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The Macroeconomic Effects of Funding U.S. Infrastructure

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The Macroeconomic Effects of Funding U.S. Infrastructure*

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Abstract

This paper quantitatively assesses the macroeconomic effects of the recently agreed U.S. bipartisan infrastructure spending bill in a neoclassical growth model. We add to the literature by considering a more detailed tax structure, different types of infrastructure spending and linkages between the final and intermediate goods sectors. We find that infrastructure spending cannot fully pay for itself despite public and private capital being underprovided. We further find long-run output multipliers above unity if infrastructure spending and rising public debt are financed by consumption, dividend and labour income taxes and below one for corporate taxes. We also show that except for the consumption tax, the size of the multipliers critically depends on the Frisch labour supply elasticity. Finally, when we compute differences in welfare across different public financing regimes, the net welfare gains and losses are relatively minor.

Keywords: Infrastructure investment, public capital, fiscal multipliers, taxation
JEL Codes: E62, H41, H54

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1 Introduction

A substantial and continuously expanding literature on the macroeconomic effects of government infrastructure spending has emphasised that these outcomes crucially depend on the public financing instruments used to stabilise the rising public debt and the productivity of public capital. This literature has also discussed the importance of investment adjustment costs, external habits in consumption, and implementation lags, including the time it takes to spend the authorised budget allocation, and the time it takes to build the infrastructure capital before it becomes productive.[1]

This paper quantitatively assesses the macroeconomic effects of the recently agreed U.S. bipartisan infrastructure spending bill, taking all the above considerations on board. Additionally, we add to this literature by incorporating (i) a more detailed tax structure (including corporate and dividend taxes); (ii) different types of infrastructure spending (including equipment, structures and intellectual property products); and (iii) linkages between final and intermediate goods sectors that affect the size of multipliers. In the remainder of this section, we provide further details motivating why we have concentrated our efforts on these three areas.

1.1 Tax Structure

It is well established that the way fiscal instruments react to rising public debt is essential for understanding the short- and long-term effects of exogenous increases in public spending (see, e.g. Leeper *et al.* (2009) for the U.S. and the review in Coenen *et al.* (2012)). The modelling of fiscal policy using feedback Taylor-type rules allows budgetary instruments to respond to deviations of public debt from targets. Typically, the more distorting the policy instrument, the smaller the multiplier.

Most of the literature on government investment multipliers (e.g. Leeper *et al.* (2009, 2010) and Sims and Wolff (2018) for the U.S.) has focused on consumption, labour and capital income taxes as potential public financing instruments (as well as lump-sum government transfers which serve as a benchmark case). The current U.S. administration has raised the possibility, on the other hand, that it would prefer to finance the recently agreed fiscal stimulus of roughly half a trillion dollars via higher corporate and dividend taxes.

While capital income taxes can proxy corporate taxes under some specific assumptions, to more closely capture the financing proposals of the current

[1] Influential recent studies include Leeper *et al.* (2010), Sims and Wolff (2018) and Ramey (2020)).

U.S. administration, we also allow for corporate and dividend taxes adopting the approach of McGrattan and Prescott (2005) and Miao (2014, ch. 14.1). In this setup, households pay taxes on dividend income, and firms pay corporate taxes.

Figure 1: U.S. Tax Rates (2000-2019)

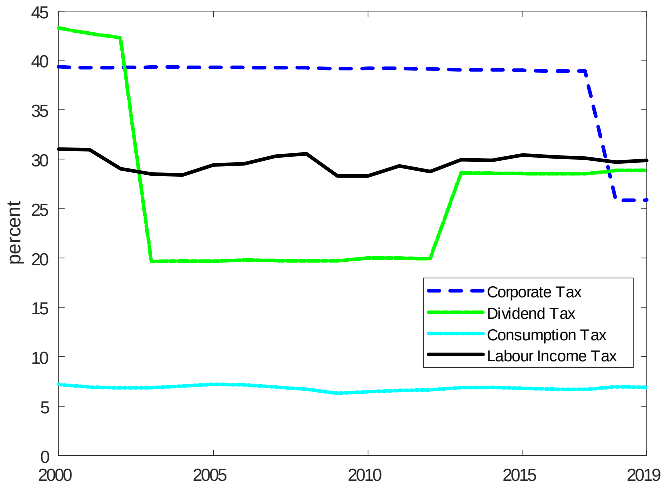


Figure 1 shows the current tax structure in the U.S.[2] As of 2019, corporate, dividend, consumption and labour income tax rates were roughly 26%, 29%, 30% and 7%, respectively.[3] Figure 1 further shows that the effective corporate tax rate remained roughly 39% from 2000 until 2018. After that, the previous U.S. administration cut this rate to approximately 25%. In contrast, the overall statutory dividend tax rate fell from its peak of roughly 43% in 2000 to about 20% in 2003. It remained at this rate until rising in 2013 to an average of approximately 28.5% for the remainder of the period. Finally, the effective labour income and consumption taxes have been relatively stable throughout this time. The labour income tax rate averaged about 30% from 2000-2019, with minimum and maximum values of roughly 28% and 31%, respectively. In contrast, the consumption tax rate mean was approximately 6.9%, with minimum and maximum values of roughly 6.3%

[2]Note that the effective corporate tax rate and the overall statutory dividend tax are from the Tax Foundation and the OECD, respectively. The effective consumption and labour income tax rates are our own calculations following Jones (2002). See Appendix A for further details.

[3]Note that the availability of the dividend tax data constrains the start date for this Figure, and the end date coincides with the year we will use for the calibration of the policy instruments (see Section 3 for further details).

and 7.2%, respectively.[4]

1.2 Infrastructure spending by type

It is well known in the infrastructure literature that the size of long-run multipliers critically depends on the elasticity of output to public capital. This literature generally employs an aggregate elasticity of between 0.05 and 0.1 (see, e.g. Baxter and King (1993), Leeper *et al.* 2010) and Sims and Wolff (2018)). More recently, Ramey (2020) has argued that "*the aggregate production function elasticity of output to public capital is probably between 0.065 and 0.12, similar to the range found by Bom and Ligthart's (2014) meta-analysis*". We calculate this elasticity for final goods and intermediate goods firms based on the approach in Cooley and Prescott (1995) and Lowe *et al.* (2019). We further allow for differences in the marginal product of different types of public capital. In particular, we break out infrastructure spending into the three broad categories reported in the Bureau of Economic Analysis (BEA) Fixed Asset Tables, i.e. equipment, structures and intellectual property products.[5] Using BEA data for the capital stock and depreciation and the model solution at the steady-state, we calculate the elasticity of public capital for each of these three categories of investment for both final and intermediate goods firms. The implied aggregate elasticities for these firms are 0.074 and 0.092, respectively, which coheres well with the literature mentioned above.

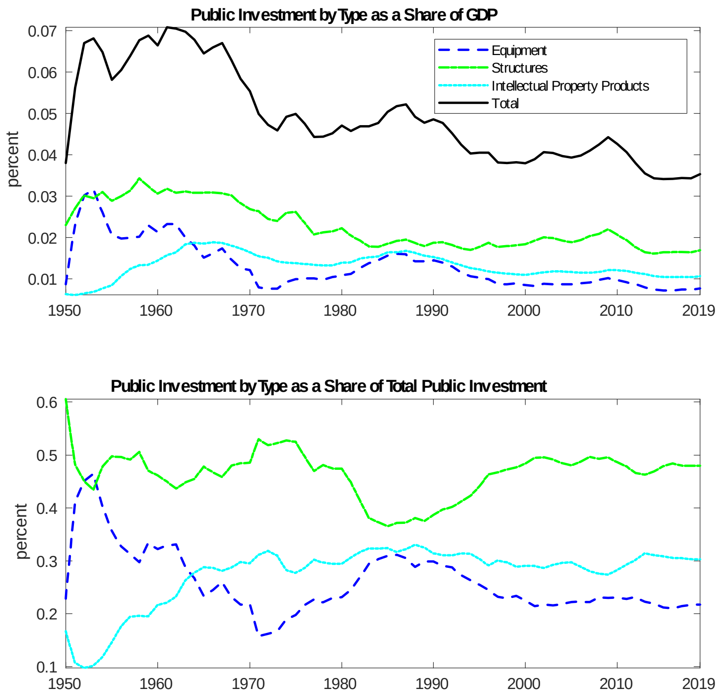
To understand how investment in government fixed assets has evolved since 1950, Figure 2 plots the share of each component of public investment to GDP and total public investment. We can see from the first subplot that, except for a few years in the mid-1950s, structures investment has the relatively largest share of GDP and the equipment share of GDP has been the smallest since the mid-1960s. Moreover, there has generally been a secular decline in the three shares of GDP since the mid-1960s. For example, relative to the past peak values of roughly 3% for equipment, 3.4% for structures and 1.9% for intellectual property products, in 2019, these shares were 0.77%,

[4] We include consumption taxes following the academic literature. However, there is no actual federal mechanism for enforcing a general consumption tax in the U.S. Thus, the consumption tax considered is an average of different sales taxes across states.

[5] Note that examples of equipment include power and distribution machinery, speciality transformers, electricity and signal testing instruments, electromedical machinery and medical instruments, internet switches, routers and hubs, cloud computing hardware and vehicles. Examples of structures by type include residential, industrial, office, commercial, health care, educational, public safety, amusement and recreation, transportation, power, highways and streets. Finally, intellectual property products include software and research and development.

1.69% and 1.07%, respectively. Further note, total public investment as a share of GDP fell from its peak of 7% in the mid-1960s to 3.53% in 2019. Regarding the percentages of total public investment, the second subplot in Figure 1 shows that structures absorb nearly half of public investment, followed by roughly 30% into intellectual property products, with the remaining 20% going to equipment.

Figure 2: Investment in Government Fixed Assets, 1950-2019



1.3 Linkages between final and intermediate goods

Jones (2011) shows that ignoring intermediate goods in growth models misses critical inter-sectoral linkages, leading to higher multipliers associated with exogenous changes due to technological change and economic policy. He argues that such connections through intermediate goods can deliver a multiplier effect similar to the standard capital multipliers in the neoclassical growth model. Jones (2011) further points out that intermediates goods are a significant share of gross output. Indeed, data from the BEA on gross output and intermediate inputs by industry tables suggest that between 1997 and 2019, the mean percentage was roughly 44%, with minimum and maximum over this period of 42% and 45%, respectively.

Taking into account the arguments of Jones (2011) and the evident quantitative importance of intermediates in the data, we allow for both final and intermediate goods-producing firms. As in the widely-used Dixit-Stiglitz production environment, we assume that final goods firms use intermediate goods as inputs and that intermediate goods firms act as monopolists in their own product market. In our model, final goods firms choose capital, labour and intermediate goods, while intermediate goods firms choose capital and labour as in Mendoza and Yue (2012). We further assume that public capital enters the production function of both final and intermediate goods firms to enhance the productivity of private inputs. Our setup differs from the related literature on public investment. This literature assumes that final goods firms use intermediate goods only (as in the baseline Dixit-Stiglitz model) and that public capital only enters the intermediate goods firms' production function (see, e.g. Sims and Wolff (2018) and Ramey (2020)).

We show that the presence of intermediate goods in this fashion amplifies changes in fiscal policy on final output or GDP.[6] Specifically, a rise in public investment spending exerts both direct and indirect positive effects on final output, other things equal. The direct effect happens because this investment enhances private capital and labour productivity, as in Barro's (1990) seminal paper on endogenous long-term growth. The indirect effect occurs since it also increases the productivity of the private factors used to produce the intermediate input, which the final goods firms, in turn, use to create more output.

1.4 Key findings

When we simulate the model with the currently agreed U.S. infrastructure spending stimulus, our results show that some policies need to adjust in the future to create enough fiscal surpluses to finance the increased debt obligations.[7] Feedback fiscal rules drive these adjustments whereby tax or spending instruments react to the rising public debt.[8] In other words, the required increase in fiscal surpluses will not be possible without higher tax

[6]See Appendix B for a simple model with an analytical solution that illustrates this point.

[7]See, e.g. Davig *et al.* (2010) for an early paper on unfunded public liabilities and debt sustainability in the U.S. This point is also related to the relationship between GDP growth and real interest rates on sovereign bonds addressed in Section 4.2 below.

[8]Our approach follows most of the related literature on public investment (see, e.g. Leeper et al. (2009, 2010), Coenen *et al.* (2012) and Sims and Wolff (2018)). In contrast, Davig *et al.* (2010) and Bi *et al.* (2013) study additional policy adjustments over time, including spending cuts, tax rises and inflation creation, as in the literature on public debt consolidation.

rates and (or) cuts in non-productive transfer spending in the future. This also means that the rise in public debt will imply a fiscal cost in Blanchard's (2019) sense.

We generally find long-run output multipliers above unity if consumption, dividend, and labour income taxes adjust to the rise in public debt. However, when corporate taxes react to stabilise the debt, these multipliers are positive but below one. This is because corporate taxes directly hurt firms' investment decisions reducing the beneficial effects of infrastructure spending. Moreover, we find that the results, except for the consumption tax, critically depend on how changes in different tax instruments affect work incentives and thereby on the Frisch elasticity of labour supply. In particular, as this elasticity falls, the multipliers for dividend and corporate tax-financed infrastructure spending fall, whereas the multiplier for spending funded via labour income taxes rises.

We further find that differences in welfare across different public financing regimes in terms of consumption equivalents are relatively negligible. This is not surprising since the infrastructure spending shock is temporary, and any losses (resp. gains) in leisure mitigate consumption gains (resp. losses).

Following the approach of Lowe *et al.* (2009) and Cooley and Prescott (1995), our estimates of the net marginal products for private and public capital for both final and intermediate goods firms suggest that public capital is underprovided. We complement this exercise by solving the associated social planner's problem as in Ramey (2020) and comparing the socially optimal private and public capital allocations with the BEA data. This analysis suggests that both public and private capital are underprovided, although the former is relatively more lacking. This general underprovision of capital can rationalise the current proposed increase in U.S. infrastructure spending and is consistent with our finding of substantial positive output multipliers.

Despite the arguments for higher infrastructure spending, in all cases, as said above, we need discretionary increases in tax rates to avoid an explosive path of public debt over time. In other words, a fully pay-for-itself scenario is not feasible. The discretionary rise in tax revenues, relative to the self-generated one, depends again on the instrument used for debt stabilisation and the time frame we assess it. For example, the self-financing rates at the steady-state vary between roughly 63%-76% when we assume a permanent shock to infrastructure spending. Moreover, these rates range between 54%-88% along the transition path when implementing the agreed temporary increase in U.S. infrastructure investment.

