Appendix: For online publication

Contents

A State-level data on infrastructure

Table A.1 summarizes the state-level data that is based on the highway infrastructure investment data from Bennett, Kornfeld, Sichel, and Wasshausen (2020).

State	Avg. Rank (Infra.)	# Good Group	Portion (Infra.)	Portion (GDP)	Avg. Rank (Estab.)	Portion (Estab.)
New York	1.708	24.000	0.072	0.081	2.439	0.072
California	1.833	24.000	0.071	0.133	1.000	0.114
Texas	2.458	24.000	0.071	0.079	2.659	0.069
Florida	4.000	24.000	0.064	0.050	4.000	0.060
Illinois	5.000	24.000	0.049	0.046	5.341	0.044
Ohio	6.542	24.000	0.035	0.036	7.000	0.039
New Jersey	7.125	24.000	0.034	0.034	8.415	0.033
Georgia	8.458	24.000	0.032	0.029	11.171	0.027
Pennsylvania	8.708	24.000	0.032	0.040	5.561	0.044
Massachusetts	9.708	24.000	0.030	0.027	12.341	0.024
Minnesota	10.458	24.000	0.029	0.018	18.561	0.019
North Carolina	12.208	24.000	0.025	0.027	9.976	0.028
Wisconsin	13.083	24.000	0.025	0.017	17.439	0.020
Washington	14.250	24.000	0.024	0.024	14.561	0.022
Virginia	14.458	24.000	0.024	0.027	12.585	0.025
Michigan	16.083	24.000	0.022	0.030	9.024	0.032
Tennessee	16.917	24.000	0.021	0.018	19.195	0.019
Missouri	18.167	24.000	0.019	0.018	15.171	0.021
Indiana	18.833	24.000	0.018	0.019	15.171	0.021
Kentucky	20.292	24.000	0.018	0.011	27.415	0.013
Louisiana	21.333	24.000	0.017	0.014	22.805	0.015
Iowa	21.625	24.000	0.017	0.010	28.951	0.012
Arizona	22.875	24.000	0.016	0.017	23.756	0.016
Colorado	25.625	15.000	0.015	0.017	19.439	0.018
Kansas	25.833	13.000	0.014	0.009	30.829	0.011
Alabama	26.000	23.000	0.015	0.012	24.951	0.014
Maryland	26.042	11.000	0.015	0.020	20.415	0.018
Connecticut	26.542	10.000	0.014	0.016	25.951	0.014
Oklahoma	29.458	0.000	0.012	0.010	27.634	0.013
Mississippi	30.208	0.000	0.011	0.006	33.317	0.009
Oregon	30.500	0.000	0.011	0.011	25.659	0.014
South Carolina	31.917	0.000	0.011	0.011	26.634	0.013
Nevada	33.083	0.000	0.010	0.008	38.000	0.006
Nebraska	34.417	0.000	0.010	0.006	34.927	0.007
Arkansas	34.708	0.000	0.010	0.007	32.439	0.009
New Mexico	35.542	0.000	0.010	0.006	37.000	0.006
West Virginia	37.000	0.000	0.009	0.004	37.244	0.006
Utah	38.375	0.000	0.008	0.007	34.122	0.008
Alaska	39.167	0.000	0.007	0.003	51.000	0.002
Hawaii	39.458	0.000	0.007	0.005	41.854	0.005
Idaho	41.667	0.000	0.006	0.004	40.512	0.005
Montana	41.958	0.000	0.006	0.002	42.512	0.004
Delaware	42.375	0.000	0.006	0.004	47.317	0.003
Wyoming	44.167	0.000	0.005	0.002	49.707	0.003
South Dakota	45.042	0.000	0.005	0.002	45.073	0.003
Rhode Island	46.083	0.000	0.004	0.003	42.963	0.004
Maine	47.208	0.000	0.004	0.004	39.098	0.005
North Dakota	47.500	0.000	0.004	0.002	47.146	0.003
New Hampshire	49.000	0.000	0.003	0.004	39.963	0.005
District of Columbia	50.000	0.000	0.002	0.007	47.927	0.003
Vermont	51.000	0.000	0.002	0.002	47.829	0.003

Table A.1: State-level summary

Notes: Avg. Rank (Infra.) is the average time-series ranking of infrastructure (this variable is the sorting variable). # Good Group is how many times the state belonged to the good infrastructure group (Max:24). Portion (Infra.) is the portion of infrastructure on average. Avg. Rank (Estab.) is the average time-series ranking of the number of establishments. Portion (Estab.) is the portion of establishments on average.

B Estimation details

B.1 Implementation of SMM in a Bayesian way

The limited-information Bayesian method, as described in Kim (2002) and later advocated by Christiano, Trabandt, and Walentin (2010) and Fernández-Villaverde, Rubio-Ramírez, and Schorfheide (2016) among others, can be viewed as the Bayesian version of the simulated method of moments (SMM). The limited-information Bayesian method only uses a set of moments from the data for parameter inference.

