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Abstract

Aggregate and sectoral effects of public investment crucially depend on the interaction between the output elasticity to public capital and input-output linkages. We identify this dependence through the lens of a New Keynesian production network. This setting doubles the socially optimal amount of public capital relative to the average one-sector economy, leading to a substantial amplification of the public investment multiplier. We also document novel sectoral implications of public investment. Although public investment is concentrated in far fewer sectors than public consumption, its effects are relatively more evenly distributed across industries. We validate this model implication in the data.

Keywords: sectoral heterogeneity, input-output matrix, public capital.

JEL classification: E31, E32, E52.

Resumen

Los efectos agregados y sectoriales de la inversión pública dependen fundamentalmente de la interacción entre la elasticidad de la producción con respecto al capital público y los vínculos de la cadena de suministro. Enseñamos este hecho a través de una red de producción neokeynesiana. Este modelo duplica la cantidad socialmente óptima de capital público en relación con la economía unisectorial, lo que conduce a una amplificación sustancial del multiplicador de la inversión pública. Asimismo, documentamos nuevas implicaciones sectoriales de la inversión pública. Aunque la inversión pública se concentra en muchos menos sectores que el consumo público, sus efectos se distribuyen de una forma relativamente más uniforme entre las industrias. Validamos esta implicación del modelo en los datos.

Palabras clave: heterogeneidad sectorial, matriz *input-output,* capital público.

Códigos JEL: E31, E32, E52.

1 Introduction

In the aftermath of the Covid pandemics, governments have turned to massive public-investment projects, best exemplified by the $1.2 trillion Infrastructure Investment and Jobs Act in the U.S. and the €800 billion Next Generation EU in Europe. Policy-makers motivate these packages with the need to strengthen supply chains and foster the development of specific industries.[1] However, these mechanisms are missing in the workhorse theoretical analysis of public investment, which hinges on one-sector models. To fill this gap, this paper studies the implications of public investment through the lens of a New Keynesian production network, and shows that the aggregate and sectoral effects of public investment crucially depend on the interaction between Input-Output linkages and the output elasticity to public capital.

To ascertain the propagation of public-investment shocks through the production network, we build a sticky-price model with heterogeneous sectors that are connected by an Input-Output matrix. The government finances an exogenous stream of public spending on sectoral goods with lump-sum taxes. Public investment accumulates to the stock of public capital subject to time-to-build and time-to-spend delays, as in Leeper et al. (2010) and Ramey (2021). Public capital is productive insofar it enhances the productivity of final-good technologies, to an extent which varies across industries.

In the quantitative analysis, we consider an economy with 55 sectors—which reflect the 3-digit level of disaggregation of NAICS codes—and calibrate it with information from the 2019 Input-Output Tables of the U.S. Bureau of Economic Analysis. To discipline the heterogeneous effect of public capital across industries, we provide novel estimates of the elasticity of gross output to public capital at the sectoral level. We extend Bouakez et al. (2017)'s estimation to a panel setting and regress the logarithm of sector-specific utilization-adjusted TFP on the logarithm of public capital. Using KLEMS data from 1963 to 2016, we first recover the utilization-adjusted TFP at the sectoral level, following the procedure of Basu et al. (2006) and Fernald (2014). Then, we estimate the sector-specific elasticities with the heterogeneous cointegrated panel estimator of Pedroni (2001). We find an average elasticity of 0.0575, which is conservatively at the lower end of the estimates derived in the literature. This figure conceals a large amount of heterogeneity: the elasticity varies from 0 for the pipeline transportation industry up to 0.1363 for computer manufacturing.

Our quantitative analysis starts by uncovering to what extent sectoral heterogeneity and inter-linkages amplify the fiscal multipliers. We find that the long-run

[1] See https://www.whitehouse.gov/bipartisan-infrastructure-law/ and https://ec.europa.eu/info/strategy/recovery-plan-europe_en.

present-value public-investment multiplier in the production-network economy equals 2.12, and is 68% (or 86 cents) larger than that in the one-sector model. Crucially, the amplification is twice as large as the one associated with the public-consumption multiplier (Bouakez et al., 2023).[2] The production-network amplification is also substantial at shorter horizons.[3] Although public consumption spurs relatively more aggregate output in the very short run (Boehm, 2020; Ramey, 2021), the production network closes the gap between the public-investment and public-consumption multipliers after just 6 quarters, significantly faster than the 30 quarters required by the one-sector model. While this implies that public investment is not an ideal immediate stabilization policy, sectoral inter-linkages allow the model to be consistent with the empirical evidence showing that the stimulus effects of public investment are limited in the very short run (Boehm, 2020) but become significant after a couple of years (Ilzetzki et al., 2013).

The amplification of the public-investment multiplier fully stems from the interaction between the output elasticity to public capital and the Input-Output matrix. When public capital is unproductive, public investment barely alters output. When public capital is productive but absent the Input-Output matrix, the multipliers in the multi-sector and one-sector economies coincide. We characterize analytically the mechanism boosting the response of aggregate output to public investment. Intuitively, intermediate inputs amplify the magnitude of the public-capital productivity, as a surge in public investment benefits firms not only directly, but also indirectly: by enhancing the efficiency in the provision of intermediate inputs, public investment curtails firms' costs, allowing to expand their production. This mechanism implies relatively larger public-investment multipliers if upstream sectors feature high public-capital elasticities. However, we do not observe this in the data: the sectors' positions in the network barely correlate with their public-capital elasticities. Accordingly, heterogeneity in this dimension does not play a sizable role in the propagation of public investment

The amplification of the multiplier also depends on the way in which the production network alters the optimal level of public capital. Ramey (2021) demonstrates that output reacts relatively more to public-investment shocks when public capital is inefficiently low. Our production network doubles the socially optimal amount of public capital relative to the average one-sector economy, and puts it way above the level observed in the data. Interestingly, we also find a substantial shift in the welfare costs associated to inefficient levels of public capital: while welfare losses in the one-sector economy mainly come when public

[2]This finding holds in an comprehensive battery of robustness checks that extend the baseline economy to include features such as distortionary taxes (Leeper et al., 2010), sticky wages (Erceg et al., 2000), an investment network (Vom Lehn and Winberry, 2022), and durable consumption (Boehm, 2020).

[3]The production-network amplification of public investment is three times as large as that of public consumption at the 2-year and 4-year horizons.

capital is inefficiently high, the opposite applies in our economy. Thus, intersectoral linkages make low levels of public capital particularly costly.

We then leverage the structure of our model to uncover novel sectoral implications of public investment. First, we document that public investment is highly concentrated in a handful of sectors: just three industries—(*i*) construction, (*ii*) professional services, and (*iii*) computer systems services—account for the lion's share of public investment, with a total joint share of 78%. This marked concentration stands in stark contrast with the sectoral composition of public consumption, with contributions from almost every sectors. To the extent that recipient sectors benefit relatively more from the expansion of public spending, one should expect that the high concentration of public investment in few industries should be mirrored by an equally high concentration of the sectoral multipliers. Surprisingly, this is not the case.

To compare the sectoral implications of public investment to those of public consumption, we compute the relative sectoral-value added multipliers for both type of expenditures. These relative measures inform on how one additional dollar of the aggregate multiplier is distributed across sectors. We find that the ratio between the standard deviations of the relative sectoral multipliers and the sectoral contributions equals 0.4 for public investment and above unity for public consumption. In other words, the positive output gains of public investment are relatively more evenly distributed across industries, notwithstanding the marked concentration of its sectoral contributions.

This surprising result is again a byproduct of the interaction between the output elasticity to public capital and Input-Output linkages. Absent these features, the bulk of the output gains is concentrated in very few industries. The Input-Output matrix magnifies the positive effects of public capital across the production network, as sectors may *indirectly* benefit from the higher efficiency in the provision of intermediate inputs, even when they do not *directly* contribute to the production of the public-investment goods. As a result, the output gains of public investment propagate to a wider pool of industries. Conversely, since public consumption is not productive, its benefits mainly accrue to those sectors that are *direct* recipients of this type of spending.

Finally, we empirically validate the model prediction on sectoral value-added responses to public-investment shocks being more evenly distributed than those to public-consumption shocks. We adapt the estimation strategy of Ramey and Zubairy (2018) by extending the linear projection method of Jordà (2005) to a panel setting. We build a panel with annual observations for the 55 sectors of our model economy, from 1963 to 2015. Then, we regress sectoral value added on the interaction between aggregate defense investment expenditures and the associated sectoral contributions. We consider an analogous regression for public consumption. We saturate the regression with sector and year fixed effects, and follow Ramey and Zubairy (2018) by instrumenting aggregate public spending with both the military-spending news variable of Ramey (2011) and the timing restriction of Blanchard and Perotti (2002).

We find that the coefficients on the interactions of public investment and consumption with their sectoral contributions are positive and highly statistically significant. In line with the model predictions, the estimate of the interaction term associated with public consumption is twice as large as that associated with public investment. Notably, the empirical estimates on how the relative sectoral multipliers vary with the sectors' contributions to public spending are remarkably in line with the quantitative predictions of the model.

We add to the burgeoning literature on the aggregate effects of public investment (Baxter and King, 1993; Leeper et al., 2010; Leduc and Wilson, 2013; Bouakez et al., 2017, 2020; Boehm, 2020; Ramey, 2021), by showing that the public-investment multiplier is substantially amplified in a production network.[4] This result sheds novel insights on the values of the output elasticity to public capital required to generate large output responses. While Bom and Ligthart (2014) indicate that the average elasticity used in the literature ranges between 0.08 and 0.12, Aschauer (1988, 1989) and Fernald (1999) find values up to 0.4. An average elasticity of 0.0575 in our production-network yields a multiplier that can be reproduced by the one-sector model with the much larger elasticity of 0.1098. Thus, sectoral heterogeneity and inter-linkages generate economically meaningful multipliers with half of the public-capital elasticity required by the cations of public investment. This dimension has been neglected until now, given the prominent use of one-sector models to study the public-investment multiplier.

Our work builds on the literature that studies how business cycle fluctuations are shaped by sectoral heterogeneity and inter-sectoral linkages (Horvath, 1998, 2000; Acemoglu et al., 2012; Baqaee and Farhi, 2019; Pasten et al., 2020). In this context, we complement the body of work that looks at the propagation of fiscal shocks across heterogeneous sectors by focusing solely on the effects of *public-consumption* shocks (Acemoglu et al., 2016; Bouakez et al., 2022, 2023; Cox et al., 2022; Proebsting, 2022), by showing to what extent—and through which channels—a production network alters the effects of *public-investment* shocks.

2 Model

The economy consists of a unit mass of identical infinitely-lived households and a finite number of heterogeneous sectors, indexed by $s \in \{1, \ldots, S\}$. Sectors differ in their: (*i*) factor intensities; (*ii*) output elasticity of public capital; (*iii*) degree

[4]Our emphasis on the relevance of heterogeneity across sectors complements Roulleau-Pasdeloup (2022), which highlights the amplification of the public-investment multiplier arising from heterogeneous households.

of nominal price rigidity; (*iv*) contribution to private demand; (*v*) contribution to public demand; as well as (*vi*) use and supply of intermediate inputs from and to all the industries of the economy. The government consists of a monetary authority, which sets the nominal interest rate with a Taylor rule, and a fiscal authority, which sets a lump-sum tax on the households to finance exogenous streams of public consumption and public investment.

2.1 Households

Households have preferences over streams of private consumption, C_t, and labor, N_t, such that the present value of their life-time utility equals

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right], \tag{1}$$

where β is the time discount factor, σ captures the risk aversion, η is the inverse of the Frisch elasticity, and θ is a labor disutility shifter. The budget constraint

$$P_{C,t}C_t + P_{I,t}I_t + T_t + B_t = W_tN_t + R_{K,t}K_t + R_{t-1}B_{t-1}, \tag{2}$$

posits that every period households purchase the private-consumption good at price $P_{C,t}$, the private-investment good I_t at price $P_{I,t}$, and incur in a nominal lump-sum tax, T_t. Households earn labor income, W_tN_t, and capital income, $R_{K,t}K_t$, where W_t is the aggregate nominal wage, K_t denotes the stock of private capital and $R_{K,t}$ is its nominal return rate. Households also invest in one-period bonds, B_t, that yield the nominal rate R_t.

Private capital depreciates at the rate δ_K and its law of motion is subject to investment adjustment costs, captured by the parameter Ω, such that

$$K_{t+1} = (1-\delta_K)\,K_t + I_t \left[1 - \frac{\Omega}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right]. \tag{3}$$

To capture the limited reallocation of labor and capital across sectors at the business cycle frequency (Lee and Wolpin, 2006; Lanteri, 2018), we assume that aggregate labor N_t is a CES aggregator of sectoral labor flows $N_{s,t}$,

$$N_t = \left[\sum_{s=1}^{S} \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right]^{\frac{\nu_N}{1+\nu_N}}, \tag{4}$$

where $\omega_{N,s}$ is a sectoral weight, and ν_N captures the elasticity of substitution of labor across sectors. When $\nu_N < \infty$, sectoral nominal wages, $W_{s,t}$, do not coincide and the aggregate wage equals

$$W_t = \left[\sum_{s=1}^{S} \omega_{N,s} W_{s,t}^{1+\nu_N} \right]^{\frac{1}{1+\nu_N}}. \tag{5}$$

Analogously, the aggregate stock of private capital K_t and nominal return of private capital $R_{K,t}$ are determined by the CES aggregators

$$K_t = \left[\sum_{s=1}^{S} \omega_{K,s}^{-\frac{1}{\nu_K}} K_{s,t}^{\frac{1+\nu_K}{\nu_K}} \right]^{\frac{\nu_K}{1+\nu_K}}, \tag{6}$$

and

$$R_{K,t} = \left[\sum_{s=1}^{S} \omega_{K,s} R_{K,s,t}^{1+\nu_K} \right]^{\frac{1}{1+\nu_K}}, \tag{7}$$

where $K_{s,t}$ is the private capital supplied to the producers of sector s, $R_{K,s,t}$ is the nominal return of private capital used by sector s, $\omega_{K,s}$ is a sectoral weight, and ν_K determines the elasticity of substitution of private capital across sectors.

2.2 Firms

Each sector is operated by two layers of firms: a continuum of monopolistic producers that assemble different varieties of the sectoral good, and competitive wholesalers that bundle the varieties into the final sectoral good.

Sectoral goods are sold to competitive private- and public-consumption retailers, private- and public-investment retailers, and intermediate-input retailers which produce the final private and public consumption, the final public and private investment, and the intermediate inputs used by all sectors, respectively.

The output of private-consumption and private-investment retailers is sold to households, the output of intermediate-input retailers is sold to producers of all the sectors, and the output of public-consumption and public-investment retailers is sold to the government.

2.2.1 Producers

Each sector s is populated by a unit mass of homogeneous monopolistic producers, indexed by $i \in [0,1]$, which assemble different varieties of the sectoral good, $Z_{s,t}^i$, according to the Cobb-Douglas technology

$$Z_{s,t}^i = \left({N_{s,t}^i}^{\alpha_{N,s}} {K_{s,t}^i}^{1-\alpha_{N,s}} \right)^{1-\alpha_{H,s}} {H_{s,t}^i}^{\alpha_{H,s}} K_{G,t}^{\gamma_{G,s}}, \tag{8}$$

where $N_{s,t}^i$, $K_{s,t}^i$, and $H_{s,t}^i$ denote the labor, private capital, and intermediate inputs used by producer i in sector s, while $\alpha_{N,s}$ and $\alpha_{H,s}$ are the value-added labor share and gross-output intermediate-input share, respectively.[5]

[5] The elasticity of substitution between value added and intermediate inputs is set to one in line with the evidence of Atalay (2017). Similarly, the elasticity of substitution between labor and capital equals one.

Following Baxter and King (1993), Leeper et al. (2010), and Ramey (2021), the stock of public capital, $K_{G,t}$ affects the production of private goods. The elasticity, $\gamma_{G,s}$, disciplines the extent to which public capital enhances the productivity of the gross output of sector s. Crucially, it is heterogeneous across sectors.

Each producer i sells its sectoral variety to the wholesalers at price $P^i_{s,t}$. Prices maximize profits and are subject to a Calvo (1983)'s price-setting friction, such that producers reset their price with the sector-specific probability $1-\phi_s$.

2.2.2 Wholesalers

In each sector, the wholesalers buy the different varieties of the sectoral good, $Z^i_{s,t}$, to produce the final sectoral good $Z_{s,t}$ using the CES technology

$$Z_{s,t} = \left(\int_0^1 {Z^i_{s,t}}^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{9}$$

with elasticity of substitution across within-sector varieties ϵ. The price of the sectoral good, $P_{s,t}$, is

$$P_{s,t} = \left(\int_0^1 {P^i_{s,t}}^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}. \tag{10}$$

The goods are sold to retailers, which produce the bundles used in the production of private and public consumption, private and public investment, and intermediate inputs. Accordingly, the sectoral resource constraint reads

$$Z_{s,t} = C_{s,t} + I_{s,t} + \sum_{x=1}^{S} H_{x,s,t} + G_{s,t} + I_{G,s,t}, \tag{11}$$

where $C_{s,t}$ is the demand of private-consumption retailers of sector-s goods, $I_{s,t}$ is the demand of private-investment retailers, $H_{x,s,t}$ is the demand of intermediate-input retailers associated to sector x, $G_{s,t}$ is the demand of public-consumption retailers, and $I_{G,s,t}$ is the demand of public-investment retailers.