To provide a broader context for understanding the effects of infrastructure spending, we also simulate the model to capture the three rounds of stimulus payments between March 2020 and March 2021 to provide relief for economic hardships caused by COVID-19. In this case, the long-run output multipliers are negative or positive and less than unity, despite the short-term positive effect on aggregate consumption in most cases.[9]

We organise the rest of the paper as follows. First, we present the model in Section 2 and the calibration in Section 3. Next, Section 4 assesses whether private and public capital is underprovided. Finally, sections 5 and 6 undertake steady-state, and transition analysis, respectively and Section 7 concludes. We also include several Appendices relating to the data and simple analytical models to illustrate further the intuition underlying our key findings.

2 Model

We develop a simple neoclassical growth model with households, firms and a government. Households maximise lifetime utility by choosing consumption, labour supply and savings. Firms own the capital stock and maximise the present value of net-of-tax dividends distributed to households by choosing inputs. In turn, the government provides various public infrastructure goods/services (e.g. structures, equipment and intellectual property products), enhancing the firms' productivity. It also supplies transfer payments that augment households' income. The government finances this spending through bonds and taxes.

We consider a relatively detailed tax system in which households pay taxes on labour income, dividend income and consumption, while firms pay taxes on gross profits.[10] Firms separate into final goods firms, which are identical and produce a single final good and intermediate goods firms competitively. The latter are monopolists in their own goods market as in the standard Dixit-Stiglitz model.

2.1 Households

There are $h = 1, 2, ..., N$ identical households. Each h maximises:

$$\sum_{t=0}^{\infty} \beta^t u\left(c_{h,t}, l\right), \tag{1}$$

[9] Not surprisingly, the short-term consumption gains are not present when labour income taxes are the adjusting instrument.

[10] In Appendix C, we show the conditions under which the capital income tax and the corporate income tax can deliver identical equilibrium allocations.

where $c_{h,t}$ and $l_{h,t}$ are respectively h's consumption and work hours; and $0 < \beta < 1$ is the time discount factor.

The period utility function (see also e.g. Leeper *et al.* (2010), Ríos-Rull *et al.* (2012) and Ramey (2020)) is given by:

$$u\left(c_{h,t}, u_{h,t}\right) = \log(c_{h,t} - \xi c_{t-1}) - \mu \frac{(l_{h,t})^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}}, \tag{2}$$

where $\mu \geq 0$ is a preference parameter; $\xi \geq 0$ is an external habit persistence parameter; and $\nu > 0$ is the Frisch elasticity of labour supply.

The within-period budget constraint of each h is:

$$(1+\tau_t^c)c_{h,t} + b_{h,t+1} \equiv (1-\tau_t^y)w_t l_{h,t} + (1+r_t^b)b_{h,t} + (1-\tau_t^d)(\pi_{f,t} + \pi_{i,t}) + g_t^t, \tag{3}$$

where $b_{h,t+1}$ is one-period government bonds purchased at t; w_t is the wage rate; r_t^b is the return to bonds purchased at $t-1$; $\pi_{f,t}$ is the dividend paid by final good firms; $\pi_{i,t}$ is the dividend paid by intermediate goods firms; g_t^t is a lump-sum transfer from the government, and $0 \leq \tau_t^c$, τ_t^y, $\tau_t^d < 1$ are tax rates on consumption, labour income and dividend income. We assume that interest income from bonds is untaxed.

Thus, the first-order conditions for labour and bonds are:

$$l_{h,t}^{\frac{1}{\nu}} = \frac{(1-\tau_t^y)w_t}{(1+\tau_t^c)(c_{h,t} - \xi c_{h,t-1})}, \tag{4}$$

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1} - \xi c_{h,t})}{(1+\tau_t^c)(c_{h,t} - \xi c_{h,t-1})} = \beta(1 + r_{t+1}^b), \tag{5}$$

where equation (4) gives the labour supply function and (5) is a standard Euler condition for the demand for bonds.

2.2 Firms

Firms own capital and choose productive inputs. They also make use of public infrastructure that works like an externality. Firms pay corporate taxes on their gross profits. We will follow the modelling of McGrattan and Prescott (2005) and Miao (2014, ch. 14.1). In particular, we assume that firms maximise the present discounted value of dividends net of any extra taxes paid by households/owners on these dividends. We do not explicitly include shares in the model.[11]

[11] We could assume that firms issue shares to finance their investment where households purchase these shares. This assumption would add two different Euler equations for the

2.2.1 Final good producers

There are $f = 1, 2, ...N$ identical final good producers. We start with firms' production structure. Each f produces $y_{f,t}$ given by:

$$y_{f,t} = A\left[(u_{f,t}k_{f,t})^{\alpha}l_{f,t}^{1-a}\right]^{1-\sigma}[X_{f,t}]^{\sigma}[K_t^g]^{\gamma_f}, \tag{6}$$

where $k_{f,t}$ and $l_{f,t}$ are respectively capital and labour inputs used by firm f; $u_{f,t}$ is f's capital utilization rate; $X_{f,t}$ is a composite intermediate private good used by f; K_t^g is a composite public capital externality; the power coefficients $0 < \alpha, \sigma, \gamma_f < 1$ are efficiency parameters; and A denotes total factor productivity (TFP).

In our quantitative analysis, following the breakdown in the BEA data, we will decompose total public capital into $j = 1, 2, 3$ types: (1) equipment (2) structures and (3) intellectual property products. Thus, instead of $[K_t^g]^{\gamma_f}$, we will use:

$$[K_t^g]^{\gamma_f} \equiv \left[k_{1,t}^g\right]^{\gamma_{f,1}}\left[k_{2,t}^g\right]^{\gamma_{f,2}}\left[k_{3,t}^g\right]^{\gamma_{f,3}}, \tag{7}$$

where $0 < \gamma_{f,1}, \gamma_{f,2}, \gamma_{f,3} < 1$ are efficiency parameters associated with the three separate categories of public capital.

Final good firms' capital evolves as (see also Leeper *et al.* (2010), Schmitt-Grohé and Uribe (2012) and Sims and Wolff (2018)):

$$k_{f,t+1} = (1-\delta_{f,t})k_{f,t} + \left[1 - \frac{\psi}{2}\left(\frac{i_{f,t}}{i_{f,t-1}} - 1\right)^2\right]i_{f,t}, \tag{8}$$

where $i_{f,t}$ is f's net investment; $\psi \geqq 0$ is an adjustment cost parameter; and where the depreciation rate, $\delta_{f,t}$, follows:

$$\delta_{f,t} = \delta_0 + \delta_1(u_{f,t} - 1) + \frac{\delta_2}{2}(u_{f,t} - 1)^2, \tag{9}$$

firms' shares in the household's problem. Moreover, financing new investment would be by retained earnings and the issuance of new shares in the firm's problem. However, if we assume that the number of shares is set exogenously (usually set to 1 in the literature) before solving the firms' optimisation problem, the model solution would effectively be the same with, or without, shares. Thus, the Euler equations for shares in the households' problem would residually determine the associated share price. This is as in, e.g. McGrattan and Prescott (2005), Miao (2014, ch. 14.1) and Schmitt-Grohé and Uribe (2017, ch. 4.2) and is shown formally in our Appendix D. Considering this, for notational simplicity, we assume away shares from the very beginning. See, e.g. Brock and Turnovsky (1981), Turnovsky (1995, chps. 10 and 11), Altug and Labadie (1994, ch. 4), Auerbach (2002) and Gourio and Miao (2010, 2011) for models where the firms choose their optimal financial structure including share issuance; this leads to corner solutions, so extra assumptions need to be made.

where δ_0, δ_1 , $\delta_2 \geqq 0$ are parameters.

We define the composite intermediate private good/service as a Dixit-Stiglitz aggregator:

$$X_{f,t} \equiv \left[\sum_{i=1}^{N} \lambda_i x_{f,i,t}^{\eta}\right]^{\frac{1}{\eta}}, \tag{10}$$

where $0 < \lambda_i < 1$ is the weight given to each variety $i = 1, 2, ...N$ (where $\sum_{i=1}^{N} \lambda_i \equiv 1$ to avoid scale effects in equilibrium); $x_{f,i,t}$ is the amount of each intermediate good i used by each final good firm f; and η is a technology parameter with the elasticity of substitution between these intermediate goods being $1/(1-\eta)$ and $0 < \eta \leq 1$.

We continue with firms' objective function. Working as in e.g. McGrattan and Prescott (2005) and Miao (2014, ch. 14.1), the net cash flow of firm f at t is:

$$\pi_{f,t} \equiv (1-\tau_t^f)(y_{f,t} - w_t l_{f,t} - \sum_{i=1}^{N} p_{i,t}\lambda_i x_{f,i,t}) - i_{f,t}, \tag{11}$$

where $p_{i,t}$ is the price of each intermediate variety i relative to the price of the final good used as a *numeraire;* and $0 \leq \tau_t^f < 1$ is the corporate tax rate on the firm's gross profits (see Appendix D for details).

As in the above mentioned papers, each f maximises the discounted sum of its net cash flows net of taxes paid by its owners:

$$\sum_{t=0}^{\infty} \beta_{f,t}(1-\tau_t^d)\pi_{f,t}, \tag{12}$$

where $\beta_{f,0} \equiv 1$, $\beta_{f,1} \equiv \frac{\beta(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}$, etc., since firms are owned by households.

Final good firms act competitively taking public infrastructure capital as given. The first-order conditions for $l_{f,t}$, $x_{f,i,t}$, $k_{f,t+1}$, $i_{f,t}$ $u_{f,t}$ are respectively:

$$w_t = \frac{(1-\sigma)(1-\alpha)y_{f,t}}{l_{f,t}}, \tag{13}$$

$$p_{i.t} = \frac{\sigma y_{f,t} x_{f,i,t}^{\eta-1}}{\left[\sum_{i=1}^{N} \lambda_i x_{f,i,t}^{\eta}\right]}, \tag{14}$$

$$\begin{aligned} &\mu_{f,t}\left[\tfrac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}\right] = \\ &= \beta\left[\mu_{f,t+1}(1-\delta_{f,t+1}) + \tfrac{(1-\tau_{t+1}^d)(1-\tau_{t+1}^f)(1-\sigma)\alpha y_{f,t+1}}{k_{f,t+1}}\right], \end{aligned} \tag{15}$$

$$
\begin{aligned}
(1-\tau_t^d) = \mu_{f,t}\left[1-\tfrac{\psi}{2}\left(\tfrac{i_{f,t}}{i_{f,t-1}}-1\right)^2\right] - \mu_{f,t}\psi\left(\tfrac{i_{f,t}}{i_{f,t-1}}-1\right)\tfrac{i_{f,t}}{i_{f,t-1}}+ \\
+\beta\left[\tfrac{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}\right]\mu_{f,t+1}\psi\left(\tfrac{i_{f,t+1}}{i_{f,t}}-1\right)\left(\tfrac{i_{f,t+1}}{i_{f,t}}\right)^2,
\end{aligned}
\tag{16}
$$

$$
\mu_{f,t}k_{f,t}\frac{d\delta_{f,t}}{du_{f,t}} = \frac{(1-\tau_t^d)(1-\tau_t^f)(1-\sigma)\alpha y_{f,t}}{u_{f,t}}, \tag{17}
$$

where $\frac{d\delta_{f,t}}{du_{f,t}} = \delta_1 + \delta_2(u_{f,t}-1)$ and $\mu_{f,t}$ is the Lagrange multiplier associated with the motion of the capital stock in equation (8). Equation (13) gives f's demand for labour services, (14) is an inverse demand function for each intermediate variety i, (15) is an Euler-type equation for capital, (16) is the optimality condition for investment and (17) gives the optimal choice of the capital utilisation rate, all from the point of view of firm f.

2.2.2 Intermediate goods producers

There are $i = 1, 2, ...N$ intermediate goods producers one for each good variety i. Their problem is similar to that of final good firms above except that, to the extent that they consider the demand for their product coming from the final good firms' optimality condition above, they can enjoy market power in their own product market.

Each i produces $x_{i,t}$ where the production function is:

$$
x_{i,t} = A\left[k_{i,t}^a l_{i,t}^{1-a}\right]\left[K_t^g\right]^{\gamma_i}, \tag{18}
$$

where $k_{i,t}$ and $l_{i,t}$ are respectively capital and labour inputs used by firm i and γ_i is a new efficiency parameter that may differ from γ_f.

The equations for the capital stock, $k_{i,t+1}$, and its depreciation rate, $\delta_{i,t}$, as well as the decomposition of public capital, $[K_t^g]^{\gamma_i}$, are as above, namely:

$$
k_{i,t+1} = (1-\delta_{i,t})k_{i,t} + \left[1-\frac{\psi}{2}\left(\frac{i_{i,t}}{i_{i,t-1}}-1\right)^2\right]i_{i,t}, \tag{19}
$$

$$
\delta_{i,t} = \delta_0 + \delta_1(u_{i,t}-1) + \frac{\delta_2}{2}(u_{i,t}-1)^2, \tag{20}
$$

$$
[K_t^g]^{\gamma^i} \equiv \left[k_{1,t}^g\right]^{\gamma_{i,1}}\left[k_{2,t}^g\right]^{\gamma_{i,2}}\left[k_{3,t}^g\right]^{\gamma_{i,3}}. \tag{21}
$$

The net cash flow of firm i at t is again defined as:

$$
\pi_{i,t} \equiv (1-\tau_t^f)(p_{i.t}x_{i,t} - w_t l_{i,t}) - i_{i,t}. \tag{22}
$$

As discussed above, each i maximises the discounted sum of its net cash flows net of taxes paid to its owners:

$$\sum_{t=0}^{\infty}\beta_{i,t}(1-\tau_t^d)\pi_{i,t}, \tag{23}$$

where $\beta_{i,t}=\beta_{f,t}$ as defined above (since all firms are owned by households).

Each i acts noncompetitively, that is, it also takes into account the inverse demand function for its product (14).[12] Taking final output, $y_{f,t}$, and aggregate variables, $\sum_{i=1}^{N}\lambda_i x_{i,t}^{\eta}$, as given, the first-order conditions for $l_{i,t}$, $k_{i,t+1}$, $i_{i,t}$ and $u_{i,t}$ are respectively:

$$w_t=\frac{\eta\sigma y_{f,t}x_{i,t}^{\eta-1}}{\sum_{i=1}^{N}\lambda_i x_{i,t}^{\eta}}\frac{\partial x_{i,t}}{\partial l_{i,t}}, \tag{24}$$

$$\begin{aligned}&\mu_{i,t}\left[\tfrac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}\right]=\\&=\beta\left[\mu_{i,t+1}(1-\delta_{i,t+1})+\tfrac{(1-\tau_{t+1}^d)(1-\tau_{t+1}^f)\eta p_{i.t+1}\alpha x_{i,t+1}}{k_{i,t+1}}\right],\end{aligned} \tag{25}$$

$$\begin{aligned}&(1-\tau_t^d)=\mu_{i,t}\left[1-\tfrac{\psi}{2}\left(\tfrac{i_{i,t}}{i_{i,t-1}}-1\right)^2\right]-\mu_{i,t}\psi\left(\tfrac{i_{i,t}}{i_{i,t-1}}-1\right)\tfrac{i_{i,t}}{i_{i,t-1}}+\\&+\beta\left[\tfrac{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}\right]\mu_{i,t+1}\psi\left(\tfrac{i_{i,t+1}}{i_{i,t}}-1\right)\left(\tfrac{i_{i,t+1}}{i_{i,t}}\right)^2,\end{aligned} \tag{26}$$

$$\mu_{i,t}k_{i,t}\frac{d\delta_{i,t}}{du_{i,t}}=\frac{(1-\tau_t^d)(1-\tau_t^f)\eta p_{i.t}\alpha x_{i,t}}{u_{i,t}}. \tag{27}$$

That is, (24) gives i's demand for labour services, (25) is an Euler-type equation for capital, (26) is the optimality condition for investment and (27) gives the optimal choice of the capital utilisation rate, all from the point of view of firm i.

