiscal policy affects the prices, which we denote as the GE effect. Regarding this, one of the most important channels is lump-sum taxation to finance infrastructure investment: the household reduces consumption to pay this lump-sum tax. Thus, the marginal utility of contemporaneous consumption increases, leading to an increase in the interest rate in the equilibrium. Then, the heightened interest rate strongly crowds out the firm-level investment despite the increased future marginal product of capital.[30]

[29]The responses of output, consumption, public capital, wage, and government investment decay in slow rates due to the low infrastructure depreciation rate at $\delta_{\mathcal{N}} = 0.02$.

[30]Households have no precautionary saving motivation against the aggregate risk, as the econ-

In contrast, the employment response is not completely dampened by the GE effect. As the shock hits, employment increases by 0.41% despite the wage increase. Consumption and the GE effect are the mirror image of each other as the GE effect refers to the inverse of consumption under the log utility. In the shock period, consumption displays a mild increase due to the lump-sum taxation, but then it rapidly increases in the next period, followed by the smoothed consumption path.

5.2 The role of elasticity of substitution between private and public capital stocks

The elasticity of substitution between private and public capital stock plays a key role in determining the marginal benefit of firm-level investment given a fiscal expenditure shock. The elasticity of substitution affects the response of marginal benefit through two channels: 1) direct and 2) indirect channels. The direct channel refers to newly added capital being relatively less valuable when the public capital stocks are more substitutable with the private capital. The indirect channel refers to a change in marginal benefit of investment due to the change in the relative values of the existing public and private capital stocks. The direct channel predicts the marginal benefit of firm-level investment decreases in the elasticity, while the sign of the indirect channel cannot be analytically determined.[31]

Table 4 provides a summary of our fiscal multipliers across various scenarios over a 2-year horizon. The benchmark values stem from a heterogeneous agent general equilibrium model, with the elasticity of substitution between public and

omy is abstract from the aggregate uncertainty.

[31] The sign of the effect depends on the firm-level capital stock. The detailed derivation is available in Appendix F.

Table 4: Fiscal multipliers

Fiscal multipliers	$\lambda = 3$	$\lambda = 1.0764$ (Baseline)	$\lambda = 0.5$
Heterogeneous-agent			
Output	0.4482	1.1494	1.5295
Investment	-0.3164	-0.2055	-0.0987
Partial eq. - Output	0.7051	1.4142	1.7547
Partial eq. - Investment	0.0178	0.1454	0.1871
	$\zeta = 0.0985$	$\zeta = 0.0992$ (Baseline)	$\zeta = 0.1002$
Representative-agent			
Output	0.8870	0.8906	0.8957
Investment	-0.4375	-0.4371	-0.4366

private capital denoted as $\lambda = 1.076$. Specifically, the output multiplier is 1.149, while the investment multiplier is -0.206. In other words, the output increases by \$1.149 and investment decreases by \$0.206 in the short run for every \$1 spending in the infrastructure.

The following rows' partial equilibrium is a deviation from the baseline by setting the inter-temporal prices fixed at the steady-state price. Thus, the labor market still operates to set the competitive wage. The partial equilibrium model yields significantly greater multipliers: a 1.414 output multiplier and a 0.145 investment multiplier given $\lambda = 1.076$. Notably, this is due to the missing crowding-out effect of private investment because there are no endogenous interest rate adjustments in the partial equilibrium framework.

We also compare the fiscal multipliers under our benchmark model with heterogeneous firms to those from the representative-agent model, where the production function is following Baxter and King (1993) and the other ingredients are the same as the baseline model except for absence of the fixed adjustment cost.[32] The

[32] If the fixed adjustment cost is considered at the macro level, the aggregate investment becomes too lumpy, which is inconsistent with the observed patterns in the data.

detailed description of the representative-agent model is available in Appendix G.[33] The output multiplier under the representative agent model is observed to be less than 1 (0.891), in contrast to the baseline value of 1.149.[34] This difference arises from a more subdued investment multiplier (-0.437 vs. -0.206). First, the lower sensitivity in the heterogeneous-firm model is due to Jensen's inequality effect on the convex adjustment cost: the heterogeneous firms' average adjustment burden is greater than that of the representative (average) firm due to the convexity.[35] Specifically, at the steady state, both the representative-agent and heterogeneous-agent models feature the same i/k ratio, which is identical to δ. Then, the aggregated adjustment cost is greater for the heterogeneous-agent model than the representative-agent model due to the dispersion over the convex cost.