2.2.3 Private-Consumption Retailers

The private-consumption retailers buy the sectoral goods $C_{s,t}$ at price $P_{s,t}$, and produce the private-consumption good C_t with the CES technology

$$C_t = \left[\sum_{s=1}^{S} \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C-1}{\nu_C}}\right]^{\frac{\nu_C}{\nu_C-1}}, \tag{12}$$

where $\omega_{C,s}$ is a sectoral weight, such that $\sum_{s=1}^{S}\omega_{C,s} = 1$, and ν_C denotes the elasticity of substitution of private consumption across sectors. The final private-consumption good is sold to households at price $P_{C,t}$:

$$P_{C,t} = \left[\sum_{s=1}^{S} \omega_{C,s} P_{s,t}^{1-\nu_C}\right]^{\frac{1}{1-\nu_C}}. \tag{13}$$

2.2.4 Private-Investment Retailers

The private-investment retailers buy the goods $I_{s,t}$ at price $P_{s,t}$, and produce the private-investment good I_t with the CES technology

$$I_t = \left[\sum_{s=1}^{S} \omega_{I,s}^{\frac{1}{\nu_I}} I_{s,t}^{\frac{\nu_I - 1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I - 1}}, \tag{14}$$

where $\omega_{I,s}$ is a sectoral weight, such that $\sum_{s=1}^{S} \omega_{I,s} = 1$, and ν_I denotes the elasticity of substitution of private investment across sectors. The final private-investment good is sold to households at price $P_{I,t}$:

$$P_{I,t} = \left[\sum_{s=1}^{S} \omega_{I,s} P_{s,t}^{1-\nu_I} \right]^{\frac{1}{1-\nu_I}}. \tag{15}$$

2.2.5 Intermediate-Input Retailers

In each sector, the intermediate-input retailers buy goods from any other industry x, $H_{s,x,t}$, at price $P_{x,t}$, and produce intermediate-input used by sector-s producers with the CES technology

$$H_{s,t} = \left[\sum_{x=1}^{S} \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H - 1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H - 1}}, \tag{16}$$

where $\omega_{H,s,x}$ is the weight of the goods provided by sector x into the intermediate inputs used by sector s firms, such that $\sum_{x=1}^{S} \omega_{H,s,x} = 1$, and ν_H denotes the elasticity of substitution of intermediate inputs across sectors. The intermediate-input bundle is sold to the producers of sector s at price $P_{H,s,t}$:

$$P_{H,s,t} = \left[\sum_{x=1}^{S} \omega_{H,s,x} P_{x,t}^{1-\nu_H} \right]^{\frac{1}{1-\nu_H}}. \tag{17}$$

2.2.6 Public-Consumption Retailers

The public-consumption retailers purchase the goods $G_{s,t}$ at price $P_{s,t}$, and produce the aggregate public consumption good using the CES technology

$$G_t = \left[\sum_{s=1}^{S} \omega_{G,s}^{\frac{1}{\nu_G}} G_{s,t}^{\frac{\nu_G - 1}{\nu_G}} \right]^{\frac{\nu_G}{\nu_G - 1}}, \tag{18}$$

where $\omega_{G,s}$ is a sectoral weight, such that $\sum_{s=1}^{S} \omega_{G,s} = 1$, and ν_G denotes the elasticity of substitution of public-consumption goods across sectors. The final public-consumption good is sold to the fiscal authority at price $P_{G,t}$:

$$P_{G,t} = \left[\sum_{s=1}^{S} \omega_{G,s} P_{s,t}^{1-\nu_G} \right]^{\frac{1}{1-\nu_G}}. \tag{19}$$

2.2.7 Public-Investment Retailers

The public-investment retailers purchase the goods $I_{G,s,t}$ at price $P_{s,t}$, and produce the aggregate public investment good using the CES technology

$$I_{G,t} = \left[\sum_{s=1}^{S} \omega_{I_G,s}^{\frac{1}{\nu_{I_G}}} I_{G,s,t}^{\frac{\nu_{I_G}-1}{\nu_{I_G}}} \right]^{\frac{\nu_{I_G}}{\nu_{I_G}-1}}, \tag{20}$$

where $\omega_{I_G,s}$ is a sectoral weight, such that $\sum_{s=1}^{S} \omega_{I_G,s} = 1$, and ν_{I_G} denotes the elasticity of substitution of public-investment goods across sectors. The final public-investment good is sold to the fiscal authority at price $P_{I_G,t}$:

$$P_{I_G,t} = \left[\sum_{s=1}^{S} \omega_{I_G,s} P_{s,t}^{1-\nu_{I_G}} \right]^{\frac{1}{1-\nu_{I_G}}}. \tag{21}$$

2.3 Government

The government consists of a monetary and fiscal authority. The monetary authority sets the nominal interest rate subject to a standard Taylor rule

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}} \right)^{\phi_\rho} \left(\pi_t^{\phi_\pi} X_t^{\phi_x} \right)^{1-\phi_\rho}, \tag{22}$$

where $\bar{R}$ is the steady-state value of the nominal interest rate,[6] π_t is the aggregate inflation rate defined over the GDP deflator, and $X_t = \frac{Y_t}{Y_t^{\text{flex}}}$ is the output gap, defined as the ratio between the aggregate value added of the economy, Y_t, and its corresponding value in the counterfactual economy with flexible prices, Y_t^{flex}. The parameter ϕ_ρ denotes the degree of interest-rate inertia. The parameters ϕ_π and ϕ_x denote the responsiveness of the nominal interest rate to changes in aggregate inflation and the aggregate output gap, respectively.

The fiscal authority sets the lump-sum nominal tax on households, T_t, to finance exogenous streams of public consumption, G_t, and public investment, $I_{G,t}$. The government purchases the public-consumption and investment goods from the two associated retailers at prices, $P_{G,t}$ and $P_{I_G,t}$, respectively.

The purchases of public-consumption goods, G_t, and planned public-investment expenditures, $\tilde{I}_{G,t}$, are determined exogenously by the autoregressive processes

$$\log G_t = (1-\rho) \log \bar{G} + \rho \log G_{t-1} + \epsilon_{G,t}, \tag{23}$$

$$\log \tilde{I}_{G,t} = (1-\rho) \log \bar{I}_G + \rho \log \tilde{I}_{G,t-1} + \epsilon_{I,t}, \tag{24}$$

[6] Throughout the paper, we denote the steady-state value of a given variable A_t as $\bar{A}$.

where ρ denotes the persistence of the processes, $\bar{G}$ and $\bar{I}_G$ are the steady-state value of public consumption and investment, $\epsilon_{G,t}$ is the public-consumption shock, and $\epsilon_{I,t}$ is the public-investment shock.[7]

Following Leeper et al. (2010) and Ramey (2021), we consider time-to-spend and time-to-build frictions associated with public investment. The time-to-spend constraint implies that planned public investment expenditures lead to actual spending with a lag

$$I_{G,t} = \frac{1}{\zeta} \sum_{j=1}^{\zeta} \tilde{I}_{G,t-j-1}. \tag{25}$$

Accordingly, current public-investment spending averages planned lagged expenditures, with ζ capturing the horizon of the time-to-spend delay. The time-to-build friction implies that actual public investment accumulates into public capital with the law of motion

$$K_{G,t} = (1 - \delta_{K_G})\, K_{G,t-1} + I_{G,t-\mu}, \tag{26}$$

where δ_{K_G} denotes the depreciation rate of public capital, and μ captures the horizon of the time-to-build delay.

In every period, the budget constraint of the government is balanced, and taxes equal total expenditures

$$T_t = P_{G,t} G_t + P_{I_G,t} I_{G,t}. \tag{27}$$

2.4 Closing the Model

The nominal sectoral value added, $\mathcal{Y}_{s,t}$, equals the difference between the nominal values of sectoral gross output and sectoral intermediate inputs, that is

$$\mathcal{Y}_{s,t} = P_{s,t} Z_{s,t} - P_{H,s,t} H_{s,t}. \tag{28}$$

Summing across the nominal sectoral value added yields the nominal aggregate value added, which equals the sum of the nominal values of private and public consumption, as well as private and public investment:

$$\mathcal{Y}_t = \sum_{s=1}^{S} \mathcal{Y}_{s,t} = P_{C,t} C_t + P_{I,t} I_t + P_{G,t} G_t + P_{I_G,t} I_{G,t}. \tag{29}$$

Finally, the real aggregate value added is defined as the ratio between the nominal aggregate value added and the GDP deflator,[8] P_t, that is,

$$Y_t = \frac{\mathcal{Y}_t}{P_t}. \tag{30}$$

[7] In the data, government consumption spending also consists of the compensation of public employees and capital depreciation (see Moro and Rachedi, 2022). We abstract from these components following the vast literature that treats public spending solely as the purchases of goods from private-sector industries. Table E.6 in Appendix E evaluates the robustness of our results to the case in which public consumption expenditures also consist of the compensation of public employees.

[8] The GDP deflator is defined as the ratio between nominal value added and the value added measured with steady-state prices.

3 Calibration

The model is calibrated to the U.S. economy at quarterly frequency. The economy features 55 sectors, which reflect the 3-digit disaggregation level of NAICS codes.[9] Appendix A lists the sectors and provides further details on the calibration.

We consider a zero inflation rate in the steady state. The household discount rate $\beta = 0.995$ targets a 2% real annual steady-state interest rate. As standard, the risk aversion coefficient is $\sigma = 2$. The labor supply elasticity η equals 0.67 and implies a Frisch elasticity of 1.5.[10] The labor disutility parameter is set to $\theta = 36.63$ to achieve a steady-state value for total hours of $\bar{N} = 0.33$.

To set the (short-run) elasticity of substitution of private consumption, private investment, and intermediate inputs across sectors, we follow the empirical evidence that uncovers these parameters at the business cycle frequency. First, the elasticity of substitution of private consumption across sectors is set to $\nu_C = 2$, in line with the estimate of Hobijn and Nechio (2019) on the elasticity across 74 consumption categories estimated through value-added tax changes. Second, we set the elasticity of substitution of private investment across sectors to a similar value: $\nu_I = 2$.[11] Third, we calibrate the elasticity of substitution of intermediate inputs across sectors to $\nu_H = 0.1$ following Barrot and Sauvagnat (2016) and Boehm et al. (2019), which exploit natural disasters to provide evidence in favor of the high degree of complementarity of materials across industries in the short-run.

To set the elasticity of substitution of the public consumption, we follow Bouakez et al. (2023) and set $\nu_G = 1$. This choice ensures that the sectoral composition of public spending is kept constant over time, a property that Bouakez et al. (2023) refer to as composition-preserving spending shocks. Similarly, we set the elasticity of public investment to $\nu_{I_G} = 1$.[12]

Given the elasticities of substitution, the parameters $\omega_{C,s}$, $\omega_{G,s}$, $\omega_{I,s}$, $\omega_{I_G,s}$ and $\omega_{H,s,x}$ determine the heterogeneity in the sectoral contributions to private and public consumption, private and public investment, and the use of intermediate

[9] As discussed in the next section, this is the maximum level of disaggregation that allows us to derive the series of sectoral utilization-adjusted TFP, which is required to estimate the sector-specific output elasticity to public capital.

[10] This value is higher than the estimates of the Frisch elasticity at the individual level (Chetty et al., 2013). However, Erosa et al. (2016) show that a low individual Frisch elasticity is consistent with an aggregate labor supply elasticity of 1.75. We decide to set this relatively high value of the Frisch elasticity since it helps the model in generating fiscal multipliers in line with the empirical evidence (Hall, 2009). For instance, Baxter and King (1993) and Ramey (2021) consider a Frisch elasticity of 4. Table E.1 in Appendix E shows that our main results hold also in a version of the model with a Frisch elasticity of 1.

[11] Tables E.1 and E.2 in Appendix E analyze how these choices affect the results of the model. In particular, we consider a calibration with $\nu_C = 0.8$ and $\nu_I = 0.8$ so that the economy features complementarities of consumption and investment across sectors.

[12] The value of these elasticities is inconsequential for our results: Tabls E.4 and E.5 in Appendix E shows that results are virtually unchanged if we set these elasticities to either 0.5 or 2.

inputs supplied by all industries, respectively. We discipline these parameters with the Input-Output Tables of the U.S. Bureau of Economic Analysis as of 2019: $\omega_{C,s}$ targets the sectoral shares in personal consumption expenditures; $\omega_{G,s}$ targets the sectoral shares in the sum of federal (defense and non-defense) and state and local general government consumption spending; $\omega_{I,s}$ targets the sectoral shares in the nonresidential private fixed investment in structures, equipment, and intellectual property products; $\omega_{I_G,s}$ targets the sectoral shares in gross investment in structures, equipment, and intellectual property products carried out by the federal, state, and local government; and $\omega_{H,s,x}$ targets the sectoral shares in the supply and use of intermediate inputs with respect to all industries.

We then set the elasticity of substitution across within-sector varieties to $\epsilon = 4$ to obtain the 25% markup estimated by De Loecker et al. (2020). Given markups, the value-added labor share, $\alpha_{N,s}$, targets the sectoral shares of the compensation of employees in value added (i.e., the sum of the compensation of employees and the gross operating surplus). We calibrate the gross-output intermediate-input share, $\alpha_{H,s}$, in order to match the sectoral shares of the expenditures in intermediate inputs in gross output, defined as the sum of value added and the expenditures in intermediate inputs. Finally, the next subsection details the estimation of the elasticity of sectoral output to public capital, $\gamma_{G,s}$.

We follow Bouakez et al. (2023) to set the sectoral price rigidity, ϕ_s, using the duration of prices provided by Nakamura and Steinsson (2008). In respect to the monetary rule, we choose the parameters $\phi_\rho = 0.8$, $\phi_\pi = 1.5$, and $\phi_x = 0.2$ following the evidence of Clarida et al. (2000). Regarding the fiscal authority, we set the persistence of the public-consumption and public-investment shocks to $\rho = 0.95$, as in Leeper et al. (2010) and Ramey (2021).[13] The steady-state values for public consumption, $\bar{G}$, and public investment, $\bar{I}_G$, match the shares of nominal government consumption expenditures (14%) and nominal government gross investment (3.5%), as fractions of nominal GDP in 2019. We then follow Leeper et al. (2010) to set the time-to-build horizon for public capital to $\mu = 4$, and the time-to-spend horizon to $\zeta = 3$.

The elasticity of labor across sectors is set to $\nu_N = 1$ following the estimate of Horvath (2000). Similarly, the elasticity of capital across sectors is $\nu_K = 1$. To calibrate the weights of sectoral labor and capital, we impose the homogeneity in wages and returns to capital across industries at the steady state. This requires that $\omega_{N,s} = \bar{N}_s/\bar{N}$ and $\omega_{K,s} = \bar{K}_s/\bar{K}$. We calibrate the parameter that governs the private-investment adjustment cost $\Omega = 7.25$ to match the relative volatility of investment to output obtained from HP-filtered ratio of real nonresidential investment with respect real GDP from 1950Q1 to 2019Q4 in a model version

[13]Table E.5 in Appendix E considers both lower and higher persistence for the public-spending processes.

featuring only aggregate TFP shocks.[14] The depreciation rates of private capital and public capital are set to $\delta_K = 0.015$ and $\delta_{K_G} = 0.01$, respectively, based on the estimates of Ramey (2021).[15]

3.1 The Sectoral Output Elasticity of Public Capital

In the model, public capital raises the productivity of firms' technologies. To capture the idea that some industry may benefit more than others, we allow the output elasticity to public capital, $\gamma_{G,s}$, to vary across sectors. Following Bouakez et al. (2017) and Ramey (2021), we discipline this dimension of heterogeneity by estimating a cointegrating relationship between TFP and the stock of public capital. In doing so, we extend their time-series methodology to a panel setting. Instead of regressing the logarithm of *aggregate* TFP on the logarithm of the aggregate stock of public capital, our dependent variable is the logarithm of *sectoral* TFP:

$$\log TFP_{s,t} = \gamma_{G,s} \log K_{G,t} + \epsilon_{s,t}. \tag{31}$$

We then estimate the elasticity of sectoral gross output to public capital using the heterogeneous cointegrated panel approach of Pedroni (2001).[16]

To correctly identify the output elasticity, Bouakez et al. (2017) and Ramey (2021) argue that the TFP measure should be adjusted to account for the variable utilization of production factors.[17] While a utilization-adjusted TFP series has been constructed at the aggregate level (Fernald, 2014), there are no time-series that are long enough to estimate a cointegrating relationship at the sectoral level. Following Basu et al. (2006) and Fernald (2014), we build utilization-adjusted sectoral TFP series for the 55 industries defined in our calibration strategy. To do so, we use KLEMS data from 1963 to 2016 on: real and nominal gross output, real and nominal intermediate inputs, the stock of five types of capital (IT, software, R&D, art, and other) and the use of college and non-college labor.[18] We use this information jointly with the chain-type quantity index for the net stock of total government fixed assets—provided by the Fixed Assets Accounts Tables of the U.S. Bureau of Economic Analysis—to estimate regression (31).

Figure 1 reports the estimates of the sector-specific elasticity of gross output to public capital. The average output elasticity of public capital is 0.0575. This

[14]The value of adjustment cost also allows the model to replicate the response of private investment to public consumption shocks which bottoms after 8 quarters, as shown in Blanchard and Perotti (2002).

[15]Our choices are close to those of Leeper et al. (2010), in which $\delta_K = 0.025$ and $\delta_{K_G} = 0.02$. Table E.1 in Appendix E evaluates the robustness of our results to different depreciation rates.

[16]Unlike Bouakez et al. (2017), we do not control for education and R&D expenditures. This is because our measure of sectoral TFP is explicitly derived by already taking into consideration the skill-content of employment as well as the usage of R&D capital (see Appendix B).

[17]Absent this adjustment, the estimates of the elasticity $\gamma_{G,s}$ would also capture sectoral variation in slack.

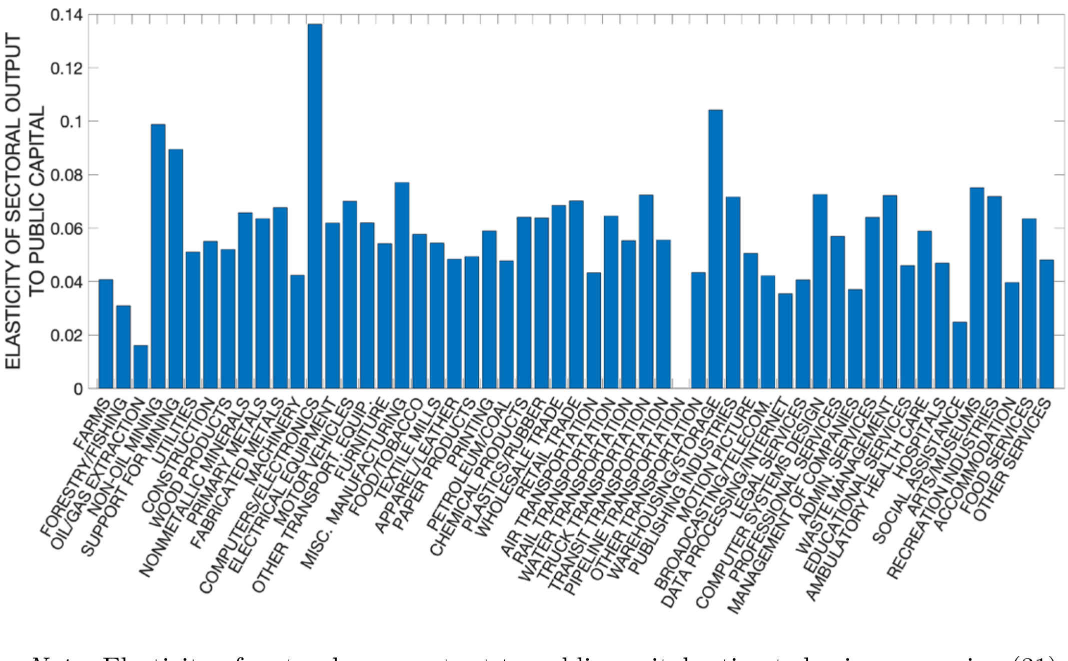
[18]We describe the procedure to derive the sector-specific utilization-adjusted TFP series in Appendix B.

value is in line with the elasticity of 0.05 used in Baxter and King (1993), Leeper et al. (2010), and Ramey (2021), and just slightly lower than the value of 0.065 estimated by Bouakez et al. (2017). To put these numbers in perspective, the meta-analysis of Bom and Ligthart (2014) on the estimates of the output elasticity to public capital shows that the average value used in the literature ranges between 0.08 and 0.12. Overall, our estimate is conservative and lies at the low end of the ballpark of the elasticities found in the literature.