Let Θ denote the parameters of interest and $\hat{\mathbf{m}}$ denote the vector of M empirical moments from the data for estimation. The likelihood of $\hat{\mathbf{m}}$ conditional on Θ is approximately

$$f(\hat{\mathbf{m}}|\Theta) = (2\pi)^{-\frac{M}{2}}|S|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\left(\hat{\mathbf{m}} - \mathbf{m}(\Theta)\right)' S^{-1}\left(\hat{\mathbf{m}} - \mathbf{m}(\Theta)\right)\right],$$

where $\mathbf{m}(\Theta)$ is the model's prediction for the moments under parameter Θ, and S is the covariance matrix of $\hat{\mathbf{m}}$. The covariance matrix S is often unknown but can be replaced by a consistent estimator of it, which can be obtained through bootstrap. Bayes' theorem tells us that the posterior density $f(\Theta|\hat{\mathbf{m}})$ is proportional to the product of the likelihood $f(\hat{\mathbf{m}}|\Theta)$ and the prior density $p(\Theta)$:

$$f(\Theta|\hat{\mathbf{m}}) \propto f(\hat{\mathbf{m}}|\Theta)p(\Theta),$$

and we can then apply the standard Markov Chain Monte Carlo (MCMC) techniques to obtain a sequence of random samples from the posterior distribution.

B.2 Implementation of multiple-block Metropolis-Hastings

We use the multiple-block Metropolis Hastings algorithm to estimate the model parameters as well as finding market clearing prices. Let's denote the moments to match (including the market clearing conditions) as $y \equiv [\hat{\mathbf{m}}, \mathbf{0}]$. $\hat{\mathbf{m}}$ is for the moments constructed from the data and $\mathbf{0}$ is associated with solving for general equilibrium. We break the parameter space into two blocks as follows: $\Theta = (\Theta^1, \Theta^2)$ where Θ^1 is for the price block and Θ^2 is for the other model parameter block. Starting from an initial value $\Theta_0 = (\Theta_0^1, \Theta_0^2)$, the algorithm works as follows:

For iteration $j = 1, \ldots, M$, and for block $k = 1, 2$.

- Propose a value $\tilde{\Theta}^k$ for the kth block, conditional on Θ_{j-1}^k for the kth block and the current value of the other block (Θ^{-k}). Θ^{-k} stands for the remaining block except for the kth block.[1]

- Compute the acceptance probability $\alpha^k = \min\left\{1, \frac{f(\tilde{\Theta}^k|\Theta^{-k}, y)}{f(\Theta_{j-1}^k|\Theta^{-k}, y)}\right\}$.
  Update the kth block as

$$\Theta_j^k = \begin{cases} \tilde{\Theta}^k & \text{w.p. } \alpha^k \\ \Theta_{j-1}^k & \text{w.p. } (1-\alpha^k) \end{cases}$$

For each iteration, we first update the price block conditional on the previous iteration's value for the price block and the remaining model parameter block. Then we sequentially update the model parameter block conditional on the updated price block.

We apply the multiple-block RWMH algorithm to simulate draws from the posterior density $f(\Theta|\hat{\mathbf{m}})$ with uniform priors. The posterior distribution is character-

[1] In our application, $\Theta^{-1} = \Theta^2$ and $\Theta^{-2} = \Theta^1$.

ized by a sequence of 2000 draws after a burn-in of 2000 draws. We initialize the chain at the point estimate from particle swam optimization routine from MATLAB.

C Notes on the market clearing conditions

In the model, there are two centralized markets: the capital market and the labor market. Thus, there are two prices to be determined endogenously.

C.1 Interest rate and capital market

Define $p := U'(c(\mathcal{S}))$. Then, from the Euler equation of the representative household,

$$\beta \mathbb{E} \frac{U'(c(\mathcal{S}'))}{U'(c(\mathcal{S}))} = \frac{1}{1 + r^B(\mathcal{S})} \iff \beta \frac{p(\mathcal{S}')}{p(\mathcal{S})} = \frac{1}{1 + r^B(\mathcal{S})}$$

As there is no aggregate uncertainty, the expectation operator can be ignored.

Then, define a modified value function $\tilde{J}(z, k, j; \mathcal{S}) = p(\mathcal{S}) J(z, k, j; \mathcal{S})$.

In the following original recursive formulation,

$$\begin{aligned} J(z,k,j;\mathcal{S}) = \max_{I, I^c} \ & \pi(z,k,j;\mathcal{S})(1-\tau^c)(1-\tau^h) \\ & + \int_0^{\bar{\xi}} \max\{-I - \xi w(\mathcal{S}) - C(I,k) \\ & + \frac{1}{1+r(\mathcal{S})} \mathbb{E} J(z', k', j'; \mathcal{S}'), \\ & - I^c - C(I^c, k) + \frac{1}{1+r(\mathcal{S})} \mathbb{E} J(z', k^c; \mathcal{S}')\} dG(\xi) \end{aligned}$$

replace $\frac{1}{1+r(\mathcal{S})}$ with $\beta\frac{p(\mathcal{S}')}{p(\mathcal{S})}$. So we have,

$$\begin{aligned}
J(z,k,j;\mathcal{S}) = &\max_{I,I^c} \ \pi(z,k,j;\mathcal{S})(1-\tau^c)(1-\tau^h) \\
&+ \int_0^{\bar{\bar{\xi}}} \max\{-I - \xi w(\mathcal{S}) - C(I,k) \\
&+ \beta\frac{p(S')}{p(\mathcal{S})}\mathbb{E}J(z',k',j';\mathcal{S}'), \\
&- I^c - C(I^c,k) + \beta\frac{p(S')}{p(\mathcal{S})}\mathbb{E}J(z',k^c;\mathcal{S}')\}dG(\xi)
\end{aligned}$$