2.3 Government budget constraint

The within-period budget identity of the government is (written in aggregate terms):

$$G_t^c+G_t^t+G_t^g+(1+r_t^b)B_t\equiv T_t+B_{t+1}, \tag{28}$$

where G_t^c is total public consumption; G_t^t is total transfer payments; G_t^g is total public investment spending so that $G_t^g=\sum_{j=1}^{3}G_{j,t}^g$; B_{t+1} is the end-of–period total public debt issued by the government; and T_t is total tax

[12] Since $x_{i,t}=\sum_{f=1}^{N}\lambda_i x_{f,i,t}$, where $\sum_{f=1}^{N}\lambda_f\equiv 1$ and final good firms are identical to each other, we have $x_{i,t}=x_{f,i,t}$. Thus, we rewrite (14) as $p_{i.t}=\frac{\sigma y_{f,t}x_{i,t}^{\eta-1}}{\sum_{i=1}^{N}\lambda_i x_{i,t}^{\eta}}$.

revenues specified below. Note that $G_t^c = Ng_t^c$, $G_t^t = Ng_t^t$ and $G_{j,t}^g = Ng_{j,t}^g$ where lower case letters denote per capita quantities.

The stock of each type of public capital ($j = 1, 2, 3$), evolves as:

$$k_{j,t+1}^g = (1 - \delta_j^g)k_{j,t}^g + g_{j,t-k}^g. \tag{29}$$

Note that to capture the time-to-build associated with infrastructure spending, we allow for k lags (see Leeper *et al.* (2010) and Ramey (2020)) in the time between when the expenditure takes place and when the new capital becomes available to final and intermediate goods producers. Given our three types of public expenditure, we will let structures take the longest time-to-build, followed by equipment and intellectual property, respectively.

Total tax revenues are (written in aggregate terms):

$$\begin{aligned} T_t \equiv\, & N(\tau_t^c c_{h,t} + \tau_t^y w_t l_{h,t}) + \tau_t^f \textstyle\sum_{i=1}^N (p_{i.t} x_{i,t} - w_t l_{i,t}) + \\ & + \tau_t^f N(y_{f,t} - w_t l_{f,t} - \textstyle\sum_{i=1}^N p_{i,t}\lambda_i x_{f,i,t}) + N\tau_t^d(\pi_{f,t} + \pi_{i,t}). \end{aligned} \tag{30}$$

2.4 Macroeconomic system

Collecting equations, the macroeconomic system, for $j = 1, 2, 3$, consists of 22 equations in $\{c_{h,t},\ l_{f,t},\ l_{i,t},\ k_{f,t+1},\ i_{f,t},\ \delta_{f,t},\ u_{f,t},\ \mu_{f,t},\ k_{i,t+1},\ i_{i,t},\ \delta_{i,t},\ u_{i,t},\ \mu_{i,t},\ k_{j,t+1}^g,\ y_{f,t},\ x_{i,t},\ w_t,\ r_t^b,\ p_{i,t},\ b_{h,t+1}\}_{t=0}^{\infty}$. This is given initial conditions and the paths of the exogenously set policy instruments, $\{g_t^c,\ g_t^t,\ g_{j,t}^g,\ \tau_t^y,\ \tau_t^c,\ \tau_t^f,\ \tau_t^d\}_{t=0}^{\infty}$. This system is presented in detail in Appendix E. In what follows, to bring the model closer to the fiscal data, we re-express public spending items as shares of GDP. In particular, we define the per capita public spending items as $g_t^c = s_t^c y_{f,t}$, $g_t^t = s_t^t y_{f,t}$ and $g_{j,t}^g = s_{j,t}^g y_{f,t} + \iota_{j,t}$, so that we replace g_t^c, g_t^t, $g_{j,t}^g$ with s_t^c, s_t^t, $s_{j,t}^g$. Note that $\iota_{j,t}$ denote the shocks to the each type of public investment per capita so that $\iota_t = \sum_{j=1}^3 \iota_{j,t}$ is the shock to the per capita level of public investment. In our simulations, we will set the paths for $\iota_{j,t}$ exogenously to simulate the agreed U.S. infrastructure spending stimulus.

Following the literature (see e.g. Sims and Wolff (2018), we assume that the exogenous policy instruments follow $AR(1)$ processes and in addition can react to the gap between the public debt to GDP ratio and its steady-state value. Namely, for $\boldsymbol{\kappa}_t \equiv [s_t^t,\ \tau_t^y,\ \tau_t^c,\ \tau_t^f,\ \tau_t^d]$, we have:

$$\boldsymbol{\kappa}_t = \boldsymbol{\kappa}_{t-1}^{\boldsymbol{\rho}^\kappa} \boldsymbol{\kappa}^{1-\boldsymbol{\rho}^\kappa} \left(\frac{b_t / y_{f,t}}{b / y_f} \right)^{\boldsymbol{\zeta}^\kappa} \tag{31}$$

where the elements of the constant term $\boldsymbol{\kappa}$ are from the data and the elements of the autoregressive parameter, $0 \leq \boldsymbol{\rho}^\kappa \leq 1$, as well as the elements of the policy reaction coefficient, $\boldsymbol{\zeta}^\kappa$, will be borrowed from the literature (see, e.g.

Sims and Wolff (2018)). The sign of the elements in $\boldsymbol{\zeta}^{\kappa}$ relating to tax rates and public spending is positive and negative, respectively.

It is worth pointing out that to the extent the real interest rate on sovereign bonds exceeds the economy's growth rate, such a feedback reaction to public debt imbalances is necessary for the dynamic stability of the public debt-to-GDP ratio. Without it, there will no be convergence to a steady-state equilibrium. We return to this point in subsection 4.2 below.

3 Calibration

To conduct our policy analysis, we calibrate the model to match key data targets and the values of policy instruments based on the 2019 pre-COVID economy (see also Ramey (2020) for a similar calibration strategy). Then, using the resulting parameterisation, we will solve for the steady-state of the model, and this solution will serve as a natural starting point for our policy experiments. In particular, departing from this initial steady-state at time 0, we will simulate the model with the proposed fiscal stimulus and provide a quantitative assessment of its intertemporal implications and how these depend on public financing and other model features.[13] The quarterly calibration draws on influential papers in the fiscal policy and business cycle literature, e.g. Leeper *et al.* (2010), Schmitt-Grohé and Uribe (2012), Sims and Wolff (2018) and Ramey (2020) and data from the BEA, the Tax Foundation and the OECD. Further details on the sources for the data, referred to below, are reported in Appendix A.

3.1 Values from the literature

The values used for capital's share, α, and the time discount rate, β, are taken from Leeper *et al.* (2010) and Ramey (2020). The discount rate implies a risk-free quarterly rate of return of 1.01%. The mean values of the external habit persistence parameter, ξ, in Leeper *et al.* (2010), Schmitt-Grohé and Uribe (2012), Sims and Wolff (2018) are 0.31, 0.85 and 0.76, respectively. We adopt the value reported by Schmitt-Grohé and Uribe (2012) and show in Appendix F that our key findings do not depend on whether we use the

[13] We could also add some adverse shocks to capture the economic downturn caused by the covid-19 pandemic and the lockdown measures taken to restrain its health implications. That is, we could have these temporary adverse shocks during, say, 2020-22 and start the fiscal stimulus during or after these shocks. However, since we are interested in long-run multipliers and lifetime welfare effects, rather than what happens on impact, we prefer to work as in Ramey (2020).

Table 1: Base Calibration

	Value	Definition	Source/Target
		Structural Parameters	
A	1.0000	TFP	normalisation
α	0.3600	capital's share of output	literature
β	0.9900	time discount factor	literature
$\gamma_{f,1}$	0.0097	y_f elasticity to equipment capital (final goods)	data/model
$\gamma_{f,2}$	0.0513	y_f elasticity to structures capital (final goods)	data/model
$\gamma_{f,3}$	0.0127	y_f elasticity to intellectual property capital (final goods)	data/model
$\gamma_{i,1}$	0.0121	y_i elasticity to equipment capital (int. goods)	data/model
$\gamma_{i,2}$	0.0643	y_i elasticity to structures capital (int. goods)	data/model
$\gamma_{i,3}$	0.0160	y_i elasticity to intellectual property capital (int. goods)	data/model
δ_0	0.0149	full-capacity depreciation rate on private capital	data
δ_1	0.0250	slope on linear term in $\delta_{f,t}$ and $\delta_{i,t}$	$u_i = u_f$ =1
δ_2	0.0670	slope on quadratic term in $\delta_{f,t}$ and $\delta_{i,t}$	literature
$\delta_{g,1}$	0.0331	depreciation rate on public equipment capital	data
$\delta_{g,2}$	0.0047	depreciation rate on public structures capital	data
$\delta_{g,3}$	0.0422	depreciation rate on public intellectual property capital	data
η	0.8751	$\frac{1}{1-\eta}$, elasticity of substitution between intermediates	$\frac{\pi_f+\pi_i}{y_f+p_i x_i}$=0.10
μ	16.246	labour effort weight in utility	$l_f + l_i$=0.31
ν	0.7200	Frisch elasticity of labour supply	literature
ξ	0.8500	external habit persistence	literature
σ	0.7544	y_f elasticity w.r.t. intermediate goods	$\frac{p_i x_i}{y_f+p_i x_i}$=0.43
ψ	5.0000	investment adjustment costs parameter	literature
		Policy Variables and Parameters	
$\frac{b}{y_f}$	1.0577	debt to output ratio	data
ρ^{κ}	0.9000	AR1 parameter for policy rules	literature
s^c	0.1397	public consumption to output ratio	data
s_1^g	0.0077	public equipment investment to output ratio	data
s_2^g	0.0169	public structures investment to output ratio	data
s_3^g	0.0107	public intellectual property investment to output ratio	data
ς^{κ}	0.1000	policy reaction coefficient	literature
τ^f	0.2240	corporate tax rate	data
τ^c	0.0691	consumption tax rate	data
τ^d	0.2891	dividend tax rate	data
τ^y	0.2990	labour income tax rate	data

alternative lower values. For the investment adjustment costs parameter, ψ, the mean values reported in Leeper *et al.* (2010), Schmitt-Grohé and Uribe

(2012), Sims and Wolff (2018) are 5.21, 5 and 5.89. We again adopt the value reported by Schmitt-Grohé and Uribe (2012) and show in Appendix F that our key findings do not depend on whether we use the alternative higher values.

3.2 Values based on quantitative targets

The elasticity of substitution between intermediate goods, $\frac{1}{1-\eta}$, the consumption weight in utility, μ, and final output elasticity for intermediate goods, σ, are pinned down through explicit numeric targets. For example: (i) we compute η, following most of the Dixit-Stiglitz literature, by imposing a profits share of 10% (see, e.g. Kaplan and Zoch (2020); (ii) we pin down μ by imposing that work-time is equal to 31% (see, e.g. Cooley and Prescott (1995)); and (iii) we find σ by imposing that the intermediate to gross output share is 43%, which is the value in 2019 from the Bureau of Economic Analysis (BEA) gross output and intermediate inputs by industry tables. The base value of the Frisch elasticity, $\nu = 0.72$, is the one used in Ríos-Rull *et al.* (2012) and is from the estimates provided by Heathcote *et al.* (2007). Based on other estimates in the literature, Ríos-Rull *et al.* (2012) also consider alternative calibrations for this elasticity, including 0.2, 1 and 2. Further note that Ramey (2020) employs a value for this elasticity of 4. Considering the lack of a consensus over the size of this elasticity, we will present our main results for each of the values reported in these two studies.

3.3 Depreciation

The annual full-capacity depreciation rate on private capital, δ_0, and the yearly depreciation rates on public structures, equipment and intellectual property capital, $\delta_{g,1}$, $\delta_{g,2}$ and $\delta_{g,3}$ respectively are calculated for 2019 using the BEA fixed asset tables. Thus, we divide the relevant value of depreciation in 2019 by the appropriate stock of capital in 2018 and then convert them to quarterly rates by dividing by 4.[14]

The mean values for the slope, δ_2, on the quadratic term in $\delta_{f,t}$ and $\delta_{i,t}$ are 0.067 and 0.056 respectively in Leeper *et al.* (2010) and Sims and Wolff (2018). We adopt the value reported in the former study and then solve for the value of δ_1, consistent with full capacity utilisation at the steady-state in the final and intermediate goods sectors. Note that the choice of δ_2 does not affect our main results.

[14] Note that Ramey (2020) follows the same approach for calculating depreciation rates.

3.4 Policy variables and parameters

The debt to GDP ratio, $\frac{b}{y_f}$, the public consumption to GDP ratio, s^c, and the public investment to GDP ratios for $j = 1, 2, 3$, i.e. s_1^g, s_2^g, and s_3^g, are based on data from the BEA National Income and Product Accounts (NIPA) and fixed assets accounts. We solve for the public transfer to GDP ratio, s^t, of roughly 18% residually; this is very close to its 2019 value in the data (i.e. 19%, which includes transfer payments, interest payments, and subsidies).

The consumption tax rate, τ^c, and the labour income tax rate, τ^y, are constructed following the method set out in Jones (2002) using data from the BEA. The effective average corporate and dividend tax rates, τ^f and τ^d are from the Tax Foundation and OECD, respectively. Note that in the steady-state, consumption, labour income, corporate and dividend income taxes, as shares of total tax revenues, are respectively 0.124, 0.450, 0.292 and 0.134. Finally, the AR1 parameter for the policy rules, ρ^κ, and the policy reaction coefficient, ς^κ, follow Sims and Wolff (2018).