The novelty of our approach is that we estimate the extent to which the elasticity of *sectoral* output to public capital varies across industries. Figure 1 shows that the average value of 0.0575 conceals a large amount of heterogeneity: the elasticity varies from 0 for the pipeline transportation industry up to 0.1363 for the computer and electronic products manufacturing sector.[19]

Crucially, our analysis in Sections 4 and 5 shows that heterogeneity in the elasticity of output to public capital across sectors is not quantitatively important for understanding the aggregate and sectoral implications of public investment. Thus, while we acknowledge the challenges associated with the identification of the output elasticity of public capital—especially so in a setting that aims at deriving the heterogeneity in this parameter across sectors—our approach is a proof of concept to establish the quasi-irrelevance of the variation in the productivity of public capital across industries.

Figure 1: The Elasticity of Sectoral Output to Public Capital.



Note: Elasticity of sectoral gross output to public capital estimated using regression (31).

[19]Heterogeneity in the elasticity across industries barely covaries with other sector-specific characteristics, such as the production-network centrality and the contributions to public investment.

4 Aggregate Implications of Public Investment

This section studies the response of aggregate value added to public-investment shocks. The production-network economy substantially amplifies the aggregate output response when compared to the average one-sector economy, which is defined as a model version in which: there is no input-output structure, $\alpha_{H,s} = 0$; the value-added labor intensities are set symmetrically across industries to the value-added labor share of the entire economy, $\alpha_{N,s} = \alpha_N$; the output elasticity to public capital and the Calvo price-adjustment frequency are set to their average values across sectors, $\gamma_{G,s} = \gamma_G$ and $\phi_s = \phi$; the contributions to private and public demand are symmetric across sectors, $\omega_{C,s} = \omega_{I,s} = \omega_{G,s} = \omega_{I_G,s} = 1/55$.

To carry out this exercise, we define the long-run public-investment and public-consumption multipliers in present-value terms. Specifically, the public-investment multiplier, $\mathcal{M}^{\mathcal{I_G}}$, equals the ratio between the discounted sum of the deviations of real aggregate GDP from its steady-state level and the discounted sum of the deviations of the real value of public investment from its steady-state level:[20]

$$\mathcal{M}^{\mathcal{I_G}} = \frac{\sum_{j=1}^{\infty} \beta^{j-1} \left(Y_j - \bar{Y} \right)}{\sum_{j=1}^{\infty} \beta^{j-1} \left(\frac{P_{I_G,j}}{P_j} I_{G,j} - \frac{\bar{P}_{I_G}}{\bar{P}} \bar{I}_G \right)}. \tag{32}$$

Consequently, the multiplier computes the dollar change in aggregate output associated to a one dollar rise in the value of public investment. Analogously, the public-consumption multiplier, $\mathcal{M}^{\mathcal{G}}$, is

$$\mathcal{M}^{\mathcal{G}} = \frac{\sum_{j=1}^{\infty} \beta^{j-1} \left(Y_j - \bar{Y} \right)}{\sum_{j=1}^{\infty} \beta^{j-1} \left(\frac{P_{G,j}}{P_j} G_j - \frac{\bar{P}_G}{\bar{P}} \bar{G} \right)}. \tag{33}$$

4.1 Amplification of the Aggregate Output Multiplier

We start the quantitative analysis by uncovering to what extent the sectoral heterogeneity and inter-linkages featured by our production-network economy amplify the fiscal multipliers. To this end, we compute the public-investment and public-consumption multipliers in the baseline production-network economy and the average one-sector economy. Table 1 reports the results.

In the average one-sector economy the public-investment multiplier is 1.27. This value is at the lower end of the model estimates provided in the literature. This is partly due to our conservative choice of 1.5 for the Frisch elasticity. For instance, Ramey (2021) finds a multiplier of 1.7 with a Frisch elasticity of 4. The public-investment multiplier implied by our production-network economy is sub-

[20] In our baseline definition, we compute the fiscal multipliers by discounting the flow of real value added and real public spending with the time discount parameter, β. Table E.6 in Appendix E shows that results do not change when we consider the interest rate as the discounting factor.

stantially larger, 2.12. Moving from the one-sector to the multi-sector production network economy yields an amplification of the public-investment multiplier of 68%. The amplification is also economically significant, as one dollar of public investment yields an additional 86 cents of aggregate value added.[21]

Table 1: Long-Run Public-Investment and Public-Consumption Multipliers.

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Panel A: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.27	2.12	68%	0.86
Panel B: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	30%	0.10

Note: Panel A reports the long-run present-value public-investment multipliers in the average one-sector economy in Column (1), the baseline multi-sector production-network economy in Column (2), as well as the difference in the multipliers between the production-network economy and the average one-sector economy in percentage values and absolute values in Columns (3) and (4), respectively. Panel B reports similar statistics for the public-consumption multipliers.

This result sheds novel insights on the values of the output elasticity to public capital required to generate large output responses. While the one-sector model requires an elasticity of 0.1098 to imply a multiplier of 2.12, the production-network economy needs an average elasticity of only 0.0575. Thus, sectoral heterogeneity and inter-linkages generate economically meaningful multipliers with half of the public-capital elasticity required by the one-sector economy.

How does the amplification of the long-run present-value public-investment multiplier compare with the one of the public-consumption multiplier? We explore this question in Panel B of Table 1. Moving from the one-sector economy to the production network raises the public-consumption multiplier by 30% (and 10 cents). While the amplification is in line with the findings in Bouakez et al. (2023), it is not as large as the one observed for public investment. This comparison highlights the first contribution of our paper: the amplification of the public-investment multiplier due to multi-sector production network is twice as large as that of the public-consumption multiplier. Accordingly, abstracting from sectoral heterogeneity and inter-linkages yields a substantially more biased (and muted) measurement of the output effects of public investment relatively to those of public consumption.

[21] Table C.1 in Appendix C shows that the results of Table 1 hold even when looking separately at private consumption and investment.

Appendix F shows that the production-network amplification is also substantial at shorter horizons, such as for the case of 2-year and 4-year multipliers. This is particularly interesting since it is well documented that public consumption spurs relatively more aggregate output in the very short run (Boehm, 2020; Ramey, 2021). Appendix F documents that the production network closes the gap between the public-investment and public-consumption multipliers at a horizon of 6 quarters, whereas the same happens in the one-sector model only after 30 quarters.[22] While these results imply that public investment is not an ideal immediate stabilization policy, sectoral inter-linkages allow the model to be consistent with the empirical evidence showing that the stimulus effects of public investment are limited in the very short run (Boehm, 2020) but become significant after a couple of years (Ilzetzki et al., 2013).

4.2 Robustness Checks

The amplification of the public-investment multiplier holds in an extensive battery of robustness checks. We replicate the results of Table 1 under 24 alternative specifications of our model (see Tables E.1 - E.6 in Appendix E).

First, we perform sensitivity analysis and consider: *(i)* a lower Frisch elasticity (i.e., $\eta = 1$); *(ii)* lower and higher depreciation rates of private and public capital (i.e., $\delta_K = 0.01$, $\delta_{K_G} = 0.005$, and $\delta_K = 0.025$, $\delta_{K_G} = 0.02$, respectively); and *(iii)* complementarity of consumption and investment goods across sectors (i.e., either $\nu_C = 0.8$, or $\nu_I = 0.8$, or $\nu_C = \nu_I = 0.8$). Second, we look at the role of labor and capital reallocation across sectors and consider: *(i)* an economy with fully mobile labor and capital across industries (i.e., $\nu_N, \nu_K \to \infty$), and *(ii)* an economy with sector-specific private capital and a production network for assembling the sectoral investment goods, as in Vom Lehn and Winberry (2022). Then, we consider alternative specifications of the model in which: *(i)* prices are fully flexible, $\phi = 0$; *(ii)* wages are sticky à la Erceg et al. (2000); or *(iii)* consumption is durable with sector-specific depreciation rates, as in Boehm (2020).

We also consider changes in the setup and calibration of the fiscal and monetary authority. We study an economy in which the additional out-of-steady-state public spending is financed with distortionary labor-income taxes as in Leeper et al. (2010), economies with either no time-to-build delay (i.e., $\mu = 0$), or no time-to-spend delay (i.e., $\zeta = 0$), or no delay at all (i.e., $\mu = \zeta = 0$), economies with either complementarity across sectoral public goods (i.e., $\nu_G = \nu_{I_G} = 0.5$), or substitutability (i.e., $\nu_G = \nu_{I_G} = 2$), as well as a model in which steady-state public investment is set to 1.5% of GDP rather than 3.5%. We also study a case in

[22] The robustness checks of Appendix E show that the amplification results for the long-run present-value multiplier hold also when abstracting from the modeling feature that mostly capture the dynamics of the economy in the very short run, such as sticky prices and limited mobility of labor and capital across sectors.

which government consumption spending consists of both the purchases of goods from the private sectors and the compensation of public employees, as in Moro and Rachedi (2022). In addition, we evaluate an economy in which the autoregressive processes for public spending are either less persistent (i.e., $\rho = 0.86$ as in Boehm, 2020) or more persistent (i.e., $\rho = 0.97$ as in Kormilitsina and Zubairy, 2018), and a monetary authority that either reacts relatively more to changes in inflation (i.e., $\phi_\pi = 15$) or does not react to changes in the output gap (i.e., $\phi_x = 0$). Finally, we compute the multipliers by using the real interest rate as the discount factor.

By and large, the amplification of the public-investment multiplier in the production network economy relative to the one-sector model is always around 60%-80%, and at least twice as large as the one of the public-consumption multiplier.

4.3 Inspecting the Amplification Mechanism

What drives the amplification of the public-investment multiplier in the production network and to what extent it differs from that of public consumption? We address this question by examining six alternative multi-sector model specifications which abstract in turn from different modeling features: (*i*) a version that abstracts from the Input-Output matrix, by setting $\alpha_{H,s} = 0$; (*ii*) a version that features the Input-Output matrix but abstracts from heterogeneity in the inter-sectoral linkages, by setting $\omega_{H,s,x} = 1/55$; (*iii*) a version that abstract from sectoral heterogeneity in price rigidity, by setting the Calvo parameters to their average value, so that $\phi_s = \phi$; (*iv*) a version that abstract from heterogeneity in the sector's contribution to public demand, by setting $\omega_{G,s} = \omega_{I_G,s} = 1/55$; (*v*) a version that abstract from heterogeneity in the sector's contribution to both private and public demand, by setting $\omega_{C,s} = \omega_{I,s} = \omega_{G,s} = \omega_{I_G,s} = 1/55$; and (*vi*) a version that abstracts from sectoral heterogeneity in factor intensities, by setting them to their economy-wide values, so that $\alpha_{H,s} = \alpha_H$, $\alpha_{N,s} = \alpha_N$, and $\gamma_{G,s} = \gamma_G$.

Table 2 reports the contribution of each modeling feature to the amplification of both the public-investment and the public-consumption multipliers. To make the comparison meaningful, each column shuts down in isolation a different modeling feature *without* altering the implications of the associated average one-sector economy. Accordingly, modeling features whose absence implies lower multipliers are the key ones to the amplification mechanism.

The public-investment amplification is entirely due to the presence of the Input-Output matrix. If we consider a multi-sector model with heterogeneity in all dimensions but with no production network, the public-investment multiplier drops from 2.12 to 1.24, which almost exactly replicates the 1.27 multiplier of the average one-sector economy. The other five model dimensions barely matter.

Conversely, the amplification of the public-consumption multiplier is due to both the presence of the Input-Output matrix and heterogeneity in the price

Table 2: Sources of Amplification of the Aggregate Value-Added Multiplier.

Alternative Production-Network Economies Without …					
IO Matrix	IO Matrix Heterogeneity	Price Rigidity Heterogeneity	Public Demand Heterogeneity	Final Demand Heterogeneity	Factor Intensities Heterogeneity
(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I_G}}$					
1.24	2.11	2.04	2.29	2.30	2.17
Panel B: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$					
0.40	0.43	0.41	0.49	0.44	0.44

Note: Panel A reports the public-investment multipliers in six alternative specifications of the baseline production-network economy: without Input-Output matrix, $\alpha_{H,s} = 0$, Column (1); without heterogeneity in the Input-Output matrix, $\omega_{H,s,x} = 1/55$, Column (2); without heterogeneity in price rigidity, $\phi_s = \phi$, Column (3); without heterogeneity in the contributions to public demand, $\omega_{G,s} = \omega_{I_G,s} = 1/55$, Column (4); without heterogeneity in the contributions to final demand, $\omega_{C,s} = \omega_{I,s} = \omega_{G,s} = \omega_{I_G,s} = 1/55$, Column (5); without heterogeneity in the factor intensities, $\alpha_{N,s} = \alpha_N$ and $\alpha_{H,s} = \alpha_H$, Column (6). Panel B reports similar statistics for the public-consumption multiplier.

rigidity across sectors, confirming the findings in Bouakez et al. (2023). Both modeling features flatten the aggregate Phillips curve, thus triggering a mildly inflationary rise in GDP, which does not require a spike in nominal interest rates.

How does the amplification of the public-investment multiplier depend on the values of the output elasticity to public capital? To show that the large response of aggregate value added to public investment in the multi-sector model stems from the interaction between the production network and the output elasticity to public capital, we measure the public-investment multiplier in five alternative specifications of the production-network economy that differ only in the calibration of the output elasticity to public capital. Since changes in $\gamma_{G,s}$ do not alter the public-consumption multiplier, we focus only on the public-investment multiplier. Table 3 reports the results.

We start by considering a version of the baseline model where the output elasticity to public capital is zero, $\gamma_{G,s} = 0$. In this case, public investment resembles public consumption, with the additional time-to-build friction and time-to-spend delays. The amplification is minimal, with public-investment multipliers of the one-sector and production-network economy equal to 0.32 and 0.37, respectively.

We then look at a multi-sector model where the average value of the output elasticities is scaled down to 0.0287, exactly half of the average elasticity in the benchmark model. The public-investment multiplier amplification drops from 68% of Table 1 to 57%. These results together with the ones in Table 2 imply that the interaction between the production network and the output elasticity to public capital plays a crucial role to explain the larger response of aggregate value added to public investment in the multi-sector economy.

Table 3: Public-Investment Multipliers and the Output Elasticity to Public Capital.

	One-Sector Economy	Production-Network Economy	Δ%	Δ$
	(1)	(2)	(3)	(4)
Panel A: No Output Elasticity to Public Capital				
	0.32	0.37	18%	0.06
Panel B: Low Output Elasticity to Public Capital				
	0.79	1.24	57%	0.45
Panel C: No Heterogeneity in the Output Elasticity to Public Capital				
	1.27	2.05	62%	0.79
Panel D: Higher Output Elasticity to Public Capital in Upstream Sectors				
	1.27	2.46	94%	1.19
Panel E: Higher Output Elasticity to Public Capital in Downstream Sectors				
	1.27	1.72	36%	0.46

Note: This table reports similar statistics on the public-investment multiplier to Table 1 with the difference that Panel A considers a model version in which the output elasticity to public capital is zero. Panel B considers a model version in which the output elasticities are set to half of those of the baseline economy. Panel C considers a model version in which the output elasticities are set to average value across sectors, Panel D considers a model economy in which the sectoral output elasticities to public capital are sorted such that the largest values are assigned to the most upstream sectors. Panel E considers a model economy in which the sectoral output elasticities to public capital are sorted such that the largest values are assigned to the most downstream sectors.

To examine the contribution of heterogeneity in the elasticity of public capital across sectors, we quantify the public-investment multiplier in an economy where the sectoral elasticity to public capital is homogeneous and equals the average value across sectors. Abstracting from this source of heterogeneity barely alters the public-investment multiplier, which goes from 2.12 to 2.05. Accordingly, while the amplification of the public-investment multiplier in the production network crucially hinges on the *level* of the output elasticity to public capital, *heterogeneity* in this elasticity is not quantitatively relevant. The reason is that heterogeneity in the sectoral output elasticity does not correlate with the sector's position in the production network. If we assign the highest elasticities to the most upstream sectors (to induce a correlation of 1 between the elasticity to public capital and sector's centrality), the public-investment multiplier raises up to 2.46. To put this number into perspective, a production network with homogeneous public-capital elasticities across sectors can attain a multiplier of 2.46 only with an elasticity of 0.0715, well above the average value of 0.0575 of the benchmark calibration. Alternatively, if we assign the highest elasticities to the most downstream sectors (to induce a correlation of -1 with sector's centrality), the multiplier drops by 30%, down to 1.72. Intuitively, a higher elasticity in upstream sectors allows these industries to benefit relatively more from the expansion in public investment. Since these sectors are the providers of intermediate inputs to all the other industries in the economy, the positive effects of public capital propagate through the production network, and ultimately raise the efficiency of all sectors.

4.4 Analytical Intuition

This section analytically formalizes the mechanism through which output response to public investment crucially depends on the presence of intermediate inputs and the value of the public-capital elasticity.