Then, multiply $p(\mathcal{S})$ to both sides. It leads to

$$\begin{aligned}
p(\mathcal{S})J(z,k,j;\mathcal{S}) = &\max_{I,I^c} \ p(\mathcal{S})\pi(z,k,j;\mathcal{S})(1-\tau^c)(1-\tau^h) \\
&+ \int_0^{\bar{\bar{\xi}}} \max\{ - p(\mathcal{S})I - p(\mathcal{S})w(\mathcal{S})\xi \\
&\qquad - p(\mathcal{S})C(I,k) \\
&\qquad + \beta p(\mathcal{S}')J(z',k',j';\mathcal{S}'), \\
&\qquad - p(\mathcal{S})I^c - p(\mathcal{S})C(I^c,k) \\
&\qquad + \beta p(\mathcal{S}')J(z',k^c;\mathcal{S}')\}dG(\xi)
\end{aligned}$$

Thus, we have

$$
\begin{aligned}
\tilde{J}(z,k,j;\mathcal{S}) = \max_{I,I^c}\ & p(\mathcal{S})\pi(z,k,j;\mathcal{S})(1-\tau^c)(1-\tau^h) \\
+ \int_0^{\bar{\xi}} \max\{ & -p(\mathcal{S})I - p(\mathcal{S})w(\mathcal{S})\xi \\
& - p(\mathcal{S})C(I,k) \\
& + \beta\tilde{J}(z',k',j';\mathcal{S}'), \\
& - p(\mathcal{S})I^c - p(\mathcal{S})C(I^c,k) \\
& + \beta\tilde{J}(z',k^c;\mathcal{S}')\}dG(\xi)
\end{aligned}
$$

Therefore, a firm's problem is perfectly characterized by the price

$$p(\mathcal{S}) = U'(c(\mathcal{S})) = 1/c(\mathcal{S}).$$

C.2 Wage and labor market

From the representative household's intra-temporal optimality condition (with respect to the labor supply),

$$\eta L^{\frac{1}{\chi}} = U'(c(\mathcal{S}))w(\mathcal{S})(1-\tau^h)$$

Therefore,

$$\eta L^{\frac{1}{\chi}} = p(\mathcal{S})w(\mathcal{S})(1-\tau^h) \implies w(\mathcal{S}) = \frac{\eta}{p(\mathcal{S})(1-\tau^h)}L^{\frac{1}{\chi}}$$

The optimal labor supply L depends upon w, and w can be determined only when the labor supply L is known, leading to a fixed-point problem. Therefore, w needs to be tracked together with p for the computation.[2]

D Equilibrium

In the stationary recursive competitive equilibrium, the interest rate and the wage are determined in the competitive market. Specifically, the following market clearing conditions determine each price.[3]

$$\text{[Capital]} \quad \int \underbrace{\mathbb{E}J(z',k'(z,k);\mathcal{S})d\Phi}_{\text{Capital demand}} = \underbrace{a'(a;\mathcal{S})}_{\text{Capital supply}}$$

$$\text{[Labor]} \quad \underbrace{\int \left(n(z,k,j;\mathcal{S}) + \left(\frac{\min\{\xi^*,\bar{\xi}\}^2}{2\bar{\xi}}\right)\right) d\Phi}_{\text{Private labor demand}} = \underbrace{L(a;\mathcal{S})}_{\text{Labor Supply in the private market}}$$

The aggregate dividend is a sum of individual after-corporate-tax operating profits net of investment, and the ex-dividend portfolio value $P(\mathcal{S})$ is a sum of all the firms' values after the dividend payout:

$$\text{[Aggregate Dividend]} \quad D(\mathcal{S}) = \int \Big(\pi(z,k,j;\mathcal{S})(1-\tau^c) - I^*(z,k,j;\mathcal{S}) - C(I^*(z,k,j;\mathcal{S}),k) - \mathbb{I}\{I^* \notin \Omega(k)\}w(\mathcal{S})\xi\Big) d\Phi$$

$$\text{[Ex-dividend Portfolio Value]} \quad P(\mathcal{S}) = \int J(z,k,j;\mathcal{S})d\Phi - D(\mathcal{S})$$

And the government budget constraint and the spending constraint clear:

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[2] If $\chi \to \infty$, p is the only price to be tracked as in Khan and Thomas (2008).

[3] On the private labor demand side, overhead labor demand is computed by multiplication of the probability of implementing lumpy investment $\frac{\min\{\xi^*,\bar{\xi}\}}{\bar{\xi}}$ and the conditional expectation $\frac{\min\{\xi^*,\bar{\xi}\}}{2}$, where $\xi^* = \xi^*(z,k,j;\mathcal{S})$ is the threshold rule for making lumpy investments, as in Khan and Thomas (2008).

$$[\text{Government Budget}] \quad \mathcal{G}(\mathcal{S}) = \tau^h(w(\mathcal{S})L(a;\mathcal{S}) + D(\mathcal{S})) + \int \tau^c(\pi(z,k,j;\mathcal{S}) - \delta k)d\Phi + \frac{B'}{1+r^B(\mathcal{S})} - B$$

$$[\text{Infrastructure Investment}] \quad \mathcal{F}(\mathcal{S}) = \varphi(\mathcal{G}(\mathcal{S}) - w(\mathcal{S})\mathcal{E})$$

$$[\text{Lump-sum Subsidy}] \quad \mathcal{T}(\mathcal{S}) = (1-\varphi)(\mathcal{G}(\mathcal{S}) - w(\mathcal{S})\mathcal{E})$$