3.5 Public capital elasticities: final good

The elasticity of output for public capital or public capital's share of final output, γ_f, can be calculated by following Lowe *et al.* (2009) and Cooley and Prescott (1995). This approach makes two assumptions. First, the net return to capital, r, is the same for the private and public sectors. As Lowe *et al.* (2009, p. 350) point out, "*This can be justified when governments compete with private enterprises in the loanable-funds market to borrow from private agents and finance budget deficits.*" Second, since the GDP in the NIPA accounts includes only goods and services transacted in markets, it does not include the flow of services from infrastructure capital. Hence, following Cooley and Prescott (1995, pp. 18-20), we proxy the latter by the income on the stock of government capital, which using our model's notation is $y_g \equiv (r + \delta_g)K^g$. Since the NIPA measure of final output already includes $\delta_g K^g$, adjusted income, $\widetilde{y}_f$, is written as:

$$\widetilde{y}_f = y_f + y_g = y_f + rK^g, \tag{32}$$

where $r \equiv (1 - \tau_t^f)\frac{\alpha(1-\sigma)y_f}{k_f} - \delta_f$ is the return to capital net of corporate taxes and depreciation in our model.

Given the above definitions, following Lowe *et al.* (2009, pp. 349-350), the share of public capital in adjusted final output/income, γ, can be defined as:

$$\gamma_f = \frac{(r + \delta_g)\, K^g}{y_f + rK^g}. \tag{33}$$

Since we decompose total public capital structures into $j = 1, 2, 3$ types, we can also write for each type:

$$\gamma_{f,j} = \frac{(r + \delta_{g,j})\, K_j^g}{y_f + rK^g}, \tag{34}$$

where the $j = 1, 2, 3$ refer respectively to structures, equipment and intellectual property products implying that we can obtain the aggregate elasticity as follows:

$$\gamma_f = \sum_{j=1}^{3} \gamma_{f,j} = \frac{(r+\delta_{g,1})K_1^g + (r+\delta_{g,2})K_2^g + (r+\delta_{g,3})K_3^g}{y_f + rK^g} = \frac{(r+\delta_g)K^g}{y_f + rK^g}, \tag{35}$$

since $\delta_g K^g = \sum_{j=1}^{3} \delta_{g,j} K_j^g$.

Our steady-state calculations suggest that structures have the largest elasticity of 0.0513, followed by intellectual property products and equipment whose elasticities are 0.0127 and 0.0097, respectively. The aggregate elasticity, implied by these estimates, is 0.0737, which, as pointed out in the introduction, is within the range used in the literature.[15]

3.6 Public capital elasticities: intermediate goods

Following the above approach, these elasticities are calculated as follows for $j = 1, 2, 3$:

$$\gamma_j^i = \frac{(r + \delta_{g,j})\, K_j^g}{p_i x_i + (r + \delta^g)\, K^g}, \tag{36}$$

where $r \equiv (1 - \tau_t^f)\eta p_i \alpha \frac{x_i}{k_i} - \delta_i$ is again the return to capital net of corporate taxes and depreciation. Note that now $(r + \delta^g)$ appears in the denominator of the above expression since, unlike final goods, intermediate output does not include depreciation. In this case, our steady-state results imply that structures have the largest elasticity of 0.0643, followed by intellectual property products and equipment whose elasticities are 0.016 and 0.0121, respectively. The aggregate elasticity implied by these estimates is 0.0924, which again coheres well with the literature.

[15] We use the depreciation rates from the BEA fixed asset tables and the model's steady-state values for the remaining variables to obtain these estimates. The model, in this case, excludes public capital in the final and intermediate goods production functions.

3.7 Marginal Products of Public and Private Capital

To understand the implications of the above elasticity estimates for the productivity of public capital, Table 2 presents the gross marginal products of public capital (MPPKs) for final and intermediate goods firms and each of the three types of public capital. These MPPKs are simply the products of the elasticities of final and intermediate output to public capital in columns 2 and 5 and the final and intermediate output to public capital ratios in columns 3 and 6.[16] Note that these are quarterly MPPKs that must be multiplied by 4 to convert to annual units.

Table 2: Gross Marginal Products of Public Capital (MPPK)

	Final Goods			Intermediate Goods		
	$MPPK_{f,j}$	$\gamma_{f,j}$	$\frac{y_{f,j}}{k_j^g}$	$MPPK_{i,j}$	$\gamma_{i,j}$	$\frac{x_{i,j}}{k_j^g}$
	[1]	[2]	[3]	[4]	[5]	[6]
Equipment	0.0415	0.0097	4.2955	0.0673	0.0121	5.5630
Structures	0.0142	0.0513	0.2766	0.0230	0.0643	0.3583
Intellectual Property	0.0502	0.0127	3.9416	0.0815	0.0160	5.1047

The first column of Table 2 shows that the MPPK for final private goods is the highest for intellectual property, followed by equipment and then structures. Notice that despite structures having the highest output elasticity, γ_f, they also have the lowest MPPK. This result is clearly due to its relatively low output to structures capital ratio, $\frac{y_f}{k^g}$, which follows from Figure 1. Recall that since structures are the dominant component of public investment, they are also in terms of capital. On the other hand, intellectual property public capital has the highest MPPK, resulting from an output to public capital elasticity greater than one percent and a relatively large output share.

The same relative patterns emerge for the MPPK for intermediate private goods in columns 4-6 of Table 2. Further note that the MPPKs for intermediates in column 4 are higher than their final goods counterparts in column 1. These differences are due to the combination of relatively higher output to public elasticities (compare columns 5 and 2) and a somewhat higher intermediate output to public capital share than in the case of the final private goods (compare columns 6 and 3).

Table 3 next looks at the marginal products of private and public capital for aggregate final and intermediate goods. We can see that the gross returns to capital for final and intermediate goods firms exceed that of public capital. For example, $MPK_f = 0.0337 > MPPK_f = 0.0180$ and

[16]These direct relationships follow from the final and intermediate goods production functions, respectively (see equations (6) and (18)).

$MPK_i = 0.0337 > MPPK_i = 0.0292$. In contrast, public capital's net returns exceed those of private capital when we consider net returns. For example, $MPPK_f^{net} = 0.0133 > MPK_f^{net} = 0.0101$ and $MPPK_i^{net} = 0.0216 > MPK_i^{p,net} = 0.0101$.[17] These results suggest that public capital is underprovided relative to private capital, as Ramey (2020) argued.

Table 3: Gross and Net Marginal Products

Private Capital Final		Private Capital Intermediate	
MPK_f	MPK_f^{net}	MPK_i	MPK_i^{net}
0.0337	0.0101	0.0337	0.0101

Public Capital Final		Public Capital Intermediate	
$MPPK_f$	$MPPK_f^{net}$	$MPPK_i$	$MPPK_i^{net}$
0.0180	0.0133	0.0292	0.0216

4 Is Capital Optimally Provided?

To further explore whether capital is under or over provided, we first solve the associated social planner's problem (see also Ramey (2021) and Appendix G) and compare the socially optimal allocations of private and public capital with the BEA data. We then compare the GDP growth and returns to capital and bonds using the data and our model predictions.

4.1 Social planner's problem

Table 4 presents the optimal steady-state public capital to output ratios for the three types considered and for aggregate public capital and the private capital to output ratios. We can see that comparisons with the actual data in 2019 and the means from 1929-2019 suggest that each type of public investment is underprovided. The most significant gap between actual and optimal is for structures and the smallest for equipment. Moreover, this gap is much more extensive for aggregate public capital than for private capital. For example, the ratios of actual to optimal for the 1929-2019 period are approximately 0.38 and 0.85, respectively.

[17] Note that net private capital rates for final and intermediate producers are after deducting depreciation and corporate taxes. In contrast, the net public MPPKs are after corporate taxes have been deducted since firms do not directly pay depreciation costs on these exogenously provided goods/services.

Table 4: Optimal Private & Public Capital

	Optimal steady-state	Data 2019	Data (mean) 1929-2019
k_1^g/y_f	0.1090	0.0506	0.1000
k_2^g/y_f	1.6858	0.6234	0.5720
k_3^g/y_f	0.1184	0.0597	0.0545
K^g/y_f	1.9132	0.7337	0.7265
K/y_f	2.5640	2.3072	2.2105

Note that these are annualised shares and $K = k^f + k^i$.

These results help to condition our expectations regarding the extent of the productivity-enhancing effects of infrastructure spending, which follows in the multiplier analysis below. In particular, depending on the financing instrument used, we generally expect sizeable output multipliers given the significant unexploited social returns to public capital and the relatively more modest ones associated with private capital.

4.2 GDP growth, real interest rate & returns to capital

Recall that the fiscal cost of public debt and the under or over-provision of capital also relate to the relationship between output growth and the real interest rate. If the growth rate, g_y, exceeds the real interest rate on sovereign bonds, r, the government can roll over its debt without the need to ever raise taxes or cut spending (see, e.g. Blanchard (2019)), which would imply that the feedback reaction in (31) is unnecessary. Also, suppose the growth rate exceeds the net return to capital, MPK. In that case, the economy accumulates too much capital so that, in this dynamically inefficient economy, all generations will be better off if they reduce investment (see, e.g. Blanchard and Fischer (1989, chapter 3), Mankiw (2015) and Reis (2021)).

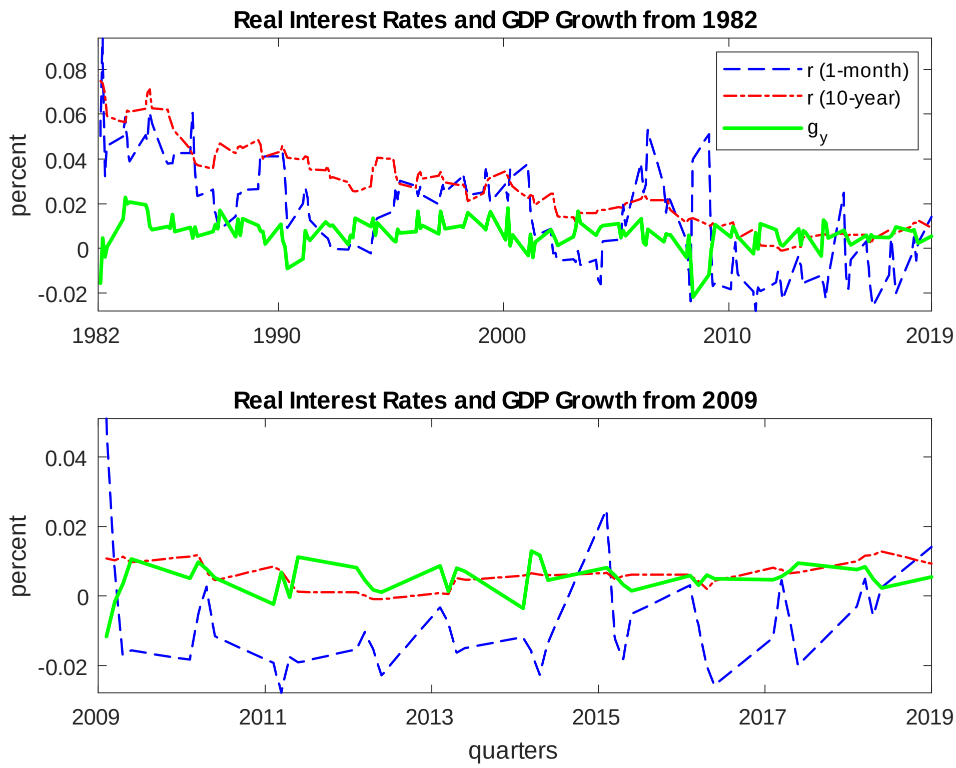
Figure 3 plots the growth rate of real gross domestic product against different real interest rates on an annualised basis.[18] The latter measures are from the Federal Reserve Bank of Cleveland from 1982 and include the 1-month and 10-year real interest rates.[19] We plot the data through 2019 to correspond with our calibration. As can be seen, most of the time, $r > g_y$. An exception is the decade following the global financial crisis, during

[18] In our model, the real interest rate on bonds equals the net return to private capital in equilibrium.

[19] The quarterly seasonally adjusted GDP data are from the FRED database. This data is in billions of chained 2012 dollars. The interest rate data are available monthly; see www.clevelandfed.org/en/our-research/indicators-and-data/inflation-expectations.aspx

which the real interest was low (actually, negative most of the time) due to "unconventional" monetary policy measures. Noticeably, r is greater than g_y in 2019, which serves as our departure year for the simulations reported below. Thus, our approach, which allows for a fiscal cost to public debt via the reaction function in (31), appears to cohere well with the recent U.S. r and g_y data. Moreover, note that the average growth rate of real GDP from 1982-2019 is lower than the annual net private and public capital annual returns reported in Table 3. This further supports our claim above that private and public capital are underprovided, especially the latter.

Figure 3: Real Interest Rates and GDP Growth



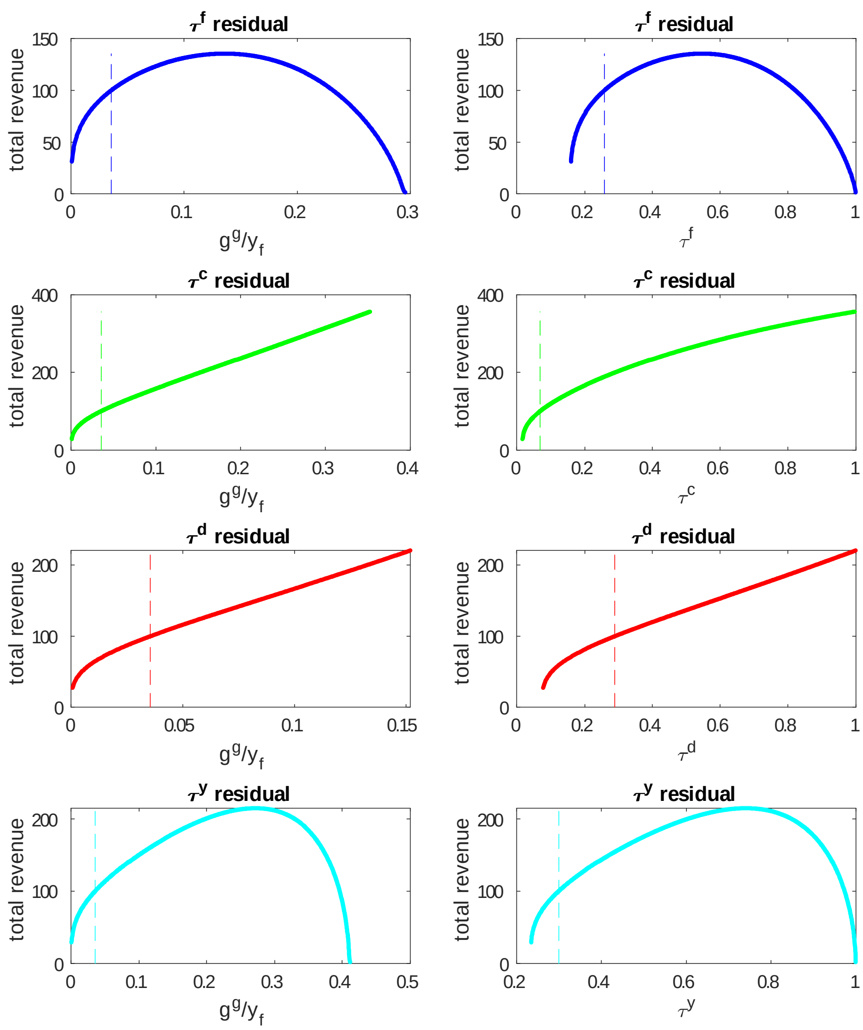
5 Steady-State Results

In this section, we study some relevant steady-state properties of the model to provide context for the dynamic analysis of the next section. In particular, we discuss spending and tax Laffer curves and the extent to which infrastructure spending can be self-financed at the steady-state.