Consider a simplified version of our model, with one sector ($S = 1$), no physical capital ($\alpha_N = 1$), flexible prices ($\phi = 0$), and perfectly competitive goods markets ($\epsilon \to \infty$). Let us abstract from public consumption, $G_t = 0$, and set public investment to a fraction of aggregate GDP: $I_{G,t} = \chi Y_t$. Let us assume full depreciation of public capital ($\delta_{K,G} = 1$), neither time-to-build nor time-to-spend delays ($\zeta = 0$ and $\mu = 0$). In addition, consider a logarithmic utility over consumption ($\sigma \to 1$), and linear over labor ($\eta = 0$). With these restrictions, the model is static and can be solved analytically.[23] The households' problem reduces to

$$\max_{C_t, N_t} \log C_t - \theta N_t, \tag{34}$$

$$\text{s.t. } W_t N_t = C_t + T_t, \tag{35}$$

the government budget constraint reads

$$I_{G,t} = T_t, \tag{36}$$

and the gross-output production function equals

$$Z_t = N_t^{1-\alpha_H} H_t^{\alpha_H} K_{G,t}^{\gamma_G}. \tag{37}$$

Our simplified model implies that the response of aggregate value added to an increase in public investment—modeled as a relatively higher value of χ—increases with the share of intermediate-input in gross output, α_H,

$$\frac{\partial^2 Y_t}{\partial \chi \partial \alpha_H} / Y_t = \frac{\gamma_G}{(1-\chi)\,\chi\,[\gamma_G - (1-\alpha_H)]^2} > 0. \tag{38}$$

In other words, the stimulus effect of public investment increases with the use of intermediate inputs.

[23] We derive our theoretical insights in a one-sector economy with a roundabout production structure rather than a multi-sector economy with an Input-Output matrix as in Acemoglu et al. (2016) for two reasons. First, this is the simplest framework that rationalizes our quantitative findings on the key role played by intermediate inputs in the amplification of the public-investment multiplier. Second, this simplification is without loss of generality, since our focus is on the aggregate effects of public spending. While the model of Acemoglu et al. (2016) generates different production-network propagations for sectoral government spending shocks, the response of aggregate output is invariant to the sectoral origin of the shock (Bouakez et al., 2022).

Importantly, the presence of intermediate inputs does not increase public investment via the same mechanism through which it amplifies the effects of public consumption. First, Bouakez et al. (2023) show that the intermediate inputs amplify the public-consumption multiplier insofar as they flatten the aggregate Phillips curve. Second, the fact that the derivative of Equation (38) with respect to the public-capital elasticity, γ_G, is positive implies that the response of output to public investment is further amplified at relatively higher values of both the share of intermediate inputs and the public-capital elasticity.[24] This is why we argue that the public-multiplier amplification hinges on the interaction of the production network with the output elasticity to public capital.

How does the presence of a production network amplify the public-investment multiplier? The production function of gross output in (37) implies that aggregate value added equals

$$Y_t = (1-\alpha_H)\,\alpha_H^{\frac{\alpha_H}{1-\alpha_H}} N_t K_{G,t}^{\frac{\gamma_G}{1-\alpha_H}}. \tag{39}$$

This formulation crystallizes that any given *gross-output elasticity* to public capital, γ_G, implies a relatively higher *value-added elasticity* to public capital, $\frac{\gamma_G}{1-\alpha_H}$, which increases with the share of intermediate inputs in gross output, α_H. Intuitively, intermediate inputs amplify the productivity-enhancing effect of public capital as firms not only benefit directly from a surge in public investment, but do so also indirectly. Specifically, public investment raises the efficiency in the provision of intermediate inputs, and thus curtails their cost. Consequently, firms expand the purchase of intermediate inputs and optimally scale up their production.

The amplification of the multiplier also depends on the way in which the production network alters the optimal level of public capital.[25] Ramey (2021) shows a stronger output response to public-investment shocks when public capital is below its optimal level.[26] We find that intermediate inputs raise the optimal amount of public capital for any given output elasticity to public capital. In particular, Equation (39) implies that the optimal ratio of public capital to GDP is

$$\frac{\bar{K}_G}{\bar{Y}} = \beta \frac{\gamma_G}{1-\alpha_H}. \tag{40}$$

Thus, intermediate inputs lead to a higher socially optimal level of public capital, highlighting once again the key role of the interaction between the public-capital productivity and the production network. The next section quantifies how the optimal level of public capital varies with the different features of our model.

[24] This is consistent with the findings of Panel B in Table 3.

[25] As in Ramey (2021), the optimal amount of public capital is that maximizing households' utility in the steady state. For the analysis on the optimal public spending in recessions, see Bouakez et al. (2020).

[26] See Table E.6 of Appendix E for a quantification of this mechanism in our setting.

4.5 The Socially Optimal Amount of Public Capital

How does our production-network economy alter the implications on the socially optimal amount of public capital? Table 4 quantifies the optimal levels of public capital and public investment in the one-sector and production-network economy, as well as in a series of alternative multi-sector models that abstract in turn from different modeling features, similarly to the exercises of Tables 2 and 3.

Table 4: Optimal Public Investment and Public Capital.

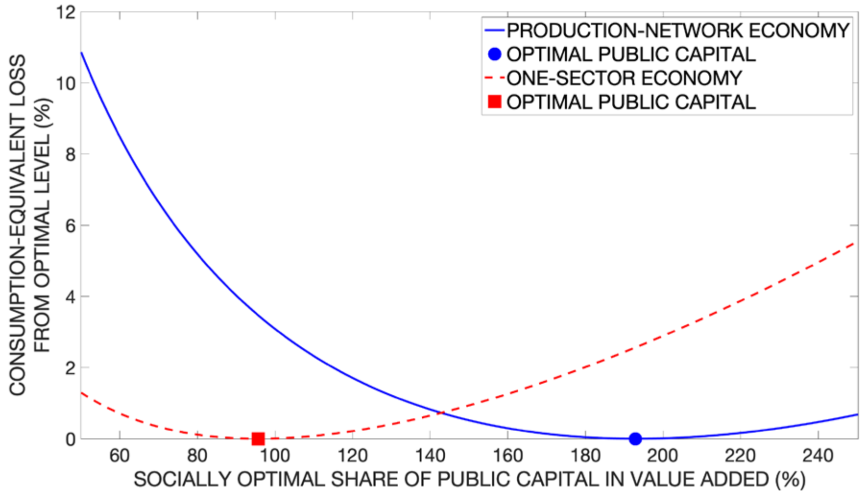
One Sector Economy	Production Network Economy	Alternative Production-Network Economies Without ...					
		IO Matrix Heterog.	IO Matrix Heterog.	Public Demand Heterog.	Final Demand Heterog.	Factor Intensities Heterog.	Public-Capital Elasticity Heterog.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Optimal Share of Public Capital in Value Added							
98.5%	198.7%	85.5%	193.1%	201.2%	203.8%	202.2%	191.1%
Panel B: Optimal Share of Public Investment in Value Added							
3.9%	7.8%	3.4%	7.6%	7.9%	8.0%	8.0%	7.5%

Note: Panel A reports the optimal share of public capital in (annualized) value added in the one-sector economy, the baseline production-network economy, and six alternative production-network models considered in Tables 2 and 3. Panel B reports similar statistics for the optimal share of public investment in value added.

The optimal amount of public capital *doubles* when moving from the one-sector to the production-network economy: the ratio of optimal public capital to annualized aggregate value added equals 98.5% in the former, and 198.7% in the latter. Similarly, the optimal level of public investment changes from 3.9% to 7.8%. Once again, this amplification is entirely due to the Input-Output matrix—as absent this feature we observe hefty drops in the optimal levels. To put these numbers in perspective, in the data public capital equals 73% of GDP, whereas public investment equals 3.3% of GDP (Ramey, 2021). Thus, accounting for sectoral heterogeneity and inter-linkages leads to an optimal level of public capital which is way above that observed in the data.

Our model yields novel insights on the costs associated to inefficient levels of public capital. To do so, we compute the welfare losses in consumption-equivalence terms—that is, the constant rate of change imposed on households' lifetime consumption to bring them to the value they would achieve in an economy featuring the optimal amount of public capital. Figure 2 reports how the welfare losses vary with the share of public capital in value added in the production-network and one-sector economy. The production-network economy substantially increases the costs of inefficiently low levels of public capital, while dampening the losses of inefficiently high levels. In other words, inefficiently low levels of public capital become particularly costly when accounting for inter-sectoral linkages.

Figure 2: Welfare Loss as a Function of the Share of Public Capital in Value Added.



Note: The blue solid line and the dash orange line represent, respectively, the welfare loss – measured in consumption-equivalent terms – as a function of the share of public capital in value added for the production-network economy and the one-sector economy.

5 Sectoral Implications of Public Investment

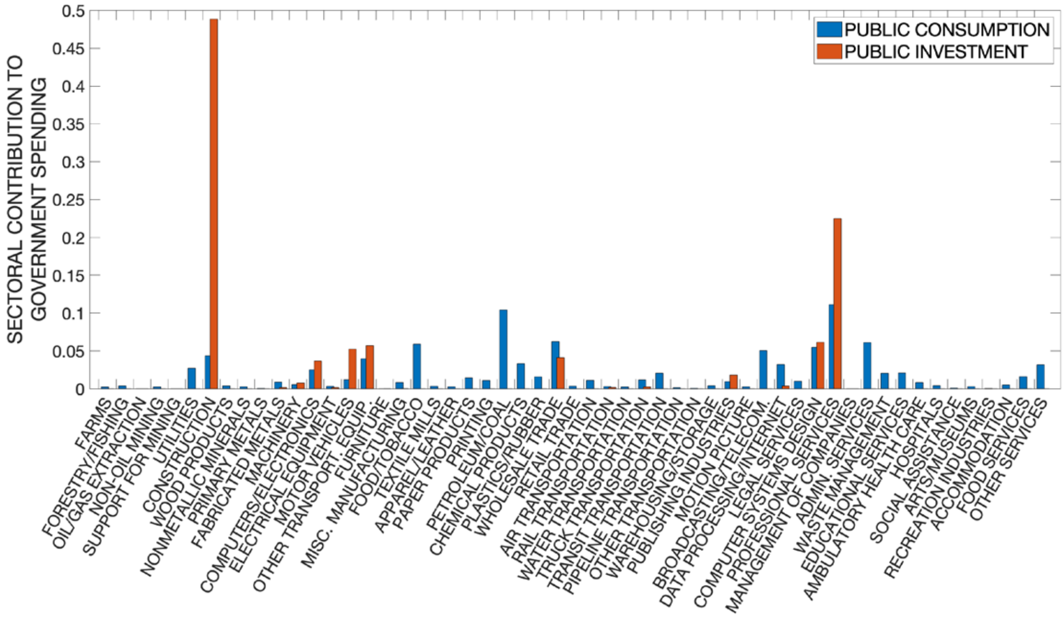
We leverage the structure of the model to uncover how the stimulus effect of public spending is allocated across industries. We start by showing that public investment is concentrated in a handful of industries, while public consumption requires contributions from almost any sector. Notwithstanding this marked concentration, the output gains associated to public investment are relatively more evenly distributed across sectors. We reconcile this surprising result as a byproduct of the interaction between the output elasticity to public capital and Input-Output linkages. Finally, we validate this model prediction in the data.

5.1 The Sectoral Concentration of Public Investment

How do government spending in consumption and investment vary across sectors? To address this question, we compare the sectoral contribution to government consumption and investment spending, defined as the share of total spending which is allocated to each individual sector, as derived from the Input-Output Tables of the 2019 U.S. Bureau of Economic Analysis.

Figure 3 shows that only nine sectors contribute more than 0.5% of total public investment. Just three industries—(i) construction, (ii) professional, scientific and technical services, and (iii) computer systems services—account for the lion's share of public investment, with a total joint share of 78%. This marked concentration stands in stark contrast with the sectoral composition of public consumption. In this case, thirty-one sectors feature a share above 0.5%, and to derive a total joint share of 78% requires summing over the largest fifteen recipient industries. The concentration of public investment across sectors is even

Figure 3: The Sectoral Composition of Public Spending.



Note: Sectoral contribution to total government consumption spending (blue bars) and total government investment spending (orange bars), as derived from the Input-Output Tables of the U.S. Bureau of Economic Analysis as of 2019.

larger than that of private investment: 78% of private investment is accounted for by the largest six providing industries.[27]

5.2 Relative Sectoral Value-Added Multipliers

This section quantities to what extent the variation in the sectoral contributions to government expenditures shapes the dispersion in sectoral value-added responses to public investment and public consumption. As long as sectors directly benefit from the expansion of public spending if they supply relatively more goods to the government, one should expect that the high concentration of public investment in few industries should be mirrored by an equally high concentration of the sectoral multipliers. Surprisingly, this is not the case.

To assess the dispersion in sectoral value added responses to public investment and public consumption, we need a measure that control for the (five-fold) difference in magnitude between the aggregate public-investment and public-consumption multipliers. To this end, we compute the *relative* sectoral value-added public-investment multiplier, $\mathcal{R}_s^{\mathcal{I_G}}$:

$$\mathcal{R}_s^{\mathcal{I_G}} = \frac{\mathcal{M}_s^{\mathcal{I_G}}}{\mathcal{M}^{\mathcal{I_G}}}, \quad (41) \qquad \mathcal{M}_s^{\mathcal{I_G}} = \frac{\sum_{j=1}^{\infty} \beta^{j-1} \left(Y_{j,s} - \bar{Y}_s \right)}{\sum_{j=1}^{\infty} \beta^{j-1} \left(\frac{P_{I_G,j}}{P_j} I_{G,j} - \frac{\bar{P}_{I_G}}{\bar{P}} \bar{I}_G \right)}, \quad (42)$$

[27] The distribution of government investment expenditures across the production network does not significantly differ from that of public consumption. The weighted average of the Katz-Bonacich measure of production-network centrality is 0.0276 for public investment and 0.0274 for public consumption.

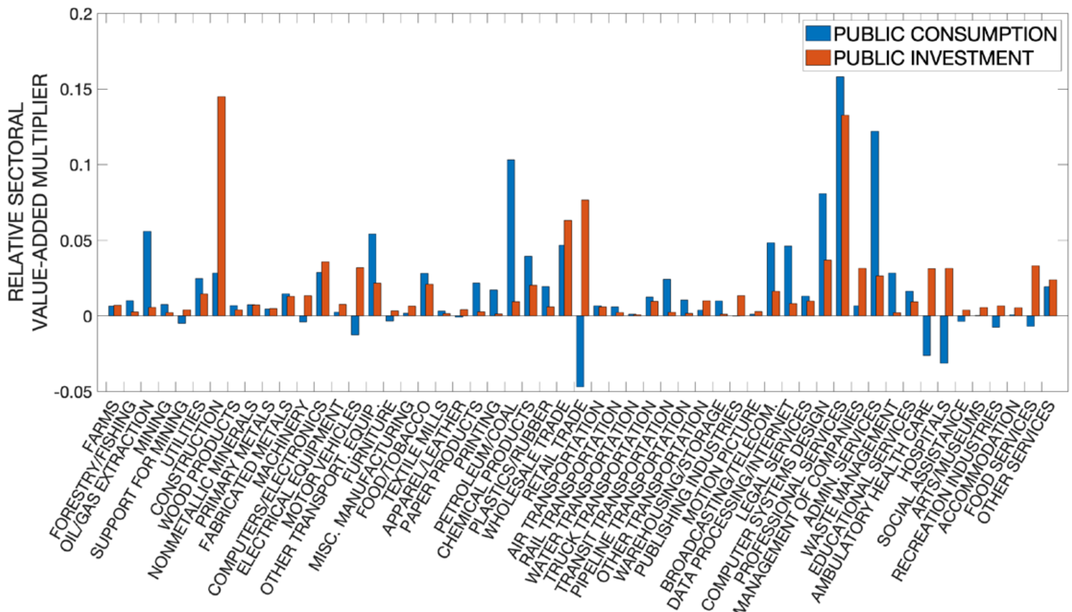
where $\mathcal{M}_s^{\mathcal{I}_\mathcal{G}}$ is the sectoral value-added public-investment multiplier, and $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$ is the aggregate public-investment multiplier defined in Equation (32). This relative measure informs how one additional dollar of the aggregate public-spending multiplier is distributed across sectors. Analogously, we define the relative sectoral value added public-consumption multiplier as $\mathcal{R}_s^{\mathcal{G}}$:

$$\mathcal{R}_s^{\mathcal{G}} = \frac{\mathcal{M}_s^{\mathcal{G}}}{\mathcal{M}^{\mathcal{G}}}, \qquad (43) \qquad\qquad \mathcal{M}_s^{\mathcal{G}} = \frac{\sum_{j=1}^{\infty} \beta^{j-1} \left(Y_{j,s} - \bar{Y}_s\right)}{\sum_{j=1}^{\infty} \beta^{j-1} \left(\frac{P_{G,j}}{P_j} G_j - \frac{\bar{P}_G}{\bar{P}} \bar{G}\right)}, \qquad (44)$$

where $\mathcal{M}_s^{\mathcal{G}}$ is the sectoral value-added public-consumption multiplier.

Figure 4 reports the relative value-added multipliers for public investment, $\mathcal{R}_s^{\mathcal{I}_\mathcal{G}}$, and public consumption, $\mathcal{R}_s^{\mathcal{G}}$, implied by the baseline production-network economy for each of the 55 sectors of our model. The sectoral decomposition of the aggregate multiplier considerably depends on the type of public expenditure that is implemented by the fiscal authority. Public consumption benefits relatively more industries such as professional services, administrative services, and petroleum manufacturing, with each of them absorbing about 15 cents out of one dollar of the aggregate multiplier. Conversely, public investment generates the largest gains for sectors such as professional services and construction, with both of them accounting for about 13 cents out of one dollar of the aggregate multiplier.

Figure 4: The Sectoral Effects of Public Spending



Note: Relative sectoral value-added multipliers for both public consumption and public investment in the production-network economy.

While there is no industry which is worse off in the aftermath of a public investment shocks, twelve sectors report negative relative public-consumption multiplier, with retail trade being the one with the lowest value, featuring a drop in value added by 5 cents for each dollar of the aggregate public-consumption multiplier.