From the law of motion of the infrastructure, the stationary infrastructure stock is obtained.[4]

$$[\text{Infrastructure}] \quad \mathcal{N}_A = \frac{1+\sqrt{1-2\mu\delta_{\mathcal{N}}}}{2\delta_N}\mathcal{F}(\mathcal{S}), \qquad \mathcal{N}_j = \zeta_j \mathcal{N}_A \quad \text{for } j \in \{P, G\}$$

Lastly, there is no arbitrage between the wealth return and the bond return.

$$[\text{No Arbitrage}] \quad r(\mathcal{S}) = r^B(\mathcal{S})$$

E Fiscal multipliers and corporate taxation

In this section, we compare the fiscal multipliers when the infrastructure spending is combined with different tax policies. Three different policies are considered. The first policy is decreasing the corporate tax rate by 33% from the baseline level (27%→18%). The second policy uses the baseline level (27%), and the last policy increases the corporate tax rate by 33% from the baseline level (27%→36%).[5] The remaining balance in the fiscal budget after the change in taxation is financed by the lump-sum tax. Thus, the third policy collects the least amount of lump-sum

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

[5] The third policy mimics the Biden administration's original plan to increase the corporate tax rate by 33%. As our baseline tax level is 27% while the corporate tax rate of 2022 is 21%, there is a level difference in the tax rate.

tax among the three policies.[6]

Table E.2: Fiscal multipliers

Fiscal multipliers	Low Tax	Baseline	High Tax
Output			
Short-run	1.2267	1.0878	0.9517
Long-run	2.1738	1.9206	1.6721
Short-run (2 years)			
Consumption	0.1014	0.1479	0.1933
Investment	0.0891	-0.0434	-0.1734
Public capital	1.6683	1.6695	1.6709
Labor income	0.8764	0.7134	0.5550
Long-run (5 years)			
Consumption	1.0035	0.9376	0.8727
Investment	0.1245	-0.0137	-0.1495
Public capital	4.0092	4.0102	4.0114
Labor income	1.6049	1.3636	1.1281

Table E.2 reports the fiscal multipliers across the three corporate tax policies. In the first policy with low corporate tax, the short-run multiplier is around 1.227, which is the greatest among the three. In the last policy with high corporate tax, the short-run multiplier is around 0.952, which is the lowest among the three. The same ranking is observed for the long-run multipliers.

One of the main channels that cause the differences in the fiscal multipliers is the firm-level investment. When the fiscal spending is combined with the low corporate tax policy, due to the increased incentive of cumulating the future capital stock, the private investment crowds in, as can be seen from the positive investment multiplier of 0.089. However, in other cases, the greater public capital stock

[6] Our fiscal multiplier analysis is based on the impulse response to the MIT fiscal spending shock under perfect foresight. Therefore, the representative household becomes indifferent between lump-sum tax financing and debt financing as long as the lifetime income is unaffected. If the model considers household heterogeneity under the borrowing limit and frictional financial market, this indifference collapses, leading to divergent fiscal multipliers between tax financing and debt financing as in Hagedorn, Manovskii, and Mitman (2019).

crowds out the private capital investment. A similar pattern is observed in the long-run fiscal multipliers of private investment.

The differences in the response of private capital investment to the fiscal policy lead to the differences in the labor income response. The greater the private investment, the greater the employment effect on the economy. In the low corporate tax policy, the labor income multiplier is 0.876; in the baseline corporate tax policy, the labor income multiplier is 0.713; in the high corporate tax policy, the labor income multiplier is 0.555.

However, the low corporate tax policy is not a free lunch. The low corporate tax policy leads to the lowest consumption multiplier of 0.101 in the short run. This is because this tax policy requires the greatest lump-sum tax to finance the spending shock. This clearly shows what is the trade-offs in corporate tax policies; the low tax policy sacrifices the short-run welfare to achieve long-run welfare. In the long run, due to the private investment and labor income channels, the fiscal multiplier is the greatest for the low corporate tax policy.

F Assumptions for the cross-state analysis

In this section, we specify the assumptions to implement the cross-state analysis using the baseline model. As there is only a representative household in this economy, the state-level consumption is defined under the following assumptions:

- All the incomes are state-specific, and there is no cross-state transfer.
- Each equity is exclusively owned by the state's household.

- Bond holding and lump-sum subsidies are attributed to each state proportionately to the exogenous fiscal spending ratio.

Given these assumptions, the state-level consumption can be properly defined due to the separate budget clearing across the states. One can introduce two households in the model to capture Poor and Good households separately, but this can be done only at a high computational cost and the model complication.

G The marginal product of private and infrastructure capital

In this section, we assess the equilibrium level of the marginal product of private and public capital stock. Table G.3 shows the marginal product of private and infrastructure capital stocks for the entire economy (column 1), the Good state (column 2), and the Poor state (column 3). In this economy, due to the presence of the capital adjustment cost at the firm level, the marginal product of capital varies across the firms.[7] We use the average marginal product of capital for the analysis.