5.1 Infrastructure spending Laffer curves

In column 1 of Figure 4, we examine the relationship between total tax revenues and different hypothetical values of public infrastructure spending as a share of GDP.

Figure 4: Infrastructure Spending Laffer Curves



In this experiment, we assume that one of the tax rates (τ^f, τ^c, τ^d and τ^y) adjusts to close the government budget constraint at the steady-state, other things equal.[20] In other words, all other fiscal instruments, including the public debt to GDP ratio, remain as in the baseline calibration (see subsection 3.4 above). Column 2 of Figure 4 also plots the resulting value of the adjusting tax rate in each case studied. The vertical lines refer to the steady-state values of policy instruments corresponding to their values in the year 2019.

The first and last rows of Figure 4 reveal that total tax revenues respond non-monotonically to the infrastructure spending rate and the adjusting tax rate for both the corporate and labour income tax rates. These results are not surprising since these taxes continue to distort private decisions at the steady-state. So, naturally, after a point, the beneficial effects from higher public capital are offset by the required rise in the respective tax rates. Further, notice that for corporate and labour income taxes, the peaks of the parabolas are well beyond their values in the actual data, implying that a further increase in public infrastructure spending will be beneficial. Although this is a hypothetical steady-state experiment, its message is consistent with the dynamic analysis below which studies the effects of the currently agreed U.S. stimulus over time.

Finally, rows 2 and 3 of Figure 4 show that total tax revenues respond monotonically to the infrastructure spending rate and the adjusting tax rate for consumption and dividend taxes. This is because dividend taxes are reduced to lump-sum taxes in the steady-state if $0 \leq \tau^d < 1$. Moreover, it is well established that consumption taxes do not have adverse effects in the steady-state to finance public spending. This finding maintains even at unrealistically high values (see, also, e.g. Trabandt and Uhlig (2011, Figure 8) and, in a normative Ramsey policy paper, Coleman (2000)).

5.2 Self-financing rate

Before we move on to transition results, we address a much-discussed policy question about whether a fiscal stimulus can pay for itself. In other words, can the increase in tax bases and hence tax revenues, made possible by the rise in economic activity triggered by a fiscal stimulus, be enough to finance the higher public spending without the need to increase any tax rate or to decrease other categories of public expenditure?

The required increase in government revenues is the sum of revenues generated by larger tax bases and those raised by increasing a tax rate. In other words, these are the self-financing and discretionary components,

[20] In Figure 4, we assume that public infrastructure as a share of GDP starts at zero and increases until the value of this share implies that the endogenously responding tax rate is equal to unity.

respectively (see Appendix H for details).[21] So, naturally, if a fully pay-for-itself scenario were feasible, the discretionary revenue as a share of total revenue would be zero. Equivalently, if the self-financing component as a share of total revenue were one, the stimulus would have no fiscal cost in Blanchard's (2019) sense.

Although this issue is studied below when we simulate the model to quantify the implications of the currently agreed temporary U.S. fiscal stimulus over time, it is also worth understanding what happens at the steady-state when the change in public spending is permanent. In particular, to make steady-state and transition results comparable, at least concerning the shock size, we assume a 75% increase in the public investment to GDP ratio. In other words, this corresponds to a permanent rise in the level of public investment of the same magnitude as the agreed temporary stimulus of 566 billion dollars (see the next section for details). The results for this experiment reported in Table 5 suggest that a significant proportion of the required revenues to pay for additional infrastructure can be self-financed at the steady-state for all tax rates. The largest self-financing rate arises from dividend taxes (which is the least distorting tax instrument at steady-state) and the lowest from corporate taxes (which is the most distorting tax instrument at steady state). As confirmed in the next section, the ranking of tax instruments in Table 5, regarding the self-financing rate, is generally similar to their order in terms of long-run output multipliers.[22] In other words, the public financing instruments which produce the most significant output multipliers, and hence the most extensive tax bases, also generate the highest self-financing rates at the steady-state.

Table 5: Self-financing rates

residual instrument	rate
τ^f	0.6312
τ^c	0.7483
τ^d	0.7648
τ^y	0.7330

[21] Note that Appendix H shows how the self-financing rate relates to the slope of the Laffer curve between total revenue and the tax rate at the steady-state (see also Trabandt and Uhlig (2011)).

[22] Strictly speaking, as we shall see below in the transition results, consumption taxes score better than dividend taxes in terms of long-run output multipliers. However, as said above, dividend taxes are reduced to lump-sum taxes in the steady-state when $0 \leq \tau^d < 1$.

6 Transition Results

The section first discusses how we apply the agreed 566 billion dollar infrastructure package to our model. We then report the infrastructure spending multipliers and, in turn, the social welfare associated with the different public financing instruments. We next study whether the increase in public investment spending can pay for itself over the transition. Finally, we compare the effects of the agreed 566 billion dollar infrastructure package with the 869 billion dollars 2020-21 Covid-19 stimulus package involving three separate payments to all eligible U.S. individuals.[23]

6.1 The U.S. infrastructure stimulus

The recently agreed $1.2 trillion bipartisan infrastructure bill provides budget authority for roughly half a trillion dollars in new spending. In particular, Stein and Laris (Washington Post (WP), August 10, 2021) report that: "*Of the infrastructure legislation's $566 billion in new spending, only about $20 billion will be spent by the end of the fiscal year 2022, according to estimates based on Congressional Budget Office reports by Marc Goldwein, senior vice president of the Committee for a Responsible Federal Budget, a nonpartisan think tank, and Donald Schneider, who served as an economist for Republicans on the House Ways and Means Committee.*"

The WP article further reports that "*Roughly $125 billion, or about a quarter of the funding, will go out by September 2024 - right ahead of the 2024 presidential election, Goldwein and Schneider have found. Annual federal spending from the bill ramps up from there in fiscal years 2025, 2026 and 2027.*"

In our model simulations, to approximate the agreed fiscal stimulus, we will allow for time-to-spend of six years, as shown in Table 6 and further allocate spending to each of the types considered using there 2019 shares of total infrastructure investment, i.e. $\frac{g_1^g}{g^g}$ =0.217, $\frac{g_2^g}{g^g}$ =0.480 and $\frac{g_3^g}{g^g}$ =0.303.

Table 6: New Infrastructure Spending

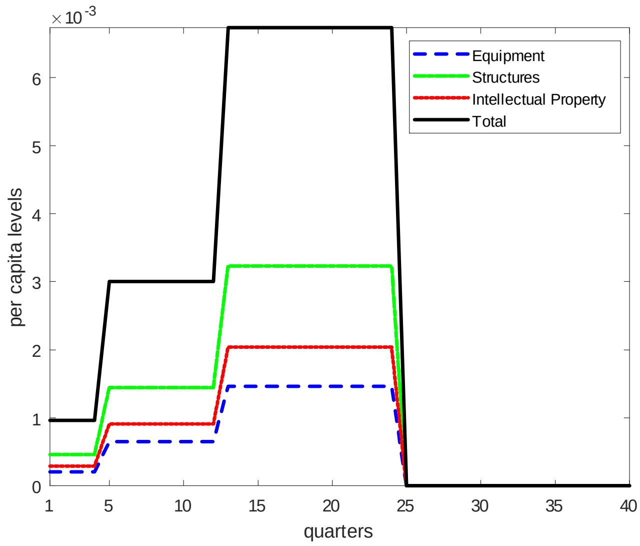
	2022	2023	2024	2025	2026	2027	total
Spending $bill	20.00	62.50	62.50	140.33	140.33	140.33	566
Share of budget authorisation	0.035	0.110	0.110	0.248	0.248	0.248	1

[23]Note that in Appendix F, we also examine changes to the base model by altering some key parameters that are either not directly calibrated using the data or pinned down using data targets. In particular, we examine the effects on the long-run multipliers of altering time-to-build, the policy reaction coefficient, adjustment costs and consumption habits.

In our solutions, we assume that all this is common knowledge. Thus, we solve the model under perfect foresight by using a non-linear Newton-type method implemented in Dynare.

Furthermore, to provide context for the Figures reported below involving dynamic transition paths of key variables during and after the spending shocks, we plot the per capita spending shocks over six years (24 quarters) for each component of infrastructure investment, and their total, in Figure 5. Recall from Appendix E that we solve the model in per capita units.

Figure 5: New Infrastructure Spending



6.2 Multipliers

We consider long-run output multipliers across public financing instruments and Frisch elasticities, starting with the base model. Throughout our analysis, we calculate cumulative present value multipliers following e.g. Leeper *et al.* (2010). For example, the output multiplier is given by:

$$FM_{y_f} \equiv \frac{\sum_{j=0}^{k}\left(\prod_{i=0}^{j} R_{t+i}^{-1}\right)\Delta y_{f,t+j}}{\sum_{j=0}^{k}\left(\prod_{i=0}^{j} R_{t+i}^{-1}\right)\Delta \boldsymbol{\kappa}_{t+j}}, \tag{37}$$

where $R_t = (1 + r_t^b)$; $\Delta y_{f,t} = (y_{f,t} - y_f)$; $\Delta \boldsymbol{\kappa}_t = (\boldsymbol{\kappa}_t - \boldsymbol{\kappa})$; and non-time subscripted variables refer to their steady-state values.

6.2.1 Role of public financing instruments

Inspection of the results in Table 7, which are for the baseline parameterisation reported in Table 1, reveals that all long-term output multipliers associated with the agreed infrastructure spending stimulus are positive and greater than unity, except for corporate taxes. However, their relative size depends crucially on which fiscal instrument needs to react to the rising public debt over time. As a reaction to the latter, transfers need to fall, and tax rates need to rise.

Table 7: Long-run Output Multipliers, ν =0.72

	s^t	τ^c	τ^d	τ^y	τ^f
FM_{y_f}	2.13	1.54	1.47	1.04	0.58

The output multiplier for transfers as a share of output, s^t, is higher than 2. Such a considerable value is not surprising since transfers are a lump-sum policy instrument in this class of models.[24] Hence, as in most of the related literature, transfer spending can serve as a natural benchmark against which to compare the other public financing instruments.

At the other extreme, the least effective public financing tool is corporate taxes, τ^f, where the long-run output multiplier, although positive, is well below unity, followed by labour income taxes, τ^y, at around unity. These two multipliers are lower than the others since rises in τ^f and τ^y exert direct detrimental effects on the incentive to invest on the firms' side and the incentive to work on the household's side, respectively.[25]

The superiority of consumption taxes, τ^c, relative to other taxes is well-established in the literature, at least when the criterion is aggregate efficiency. They are generally the second-best after the benchmark case of transfers. In particular, taxes on final goods are less distorting than taxes on factors or output (see, e.g. Atkinson and Stiglitz (1980), while, for optimal Ramsey taxation, see, e.g. Coleman (2000)).

Finally, consider the case when the tax rate on dividends, τ^d, plays the role of the adjusting fiscal instrument. The size of the multiplier with τ^d is close to that with τ^c. This finding may look surprising at first sight since an increase in the dividend tax rate reduces the firms' effective time discount

[24] In the final system in Appendix E, transfers only appear in equation E.18. In the sense that public debt does not matter to the real allocation, Ricardian equivalence holds only in this benchmark public financing case.

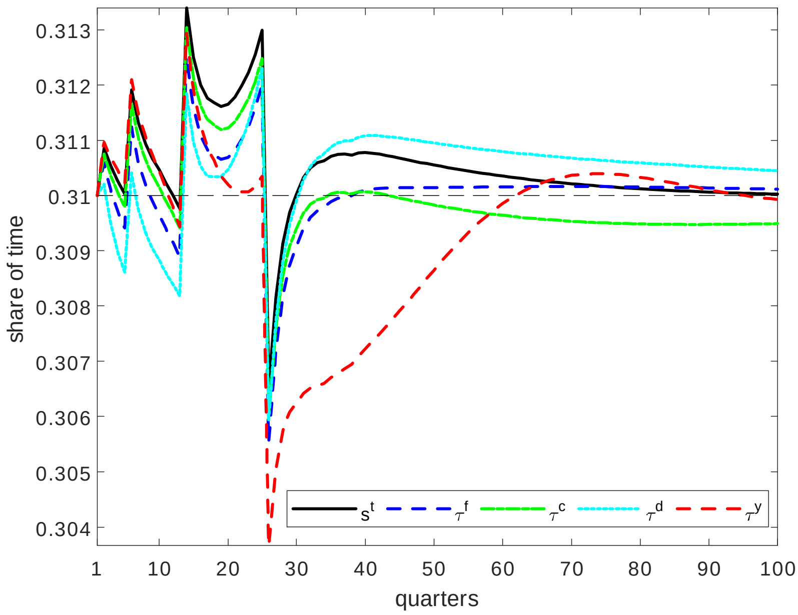
[25] See equation E.1 in Appendix E for the direct effect of labour income taxes on labour supply and equations E.9 and E.11 for the final good firms. Also, see equations E.15 and E.17 for intermediate goods firms for the direct effect of corporate taxes on firms' capital decisions.

factor, hurting private investment.[26] However, when τ^d rises, there is also an indirect crowding-in effect on work hours that helps growth. This happens because an increase in the dividend tax rate reduces the ratio of net-of-taxes dividend income to net-of-taxes income from work in the households' problem, strengthening their incentive to work.[27] Work hours thus play a critical role which we will analyse further next.

6.2.2 Role of work time and the Frisch elasticity

Figure 6 plots the time paths of equilibrium work hours per capita under the five public financing instruments with the same baseline parameterization as Table 7.

Figure 6: Dynamic Paths of Equilibrium Work Time



As can be seen, different public financing instruments have differing implications for work time. For example, the equilibrium work time response associated with higher dividend taxes, τ^d, is higher than the other instruments and takes longer to return to equilibrium. Actually, for the reasons explained below, the increase in work hours is stronger when we use divi-

[26] See equations E.9-E.11 for final good firms, and equations E.15-E.17 for intermediate goods firms, in Appendix E.