Second, our baseline model incorporates the fixed adjustment cost, which allows the model to capture realistic firm-level investment dynamics, while the representative-agent model does not. The fixed adjustment cost dampens the sensitivity of the firm-level investment due to the extensive margin decision to stay inactive. For these reasons, the dampened negative investment response in the heterogeneous-agent model leads to a greater output multiplier. We further analyze the impact of the extensive margin investment in the following section.

Finally, the comparison extends to fiscal multipliers across different values of the elasticity of substitution. In the benchmark heterogeneous agent model, the fiscal multipliers exhibit notable variation with changes in λ values. Specifically,

[33] The representative-agent model's parameter levels are assumed to be at the same level as the baseline model, except for the scale parameter in the production function and the fiscal spending level. The latter is recalibrated to match the observed level.

[34] The analysis of the posterior distribution of fiscal multipliers reveals a statistically significant difference between the heterogeneous-firm model and the representative-firm model. These results are provided in Appendix D.6.

[35] Ramey (2020) showed that convex adjustment contributes to a higher fiscal multiplier through the dampened crowding-out effect. Our paper extends this finding in the heterogeneous-firm context through the comparison with the representative-firm counterpart with convex adjustment cost.

under $\lambda = 3$ (indicating high substitutability between public and private capital), the output multiplier is 0.448, significantly smaller than the benchmark value of 1.149. Conversely, under $\lambda = 0.5$, reflecting complementarity between private and public capital, the output multiplier is markedly higher at 1.530.

For a comparable analysis within the representative agent model framework, we calculate the implied returns to scale parameter (ζ) corresponding to each λ value. We find that the variations in fiscal multipliers across different λ values are relatively modest. The reason for observing more pronounced variations under the heterogeneous agent model is the influence of the non-rivalry of public capital in each heterogeneous firm's production function. This underscores the significance of accurately estimating the elasticity parameter when seeking to analyze the fiscal multiplier of non-rivalrous public investment incorporating heterogeneous firms' decisions.

The returns to scale parameters in Table 4 are within a range Ramey (2020) provides: 0.07 to 0.12. Fiscal multipliers obtained based on these scale parameter values vary from 0.847 to 0.882, which is highly consistent with our results. Hence, the fiscal multipliers under the representative agent model, without considering firms benefiting from non-rivalrous public capital, are much lower than the multipliers from our heterogeneous agent model.[36]

5.3 Firm-level responses: Extensive vs. intensive margins

In this section, we analyze the role of the intensive and extensive margin investments in the crowding-out effect. Table 5 reports the decomposition of fiscal multi-

[36]In Appendix I.3, we provide additional robustness checks over different Frisch elasticities. Consistent with Ramey (2020), a low Frisch elasticity decreases the fiscal multiplier; the elasticity of 0.5 results in a fiscal multiplier of 0.731 in our model.

Table 5: Decomposition of fiscal multipliers by the investment margins

	Baseline	Extensive-only	Intensive-only	No resp.
Output	1.1494	1.2045	1.2769	1.3357
Investment	-0.2055	-0.1417	-0.0688	

pliers along with the different firm-level investment margins. The column labeled "Extensive-only" corresponds to the scenario where only adjustments to the extensive margin of investment are allowed, while the intensive margin is fixed at the stationary equilibrium level. In contrast, the column labeled "Intensive-only" represents the case where only adjustments to the intensive margin of investment are permitted, while keeping the extensive margin at the stationary equilibrium level.

In this analysis, we note that both the extensive and intensive margins play a role in the crowding out of investment, with a significantly more pronounced effect originating from the extensive margin. Specifically, the investment multiplier is -0.206 under the baseline, and approximately 69% of this baseline multiplier is obtained in the "Extensive-only" scenario.

The column labeled "No resp." corresponds to the scenario where investment responses are held constant at the stationary equilibrium level in response to the fiscal spending shock. Without alterations in investment behavior, the fiscal multipliers would have been higher at 1.336 compared to the baseline value of 1.149.