Counterintuitively, the sectoral responses to public consumption are far more concentrated than the ones of public investment. To illustrate this point, we count the number of industries that account for 80% of the aggregate spending multiplier: while this share is accounted for only by eleven industries for the case of public consumption, we have to consider up to nineteen industries for public investment. This finding is surprising given the fact that public investment is highly concentrated in a handful of industries, while public consumption is much more evenly distributed (Figure 3). To put it in perspective, the standard deviation of the sectoral contributions to public consumption and public investment are 2.5% and 7.3%, respectively, as opposed to the standard deviations of relative sectoral multipliers, that are 3.5% for public consumption and 2.8% for public investment.

What drives the relatively more even distribution of the output effects of public investment across industries notwithstanding the striking concentration of the associated sectoral contributions? As for the amplification of the aggregate multiplier, this result stems from the interaction of the output elasticity to public capital and the production network. Specifically, public investment generates a differential effect across sectors via four channels: (*i*) the direct exposure due to the sector's contribution to public spending, $\omega_{I_G,s}$; (*ii*) the indirect exposure via the demand of intermediate inputs from customer sectors towards upstream industries through the Input-Output matrix; (*iii*) the indirect exposure via the output elasticity to public capital, $\gamma_{G,s}$, through which a sector with a relatively higher elasticity benefits more from the productivity-enhancing effects associated with public investment; and (*iv*) the indirect exposure through the way in which the Input-Output matrix magnifies the positive effects of public capital across the production network, as sectors may benefit from the higher efficiency in the provision of intermediate inputs, even when their own direct exposure to public investment is null. Since public consumption is not productive, the last two channels are not active in its propagation. Consequently, public consumption benefits disproportionately more the sectors with the highest direct exposure to this type of spending.

To illustrate this point, we compare the standard deviation of the relative sectoral public-investment and public-consumption multipliers with that implied by a model in which the sectoral contributions to public investment replicate those of public consumption, $\omega_{I_G,s}$, and in eight alternative economies that abstract each time from certain dimensions of sectoral heterogeneity, as in Table 2. Table 5 reports the results of this exercise. When public investment contributions replicate those of public consumption, the standard deviation of the relative sectoral public-investment multipliers drops even further, from 2.8% to

1.9%. Thus, even when fixing the same variation in the sectoral contributions to the two types of public spending, the dispersion in the sectoral effects of public consumption is more than twice as large as that of public investment. Our analysis implies that the two features that account for the low concentration of the sectoral public-investment multipliers are the Input-Output matrix and the public-capital elasticity: abstracting from these two features raises the standard deviation of the relative multipliers up to 5% and 11.5% respectively. Instead, when we shut down all other modeling features, the standard deviation barely increases, and in some cases even shrinks substantially.

Interestingly, heterogeneity in the public-capital elasticity does not play a sizable role even for the sectoral implications of public investment.[28] For instance, the industry with the highest public-capital elasticity—computer and electronic

Table 5: The Sectoral Effects of Public Investment and Consumption - Channels

	Std. Dev. Relative Sectoral Multipliers	
Model	Public Investment	Public Consumption
Production-Network	2.8%	3.5%
$\omega_{I_G,s} = \omega_{G,s}$	1.9%	3.5%
No IO Matrix	5.0%	4.4%
No IO Matrix Heterogeneity	2.4%	3.1%
No Public-Capital Elasticity	11.5%	3.5%
No Public-Capital Elasticity Heterogeneity	2.9%	3.5%
No Price Rigidity Heterogeneity	2.9%	3.9%
No Factor Intensities Heterogeneity	2.7%	3.8%
No Public Demand Heterogeneity	1.5%	1.3%
No Final Demand Heterogeneity	0.9%	0.9%

Note: The table reports the standard deviation of the relative sectoral public-investment and public-consumption multipliers in the baseline production network and in a series of alternative model economies: without Input-Output matrix; without heterogeneity in the Input-Output matrix; without public-capital elasticity; without heterogeneity in the elasticity of sectoral gross output to public capital; without heterogeneity in the degree of price rigidity; without heterogeneity in the contributions to public demand; without heterogeneity in the contributions to total demand; without heterogeneity in the factor intensities.

products manufacturing with an elasticity of 0.1363—features sectoral public-investment multipliers of 0.08 (i.e., a relative multiplier of 3.6%) in the baseline production network and 0.07 (i.e., a relative multiplier of 3.2%) in the alternative version with symmetric elasticities, in which $\gamma_{G,s} = 0.0575$ for all sectors.

Overall, we show that although the sectoral contributions to public investment are much more concentrated than those to public consumption, the benefits of public investment are relatively more evenly distributed across industries due to the interaction between the public-capital elasticity and the production network.

[28]The correlation between the (relative) sectoral public-investment multipliers in the baseline production network and the alternative version with symmetric elasticities to public capital is 0.9.

5.3 Empirical Validation

Our model predicts that sectoral value-added responses to public-investment shocks are relatively more evenly distributed than those generated by public-consumption shocks. We test this prediction in the data by generalizing the time-series approach of Ramey and Zubairy (2018) to a panel setting. We extend the linear projection method of Jordà (2005) and estimate the following panel regressions for public investment and public consumption, respectively

$$\sum_{t=0}^{\mathcal{H}} \frac{Y_{s,t}}{\tilde{Y}_t} = \beta_{I_G} \sum_{t=0}^{\mathcal{H}} \frac{I_{G,t}}{\tilde{Y}_t} \times \omega_{I_{G,s}} + \alpha_s + \delta_t + \epsilon_{s,t}, \tag{45}$$

$$\sum_{t=0}^{\mathcal{H}} \frac{Y_{s,t}}{\tilde{Y}_t} = \beta_G \sum_{t=0}^{\mathcal{H}} \frac{G_t}{\tilde{Y}_t} \times \omega_{G_s} + \alpha_s + \delta_t + \epsilon_{s,t}. \tag{46}$$

The dependent variable in (45) is the ratio between real sectoral value added and real potential GDP, cumulated up to horizon $\mathcal{H}$, $\sum_{t=0}^{\mathcal{H}} \frac{Y_{s,t}}{\tilde{Y}_t}$. This term is regressed on the interaction between the ratio of real aggregate public investment and real potential GDP, also cumulated up to horizon $\mathcal{H}$, and the sectors' direct contribution to aggregate public investment, $\sum_{t=0}^{\mathcal{H}} \frac{I_{G,t}}{\tilde{Y}_t} \times \omega_{I_{G,s}}$. Equation (46) replaces the independent variable with the interaction between the ratio of cumulated real aggregate public consumption and real potential GDP, and the sectors' direct contribution to aggregate public consumption, $\sum_{t=0}^{\mathcal{H}} \frac{G_t}{\tilde{Y}_t} \times \omega_{G,s}$.

Both regressions include sector fixed effects, α_s, to capture time-invariant unobserved heterogeneity across industries, and time fixed effects, δ_t, to capture the average effect of public spending over sectoral value added. The coefficients β_{I_G} and β_G measure how the value-added multiplier of a given industry varies with its own direct contribution to public spending above and beyond the average sector value-added multiplier. In this way, these estimates naturally map into the way in which the relative sectoral multipliers vary with the sectors' contribution to government expenditures.

We follow Ramey and Zubairy (2018) to identify these coefficients. First, we focus on the public investment and consumption of the federal defense government. Second, to uncover the exogenous variation in public spending which is not already incorporated in agents' expectations, we instrument both types of expenditures with two variables: the military-spending news variable of Ramey (2011), and the timing restriction of Blanchard and Perotti (2002). In our setting, these instruments are both interacted with the sectoral direct contribution to either public investment or public consumption.

To estimate the coefficients in (45) and (46), we merge information on sectoral value added with data on aggregate public investment and consumption, as well as with sector's direct contribution to public spending. The bulk of our data comes from the U.S. Bureau of Economic Analysis. Specifically, we take nominal sectoral value added, nominal public investment from the defense government, and the nominal purchases of goods and services from the defense government as a measure of public consumption. These variables are divided by the associated chain-type price index. We then take the real potential GDP from the estimates of the Congressional Budget Office, and the Ramey (2011)'s news variable from Ramey and Zubairy (2018). We end up with a panel across the 55 sector of our model at the annual frequency, from 1963 to 2015.[29]

Table 6: Sectoral Implications of Public Consumption and Investment in the Data.

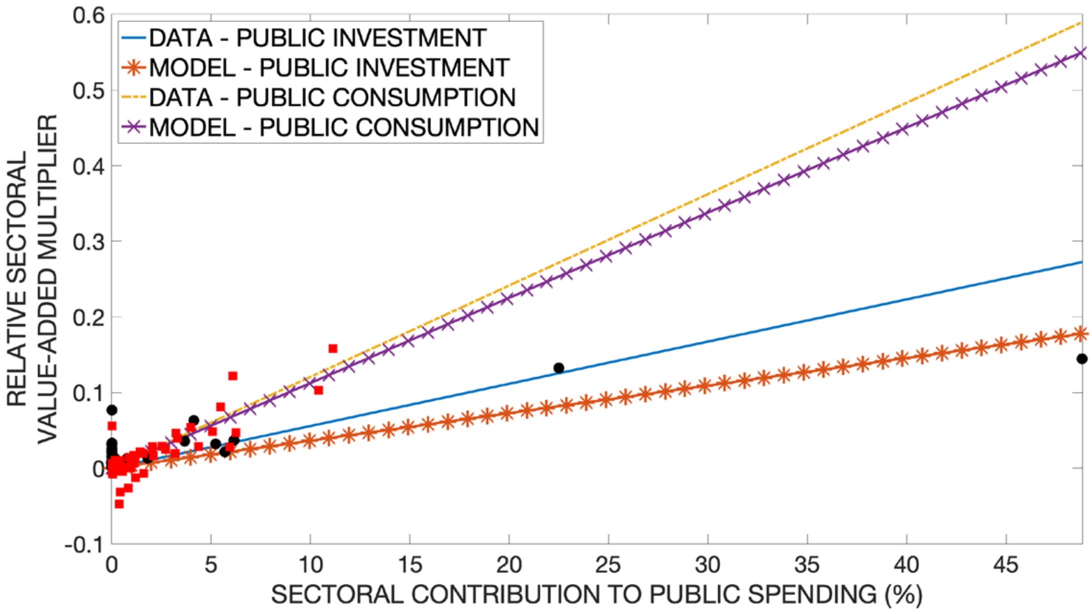
	Dependent Variable: $\sum_{t=0}^{\mathcal{H}} \frac{Y_{s,t}}{\tilde{Y}_t}$			
	$\mathcal{H}=1$		$\mathcal{H}=5$	
	(1)	(2)	(3)	(4)
$\sum_{t=0}^{\mathcal{H}} \frac{I_{G,t}}{\tilde{Y}_t} \times \omega_{I_{G,s}}$	0.66***		0.66***	
	(0.09)		(0.10)	
$\sum_{t=0}^{\mathcal{H}} \frac{G_t}{\tilde{Y}_t} \times \omega_{G_s}$		0.77***		1.21***
		(0.31)		(0.40)
Sector Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
N. Observations	2,805	2,805	2,585	2,585

Note: The table reports the estimates of a panel regression at yearly frequency from 1963 to 2015 and across 55 sectors. The dependent variable is the change in sectoral value added, scaled by real aggregate potential output, to a public spending shock cumulated over 1 year in Columns (1) and (2), and 5 years in Columns (3) and (4). Columns (1) and (3) focus on the 1-year and 5-year scaled cumulative defense public-investment shocks, and interact them with the sectoral contribution to total defense public-investment spending. Columns (2) and (4) focus on the 1-year and 5-year scaled cumulative defense public-consumption shocks, and interact them with the sectoral contribution to total public-consumption spending. In all cases, government spending is instrumented with the Blanchard and Perotti (2002) timing restriction and the Ramey (2011) news variable, and their interactions with the sector's contribution to either public investment or public consumption. All cases also control for both industry and year fixed effects. Standard errors double-clustered at the sector-year level are reported in parentheses. *** denotes statistical significance at the 1% level.

Table 6 reports the estimates of the interaction terms of regressions (45) and (46): the interaction terms for the public-investment and public-consumption regressions are positive and highly statistically significant. Importantly, the estimates confirm the model predictions on how the relative sectoral multipliers vary with the direct contributions to government spending: the estimates of β_G are larger than those of β_{I_G}, especially at the five-year horizon. These differences are highly economically significant. If we put the estimates in perspective of the vari-

[29]The year 2015 is the latest year for which the series of Ramey (2011)'s news variable is available.

Figure 5: Sectoral Multipliers and Contribution to Public Spending: Model vs. Data



Note: The figure scatters in black circles the model-implied relative sectoral value-added public-investment multipliers, and in red squares relative sectoral value-added public-consumption multipliers, vis-à-vis the sectors' contribution to public spending (i.e., the contribution to public investment, $\omega_{I_G,s}$, for the relative public-investment multipliers, and the contribution to public consumption, $\omega_{G,s}$, for the relative public-consumption multipliers.) The continuous and starred lines report the regression line between the relative sectoral public-investment multipliers and sectors' contributions to public investment, as implied by the estimates of regression (45) and the baseline model, respectively. The dashed line and crossed lines report the regression line between the relative sectoral public-consumption multipliers and sectors' contributions to public consumption, as implied by the estimates of regression (46) and the baseline model, respectively.

ation of the contributions to public investment, one additional standard deviation in the sectoral contributions to fiscal expenditures raises the 5-year relative sectoral value-added response to public consumption by 9 cents, whereas the same increase raises the relative sectoral public-investment multiplier by less than 5 cents.

We then compare the estimated sensitivities of the sectoral multipliers to the sectoral direct contributions to public spending to those generated by the model. We do so in Figure 5, which scatters the relative sectoral multipliers for both public investment and public consumption with respect to the sectors' direct contribution to either type of expenditure. Then, we report the regression lines implied by the estimates of β_{I_G} and β_G at the 5-year horizon with those implied by the model.

This exercise highlights two main findings. First, the empirical estimates on how the relative sectoral multipliers vary with the sectors' direct contributions to public spending are remarkably in line with the ones generated by the model. This result lends credence to the quantitative predictions of our production network. Second, the regression lines associated to public consumption are much steeper than those of public investment, so that the sensitivity of the relative sectoral multiplier of public consumption to the sector's direct contribution is relatively *public-consumption* multiplier of around 0.6 in both the data and the model.

This empirical evidence on the sectoral implications of fiscal expenditures validates both qualitatively and quantitatively the model predictions on the relationship between the high concentration of the sectoral contributions to public investment and the relatively more even distribution across industries of the output gains due to public investment shocks.

6 Conclusion

Aggregate and sectoral implications of public investment crucially depend on the interaction between the output elasticity to public capital and the presence of Input-Output linkages. We use a production-network New Keynesian model to show that the socially optimal amount of public capital doubles that predicted by the average one-sector economy, which leads to a substantial amplification of the public-investment multiplier. In addition, the model gives a novel prediction on how sectors react to public investment. Although public investment is concentrated in just a handful of industries, its effects are more evenly distributed across sectors than the ones of public consumption. We use linear projection methods on a panel of sectoral value added and aggregate public spending to validate this prediction in the data.

While this work has considered public investment as an homogeneous good, in future research we will evaluate whether different types of public investment, such as expenditures on structures, equipment, and intangible, can generate heterogeneous effects at both the aggregate and sectoral levels.

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A More on the Calibration

This section provides additional details to the calibration of the model in Section 3. Tables A.1-A.2 report the exhaustive list of the 55 sectors considered in our model. This level of disaggregation roughly corresponds to the 3-digit NAICS code level. As we describe in Section 3.1, the choice of the sectors to consider in our model is defined by the industries for which we can estimate the sector-specific output elasticity to public capital, using data from the KLEMS project.

Table A.3 shows the entire set of parameters that do not vary across sectors, with details on the target or source for each of their calibrated value. Table A.4 shows the calibration strategy for all the sector-specific parameters, defining again the target or source that pins down their values. The entire list of the values of the sector-specific parameters is available upon request.

Table A.1: Sectors 1-30.

Number	Name	NAICS Code
1	Farms	111CA
2	Forestry, fishing, and related activities	113FF
3	Oil and gas extraction	211
4	Mining	212
5	Support activities for mining	213
6	Utilities	22
7	Construction	23
8	Wood products	321
9	Nonmetallic mineral products	327
10	Primary metals	331
11	Fabricated metal products	332
12	Machinery	333
13	Computer and electronic products	334
14	Electrical equipment, appliances, and components	335
15	Motor vehicles, bodies and trailers, and parts	3361MV
16	Other transportation equipment	3364OT
17	Furniture and related products	337
18	Miscellaneous manufacturing	339
19	Food and beverage and tobacco products	311FT
20	Textile mills and textile product mills	313TT
21	Apparel and leather and allied products	315AL
22	Paper products	322
23	Printing and related support activities	323
24	Petroleum and coal products	324
25	Chemical products	325
26	Plastics and rubber products	326
27	Wholesale trade	42
28	Retail trade	44
29	Air transportation	481
30	Rail transportation	482

Table A.2: Sectors 31-55.

Number	Name	NAICS Code
31	Water transportation	483
32	Truck transportation	484
33	Transit and ground passenger transportation	485
34	Pipeline transportation	486
35	Other transportation and support activities	487OS
36	Warehousing and storage	493
37	Publishing industries, except internet (includes software)	511
38	Motion picture and sound recording industries	512
39	Broadcasting and telecommunications	513
40	Data processing, internet publishing, and other information services	514
41	Legal services	5411
42	Computer systems design and related services	5415
43	Miscellaneous professional, scientific, and technical services	5412OP
44	Management of companies and enterprises	55
45	Administrative and support services	561
46	Waste management and remediation services	562
47	Educational services	61
48	Ambulatory health care services	621
49	Hospitals and residential care facilities	622-623
50	Social assistance	624
51	Performing arts, spectator sports, museums, and related activities	711AS
52	Amusements, gambling, and recreation industries	713
53	Accommodation	721
54	Food services and drinking places	722
55	Other services, except government	81

Table A.3: Calibration of the Aggregate Parameters.