[27] In Appendix I, we use a simple version of our model to show this analytically.

dend taxes, τ^d, than when we use transfers, s^t.[28] At the other end, the use of τ^y (higher labour income taxes) exerts a significant detrimental effect on work hours in the short term, although they then rise perhaps as the benefits from higher infrastructure take hold. But as will be shown next, the value of the Frisch elasticity exerts a quantitatively important role on work time and hence the value of the multipliers.

Figure 7: Long-Run Output Multipliers Over Frisch Elasticities

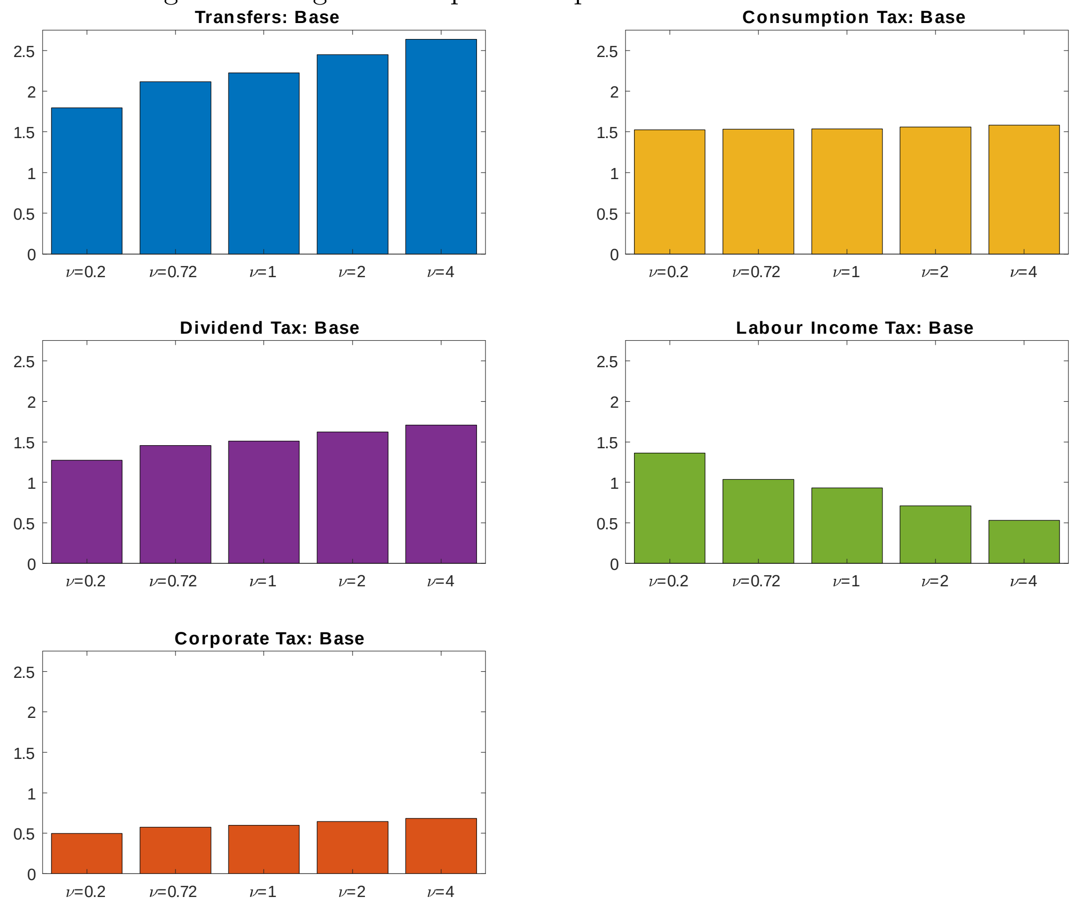


Figure 7 above shows how the Frisch elasticity (ν) affects the value of the multipliers reported in Table 7. In particular, we can see that as the labour supply becomes more elastic, the multipliers increase for transfers, the dividend tax and the corporate tax. In contrast, the multiplier falls for

[28] When lump-sum transfers stabilise the rising public debt, an increase in public infrastructure spending exerts a direct allocative effect only. Note, however, that even if work hours increase by more when we use dividend taxes than lump-sum transfers, the output multiplier is bigger under transfers. This is simply because dividend taxes have additional adverse effects on firms' incentives, as shown by their optimality conditions.

the labour income tax, while it is roughly constant for the consumption tax rate that remains around 1.5 across experiments.

To better understand the results in Table 7 and Figures 6 and 7, recall that when tax rates react to rising public debt, an increase in public infrastructure spending has both direct allocative effects and indirect, incentive effects via the changing tax rates.

In the case of labour income taxes, τ^y, the detrimental effect on labour supply becomes worse as the Frisch elasticity rises. Hence, the multiplier clearly gets smaller and smaller as ν rises. On the other hand, the opposite happens when we use the corporate tax rate, τ^f, where the multiplier, although always below unity, increases monotonically with ν. This happens because an increase in the corporate tax rate reduces the net-of-tax dividend received by the household and this, other things equal, is good for the incentive to work, as in the case of a rise in dividend taxes. But, of course, this happens in parallel to the positive direct effects from the fiscal stimulus and the negative impact that an increase in the corporate tax rate has on firms' investment decisions. Hence, the net result from a higher Frisch elasticity is a quantitative matter.

Finally, consider the case when the tax rate on dividends, τ^d, plays the role of the reacting fiscal instrument. The size is around 1.5 on average, but the exact magnitude depends again on the Frisch elasticity. When ν is relatively high, the multiplier with dividend taxes exceeds even the multiplier with consumption taxes. But as ν falls, the multiplier with dividend taxes gets smaller and smaller. For example, when $\nu = 0.2$, the multiplier for τ^y becomes bigger than the multiplier for τ^d. As discussed above, this happens because an increase in the dividend tax rate reduces the ratio of net-of-taxes dividend income to net-of-taxes labour income, which strengthens the incentive to work, and this crowding-in effect on work time increases with the value of ν.

6.3 Social Welfare

To complement multiplier results, we next report results for welfare, defined as discounted lifetime utility and measured in terms of consumption equivalents. In particular, we compute the permanent consumption subsidy or supplement, denoted as χ, that the household needs to be as well off before the increase in public infrastructure spending as after it (see Appendix J for algebraic details). If $\chi > 0$ (resp. $\chi < 0$), there is a welfare gain (resp. loss) from higher public infrastructure spending. For example, a value of $\chi = 1$ would mean that the household enjoys a 1 percent increase in consumption in each time-period vis-a-vis the initial steady-state, thanks to higher public infrastructure spending.

Table 8: Long-run Multipliers & Welfare, ν =0.72

	s^t	τ^c	τ^d	τ^y	τ^f
FM_{y_f}	2.13	1.54	1.47	1.04	0.58
χ	-0.20	0.15	-0.20	0.42	-0.01
$\widetilde{\chi}$	0.22	0.09	0.12	-0.02	0.07

Note that $\widetilde{\chi}$ holds when $\mu = 0$ in the utility function.

We report results for χ in Table 8 above, which, for convenience, includes the multiplier results of Table 7. Also, to understand the size and sign of the welfare results as measured by χ, we calculate *ex-post* the value of the consumption subsidy when the disutility of work receives a zero weight in the period utility function, $\widetilde{\chi}$.

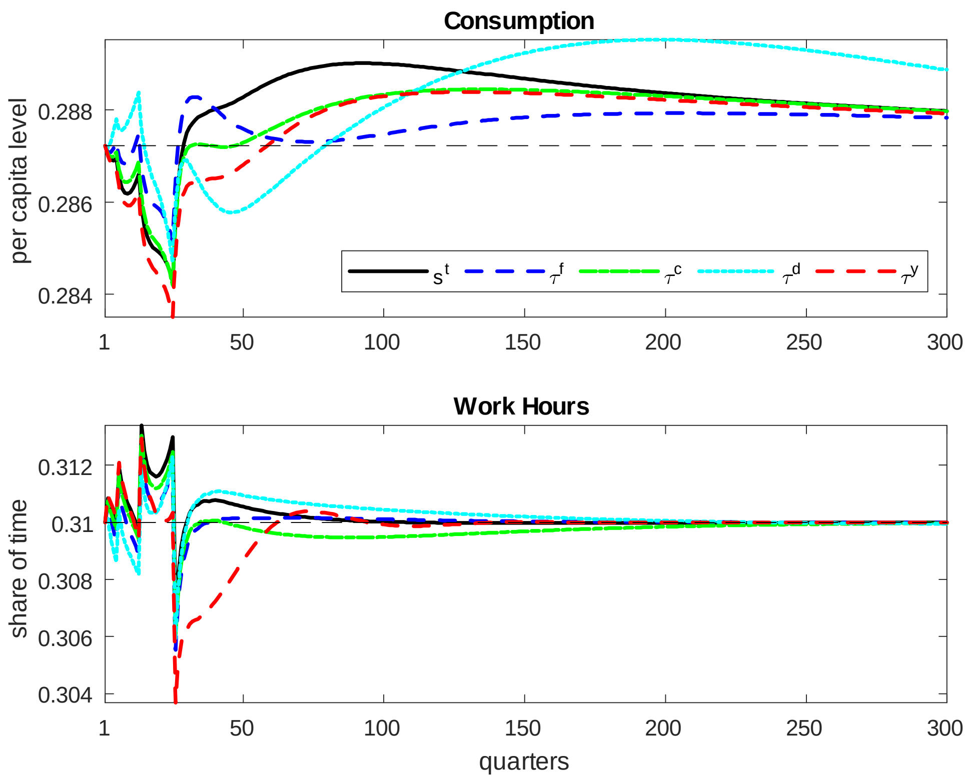
There are two messages from Table 8. First, the χ and $\widetilde{\chi}$ values are small in absolute value and less than half a percent. This is not surprising since the increase in infrastructure spending is temporary and, as such, is small relative to lifetime household income. Thus, it follows that we should not expect anything more than minor changes in aggregate consumption and welfare. To further place these magnitudes into context, recall that Lucas (1990, p. 313) finds welfare gains between 0.75-1.25 percent when considering a radical reform involving permanently replacing the existing U.S. tax structure with an optimal Ramsey tax mix resulting in zero capital taxation. Second, the ranking in terms of welfare given by χ is almost the opposite of the long-run output multipliers ranking. For instance, under the baseline value of the Frisch elasticity ($\nu = 0.72$), the order from highest to lowest for the long-run output multipliers (FM_{y_f}) is: transfers, consumption taxes, dividend taxes, labour income taxes and corporate taxes, while, the welfare ranking, χ, is labour income taxes, consumption taxes, corporate taxes and, at the end, dividend taxes and transfers.

We can next see by examining $\widetilde{\chi}$ that the negative correlation between the multiplier and welfare ranking is explained mainly by the role of work hours or, by implication, leisure as an argument in the utility function. When output increases, for instance, due to higher public infrastructure spending, this implies increased work hours or reduced leisure, which mitigates the welfare gains from moving to a more productive economy. When we set aside the adverse effects of work time, the welfare ranking is similar to output multipliers. Namely, as Table 8 shows when we look at $\widetilde{\chi}$, transfers come first again, followed by dividend taxes and consumption taxes, while corporate taxes and labour income taxes are at the end.

To better understand these results, Figure 8 presents the time-paths of the two arguments in the utility function, namely, private consumption and work hours, for transfers and each tax instrument. As can be seen, consumption rises in the medium run thanks to higher public infrastructure, irrespective of which public financing tool stabilises the increase in public debt. However, the start and the magnitude of the rise in consumption vary across the fiscal instrument used. For example, the increase in dividend taxes, τ^d, exerts a relatively strong positive effect on private consumption after the 100th quarter. Still, with τ^d, the substantial increase in work hours for the reasons explained above mitigates the welfare gains as measured by χ.

In contrast, the use of labour income taxes, τ^y, and corporate taxes, τ^f, leads to a fall in work hours in the periods immediately after the completion of the fiscal stimulus, which is good for welfare (see the χ row), and this is stronger in the case of τ^y. Finally, although consumption taxes, τ^c, need to increase for some time as public debt rises, consumption increases in the medium run since this kind of taxation is not so distorting, as explained above. Also, as consumption rises over time, leisure rises (*ceteris paribus*, consumption and leisure are complements), and all this allows consumption taxes to score persistently well across experiments and criteria.

Figure 8: Welfare Inputs



The above effects naturally become more pronounced for a high value of the Frisch elasticity. Thus, for example, if we allow labour to become significantly more responsive to changes in macro policy by moving from $\nu = 0.72$ to $\nu = 4$, Table 9 shows, via the Spearman rank correlation, that the negative correlation between the long-run output multipliers, FM_{y_f}, and welfare including leisure, χ, and the positive correlation between FM_{y_f} and welfare excluding leisure, $\widetilde{\chi}$, increases.

Table 9: Correlation between multiplier & welfare ranks

Frisch elasticity	$\rho(FM_{y_f}, \chi)$	$\rho(FM_{y_f}, \widetilde{\chi})$
$\nu = 0.72$	-0.50	0.80
$\nu = 4$	-0.90	0.90

6.4 Self-financing along the transition path

In contrast to our steady-state analysis in subsection 5.2, we now study the extent to which the currently agreed U.S. public infrastructure stimulus described in subsection 6.1 can be self-financed along the transition path. Since this increase in public spending is temporary, we start and end at the same steady-state solution. Thus, it is valid by construction that the cumulative sum of changes in total government expenditures, where the latter include the associated public debt interest payments, equals the cumulative sum of changes in total government revenues. As above, these revenues comprise those related to larger tax bases or the self-financed part and those raised by increasing a tax rate, decreasing another public spending item, or combining both. Naturally, a fully pay-for-itself scenario will be feasible with zero discretionary taxation (see Appendix H).

Table 10 reports the average self-financing rates over different periods along the transition path.[29] Additionally, the final column in this table includes, for convenience, the steady-state results of Table 5 in subsection 5.2. Recall that, in the transition analysis, it is the end-of-period public debt that closes the government budget identity in each period with one of the tax rates reacting to the debt gap as in (31) for dynamic stability reasons. By contrast, in the steady-state analysis above, the same stimulus is permanent, and one of the tax rates closes the identity with the public debt to GDP ratio set as in the data. Thus, although the two experiments are not comparable quantitatively, it is interesting to examine how the ranking changes in the transition relative to the steady-state.

[29] Note that we do not include the case in which transfers fall to bring lower public debt down since it is less interesting.

Table 10: Mean self-financing rates

	10 years	25 years	50 years	100 years	steady-state
τ^f	0.2658	-0.0083	0.2966	0.6377	0.6312
τ^c	-0.5673	-0.0909	0.1967	0.5439	0.7483
τ^d	0.4390	0.1982	0.3731	0.6545	0.7648
τ^y	0.2824	0.5011	0.7236	0.8760	0.7330

The results in Table 10 suggest that within each time window, the self-financing rate is relatively higher when labour income and dividend tax rates (τ^y and τ^d) react to rising debt compared with corporate profits and consumption tax rates (τ^f and τ^c). Specifically, let's leave aside the early ten years characterised by staggered spending and time-to-build lags. We can then see that the self-financing rate is systematically higher with labour income taxes followed by dividend, corporate taxes and consumption taxes.