Table G.3: The marginal product of private and public capital

Marginal product of capital (MPK)	Aggregate	Good state	Poor state
Private	0.2840	0.3345	0.0426
Infrastructure	0.4799	0.5449	0.1691

The marginal product of public capital stock is substantially higher than the private counterpart. This shows that the current stock of public capital is less than

[7]The convex adjustment cost depends on the capital stock of the firm, which makes the marginal cost of investment different across the firms. This leads to the heterogeneous marginal product of capital stock in equilibrium.

the socially desired level.[8] Moreover, the public-to-private MPK ratio is more than twice greater in the Poor state than in the Good state. This shows that the relative shortage of public capital provision is more severe in the Poor state than in the Good state in equilibrium. However, this relative shortage is an efficient outcome in the model, so the normative interpretation is limited.

H The role of time to build

In this section, we analyze the role of time to build on the fiscal multiplier. On top of the one-year time to build in the baseline, we assume there is an extra year of time to build for capital stock to be utilizable after the investment as in Ramey (2020) (two years, in total). Therefore, the law of motion of the public capital stock is as follows:[9]

$$\mathcal{N}_{A,t+2} = \mathcal{N}_{A,t+1}(1-\delta_{\mathcal{N}}) + \mathcal{F}_t - \frac{\mu}{2}\left(\frac{\mathcal{F}_t}{\mathcal{N}_{A,t+1}}\right)^2 \mathcal{N}_{A,t+1}$$

$$\mathcal{N}_{j,t+1} = \zeta_j \mathcal{N}_{A,t+1} \quad \text{for } j \in \{P, G\}$$

$$F_t = \begin{cases} F^{ss} + \Delta G & \text{if } t = 1 \\ F^{ss} & \text{otherwise} \end{cases}$$

where F^{ss} is the stationary equilibrium level of fiscal spending on infrastructure. Due to the time lag between the fiscal policy shock and the arrival of the public capital stock, there exists a news component in the policy, which will be analyzed further in this section.

For this analysis, the fiscal multiplier is measured by the sum of the present values over the first three years for the short run and over the six years for the long

[8] If there were a competitive market for public capital, the price of the public capital would adjust in the direction to equate the shadow value of private and public capital.

[9] For the consistency in the notation with the previous formulations, we leave the time index of the future public capital stock to be $t + 1 + s$ where $s = 1$.

Table H.4: Fiscal multipliers across the states under time to build of two years

Fiscal multipliers	T2B	T2B - PE	Baseline	Baseline - PE
Output				
Short-run	1.0280	2.0301	1.0878	1.8582
Long-run	1.8476	5.4015	1.9206	5.0314
Short-run (2 years)				
Consumption	0.1274	0.6414	0.1479	0.6052
Investment	-0.0726	0.2897	-0.0434	0.1892
Public capital	1.6327	1.6383	1.6695	1.6728
Labor income	0.6596	1.4504	0.7134	1.2935
Long-run (5 years)				
Consumption	0.9038	3.6506	0.9376	3.4216
Investment	-0.0435	0.5858	-0.0137	0.4769
Public capital	3.9734	3.9789	4.0102	4.0135
Labor income	1.3011	3.7605	1.3636	3.4781

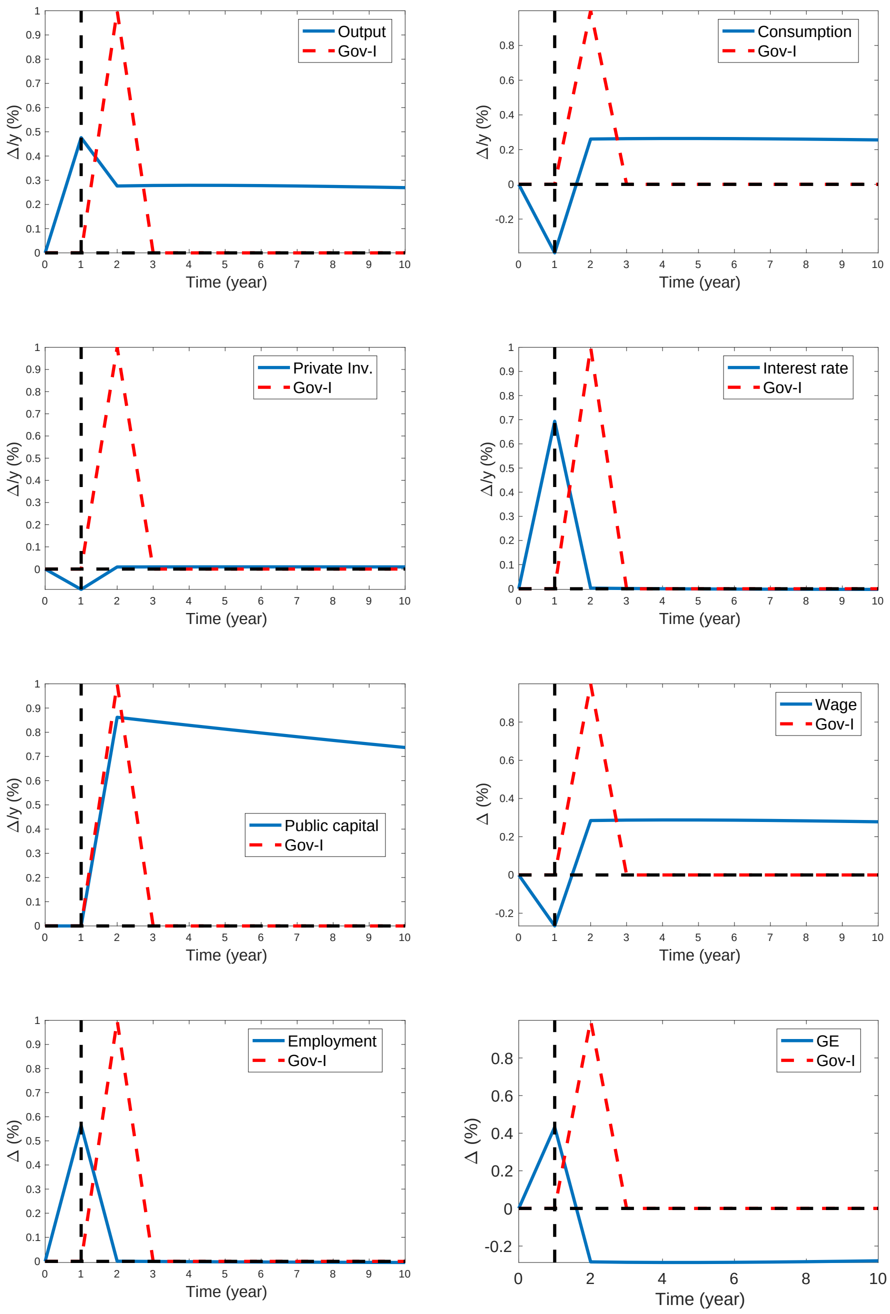
run after the initial fiscal spending shock.[10]