Parameter	Description	Target/Source
$S = 55$	Number of sectors	3-digit NAICS code level
$\beta = 0.995$	Time discount factor	2% annual real rate
$\sigma = 2$	Risk aversion	Standard value
$\eta = 1/1.5$	Inverse of the Frisch elasticity	Erosa et al. (2016)
$\theta = 36.63$	Labor disutility shifter	$\bar{N} = 0.33$
$\Omega = 7.25$	Private investment adjustment cost	Relative volatility of investment
$\delta_K = 0.015$	Private capital depreciation rate	Ramey (2021)
$\delta_{K_G} = 0.01$	Public capital depreciation rate	Ramey (2021)
$\tau = 4$	Public capital time-to-build	Leeper et al. (2010)
$\zeta = 3$	Public investment time-to-spend	Leeper et al. (2010)
$\rho = 0.95$	Auto-regressive coefficient for public spending	Leeper et al. (2010), Ramey (2021)
$\bar{G} = 0.0249$	Steady-state value of public consumption	$\bar{P}_G \bar{G}/\bar{\mathcal{Y}} = 0.14$
$\bar{I}_G = 0.0051$	Steady-state value of public investment	$\bar{P}_{I_G} \bar{I}_G/\bar{\mathcal{Y}} = 0.035$
$\phi_\rho = 0.8$	Taylor rule responsiveness to lagged interest rates	Clarida et al. (2000)
$\phi_\pi = 1.5$	Taylor-rule responsiveness to aggregate inflation	Clarida et al. (2000)
$\phi_x = 0.2$	Taylor-rule responsiveness to aggregate output gap	Clarida et al. (2000)
$\nu_C = 2$	Elasticity of substitution b/w sectoral private-consumption goods	Hobijn and Nechio (2019)
$\nu_I = 2$	Elasticity of substitution b/w sectoral private-investment goods	$\nu_I = \nu_C$
$\nu_H = 0.1$	Elasticity of substitution b/w sectoral intermediate inputs	Barrot and Sauvagnat (2016) and Boehm et al. (2019)
$\nu_G = 1$	Elasticity of substitution b/w sectoral public-consumption goods	Bouakez et al. (2023)
$\nu_{I_G} = 1$	Elasticity of substitution b/w sectoral public-investment goods	$\nu_{I_G} = \nu_G$
$\nu_N = 1$	Elasticity of substitution b/w sectoral labor flows	Horvath (2000)
$\nu_K = 1$	Elasticity of substitution b/w sectoral capital services	$\nu_K = \nu_N$
$\epsilon = 4$	Elasticity of substitution b/w within-sector varieties	De Loecker et al. (2020)

Table A.4: Calibration of the Sector-Specific Parameters.

Parameter	Description	Target/Source
$\alpha_{N,s}$	Value-added labor intensity	Sectoral value-added labor share
$\alpha_{H,s}$	Gross-output intermediate input intensity	Sectoral gross-output intermediate input share
$\gamma_{G,s}$	Elasticity of sectoral output to public capital	Estimated
$\omega_{C,s}$	Contribution to private consumption	Sectoral share in total personal consumption expenditures
$\omega_{I,s}$	Contribution to private investment	Sectoral share in total non-residential private investment expenditures (equipment, structures, and IPP)
$\omega_{H,s,x}$	Contribution to sectoral intermediate inputs	Sectoral shares in Input-Output matrix
$\omega_{G,s}$	Contribution to public consumption	Sectoral share in total government consumption expenditures (federal defense and nondefense, state and local government)
$\omega_{I_G,s}$	Contribution to public investment	Sectoral share in total government gross investment (federal defense and nondefense, state and local government – equipment, structures, and IPP)
$\omega_{N,s}$	Sectoral labor weight	$\omega_{N,s} = \bar{N}_s/\bar{N}$
$\omega_{K,s}$	Sectoral capital weight	$\omega_{K,s} = \bar{K}_s/\bar{K}$
ϕ_s	Sectoral degree of price rigidity	Nakamura and Steinsson (2008) and Bouakez et al. (2023)

B More on the Estimation of the Output Elasticity to Public Capital

In Section 3.1, we estimate the elasticity of sectoral gross output to public capital, and to do so, we follow the approach of Bouakez et al. (2017) and Ramey (2021) in regressing the logarithm of utilization-adjusted TFP on the logarithm of capital. While a series of utilization-adjusted TFP at the aggregate level is provided by Fernald (2014), there is no available series for utilization-adjusted TFP at the sectoral level over a period of time sufficiently long for the estimation of a cointegrating regression. To fill this gap, we build a series utilization-adjusted sectoral TFP using KLEMS information over the 55 industries of our economy at the annual frequency from 1963 to 2016.

We compute the utilization-adjusted sectoral TFP in a six-step approach. First, we compute the sectoral-level share of intermediate inputs, each of the five types of capital and two types of labor in total nominal costs. Second, given the shares and the log-difference in the real values of these eight production inputs, we derive the log-difference of real costs at the sectoral level. Third, we compute the log-difference of real sectoral gross output. Fourth, to adjust for the utilization in inputs, we compute a measure of hours worked per employee. To focus on the variation at the relevant business cycle frequency, we detrend the logarithm of hours worked per employee through the bandpass filter of Christiano and Fitzgerald (2003) isolating the frequency components between 2 and 8 years. Fifth, we run a panel estimation in which the log-difference of real sectoral gross output is regressed on both the log-difference of real costs as well as the variation of the logarithm of hours worked per employee around the bandpass filter trend. Importantly, we consider a panel setting featuring heterogeneous slopes to capture potential variation across industries in the degree of utilization. Sixth, since the residuals of this regression gives us the log-deviations in sectoral productivity, we use them to back out the utilization-adjusted sectoral TFP in levels.

C More on the Amplification of the Multipliers

Results of Table 1 keep holding even when looking separately at private consumption and private investment, rather than looking at total value added. To illustrate this point, Table C.1 replicates the analysis of Table 1 by computing the multipliers for private consumption and private investment. Also in these cases, the multi-sector economy leads to substantially larger effects of public investment compared to public consumption. While in relative terms the amplification is larger for private investment, with a 955% surge in the multiplier moving from the average one-sector economy to the production network, in absolute terms the amplification is more accentuated for private consumption: out of the 86 cents of additional value added due to sectoral heterogeneity and inter-linkages, 69 cents come from private consumption and 15 cents from private investment. This stands in contrast to the case of public consumption, whose additional output effects—in absolute value—are tilted towards private investment.

Table C.1: The Response of Private Consumption and Private Investment

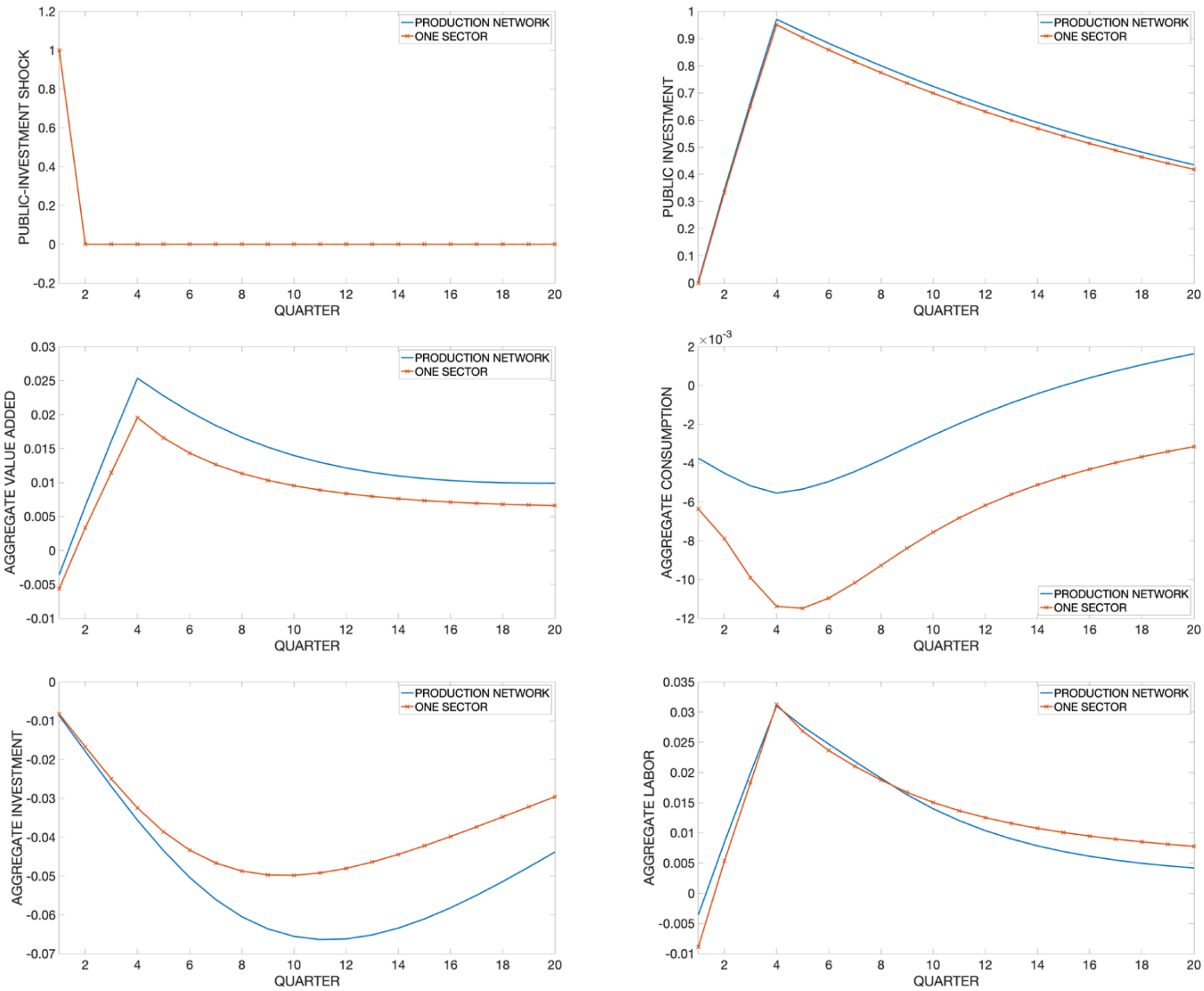
One-Sector Economy	Production-Network Economy	Δ%	Δ$
(1)	(2)	(3)	(4)
Private Consumption			
Panel A.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
0.25	0.94	276%	0.69
Panel A.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
-0.42	-0.40	4%	0.02
Private Investment			
Panel B.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
0.02	0.17	955%	0.15
Panel B.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
-0.24	-0.15	35%	0.08

Note: Panels A.1 and A.2, and Panels B.1 and B.2 report similar statistics of Table 1 associated to private consumption and private investment, respectively.

D Impulse-Response Functions

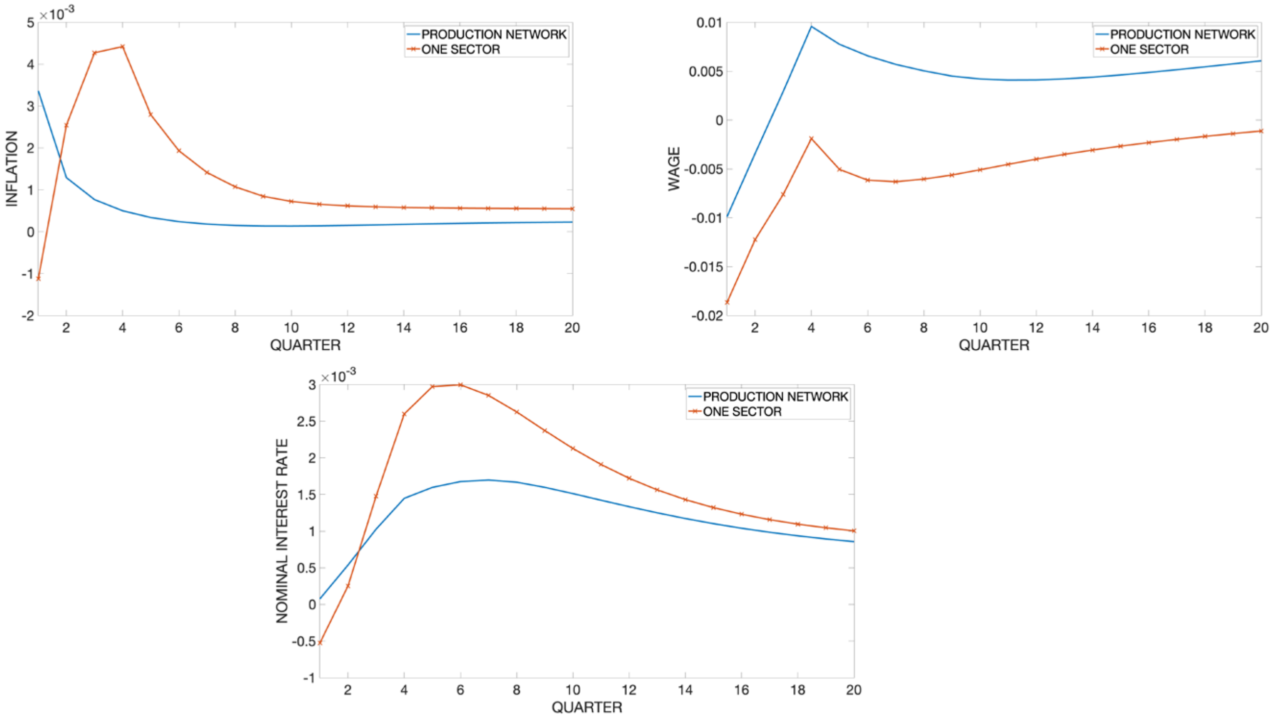
This section reports the entire set of impulse-response functions for the aggregate variables of the model. Figures D.1 and D.2 focus on a 1 percent public-investment shock as the impulse, and show the responses of the shock itself, aggregate public investment, aggregate value added, aggregate private consumption, aggregate private investment, aggregate labor as well as inflation, the wage, and the nominal interest rate. Figures D.3 and D.4 report similar statistics (with the only distinction of showing the response of public consumption rather than that of public investment) associated to a 1 percent public-consumption shock as the impulse.

Figure D.1: Responses to a Public-Investment Shock.



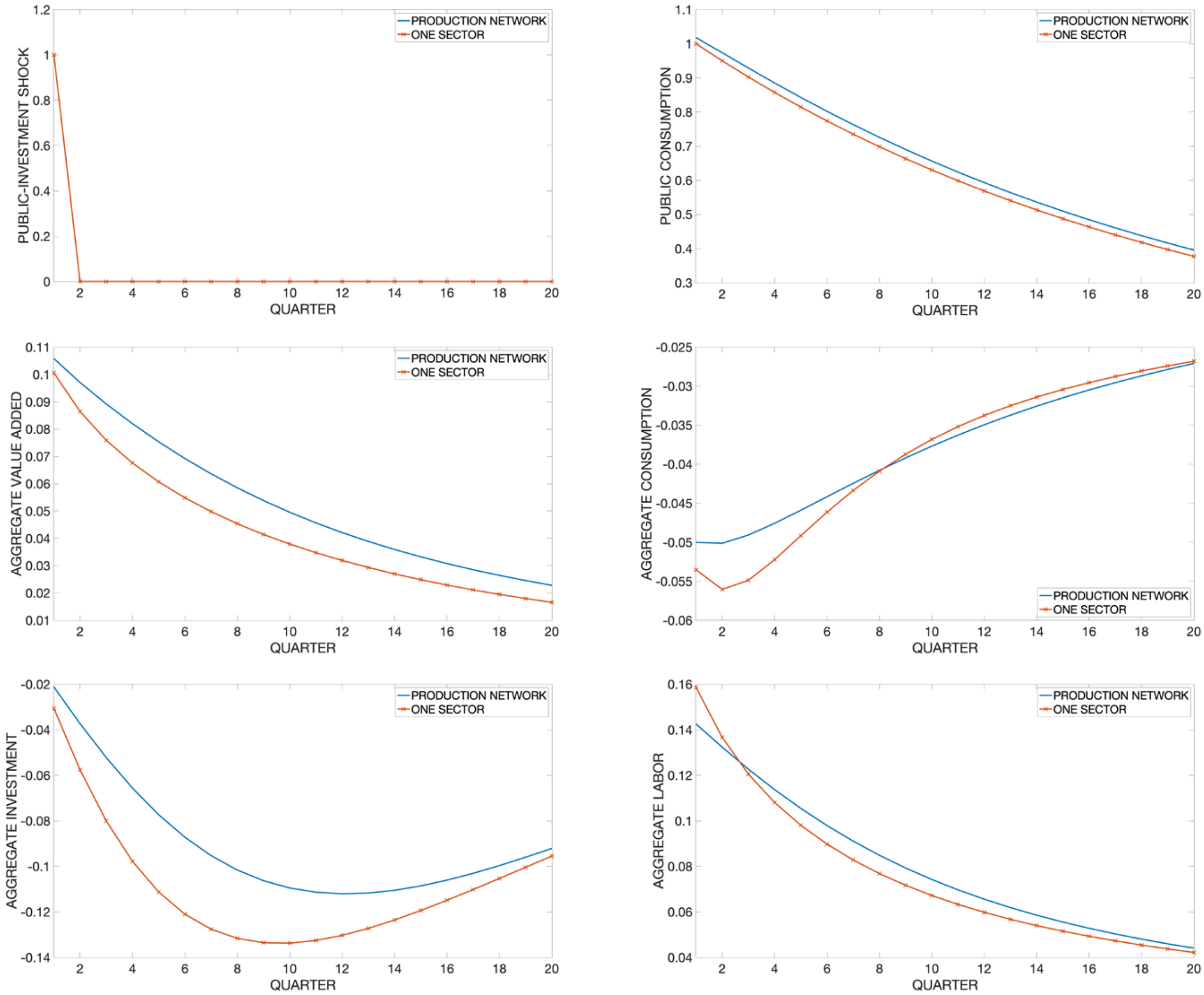
Note: The graph reports a 1 percent impulse of a public-investment shock together with the associated responses of aggregate public investment, aggregate value added, aggregate private consumption, aggregate private investment, and aggregate labor. The continuous line denotes the responses implied by the production-network economy, whereas the crossed line denotes the responses implied by the one-sector economy.

Figure D.2: Responses to a Public-Investment Shock (cont.).