The above transition ranking can be explained by each tax rate's contribution to total tax revenues and by the size of the long-run output multiplier associated with each. For example, although τ^y has a long-run output multiplier less than τ^c and τ^d, it scores the highest in terms of self-financing since it contributes significantly more than all other taxes to total tax revenues. For example, we know from the calibration that its share in total tax revenues is not far off half of all revenue at 45%. Moreover, while τ^f may contribute more than τ^d to total tax revenues, i.e. 29% vs 13%, dividend taxes experience a higher self-financing rate since they produce bigger long-run output multipliers and hence larger tax bases in general. Finally, although τ^c also generates relatively large long-run output multipliers similar to dividend taxes, the share of consumption taxes in total tax revenues is small in the U.S. at around 12%.

Comparing the ranking of different public financing regimes in terms of self-financing rates in the steady-state (last column) to their ranking over the transition (see, for example, the 100 years column), we can draw the following policy conclusions. First, at the steady-state, where the driving force is a permanent public investment stimulus, all tax bases generally move in the same direction as output so that their ranking is shaped by the size of long-run output multipliers, as already discussed in subsection 5.2.[30] Second, along the transition path, when the shock is temporary, the four different tax bases (associated with τ^f, τ^c, τ^d and τ^y) can move differently from changes in

[30]Notice that this happens even in the case of the consumption tax rate, τ^c. That is, although τ^c rises to finance the increase in public spending, consumption, and hence the tax base of consumption taxes, rise in equilibrium thanks to the crowding-in effect from a permanent rise in public infrastructure.

output over time. This is because the temporary public investment stimulus produces phases of crowding-in and crowding-out that affect the model's endogenous variables (including output and the four tax bases) differently, at least until these variables reach the steady-state. As a result, in the transition, the ranking of tax instruments in terms of self-financing rates has to do more with their initial shares in total tax revenues rather than with output multipliers. As also argued by Trabandt and Uhlig (2011) in a different policy experiment with tax cuts, steady-state results can differ substantially from transition results.

6.5 Infrastructure versus transfer spending

To understand the effects of infrastructure spending in a broader context, we next compare the macroeconomic effects of the \$566 billion infrastructure package analysed above with the \$869 billion Covid-19 stimulus package of 2020-21. In particular, we will examine the parts of the April 2020 CARES Act, the Dec. 2020 COVID-19 related Tax Relief Act and the March 2021 American Rescue Plan, which involved issuing per person payments of \$1,400, \$1,200, and \$600, respectively, to all eligible Americans. Despite the cost of these direct transfers being roughly 1.5 times higher than the proposed infrastructure spending stimulus, these payments were solely debt-financed. Nonetheless, since the additional debt and associated interest payments will eventually need to be settled, we treat the financing of these stimulus payments as we have with infrastructure spending.

Table 11: Fiscal Stimulus 2020-21

	Payment 1	Payment 2	Payment 3	Total
authorised \$ bill	411	294	164	869
disbursed \$ bill	400	274	141	815

See: www.covidmoneytracker.org/.

To implement this counterfactual shock in our model, we employ data made available by the Committee for Responsible Federal Budget, which we report in Table 11. The shocks implied by the three transfers occur in quarters 2 and 4 of 2020 and quarter 1 of 2021.[31]

We treat this additional spending as pure transfer payments. We realize, of course, that several types of transfer spending can cover productive needs, like health, education, social insurance or work-complement goods/services. However, the model features required to pick these up are not part of our

[31] Note that we use the data in the second row of Table 5 to shock the model since it has already been disbursed.

current setup. Therefore, we can think of our results as a polar case relating to the effects of pure transfer spending working like "helicopter money".

Table 12 summarises results relating to the long-run multipliers and associated welfare when we add this path of extra transfer spending to our initial public transfer to GDP ratio, s^t, of roughly 18%.[32] Note that the first three rows of Table 12, relating to the results for infrastructure spending, are those of Table 8 and are repeated here for convenience (excluding s^t). Concerning transfer spending, we find that in all cases except when we use dividend taxes to stabilise the rising public debt, the long-run output multipliers, FM_{y_f}, are negative. This is despite a short-term increase in aggregate consumption (except when labour income taxes adjust). At the same time, the welfare gains reflected by χ are positive. These findings relate to the reduction of work time resulting from the increase in transfer spending. In other words, an increase in transfers relative to income from work distorts the incentive to work so that work hours and output are lower, while, by contrast, welfare can rise as a result of increased leisure time.

Table 12: Long-run Multipliers & Welfare, ν =0.72

	τ^c	τ^d	τ^y	τ^f
	Infrastructure Spending			
FM_{y_f}	1.54	1.47	1.04	0.58
χ	0.15	-0.20	0.42	-0.01
$\widetilde{\chi}$	0.09	0.12	-0.02	0.07
	Transfer Spending			
FM_{y_f}	-0.40	0.60	-1.73	-1.55
χ	0.36	-0.04	0.63	0.19
$\widetilde{\chi}$	-0.11	0.08	-0.26	-0.09

Moreover, the adverse effects on output due to lower work hours are not offset by any productivity-enhancing output effects since this fiscal expansion relates to pure transfers. Finally, when we set aside the benefits of increased leisure by using $\widetilde{\chi}$, the welfare gains turn to losses. All of these effects apply when consumption, labour income or corporate taxes adjust to rising public debt.

In the case of dividend taxes, τ^d, the results are symmetrically opposite. Namely, FM_{y_f} and $\widetilde{\chi}$ are positive, while χ is negative. Again this is explained by work hours. While an increase in transfers hurts work incentives, the increase in dividend taxes, required for debt stabilisation, works oppositely on work time, as explained in subsection 6.1. Our quantitative results imply

[32] Changes in transfers can affect the real allocation because when transfers rise, public debt rises other things equal, and in turn, tax rates react to increasing public debt.

that the latter effect dominates so that work hours increase in equilibrium which explains the positive values of FM_{y_f} and $\widetilde{\chi}$, as well as the negative value of χ that takes into account the disutility of reduced leisure time.

7 Summary and Conclusions

Our results suggest that the recently agreed U.S. infrastructure spending package can play an essential role in increasing output in the long-run. However, the size of the multiplier depends crucially on which public financing instrument reacts to stabilise public debt and the Frisch elasticity of labour supply. More specifically, our results are as follows.

First, our estimates of the net marginal products for private and public capital and the social planner's solution suggest that both types are underprovided, especially the latter.

Second, at least one tax instrument must adjust to pay for infrastructure spending and avoid excessive public debt. Thus, the infrastructure stimulus cannot fully pay for itself. The self-financing rates at the steady-state vary between roughly 63%-76% when we consider a permanent shock to infrastructure spending. Moreover, these rates range between 54%-88% along the transition path when implementing the agreed temporary increase in U.S. infrastructure investment.

Third, we generally find that the most significant long-run output multiplier (around 2) is when government transfers adjust to rising public debt. In contrast, the smallest of 0.6 is when corporate taxes play this role. As in the literature, the former can only serve as a benchmark since transfers are a lump-sum policy instrument in this class of model. On the other hand, distorting corporate taxes directly hurt firms' investment decisions, eliminating most of the beneficial effects of higher public infrastructure over time.

Fourth, between the first-best and first-worst multiplier responses, we have consumption taxes, dividend income taxes and labour income taxes, whose multiplier ranking depends crucially on how these different public financing instruments affect the incentive to work. For values of the Frisch elasticity in the middle of the range used by the literature, say 0.72, consumption taxes score better (with a long-run output multiplier just above 1.5), followed by dividend income taxes (with a multiplier just below 1.5) and finally by labour income taxes (with a multiplier just above 1). On the other hand, while the long-run multiplier associated with the consumption tax rate remains insensitive to changes in the Frisch elasticity, the multiplier linked with the dividend tax rate falls when the Frisch elasticity is lower. In contrast, the multiplier related to the labour income tax rate rises for lower values of the Frisch elasticity.

Fifth, welfare across different public financing regimes in terms of consumption equivalents is relatively small. This happens since the fiscal shock we consider is temporary, and any gains (resp. losses) in consumption are mitigated by losses (resp. gains) in leisure. Thus, for example, while corporate and labour income taxes are the worst in terms of long-run output multipliers, they score higher in welfare terms because a fall in work hours accompanies any fall in output and consumption.

Sixth, pure transfer spending also leads to small welfare gains and losses. However, despite short-run increases in aggregate consumption for most financing instruments, it generates negative long-run multipliers since it is not productive and discourages labour supply.

We close with some possible extensions. For example, it would be interesting to add heterogeneity across households and study both aggregate and distributional implications of financing public infrastructure spending. It would also be helpful to add other types of public expenditure like public education, public health or social insurance to address funding issues relating to the second round of potential spending currently under debate in the U.S.

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Appendix A: Data Sources

1. The effective consumption tax rate follows the calculations in Jones (2002) and uses data from NIPA Table 3.1 (Government Current Receipts and Expenditures), lines 2, 4 and 9.

2. The effective labour income tax rate follows the calculations in Jones (2002) and uses data from (i) NIPA Table 1.12 (National Income by Type of Income), lines 2, 3, 6, 9, 12, 13 and 18; (ii) NIPA Table 3.2. (Federal Government Current Receipts and Expenditures), line 3; and (iii) NIPA Table 3.3. (State and Local Government Current Receipts and Expenditures), line 3.

3. The effective corporate profits tax rate is from the Tax Foundation: https://taxfoundation.org/corporate-tax-rates-around-the-world-2020/

4. The overall statutory tax rate on dividend income is from the OECD: https://stats.oecd.org/index.aspx?DataSetCode=TABLE_II4#

5. The debt to GDP ratio is from the Fred database and refers to gross federal debt as a share of GDP.

6. NIPA Table 1.1.5 (Gross Domestic Product) is used to calculate the public consumption (line 22) to GDP (line 1).

7. The numerator of public transfers as a share of GDP is from NIPA Table 3.1 (Government Current Receipts and Expenditures), i.e. the sum of lines 22, 27 and 30.

8. The intermediate goods share of gross output used to target the output elasticity to intermediate goods is from the BEA gross output and intermediate inputs data by industry Tables. We employ line 1 of each table.

9. The private and public capital stock data is from the BEA Table 1.1 (Current-Cost Net Stock of Fixed Assets and Consumer Durable Goods), lines 3 and 9, respectively.

10. The private and public depreciation data is from BEA Table 1.3 (Current-Cost Depreciation of Fixed Assets and Consumer Durable Goods), lines 3 and 9, respectively.

11. The private and public investment data is from BEA Table 1.5 (Investment in Fixed Assets and Consumer Durable Goods), lines 3 and 9, respectively.

12. The public capital stock data by type is from BEA Table 7.1 (Current-Cost Net Stock of Government Fixed Assets), lines 2, 3 and 18, respectively.

13. The public depreciation data by type is from BEA Table 7.3 (Current-Cost Depreciation of Government Fixed Assets), lines 2, 3 and 18, respectively.

14. The public investment data by type is from BEA Table 7.5 (Investment in Government Fixed Assets), lines 2, 3 and 18, respectively.

Appendix B: Intermediate goods and the multiplier

Here we use a stylised version of our model to show the channels through which intermediate private goods increase the public investment spending multiplier. Suppose that the model is static and the production functions of the final and the intermediate goods firms follow the main paper, except that we use a stylised setup with a single intermediate good, x, and a flow rather than a stock fiscal policy variable, G:

$$y_f = \left[k_f^a l_f^{1-a}\right]^{1-\sigma} x^\sigma G^\gamma, \tag{B.1}$$

$$x = k_x^a l_x^{1-a} G^\gamma, \tag{B.2}$$

where f and x and denote final goods and intermediate goods firms respectively; y_f is private final (value-added) output; k_f, l_f, k_x, and l_x are respectively capital and labour inputs used by f and x; and the power coefficients $0 < \alpha, \sigma, \gamma < 1$ are efficiency parameters.

Further assume that labour is exogenously set at 1 and that capital for each firm is proportional to output $k_f = \kappa y_f$ and $k_x = \kappa x$ where $\kappa > 0$. After simple substitutions, final output is:

$$y_f = \kappa^{\frac{a}{1-a}} G^{\frac{\gamma(1-a+\sigma)}{(1-a)[1-a(1-\sigma)]}}, \tag{B.3}$$

where, it can be shown that the power coefficient on productive public services, $\frac{\gamma(1-a+\sigma)}{[1-a(1-\sigma)](1-a)}$, is increasing in σ which measures the elasticity of final output to intermediate goods.

Thus, equation $(B.3)$ implies that the presence of intermediate goods, x, amplifies changes in fiscal policy on final output, y_f. In particular, a rise in G exerts both direct and indirect positive effects on y_f. The former is due to the increase in productivity of private capital and labour in the production of y_f, as in Barro's (1990) seminal paper. The latter increases the productivity of the private factors used to produce the intermediate good, x, which is in turn used by the final goods firms as an input to create more output.

Appendix C: Different market arrangements and the role of taxes

This Appendix presents two market arrangements. In the first, households own capital and make investment decisions. The infrastructure literature mainly uses this setup. In the second, firms instead hold capital and make investment decisions. We then spell out the assumptions regarding the tax structure required to make these two market arrangements give identical equilibrium allocations. Finally, we use a simple version of our model working as Miao (2014, ch. 14.1).

Households own capital

Suppose that the household maximises:

$$\sum_{t=0}^{\infty} \beta^t \left[\ln c_t - \frac{(l_t)^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}} \right], \tag{C.1}$$

subject to:

$$c_t + i_t = (1-\tau_t^l) w_t l_t + (1-\tau_t^k) r_t^k k_t + (1-\tau_t^d)\pi_t, \tag{C.2}$$

where r_t^k is the return to capital and $0 \leq \tau_t^l, \tau_t^k, \tau_t^d < 1$ are tax rates on labour income, capital income and dividend income, and the rest of the notation is as in the main paper.

Investment follows from:

$$k_{t+1} = (1-\delta)k_t + i_t. \tag{C.3}$$

The first-order conditions for labour and capital are:

$$l_t^{\frac{1}{\nu}} = \frac{(1-\tau_t^l) w_t}{c_t}, \tag{C.4}$$

$$\frac{c_{t+1}}{c_t} = \beta[1-\delta+(1-\tau_{t+1}^k) r_{t+1}^k]. \tag{C.5}$$

In each period, the firm maximises current profits/dividends:

$$\pi_t = y_t - w_t l_t - r_t^k k_t, \tag{C.6}$$

where $y_t = f(k_t, l_t)$ is a production function.