To investigate the role of extensive-margin firm-level investment further, we compare the fiscal multipliers between the baseline model and the model without fixed adjustment cost for different magnitudes of spending shocks.[37] The two models share exactly the same parameters except for the fixed adjustment cost. As

[37] We acknowledge and appreciate an anonymous referee's suggestion to compare these two models over different spending shock levels.

Table 6: Fiscal multiplier variations by the shock magnitudes

(% of steady-state output level)	0.1%	1%	5%	7%
Output				
Baseline	1.2447	1.1494	0.7739	0.6085
No fixed cost	1.7098	1.5418	0.8885	0.5967
Investment				
Baseline	-0.2034	-0.2055	-0.2111	-0.2118
No fixed cost	-0.3211	-0.3336	-0.3816	-0.4058

the magnitude of spending shock increases, both models' output multipliers substantially decrease. This is mainly due to the decreasing returns to scale assumed in the production function, scaling down the output gain per $1 public investment.[38]

Without the fixed adjustment cost, the fiscal multiplier increases to 1.542 from 1.149 for the 1% shock magnitude, which directly comes from the lowered investment adjustment cost. However, the crowding-out effect is also greater when the fixed cost is muted. This reflects that the fixed adjustment cost dampens the investment response to the fiscal spending shock. Notably, as the spending shock magnitude increases, the fiscal multipliers between the two models converge, reflecting that nearly all firms invest when the spending shock is substantially large due to the significant rise in the marginal benefit of investment. However, the investment multiplier difference between the two models remains significant. This occurs because the fixed adjustment cost model's spending shock creates stronger incentives for extensive-margin investments among otherwise non-investing firms compared to the model without the fixed cost.

[38]The fiscal multiplier is measured after dividing the output response by the total government spending.

5.4 Sorting between fiscal spending and productivity

In this section, we analyze the interplay between the fiscal spending and the region-specific productivity under the non-rivalry. We fixed the firm-level parameters at the estimated level, but the fiscal spending and group-level productivity are averaged across the group, reflecting that two groups share the same distribution of firms. We confirm that the steady-state equilibrium of the symmetric group feature almost the same firm-level moments as in the baseline steady state (i.e., lumpy investment portion, i/k ratio, standard deviation of i/k), while the group-level statistics substantially deviates.

Table 7: Symmetric state grouping and short-run fiscal multipliers

	Baseline			Symmetric grouping		
	Total	Poor	Good	Total	Poor	Good
Y	1.1494	0.0537	1.0956	1.0403	0.5201	0.5201
Inv.	-0.2055	-0.0148	-0.1907	-0.2120	-0.1060	-0.1060
Earnings	2.9970	0.1653	2.8318	2.5310	1.2655	1.2655
C	2.5771	0.0560	2.5212	2.1226	1.0613	1.0613

Table 7 compares the fiscal multipliers of the baseline model (first three columns) with the ones from the symmetric group (last three columns). The short-run output multiplier decreases by around 9 percentage points due to reshuffling, and the investment is crowded out further in the symmetric group with other multipliers of a similar pattern. The discrepancy between the two multipliers is due to the sorting between fiscal spending and productivity, which becomes meaningful only under non-rivalry. That is, when a more significant portion of spending is directed to a highly productive region and the infrastructure is shared among the region's firms, the fiscal multiplier is greater. Without the non-rivalry, greater fiscal spending scales the firm-level output, which would lead to invariant fiscal multipliers over the re-grouping. Our baseline grouping based on Good and Poor regions successfully captures this multiplier gain from the observed sorting between the spending and the region-specific productivity.[39] In Appendix L, we theoretically show that our grouping ensures the most accurate (least biased) aggregation of state-level fiscal multipliers under the sorting and empirically support it.

6 Conclusion

This paper theoretically bridges the micro-level and the macro-level production functions that take the infrastructure stock as a non-rivalrous input factor. Then, it analyzes the infrastructure investment multipliers through the lens of an estimated heterogeneous-firm general equilibrium model. Our theory establishes that the non-rivalry of public capital at the firm-level combined with the gross substitutability between private and public capital leads to the aggregate-level gross complementarity in CES or the increasing returns to scale in Cobb-Douglas production function. We show the theory is consistent with the measured outcomes through a quantitative analysis. According to our estimated general equilibrium model, the output multiplier is around 1.15, which is significantly greater than the representative-firm model's prediction. A dampened crowding out due to a lower sensitivity of the firm-level frictional investment responses to the general equilibrium effect significantly contributes to this result.