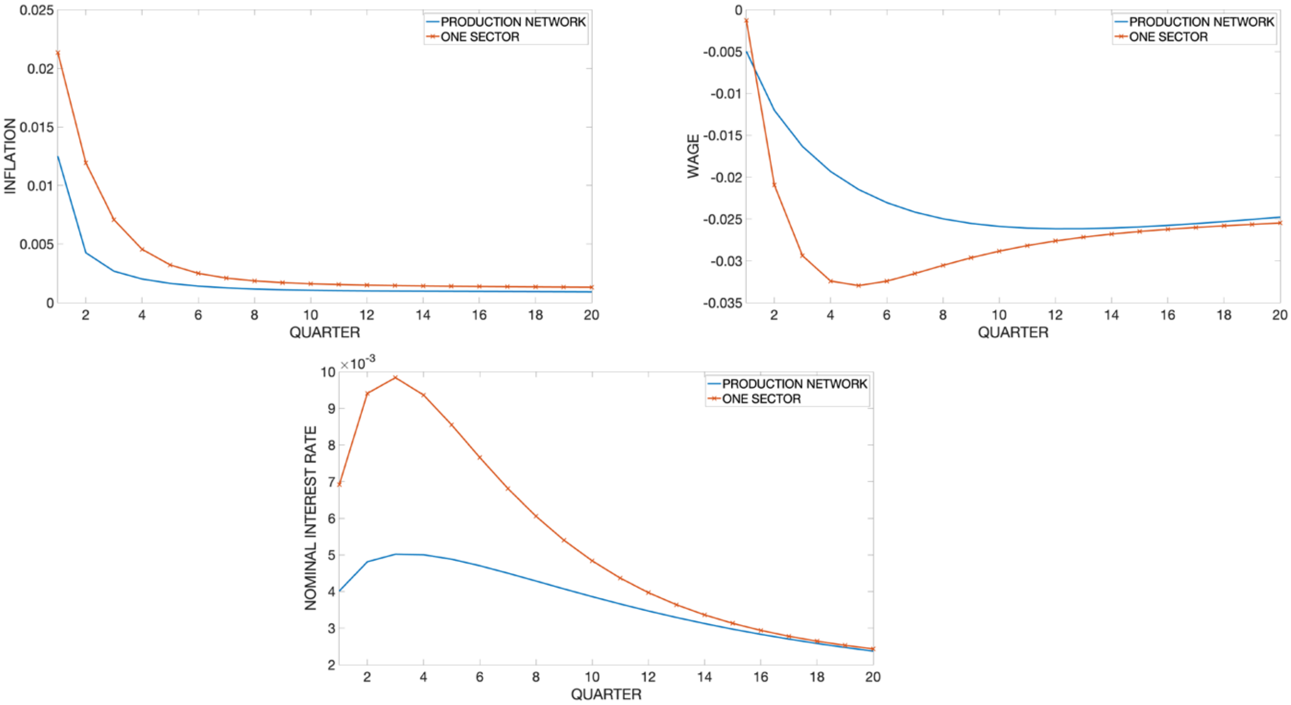
Note: The graph reports the responses of aggregate inflation, the wage, and the nominal interest rate to a 1 percent public-investment shock. The continuous line denotes the responses implied by the production-network economy, whereas the crossed line denotes the responses implied by the one-sector economy.

Figure D.3: Responses to a Public-Consumption Shock.



Note: The graph reports a 1 percent impulse of a public-consumption shock together with the associated responses of aggregate public consumption, aggregate value added, aggregate private consumption, aggregate private investment, and aggregate labor. The continuous line denotes the responses implied by the production-network economy, whereas the crossed line denotes the responses implied by the one-sector economy.

Figure D.4: Responses to a Public-Consumption Shock (cont.).



Note: The graph reports the responses of aggregate inflation, the wage, and the nominal interest rate to a 1 percent public-consumption shock. The continuous line denotes the responses implied by the production-network economy, whereas the crossed line denotes the responses implied by the one-sector economy.

E Aggregate Implications: Robustness Checks

This section provides additional checks to the main result in Table 1 on the amplification of the public-investment multiplier in a production network. Specifically, we replicate the same analysis and compute the public-investment and public-consumption multipliers in alternative versions of the production-network economy and compare them to the implications of the associated average one-sector model.

We start with a sequence of sensitivity analysis on some parameters of the model. Panels A.1 and A.2 of Table E.1 report the implications of a version of the model in which we set the Frisch elasticity of labor supply η to 1, rather than 1.5, as in the baseline calibration. We then study the implications of lower depreciation rates for private and public capital, by setting $\delta_K = 0.01$ and $\delta_{K_G} = 0.005$, in Panels B.1 and B.2 of Table E.1, and higher depreciation rates, by setting $\delta_K = 0.025$ and $\delta_{K_G} = 0.02$, in Panels C.1 and C.2 of Table E.1. Panels D.1 and D.2 of Table E.1 examine the multipliers of a version of the model in which there is complementarity across sectoral consumption goods, that is, $\omega_{C,s} = 0.8$, rather than a mild degree of substitutability as in the baseline calibration. Panels E.1 and E.2 of Table E.2 implement a similar analysis with respect to investment, by setting the elasticity of substitution of investment sectoral goods to $\omega_{I,s} = 0.8$. Then, Panels F.1 and F.2 of Table E.2 jointly consider complementarity for both sectoral consumption goods and sectoral investment goods, such that $\omega_{C,s} = 0.8$ and $\omega_{I,s} = 0.8$.

We also examine whether the amplification result varies with the degree of reallocation of labor and capital across sectors. Panels G.1 and G.2 of Table E.2 consider a perfectly mobile labor and capital by setting $\nu_N \to \infty$ and $\nu_K \to \infty$. In this way, the aggregate labor and aggregate capital aggregators of Equations (4) and (6) become, respectively:

$$N_t = \sum_{s=1}^{S} N_{s,t} \tag{E.1}$$

and

$$K_t = \sum_{s=1}^{S} K_{s,t}, \tag{E.2}$$

so that wages and capital rental rates are equalized across sectors. Panels H.1 and H.2 of Table E.2, instead, go on the opposite extreme by considering a model version in which physical capital is sector specific. In this setting, each sector features the following law of motion for physical capital:

$$K_{s,t+1} = (1 - \delta_K)\, K_{s,t} + I_{s,t} \left[1 - \frac{\Omega}{2} \left(\frac{I_{s,t}}{I_{s,t-1}} - 1 \right)^2 \right]. \tag{E.3}$$

This economy features an investment network as in Vom Lehn and Winberry (2022). Specifically, sector-s investment, $I_{s,t}$, is produced with the following aggregator

$$I_{s,t} = \left[\sum_{s=1}^{S} \omega_{I,s,x}^{\frac{1}{\nu_I}} I_{s,x,t}^{\frac{\nu_I - 1}{\nu_I}} \right]^{\frac{\nu_I}{\nu_I - 1}}, \tag{E.4}$$

where $I_{s,x,t}$ are the investment goods purchased from industry x to assemble the investment that augments the stock of physical capital of sector s, and $\omega_{I,s,x}$ is the weight of the goods provided by sector x into the total investment purchased by sector s firms. We calibrate the set of parameters $\omega_{I,s,x}$ following the estimates on the investment network of Vom Lehn and Winberry (2022) regarding the specification with 41 sectors they consider, and map these values into the 55 sectors of our model. The new aggregator for sector-s investment implies that its price, $P_{I,s,t}$, equals

$$P_{I,s,t} = \left[\sum_{s=1}^{S} \omega_{I,s,x} P_{x,t}^{1-\nu_I} \right]^{\frac{1}{1-\nu}}. \tag{E.5}$$

This model version also implies a slightly different budget constraint for the household, that now reads

$$P_{C,t} C_t + \sum_{s=1}^{S} P_{I,s,t} I_{s,t} + T_t + B_t = W_t N_t + \sum_{s=1}^{S} R_{K,s,t} K_{s,t} + R_{t-1} B_{t-1}, \tag{E.6}$$

and a different sector-specific resource constraint:

$$Z_{s,t} = C_{s,t} + \sum_{x=1}^{S} I_{x,s,t} + \sum_{x=1}^{S} H_{x,s,t} + G_{s,t} + I_{G,s,t}. \tag{E.7}$$

In this economy, the adjustment cost parameter, Ω, is set symmetrically across sectors, and we calibrate it so that the relative volatility of aggregate investment, defined as $\sum_{s,t} q_{I,s,t} I_{s,t}$, in a model version featuring just aggregate TFP shocks matches that of the data.

Next, we consider a model with fully flexible prices, by setting the Calvo price adjustment parameter to $\phi = 0$, and report the results in Panels I.1 and I.2 of Table E.3. Panels J.1 and J.2 of Table E.3 show the multipliers of a model economy with sticky wages, whose structure is defined as in Erceg et al. (2000). Specifically, households supply differentiated labor varieties indexed by $j \in [0,1]$ and the varieties are imperfectly substitutable. Accordingly, total labor is defined as

$$\tilde{N}_t = \left(\int_0^1 N_t^{j\,\frac{\epsilon_w - 1}{\epsilon_w}} dj \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{E.8}$$

where N_t^j denotes the labor of variety j, and ϵ_w is the elasticity of substitution across varieties. This total labor is then sold to firms at a wage which is subject to a Calvo price-setting adjustment, so that households can set the wage with a probability $1-\phi_w$. In equilibrium, $\tilde{N}_t = N_t$, where N_t is the aggregator that defines how total labor is split across industries. We calibrate the elasticity of substitution across labor varieties so that it equals the within-sector elasticity of substitution across goods varieties, that is, $\epsilon_w = \epsilon = 4$. We then set the wage Calvo frequency parameter to $\phi_w = 2/3$, which implies a degree of rigidity that is similar to the average rigidity that characterizes firms' price-setting problem.

Following the results of Boehm (2020) on the relevance of modeling the durability of the consumption goods when comparing the effects of public investment to those of public consumption, Panels K.1 and K.2 of Table E.3 report the multipliers of a model version in which the final consumption goods are durable, and feature a sector-specific depreciation rate. In this economy, the households' problem and budget constraint become

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{D_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right], \tag{E.9}$$

$$P_{D,t} D_t + P_{I,t} I_t + T_t + B_t = W_t N_t + R_{K,t} K_t + R_{t-1} B_{t-1}, \tag{E.10}$$

where D_t denotes the final bundle of aggregate durable consumption, with comes with a price $P_{D,t}$. This bundle is assembled by the private-consumption retailers as follows. The private-consumption retailers buy the sectoral private-consumption goods $C_{s,t}$ at the price $P_{s,t}$, to produce the aggregate private consumption good subject to CES technology:

$$D_t = \left[\sum_{s=1}^{S} \omega_{C,s}^{\frac{1}{\nu_C}} D_{s,t}^{\frac{\nu_C - 1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C - 1}}, \tag{E.11}$$

where $D_{s,t}$ is the stock of durable consumption goods of sector s, whose law of motion is defined as

$$D_{s,t} = (1 - \delta_{C,s})\, D_{s,t-1} + C_{s,t}, \tag{E.12}$$

where the stock of durable goods depreciates at a sector-specific rate $\omega_{C,s}$. While most sectors produce non-durable goods, and thus feature a depreciation rate of $\omega_{C,s} = 1$, this setting allows us to capture the durability of the goods produced by some industries of our economy, in which $\omega_{C,s} < 1$. The price of the final private-consumption good $P_{D,t}$ is then defined as:

$$P_{D,t} = \left[\sum_{s=1}^{S} \omega_{C,s} P_{D,s,t}^{1-\nu_C} \right]^{\frac{1}{1-\nu_C}}, \tag{E.13}$$

subject to the sector-specific prices $P_{D,s,t}$

$$P_{D,s,t} = P_{s,t} + \beta \Lambda_{t+1} (1 - \delta_{C,s})\, P_{s,t+1}, \tag{E.14}$$

where Λ_{t+1} denotes the households' stochastic discount factor. To set the depreciation rate of consumption, $\delta_{C,s}$, we first use information of the U.S. Bureau of Economic Analysis on both the current-cost net stock and the current-cost depreciation of consumer durable goods at the annual frequency from 1947 to 2019. In this way, we derive a measure of the average depreciation rate of consumer durables at the commodity level. We then take the concordance tables between commodities (PCE categories) and sectors (NAICS codes) for personal consumption expenditures from 1997 to 2019 to map the commodity level depreciation rates at the sectoral disaggregation level of our model.

We then turn into evaluating the role of the fiscal and monetary block of the model. We start by reporting in Panels L.1 and L.2 of Table E.3 the multipliers of a model version in which the additional public spending out of steady state is financed with distortionary labor-income taxes, $\tau_{N,t}$, as in Leeper et al. (2010). In this setting, the households' and government budget constraint read, respectively:

$$P_{C,t}C_t + P_{I,t}I_t + T_t + B_t = (1 - \tau_{N,t})\, W_t N_t + R_{K,t}K_t + R_{t-1}B_{t-1}, \tag{E.15}$$

and

$$\bar{T} + \tau_{N,t}W_t N_t = P_{G,t}G_t + P_{I_G,t}I_{G,t}, \tag{E.16}$$

where the steady-state level of the lump-sum tax is defined as $\bar{T} = \bar{P}_G\bar{G} + \bar{P}_{I_G}\bar{I}_G$. Panels M.1 and M.2 of Table E.4 evaluate the model implications when abstracting from the time-to-build delays, by setting $\mu = 0$. Panels N.1 and N.2 of Table E.4 evaluate the model implications when abstracting from the time-to-build spend, by setting $\zeta = 0$, while Panels O.1 and O.2 of Table E.4 report the multipliers of a case with neither time-to-build delays nor time-to-spend delays, so that $\mu = 0$ and $\zeta = 0$. Next, we consider a model version with either complementarity across sectoral public goods, so that $\nu_G = \nu_{I_G} = 0.5$, in Panels P.1 and P.2 of Table E.4, or substitutability across sectoral public goods, so that $\nu_G = \nu_{I_G} = 2$, in Panels Q.1 and Q.2 of Table E.5.

Then, Panels R.1 and R.2 of Table E.5 consider a model version with a lower public investment to GDP ratio: we set steady-state public investment so that the ratio is $\bar{P}_{I_G}\bar{I}_G/\bar{\mathcal{Y}} = 0.015$, which is two percentage points lower than in the baseline calibration.

A further check on the fiscal block evaluates the implications of setting the persistence of the auto-regressive processes of public investment and public consumption down from $\rho = 0.95$ to either $\rho = 0.86$, as in Boehm (2020), or $\rho = 0.97$, as in Kormilitsina and Zubairy (2018). We report the results of these exercises in Panels S.1 and S.2, and T.1, and T.2 of Table E.5, respectively. Panels U.1 and U.2 of E.6 report the multipliers associated to a model version in which public consumption expenditures consist of both the purchases of goods from the private sectors as well as the compensation of public employees, as in Moro and Rachedi (2022). Specifically, we posit that government consumption gross output (which is also total government consumption expenditures), $Y_{G,t}$, has the following technology

$$Y_{G,t} = N_{G,t}^{\xi} G_t^{1-\xi} \tag{E.17}$$

where $N_{G,t}$ is public employment, G_t is the purchases of goods which follows the autoregressive process of Equation (23), and ξ is the share of labor in government gross output. We then consider a wage specific to the public sector, $W_{G,t}$, by modifying the labor aggregator of Equation (4) as follows

$$N_t = \left\{ \left[\sum_{s=1}^{S} \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right] + \omega_{N,G}^{-\frac{1}{\nu_N}} N_{G,t}^{\frac{1+\nu_N}{\nu_N}} \right\}^{\frac{\nu_N}{1+\nu_N}}, \tag{E.18}$$

where $\sum_{s=1}^{S} \omega_{N,s} + \omega_{N,G} = 1$. Accordingly, in this economy the aggregate nominal wage equals

$$W_t = \left\{ \left[\sum_{s=1}^{S} \omega_{N,s} W_{s,t}^{1+\nu_N} \right] + \omega_{N,G} W_{G,t}^{1+\nu_N} \right\}^{\frac{1}{1+\nu_N}}. \tag{E.19}$$

In every period, total taxes cover also the compensation of public employees and thus equal

$$T_t = P_{G,t} G_t + W_{G,t} N_{G,t} + P_{I_G,t} I_{G,t}. \tag{E.20}$$

Finally, the nominal value added of this economy is

$$\mathcal{Y}_t = \sum_{s=1}^{S} \mathcal{Y}_{s,t} + \mathcal{Y}_{G,t} = P_{C,t} C_t + P_{I,t} I_t + P_{I_G,t} I_{G,t} + P_{Y_G,t} Y_{G,t}, \tag{E.21}$$

where the price of government consumption gross output, $P_{Y_G,t}$, is defined as

$$P_{Y_G,t} = \frac{W_{G,t}^{\xi} P_{G,t}^{1-\xi}}{\xi^{\xi} (1-\xi)^{1-\xi}}. \tag{E.22}$$

In this setting, the public-consumption multiplier is computed as

$$\mathcal{M}^{\mathcal{G}} = \frac{\sum_{j=1}^{\infty} \beta^{j-1} \left(Y_j - \bar{Y} \right)}{\sum_{j=1}^{\infty} \beta^{j-1} \left(\frac{P_{Y_G,j}}{P_j} Y_{G,j} - \frac{\bar{P}_{Y_G}}{\bar{P}} \bar{Y}_G \right)}. \tag{E.23}$$

We calibrate the share of public labor to $\xi = 0.6$, to reproduce the 60% share of the nominal compensation of general government employees over the sum of the nominal compensation of general government employees and the nominal value of the intermediate goods and services purchased by the general government, computed as of 2019.

Then, we consider a check regarding the monetary block in Panels V.1 and V.2 of Table E.6, by setting the responsiveness of the Taylor rule to inflation up from $\phi_\Pi = 1.5$ to $\phi_\Pi = 15$. Finally, Panels W.1 and W.2 of Table E.6 consider the implications of the baseline production network by changing the definition of the multipliers. Rather than computing them as in Equations (32) and (33), we quantify the multipliers as follows

$$\mathcal{M}^{\mathcal{I}_\mathcal{G}} = \frac{\sum_{j=1}^{\infty}\left(\prod_{i=0}^{j-1}\frac{1}{1+r_i}\right)\left(Y_j - \bar{Y}\right)}{\sum_{j=1}^{\infty}\left(\prod_{i=0}^{j-1}\frac{1}{1+r_i}\right)\left(\frac{P_{I_G,j}}{P_j}I_{G,j} - \frac{\bar{P}_{I_G}}{\bar{P}}\bar{I}_G\right)} \tag{E.24}$$

and

$$\mathcal{M}^{\mathcal{G}} = \frac{\sum_{j=1}^{\infty}\left(\prod_{0=1}^{j-1}\frac{1}{1+r_i}\right)\left(Y_j - \bar{Y}\right)}{\sum_{j=1}^{\infty}\left(\prod_{0=1}^{j-1}\frac{1}{1+r_i}\right)\left(\frac{P_{G,j}}{P_j}G_j - \frac{\bar{P}_G}{\bar{P}}\bar{G}\right)}. \tag{E.25}$$

In these cases, we discount the deviations of the value of real aggregate GDP from its steady-state level as well as the deviations of the real value of both public investment and public consumption from their respective steady-state levels with the real interest rate r_t, rather than with the time discount parameter, β.