Table H.4 reports the fiscal multipliers when there is time to build of two years. The first column is the general equilibrium multipliers under the two years of the time to build; the second reports the same one in the partial equilibrium; the third is the baseline model; and the last is the baseline model in the partial equilibrium. The output fiscal multiplier decreases in general equilibrium, when the time-to-build is extended to two years (1.088→1.028), consistent with Ramey (2020). On the other hand, the output fiscal multiplier increases in the time to build in the partial equilibrium (1.858→2.030).

To illustrate the role of the extended time to build, Figure H.1 plots the impulse responses of equilibrium allocations. Due to the extended time to build, the capitalized government expenditure in the dashed line spikes one year after the beginning of the endogenous responses in the equilibrium allocations. As the fiscal

[10]Previously, it was 2 years for the short run and 5 years for the long run without the extended time to build.

Figure H.1: The impulse responses under the time to build of two years



spending shock hits, consumption immediately drops as the lump-sum tax immediately puts downward pressure on the household's consumption. This makes the household more willing to supply the labor. On the other hand, the production side does not face any change in the infrastructure until one year after the shock. Therefore, the increased labor supply at the period of shock ($t = 1$) leads to a lower wage and greater employment. Then, this feeds back into increased output at $t = 1$. The interest rate increases as the marginal utility of consumption at $t = 1$ increases, resulting in a decrease in private investment. After the infrastructure spending becomes capitalized, the demand for labor increases while the willingness for the labor supply decreases (income effect). This leads to an increase in the wage while the employment stays almost unchanged from the stationary equilibrium level.

The news effect impacts the fiscal multiplier in the partial equilibrium, as it allows the agents with the rational expectation to adjust their allocations optimally even before the spending shock is capitalized. However, this effect is dominated by changes in the price once we consider the general equilibrium effect. The agents' adjustment before the shock capitalization results in wage and interest rate adjustment, dampening the fiscal multiplier even in a greater magnitude than the one-year time-to-build. This is because the interest rate adjustment occurs at one time, and the increased cost of investment at the period before the spending shock leads to a lowered capital stock. Under the real friction such as the convex adjustment cost, the lowered capital stock leads to a greater adjustment cost in the following period when the fiscal spending shock is materialized, leading to a substantially dampened fiscal multiplier. Therefore, this is an outcome of the interaction between the news effect and the real friction.

I The representative-agent model: An extended version of Baxter and King (1993)

We consider the following representative-firm problem where the notations are the same as the baseline model except for ζ, which is the scale parameter for the infrastructure capital. It is worth noting that we use the same Φ level for the representative-agent model as in the baseline. This is to preserve the symmetry in the adjustment costs between the private sector and the public sector.[11] Also, the household and government sides are identical to the baseline model, so we abstract from the description for the sake of brevity.

$$\begin{aligned} J(k;S) = \max_{k'} \quad & (1-\gamma)\left(\frac{\gamma}{w(S)}\right)^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} N^{\frac{\zeta}{1-\gamma}} k^{\frac{\alpha}{1-\gamma}} (1-\tau^c)(1-\tau^h) \\ & + (-k' + (1-\delta)k)(1-\tau^h) + \tau\delta k(1-\tau^h) \\ & - \frac{\mu}{2}\left(\frac{k'}{k} - (1-\delta)\right)^2 k(1-\tau^h) + \frac{1}{1+r(S)}\mathbb{E}J(k';S') \end{aligned}$$

where J is the value of the representative firm; S is the aggregate state that include the same components as the baseline model's aggregate state, except for the distribution of capital Φ replaced by the aggregate capital stock K. The first-order optimality conditions are as follows:

$$[k'] : \quad \left(1 + \mu\left(\frac{k'}{k} - (1-\delta)\right)\right)(1-\tau^h) = \frac{1}{1+r(S)}\mathbb{E}J_1(k';S')$$

[11]If the representative-agent economy's private capital adjustment cost is differently calibrated, it necessarily implies less or more efficient adjustment than the infrastructure capital adjustment. Also, it is not desirable to change the public capital adjustment cost parameter for the sake of a fair comparison of the fiscal multipliers across the models.