[39] The fiscal spending pattern was highly stable during our sample periods. Our framework is orthogonal to a question of which side of the two initially triggered the sorting in U.S. history: the spending was first, and then the productivity dispersion followed vs. the productivity dispersion triggered the different spending decisions.

References

Abel, A.B., Eberly, J.C., 2002. Investment and q with Fixed Costs: An Empirical Analysis. Working Paper .

Baxter, M., King, R.G., 1993. Fiscal policy in general equilibrium. The American Economic Review 83, 315–334. URL: http://www.jstor.org/stable/2117521.

Bennett, J., Kornfeld, R., Sichel, D., Wasshausen, D., 2020. Measuring infrastructure in the bureau of economic analysis national economic accounts. BEA Working Paper.

Caballero, R.J., Engel, E.M.R.A., 1999. Explaining Investment Dynamics in U.S. Manufacturing: A Generalized (S, s) Approach. Econometrica 67, 783–826. URL: http://doi.wiley.com/10.1111/1468-0262.00053, doi:10.1111/1468-0262.00053.

Cooper, R.W., Haltiwanger, J.C., 2006. On the nature of capital adjustment costs. Review of Economic Studies 73, 611–633.

Fernández-Villaverde, J., Rubio-Ramírez, J., Schorfheide, F., 2016. Solution and estimation methods for dsge models, in: Taylor, J.B., Uhlig, H. (Eds.), Handbook of Macroeconomics. Elsevier. volume 2, pp. 527–724.

Glomm, G., Ravikumar, B., 1994. Public investment in infrastructure in a simple growth model. Journal of Economic Dynamics and Control 18, 1173–1187.

Hagedorn, M., Manovskii, I., Mitman, K., 2019. The fiscal multiplier. NBER Working Paper.

Hasna, Z., 2021. The grass is actually greener on the other side: Evidence on green multipliers from the united states. Working Paper.

Khan, A., Thomas, J.K., 2008. Idiosyncratic shocks and the role of nonconvexities in plant and aggregate investment dynamics. Econometrica 76, 395–436.

Koby, Y., Wolf, C.K., 2020. Aggregation in heterogeneous-firm models: Theory and measurement. Working Paper.

Lee, H., 2025. Striking while the iron is cold: Fragility after a surge of lumpy investments. Working Paper.

Leeper, E.M., Walker, T.B., Yang, S.C.S., 2010. Government investment and fiscal stimulus. Journal of Monetary Economics 57, 1000–1012. URL: https://www.sciencedirect.com/science/article/pii/S0304393210001017, doi:https://doi.org/10.1016/j.jmoneco.2010.09.002.

Nakamura, E., Steinsson, J., 2014. Fiscal stimulus in a monetary union: Evidence from us regions. American Economic Review 104, 753–92. URL: https://www.aeaweb.org/articles?id=10.1257/aer.104.3.753, doi:10.1257/aer.104.3.753.

Oberfield, E., Raval, D., 2021. Micro data and macro technology. Econometrica 89, 703–732.

Ramey, V.A., 2011. Can government purchases stimulate the economy? Journal of Economic Literature 49, 673–85. URL: https://www.aeaweb.org/articles?id=10.1257/jel.49.3.673, doi:10.1257/jel.49.3.673.

Ramey, V.A., 2019. Ten years after the financial crisis: What have we learned from the renaissance in fiscal research? Journal of Economic Perspectives 33, 89–114. URL: https://www.aeaweb.org/articles?id=10.1257/jep.33.2.89, doi:10.1257/jep.33.2.89.

Ramey, V.A., 2020. The macroeconomic consequences of infrastructure investment. NBER Working Paper.

Sims, E., Wolff, J., 2018. The state-dependent effects of tax shocks. European Economic Review 107, 57–85. URL: https://www.sciencedirect.com/science/article/pii/S0014292118300746, doi:https://doi.org/10.1016/j.euroecorev.2018.05.002.

Winberry, T., 2021. Lumpy investment, business cycles, and stimulus policy. American Economic Review 111, 364–396.

Zwick, E., Mahon, J., 2017. Tax policy and heterogeneous investment behavior. American Economic Review 107, 217–248.