All in all, the amplification of the public-investment multiplier in the production-network economy relative to the average one-sector model is always around 60%-80%, and doubles that of the public-consumption multiplier.

Table E.1: The Public-Investment and Public-Consumption Multipliers: Robustness.

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Low Frisch Elasticity			
Panel A.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.20	2.13	78%	0.93
Panel A.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.21	0.33	57%	0.12
Low Capital Depreciation Rates			
Panel B.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
0.94	1.54	64%	0.60
Panel B.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.30	0.40	33%	0.10
High Capital Depreciation Rates			
Panel C.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.59	2.69	69%	1.10
Panel C.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.44	0.57	30%	0.13
Complementarity across Consumption Goods			
Panel D.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.09	65%	0.82
Panel D.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.46	30%	0.11

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels A.1 and A.2 consider a model version in which $\eta = 1$ and thus the Frisch elasticity is 1, Panels B.1 and B.2 consider a model economy in which the depreciation rates are lower than in baseline such that $\delta_K = 0.01$ and $\delta_{K_G} = 0.005$, Panels C.1 and C.2 consider a model economy in which the depreciation rates are higher than in baseline such that $\delta_K = 0.025$ and $\delta_{K_G} = 0.02$, and Panels D.1 and D.2 consider a model version in which $\nu_C = 0.8$ and thus consumption goods are complementary across sectors.

Table E.2: The Public-Investment and Public-Consumption Multipliers: Robustness (cont.).

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Complementarity across Investment Goods			
Panel E.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.12	68%	0.86
Panel E.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	30%	0.10
Complementarity across Consumption/Investment Goods			
Panel F.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.09	65%	0.82
Panel F.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.46	31%	0.11
Perfectly Mobile Labor and Capital			
Panel G.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.23	76%	0.97
Panel G.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.43	22%	0.08
Sector-Specific Capital and Investment Network			
Panel H.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.09	65%	0.82
Panel H.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	28%	0.10

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels E.1 and E.2 consider a model version in which $\nu_I = 0.8$ and thus investment goods are complementary across sectors, Panels F.1 and F.2 consider a model version in which $\nu_C = \nu_I = 0.8$ and thus both consumption goods and investment goods are complementary across sectors, Panels G.1 and G.2 consider a model version in which $\nu_N \to \infty$ and $\nu_K \to \infty$, and thus both labor and capital are perfectly mobile across sectors, and Panels H.1 and H.2 consider a model in which physical capital is sector-specific and investment for a given sector is produced with investment goods from all the other industries through an investment network.

Table E.3: The Public-Investment and Public-Consumption Multipliers: Robustness (cont.).

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Flexible Prices			
Panel I.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.26	2.01	59%	0.75
Panel I.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.33	0.38	13%	0.04
Sticky Wages			
Panel J.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.29	2.14	66%	0.85
Panel J.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.36	0.46	26%	0.10
Durable Consumption with Sector-Specific Depreciation			
Panel K.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
1.27	2.05	62%	0.78
Panel K.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.42	20%	0.07
Distortionary Labor-Income Tax			
Panel L.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_{\mathcal{G}}}$			
0.16	0.91	460%	0.75
Panel L.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
-0.69	-0.64	6%	0.05

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels I.1 and I.2 consider a version in which $\phi_1 = 0$ and thus prices are fully flexible, Panels J.1 and J.2 consider a model version in which also wages are sticky, Panels K.1 and K.2 considers a version in which sectors' consumption goods can be durable, with a depreciation that is sector-specific, and Panels L.1 and L.2 consider a model version in which public spending out of steady state is financed with a distortionary labor-income tax.

Table E.4: The Public-Investment and Public-Consumption Multipliers: Robustness (cont.).

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
No Time-to-Build Delays			
Panel M.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.32	2.21	67%	0.89
Panel M.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	30%	0.10
No Time-to-Spend Delays			
Panel N.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.32	2.20	67%	0.88
Panel N.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	30%	0.10
No Time-to-Build and Time-to-Spend Delays			
Panel O.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.37	2.28	66%	0.91
Panel O.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.45	30%	0.10
Complementarity across Public Goods			
Panel P.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.27	2.12	67%	0.85
Panel P.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.46	30%	0.11

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels M.1 and M.2 consider a model version in which $\mu = 0$ and thus there is no time-to-build delay, Panels N.1 and N.2 consider a model version in which $\zeta = 0$ and thus there is no time-to-spend delay, Panels O.1 and O.2 consider a model version in which $\mu = \zeta = 0$ and thus there is no time-to-spend and time-to-build delay, and Panels P.1 and P.2 consider a model version in which sectoral public goods are complements, such that $\nu_G = \nu_{I_G} = 0.5$.

Table E.5: The Public-Investment and Public-Consumption Multipliers: Robustness (cont.).

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Substitutability across Sectoral Public Goods			
Panel Q.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.27	2.13	68%	0.87
Panel Q.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.44	29%	0.10
Low Public Investment to GDP Ratio			
Panel R.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
2.57	4.59	78%	2.02
Panel R.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.34	0.44	28%	0.10
Low Persistence Public-Spending Process			
Panel S.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.24	2.25	81%	1.00
Panel S.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.32	0.48	49%	0.16
High Persistence Public-Spending Process			
Panel T.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.34	2.13	59%	0.79
Panel T.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.45	0.53	17%	0.07

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels Q.1 and Q.2 consider a model version in which sectoral public goods are substitutes, such that $\nu_G = \nu_{I_G} = 2$, and Panels R.1 and R.2 consider a model version in which the steady-state level of public investment is set such that $\frac{\bar{P}_{I_G}\bar{I}_G}{\bar{\mathcal{Y}}} = 0.015$, Panels S.1 and S.2 consider a model economy in which the autoregressive coefficients of the process of public-investment and public-consumption spending are set to $\rho = 0.86$, and Panels T.1 and T.2 consider a model economy in which the autoregressive coefficients of the process of public-investment and public-consumption spending are set to $\rho = 0.975$.

Table E.6: The Public-Investment and Public-Consumption Multipliers: Robustness (cont.).

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
Public Employment			
Panel U.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.11	2.03	84%	0.93
Panel U.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.46	0.70	52%	0.24
Stronger Monetary Policy Response to Inflation			
Panel V.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.25	2.04	63%	0.79
Panel V.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.33	0.39	18%	0.06
No Monetary Policy Response to Output Gap			
Panel W.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.27	2.20	73%	0.93
Panel W.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.35	0.50	43%	0.15
Interest Rate Discounting			
Panel X.1: Public-Investment Multipliers, $\mathcal{M}^{\mathcal{I}_\mathcal{G}}$			
1.89	3.24	71%	1.35
Panel X.2: Public-Consumption Multipliers, $\mathcal{M}^{\mathcal{G}}$			
0.32	0.42	34%	0.11

Note: This Table reports similar statistics to those of Table 1 with the difference that Panels U.1 and U.2 consider a model version in which public consumption expenditures consist of both purchases of goods from all sectors as well as the compensation of public employees, Panels V.1 and V.2 consider a model version in which $\phi_\pi = 15$ and thus monetary policy reacts much more to variations in inflation when setting the nominal interest rate, Panels W.1 and W.2 consider a model version in which $\phi_x = 0$ and thus monetary policy does not react to changes in the output gap, and Panels X.1 and X.2 compute the multipliers by discounting using the interest rate rather than the time discount factor.

F Multipliers Amplification in the Short Run

Table 1 of Section 4.1 shows that the production-network amplification for the aggregate effects of public investment is substantial when using the long-run present-value multipliers of Equations (32) and (33), which evaluate the entire response of aggregate output following the realization of a fiscal shock. However, the amplification result could differ if we were to evaluate the effects of public investment and public consumption at shorter horizons. Indeed, the literature shows that public investment spurs aggregate output more than public consumption only in from the medium run (Boehm, 2020; Ramey, 2021). To address this concern, this section quantifies to what extent the production-network amplification of the public-investment multiplier depends on the specific horizon at which the output response is evaluated.

To do so, we compute the public-investment multiplier at any horizon $\mathcal{H}$, $\mathcal{M}_{\mathcal{H}}^{\mathcal{I_G}}$, as follows

$$\mathcal{M}_{\mathcal{H}}^{\mathcal{I_G}} = \frac{\sum_{j=1}^{\mathcal{H}} \beta^{j-1}\left(Y_j - \bar{Y}\right)}{\sum_{j=1}^{\mathcal{H}} \beta^{j-1}\left(\frac{P_{I_G,j}}{P_j} I_{G,j} - \frac{\bar{P}_{I_G}}{\bar{P}} \bar{I}_G\right)}. \tag{F.1}$$

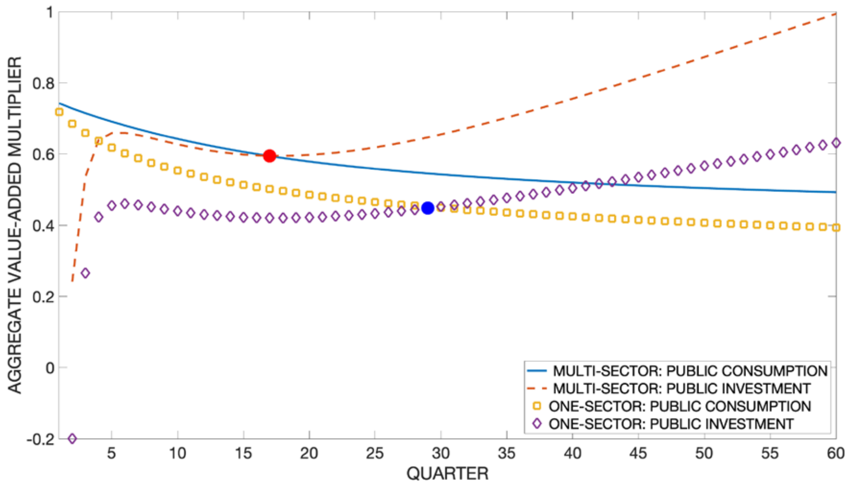
Analogously, the public-consumption multiplier at any horizon $\mathcal{H}$, $\mathcal{M}_{\mathcal{H}}^{\mathcal{G}}$, is

$$\mathcal{M}_{\mathcal{H}}^{\mathcal{G}} = \frac{\sum_{j=1}^{\mathcal{H}} \beta^{j-1}\left(Y_j - \bar{Y}\right)}{\sum_{j=1}^{\mathcal{H}} \beta^{j-1}\left(\frac{P_{G,j}}{P_j} G_j - \frac{\bar{P}_G}{\bar{P}} \bar{G}\right)}. \tag{F.2}$$

Figure F.1 reports the public-investment and public-consumption multipliers in the one-sector and production-network economy up to $\mathcal{H} = 60$ quarters. As documented in previous work (Boehm, 2020; Ramey, 2021), the impact effect of public investment on GDP is lower than the one triggered by public consumption, due to the time-to-build and time-to-spend delays, as well as the differential crowding out effects of the two fiscal instruments on private consumption and private investment.

In the one-sector model, the public-investment multiplier on impact is negative (-0.2), while the public-consumption multiplier is positive (0.72). The public-consumption multiplier then gradually decreases with the horizon of the response of aggregate output to the initial shock, whereas the opposite applies to the public-investment multiplier. After seven and half years (30 quarters) the output effects of public investment exceed those spurred by public consumption. In the multi-sector economy, the public-investment multiplier in the production network is always positive, also on impact. In addition, it takes 4 years (17 quarters) for the public-investment multiplier to be larger than the public-consumption multiplier. Crucially, the public-investment multiplier is virtually identical to the public-consumption multiplier just after 6 quarters. Accordingly, the production

Figure F.1: Dynamics of Public-Consumption and Public-Investment Multipliers.



Note: The blue solid line and the dash orange line represent, respectively, the public-consumption and investment-multiplier in the production network computed at any horizon between 1 and 60 quarters. Analogously, the yellow squares and the violet diamonds represent, respectively, the public-consumption and public-investment multiplier in the average one-sector economy.

network substantially front-loads the aggregate effects of public investment and dramatically reduce the lag required for public investment to be as stimulative as public consumption.

How do these dynamics translate into the production-network amplification of the public-investment and public-consumption multipliers? Table F.1 reports the 2-year ($\mathcal{H} = 8$) and 4-year ($\mathcal{H} = 16$) multipliers implied by the production network and the average one-sector economy. While the levels of the multipliers differ substantially from the ones of the long-run present-value multipliers in Table 1, we still find that the production network implies a relatively larger amplification for the aggregate effects of public investment when compared to the one-sector model: the production-network amplification of the public-investment multiplier is three times as large as that of the public consumption multiplier.

To further evaluate the production-network amplification in the short run, Figure F.2 reports the percentage change between the production network and the average one-sector model in both the public-investment and public-consumption multipliers at any horizon up to 60. The amplification for public investment is substantially larger independently of the horizon in which we compute the response of aggregate output to the fiscal shocks. If anything, the amplification becomes even more quantitatively relevant in the very short run, as it is shown by Figure F.3. In other words, our amplification results does not change with the horizon at which we evaluate the output response to public investment.

While these results imply that public investment is not an ideal immediate stabilization policy, sectoral inter-linkages allow the model to be consistent with

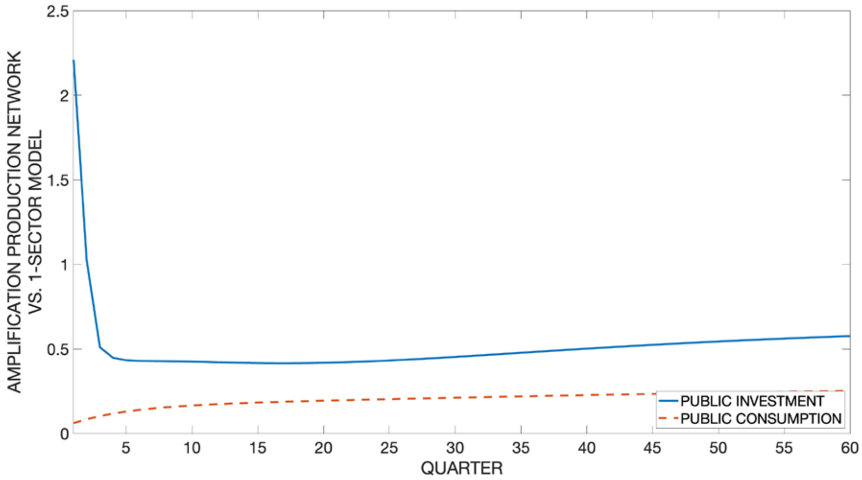
Table F.1: Multipliers at the 2-Year and 4-Year Horizons.

One-Sector Economy (1)	Production-Network Economy (2)	Δ% (3)	Δ$ (4)
2-Year Horizon ($\mathcal{H} = 8$)			
Panel A: Public-Investment Multipliers, $\mathcal{M}_8^{\mathcal{I}_\mathcal{G}}$			
0.45	0.64	43%	0.19
Panel B: Public-Consumption Multipliers, $\mathcal{M}_8^{\mathcal{G}}$			
0.58	0.66	15%	0.08
4-Year Horizon ($\mathcal{H} = 16$)			
Panel C: Public-Investment Multipliers, $\mathcal{M}_{16}^{\mathcal{I}_\mathcal{G}}$			
0.42	0.60	42%	0.18
Panel D: Public-Consumption Multipliers, $\mathcal{M}_{16}^{\mathcal{G}}$			
0.51	0.60	18%	0.09

Note: Panels A and B report the 2-year public-investment and public-consumption multipliers, respectively, in the average one-sector economy in Column (1), the baseline multi-sector production-network economy in Column (2), as well as the difference in the multipliers between the production-network economy and the average one-sector economy in percentage values and absolute values in Columns (3) and (4), respectively. Panel B reports similar statistics for the 2-year public-consumption multipliers. Panels C and D report similar statistics for the 4-year multipliers.

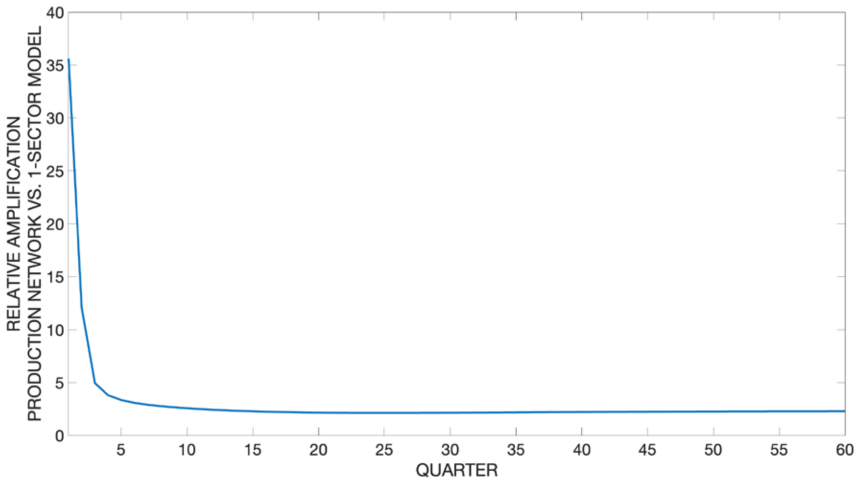
the empirical evidence showing that the limited stimulus effects of public investment in the very short run (Boehm, 2020) are reversed after a couple of years (Ilzetzki et al., 2013).

Figure F.2: Multipliers Amplification in the Short Run.



Note: The blue solid line and the dash orange line represent, respectively, the amplification of the public-investment and public-consumption multipliers between the production network and the 1-sector economy in the short run, for horizons up to 60 quarters.

Figure F.3: Relative Amplification of the Public-Investment Multiplier.



Note: The blue solid line represents the ratio between the amplification of the public-investment multiplier computed as the difference of the production network and the 1-sector economy in the short run, for horizons up to 60 quarters, and the similar statistics for the public-consumption multiplier.

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