Also, from the envelope theorem, we have

$$[k]: \quad J_1(k;S) = \frac{\alpha}{1-\gamma}(1-\gamma)\left(\frac{\gamma}{w(S)}\right)^{\frac{\gamma}{1-\gamma}} A^{\frac{1}{1-\gamma}} N^{\frac{\zeta}{1-\gamma}} k^{\frac{\alpha}{1-\gamma}-1}(1-\tau^c)(1-\tau^h)$$
$$+ (1-\delta+\tau^c\delta)(1-\tau^h) + \left(\frac{\mu}{2}\left(\frac{k'}{k}\right)^2 - \frac{\mu}{2}(1-\delta)^2\right)(1-\tau^h)$$

J Proof of Proposition 1

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:

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

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

Proof. Without loss of generality suppose $k_1 > k_2$, $z > 1$, and let $k_2 < N$. From the production functions, we have

$$
\begin{aligned}
y_1 &= z^{\frac{1}{\alpha}} B(\theta k_1^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}} \\
y_2 &= B(\theta k_2^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}} \\
y_1 + y_2 &= B(\theta (k_1 + k_2)^{\frac{\xi-1}{\xi}} + (1-\theta) N^{\frac{\xi-1}{\xi}})^{\frac{\xi}{\xi-1}}
\end{aligned}
$$

where $B := \left(\frac{1-\alpha}{w}\right)^{\frac{1-\alpha}{\alpha}}$. Therefore, the following relationships hold (from the second and the third equations above):

$$
\begin{aligned}
\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} &= \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} \\
\left(\frac{y_1+y_2}{B(k_1+k_2)}\right)^{\frac{\xi-1}{\xi}} &= \theta + (1-\theta)\left(\frac{N}{k_1+k_2}\right)^{\frac{\xi-1}{\xi}}.
\end{aligned}
$$

Suppose we are given $\lambda \geq 1$. We will prove the proposition by contradiction, so we assume $\xi \geq 1$. As $N > k_2$, $\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1$. Thus,

$$
\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1.
$$

Hence, $\frac{y_2}{Bk_2} > 1$. From the condition $\frac{y_1}{k_1} = \frac{y_2}{k_2}$,

$$
1 < \frac{y_2}{Bk_2} = \frac{y_1+y_2}{B(k_1+k_2)}.
$$

As $\xi \geq 1$, we have

$$
1 < \left(\frac{y_1+y_2}{B(k_1+k_2)}\right)^{\frac{\xi-1}{\xi}} = \theta + (1-\theta)\left(\frac{N}{k_1+k_2}\right)^{\frac{\xi-1}{\xi}}.
$$

However, $N \leq k_1 + k_2$. Thus, $\left(\frac{N}{k_1+k_2}\right)^{\frac{\xi-1}{\xi}} \leq 1$. This leads to

$$\theta + (1-\theta)\left(\frac{N}{k_1+k_2}\right)^{\frac{\xi-1}{\xi}} \leq 1,$$

which is a contradiction. Therefore, if the micro-level input elasticity satisfies $\lambda \geq 1$, then the aggregate-level input elasticity satisfies $\xi < 1$. ■

K Proof of Proposition 2

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

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

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:

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

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

Proof. Without loss of generality suppose $k_1 > k_2$, $z > 1$, and let $k_2 < N$. From the production functions, we have

$$
\begin{aligned}
y_1 &= z^{\frac{1}{\alpha}} B(\theta k_1^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}} \\
y_2 &= B(\theta k_2^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}} \\
y_1 + y_2 &= B(k_1 + k_2) N^{\frac{\zeta}{\alpha}}
\end{aligned}
$$

where $B := \left(\frac{1-\alpha}{w}\right)^{\frac{1-\alpha}{\alpha}}$. Therefore, the following relationships hold (from the second and the third equations above):

$$
\begin{aligned}
\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} &= \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} \\
\frac{y_1 + y_2}{B(k_1 + k_2)} &= N^{\frac{\zeta}{\alpha}}.
\end{aligned}
$$

Suppose we are given $\lambda \geq 1$. We will prove the proposition by contradiction, so we assume $\zeta < 0$. As $N > k_2$, $\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1$. Thus,

$$
\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1.
$$

Hence, $\frac{y_2}{Bk_2} > 1$. From the condition $\frac{y_1}{k_1} = \frac{y_2}{k_2}$,

$$
1 < \frac{y_2}{Bk_2} = \frac{y_1 + y_2}{B(k_1 + k_2)}.
$$

Thus, we have

$$
1 < \frac{y_1 + y_2}{B(k_1 + k_2)} = N^{\frac{\zeta}{\alpha}},
$$

which is a contradiction, as $\zeta < 0$ and $N > 1$. Therefore, if the micro-level input elasticity satisfies $\lambda \geq 1$ under the non-rivalry, then the public capital scale parameter satisfies $\zeta > 0$ (Baxter and King, 1993). ■

L Simple theory with the continuum of firms

Proposition 3. *Suppose we are given the micro-level data set (k_j, y_j, N), $j \in [0,1]$ s.t.*

$$\exists i \in [0,1] \ s.t. \ k_i < N, \quad N \leq \int_0^1 k_j dj, \quad \frac{y_j}{k_j} = C \in \mathbb{R}.$$

where C is a constant. Suppose the micro-level estimates (z_j, λ) and the aggregate-level estimate ξ are exactly identified by fitting the data with the production functions as follows:

$$(Normalizer) \quad z_0 = 1$$
$$f(k_j, N; \lambda, z_j) = y_j$$
$$f\left(\int k_j dj, N; \xi, 1\right) = \int_0^1 y_j dj$$

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

Proof. Without loss of generality suppose $k_0 < N$. From the production functions, we have

$$y_0 = B(\theta k_0^{\frac{\lambda-1}{\lambda}} + (1-\theta)N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}}$$
$$\int_0^1 y_j dj = B\left(\theta\left(\int k_j dj\right)^{\frac{\xi-1}{\xi}} + (1-\theta)N^{\frac{\xi-1}{\xi}}\right)^{\frac{\xi}{\xi-1}}$$

where $B := \left(\frac{1-\alpha}{w}\right)^{\frac{1-\alpha}{\alpha}}$. Therefore, the following relationships hold (from the second and the third equations above):

$$\left(\frac{y_0}{Bk_0}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_0}\right)^{\frac{\lambda-1}{\lambda}}$$
$$\left(\frac{\int_0^1 y_j dj}{B\left(\int_0^1 k_j dj\right)}\right)^{\frac{\xi-1}{\xi}} = \theta + (1-\theta)\left(\frac{N}{\int_0^1 k_j dj}\right)^{\frac{\xi-1}{\xi}}.$$

Suppose we are given $\lambda \geq 1$. We will prove the proposition by contradiction, so we assume $\xi \geq 1$. As $N > k_0$, $\left(\frac{N}{k_0}\right)^{\frac{\lambda-1}{\lambda}} > 1$. Thus,

$$\left(\frac{y_0}{Bk_0}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_0}\right)^{\frac{\lambda-1}{\lambda}} > 1.$$

Hence, $\frac{y_0}{Bk_0} > 1$. From the condition $\frac{y_j}{k_j} = C$,

$$1 < \frac{y_2}{Bk_2} = \frac{\int_0^1 y_j dj}{B\int_0^1 k_j dj}.$$

As $\xi \geq 1$, we have

$$1 < \left(\frac{\int_0^1 y_j dj}{B\left(\int_0^1 k_j dj\right)}\right)^{\frac{\xi-1}{\xi}} = \theta + (1-\theta)\left(\frac{N}{\int k_j dj}\right)^{\frac{\xi-1}{\xi}}.$$

However, $N \leq \int k_j dj$. Thus, $\left(\frac{N}{\int k_j dj}\right)^{\frac{\xi-1}{\xi}} \leq 1$. This leads to

$$\theta + (1-\theta)\left(\frac{N}{\int k_j dj}\right)^{\frac{\xi-1}{\xi}} \leq 1,$$

which is a contradiction. Therefore, if the micro-level input elasticity satisfies $\lambda \geq$

1, then the aggregate-level input elasticity satisfies $\xi < 1$. ■

Proposition 4. *Suppose we are given the micro-level data set* (k_j, y_j, N), $j \in [0,1]$ *s.t.*

$$\exists i \in [0,1] \; s.t. \; k_i < N, \quad 1 < N \leq \int_0^1 k_j dj, \quad \frac{y_j}{k_j} = C \in \mathbb{R}.$$

where C is a constant. Suppose the micro-level estimates (z_j, λ) *and the aggregate-level estimate* η *are exactly identified by fitting the data with the production functions as follows:*

$$(Normalizer) \quad z_0 = 1$$
$$f(k_j, N; \lambda, z_j) = y_j$$
$$h\left(\int k_j dj, N; \eta, 1\right) = \int_0^1 y_j dj$$

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

Proof. Without loss of generality suppose $k_0 < N$. From the production functions, we have

$$y_0 = B(\theta k_0^{\frac{\lambda-1}{\lambda}} + (1-\theta) N^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}}$$
$$\int y_j dj = B\left(\int k_j dj\right) N^{\frac{\eta}{\alpha}}$$

where $B := \left(\frac{1-\alpha}{w}\right)^{\frac{1-\alpha}{\alpha}}$. Therefore, the following relationships hold (from the second and the third equations above):

$$\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}}$$
$$\frac{\int y_j dj}{B \int k_j dj} = N^{\frac{\eta}{\alpha}}.$$

Suppose we are given $\lambda \geq 1$. We will prove the proposition by contradiction, so we assume $\eta < 0$. As $N > k_2$, $\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1$. Thus,

$$\left(\frac{y_2}{Bk_2}\right)^{\frac{\lambda-1}{\lambda}} = \theta + (1-\theta)\left(\frac{N}{k_2}\right)^{\frac{\lambda-1}{\lambda}} > 1.$$

Hence, $\frac{y_2}{Bk_2} > 1$. From the condition $\frac{y_1}{k_1} = \frac{y_2}{k_2}$,

$$1 < \frac{y_2}{Bk_2} = \frac{\int y_j dj}{B \int k_j dj}.$$

Thus, we have

$$1 < \frac{\int y_j dj}{B \int k_j dj} = N^{\frac{\eta}{\alpha}},$$

which is a contradiction, as $\eta < 0$ and $N > 1$. Therefore, if the micro-level input elasticity satisfies $\lambda \geq 1$ under the non-rivalry, then the public capital scale parameter satisfies $\eta > 0$ (Baxter and King, 1993). ■

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