The first-order conditions for the two inputs are:

$$w_t = \frac{\partial y_t}{\partial l_t}, \tag{C.7}$$

$$r_t^k = \frac{\partial y_t}{\partial k_t}. \tag{C.8}$$

Notice that if we assume that the firm maximises the net of tax profit/dividend, $(1 - \tau_t^d)\pi_t$, its first-order conditions are not affected.

The government budget constraint is:

$$g_t = \tau_t^l w_t l_t + \tau_t^k r_t^k k_t + \tau_t^d \pi_t. \tag{C.9}$$

Combining the above, given policy, the macro equilibrium is summarized by:

$$l_t^{\frac{1}{\nu}} = \frac{(1 - \tau_t^l)}{c_t} \frac{\partial y_t}{\partial l_t}, \tag{C.10}$$

$$\frac{c_{t+1}}{c_t} = \beta \left[1 - \delta + (1 - \tau_{t+1}^k) \frac{\partial y_{t+1}}{\partial k_{t+1}} \right], \tag{C.11}$$

$$c_t + k_{t+1} - (1 - \delta)k + g_t = f(l_t, k_t). \tag{C.12}$$

Firms own capital

Here we follow Miao (2014, p. 363) and Altug and Labadie (1994, pp. 171-2). The household's budget constraint is now:

$$c_t = (1 - \tau_t^l) w_t l_t + (1 - \tau_t^d)\pi_t. \tag{C.13}$$

The first-order condition for labour is the same as above, namely:

$$l_t^{\frac{1}{\nu}} = \frac{(1 - \tau_t^l) w_t}{c_t}. \tag{C.14}$$

The firm's net cash flow or dividend is now:

$$\pi_t = (1 - \tau_t^f)(y_t - w_t l_t) - i_t, \tag{C.15}$$

where $0 \leq \tau_t^f < 1$ is a corporate tax rate on gross profits.

Since the firm is owned by the household, it maximises the PDV of net-of-tax cash flows or dividends:

$$\sum_{t=0}^{\infty} \beta_{f,t}(1-\tau_t^d)[(1-\tau_t^f)(y_t - w_t l_t) - i_t], \tag{C.16}$$

subject to:

$$k_{t+1} = (1-\delta)k_t + i_t, \tag{C.17}$$

where $\beta_{f,0} \equiv 1$, $\beta_{f,1} \equiv \beta \frac{\frac{\partial u_{t+1}}{\partial c_{t+1}}}{\frac{\partial u_t}{\partial c_t}} = \beta \frac{c_t}{c_{t+1}}$, etc.

The first-order conditions for the two inputs are:

$$w_t = \frac{\partial y_t}{\partial l_t}, \tag{C.18}$$

$$(1-\tau_t^d) = (1-\tau_{t+1}^d)\beta \frac{c_t}{c_{t+1}} \left[1 - \delta + (1-\tau_{t+1}^f)\frac{\partial y_{t+1}}{\partial k_{t+1}}\right]. \tag{C.19}$$

The government budget constraint is:

$$g_t = \tau_t^l w_t l_t + \tau_t^d \pi_t + \tau_t^f (y_t - w_t l_t). \tag{C.20}$$

Combining the above, given policy, the macro equilibrium is summarized by:

$$l_t^{\frac{1}{\nu}} = \frac{(1-\tau_t^l)}{c_t}\frac{\partial y_t}{\partial l_t}, \tag{C.21}$$

$$\frac{c_{t+1}}{c_t} = \beta \frac{(1-\tau_{t+1}^d)}{(1-\tau_t^d)} \left[[1 - \delta + (1-\tau_{t+1}^f)\frac{\partial y_{t+1}}{\partial k_{t+1}}\right], \tag{C.22}$$

$$c_t + k_{t+1} - (1-\delta)k = f(l_t, k_t). \tag{C.23}$$

Therefore, if we assume $\tau_t^k = \tau_t^f$ and a constant τ^d over time, the two models deliver identical equilibrium allocations.[33]

[33] Note that Altug and Labadie (1994, pp. 171-174) present and solve the above model enriched with firm shares.

Appendix D: Shares and details on the firm's problem

In this Appendix, we add shares issued by firms and purchased by households. Then, the model in the main text follows as a special case.

Households

The budget constraint of each h is now:

$$\begin{aligned}&(1+\tau_t^c)c_{h,t}+b_{h,t+1}+q_{f,t}z_{f,t+1}+q_{i,t}z_{i,t+1}\equiv(1-\tau_t^y)w_t l_{h,t}+\\&+(1+r_t^b)b_{h,t}+[q_{f,t}+(1-\tau_t^d)\pi_{f,t}]z_{f,t}+[q_{i,t}+(1-\tau_t^d)\pi_{i,t}]z_{i,t}+g_t^t,\end{aligned} \tag{D.1}$$

where $z_{f,t+1}$ denotes the number of shares issued by final good firms and purchased by the household at t at a price $q_{f,t}$; $z_{i,t+1}$ denotes the number of shares issued by intermediate good firms and purchased by the household at t at a price $q_{i,t}$; $\pi_{f,t}$ is the dividend paid by final good firms for each share purchased at $t-1$; and $\pi_{i,t}$ is the dividend paid by intermediate good firms for each share purchased at $t-1$.

The extra Euler conditions for shareholdings are:

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}=\beta\left(\frac{q_{f,t+1}+(1-\tau_{t+1}^d)\pi_{f,t+1}}{q_{f,t}}\right), \tag{D.2}$$

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}=\beta\left(\frac{q_{i,t+1}+(1-\tau_{t+1}^d)\pi_{i,t+1}}{q_{i,t}}\right). \tag{D.3}$$

Firms

Now new investment is financed both by retained earnings and by issuing new shares. We present the problem of the final good firms only (the intermediate firm's problem is analogous). The gross profit of the firm is:

$$\pi_{f,t}^{gross}\equiv y_{f,t}-w_t l_{f,t}-\sum_{i=1}^{N}p_{i,t}\lambda_i x_{f,i,t}. \tag{D.4}$$

The gross profit is used for retained earnings, dividend payments and corporate tax payments:

$$\pi_{f,t}^{gross}\equiv RE_{f,t}+\pi_{f,t}z_{f,t}+\tau_t^f\pi_{f,t}^{gross}. \tag{D.5}$$

New investment is financed by retained earnings and issuance of new shares:

$$i_{f,t}=RE_{f,t}+q_{f,t}(z_{f,t+1}-z_{f,t}). \tag{D.6}$$

Combining the above, we have:

$$(1-\tau_t^f)(y_{f,t}-w_tl_{f,t}-\sum_{i=1}^{N}p_{i,t}\lambda_ix_{f,i,t})-i_{f,t}=\pi_{f,t}z_{f,t}-q_{f,t}(z_{f,t+1}-z_{f,t}), \quad (D.7)$$

which is as in e.g. Altug and Labadie (1994, ch. 4) or Turnovsky (1995, ch. 10).

If we impose the condition $z_{f,t}=1$ at all t, we have as in the main text:

$$\pi_{f,t}\equiv(1-\tau_t^f)(y_{f,t}-w_tl_{f,t}-\sum_{i=1}^{N}p_{i,t}\lambda_ix_{f,i,t})-i_{f,t}. \quad (D.8)$$

Appendix E: Macroeconomic system

In a symmetric equilibrium in which intermediate goods firms are alike *ex post* (see also e.g. Guo and Lansing (1999)) so that $X_{f,t}=x_{f,i,t}=x_{i,t}$, the final system is:

$$(l_{f,t}+l_{i,t})^{\frac{1}{\nu}}=\frac{(1-\tau_t^y)w_t}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}, \quad (E.1)$$

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}=\beta(1+r_{t+1}^b), \quad (E.2)$$

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}=\beta\left(\frac{q_{f,t+1}+(1-\tau_{t+1}^d)\pi_{f,t+1}}{q_{f,t}}\right), \quad (E.3)$$

$$\frac{(1+\tau_{t+1}^c)(c_{h,t+1}-\xi c_{h,t})}{(1+\tau_t^c)(c_{h,t}-\xi c_{h,t-1})}=\beta\left(\frac{q_{i,t+1}+(1-\tau_{t+1}^d)\pi_{i,t+1}}{q_{i,t}}\right), \quad (E.4)$$

$$y_{f,t}=A\left[(u_{f,t}k_{f,t})^{\alpha}l_{f,t}^{1-a}\right]^{1-\sigma}\left[x_{i,t}\right]^{\sigma}\left[k_{1,t}^g\right]^{\gamma_{f,1}}\left[k_{2,t}^g\right]^{\gamma_{f,2}}\left[k_{3,t}^g\right]^{\gamma_{f,3}}, \quad (E.5)$$

$$k_{f,t+1}=(1-\delta_{f,t})k_{f,t}+\left[1-\frac{\psi}{2}\left(\frac{i_{f,t}}{i_{f,t-1}}-1\right)^2\right]i_{f,t}, \quad (E.6)$$

$$w_t=\frac{(1-\sigma)(1-\alpha)y_{f,t}}{l_{f,t}}, \quad (E.7)$$

$$p_{i.t}=\frac{\sigma y_{f,t}}{x_{i,t}}, \quad (E.8)$$

$$\begin{aligned}&\mu_{f,t}\left[\frac{(1+\tau^c_{t+1})(c_{h,t+1}-\xi c_{h,t})}{(1+\tau^c_t)(c_{h,t}-\xi c_{h,t-1})}\right]=\\&=\beta\left[\mu_{f,t+1}(1-\delta_{f,t+1})+\frac{(1-\tau^d_{t+1})(1-\tau^f_{t+1})(1-\sigma)\alpha y_{f,t+1}}{k_{f,t+1}}\right],\end{aligned}\tag{E.9}$$

$$\begin{aligned}(1-\tau^d_t)&=\mu_{f,t}\left[1-\frac{\psi}{2}\left(\frac{i_{f,t}}{i_{f,t-1}}-1\right)^2\right]-\mu_{f,t}\psi\left(\frac{i_{f,t}}{i_{f,t-1}}-1\right)\frac{i_{f,t}}{i_{f,t-1}}+\\&+\beta\left[\frac{(1+\tau^c_t)(c_{h,t}-\xi c_{h,t-1})}{(1+\tau^c_{t+1})(c_{h,t+1}-\xi c_{h,t})}\right]\mu_{f,t+1}\psi\left(\frac{i_{f,t+1}}{i_{f,t}}-1\right)\left(\frac{i_{f,t+1}}{i_{f,t}}\right)^2,\end{aligned}\tag{E.10}$$

$$\mu_{f,t}k_{f,t}\frac{d\delta_{f,t}}{du_{f,t}}=\frac{(1-\tau^d_t)(1-\tau^f_t)(1-\sigma)\alpha y_{f,t}}{u_{f,t}},\tag{E.11}$$

$$x_{i,t}=A\left[(u_{i,t}k_{i,t})^\alpha l_{i,t}^{1-a}\right]\left[k^g_{1,t}\right]^{\gamma_{i,1}}\left[k^g_{2,t}\right]^{\gamma_{i,2}}\left[k^g_{3,t}\right]^{\gamma_{i,3}},\tag{E.12}$$

$$k_{i,t+1}=(1-\delta_{i,t})k_{i,t}+\left[1-\frac{\psi}{2}\left(\frac{i_{i,t}}{i_{i,t-1}}-1\right)^2\right]i_{i,t},\tag{E.13}$$

$$w_t=\eta p_{i,t}\frac{(1-a)x_{i,t}}{l_{i,t}},\tag{E.14}$$

$$\begin{aligned}&\mu_{i,t}\left[\frac{(1+\tau^c_{t+1})(c_{h,t+1}-\xi c_{h,t})}{(1+\tau^c_t)(c_{h,t}-\xi c_{h,t-1})}\right]=\\&=\beta\left[\mu_{i,t+1}(1-\delta_{i,t+1})+\frac{(1-\tau^d_{t+1})(1-\tau^f_{t+1})\eta p_{i.t+1}\alpha x_{i,t+1}}{k_{i,t+1}}\right],\end{aligned}\tag{E.15}$$

$$\begin{aligned}(1-\tau^d_t)&=\mu_{i,t}\left[1-\frac{\psi}{2}\left(\frac{i_{i,t}}{i_{i,t-1}}-1\right)^2\right]-\mu_{i,t}\psi\left(\frac{i_{i,t}}{i_{i,t-1}}-1\right)\frac{i_{i,t}}{i_{i,t-1}}+\\&+\beta\left[\frac{(1+\tau^c_t)(c_{h,t}-\xi c_{h,t-1})}{(1+\tau^c_{t+1})(c_{h,t+1}-\xi c_{h,t})}\right]\mu_{i,t+1}\psi\left(\frac{i_{i,t+1}}{i_{i,t}}-1\right)\left(\frac{i_{i,t+1}}{i_{i,t}}\right)^2,\end{aligned}\tag{E.16}$$

$$\mu_{i,t}k_{i,t}\frac{d\delta_{i,t}}{du_{i,t}}=\frac{(1-\tau^d_t)(1-\tau^f_t)\eta p_{i.t}\alpha x_{i,t}}{u_{i,t}},\tag{E.17}$$

$$\begin{aligned}&g^c_t+g^t_t+\textstyle\sum_{j=1}^3 g^g_{j,t}+(1+r^b_t)b_{h,t}\equiv\tau^c_t c_{h,t}+\tau^y_t w_t(l_{f,t}+l_{i,t})+\\&\quad+\tau^f_t[(y_{f,t}-w_t l_{f,t}-p_{i,t}x_{i,t})+(p_{i,t}x_{i,t}-w_t l_{i,t})]+\\&\quad+\tau^d_t(\pi_{f,t}+\pi_{i,t})+b_{h,t+1},\end{aligned}\tag{E.18}$$

$$k^g_{j,t+1}=(1-\delta^g_j)k^g_{j,t}+g^g_{j,t},\tag{E.19}$$

$$c_{h,t}+i_{f,t}+i_{i,t}+g^c_t+\sum_{j=1}^3 g^g_{j,t}=y_{f,t}.\tag{E.20}$$

Thus for $j=1,2,3$ we have a system of 22 equations in $\{c_{h,t}$, $l_{f,t}$, $l_{i,t}$, $k_{f,t+1}$, $i_{f,t}$, $\delta_{f,t}$, $u_{f,t}$, $\mu_{f,t}$, $k_{i,t+1}$, $i_{i,t}$, $\delta_{i,t}$, $u_{i,t}$, $\mu_{i,t}$, $k^g_{j,t+1}$, $y_{f,t}$, $x_{i,t}$, w_t, r^b_t, $p_{i,t}$, $b_{h,t+1}\}_{t=0}^\infty$ and 9 policy instruments, $\{g^c_t$, g^t_t, $g^g_{j,t}$, τ^y_t, τ^c_t, τ^f_t, $\tau^d_t\}_{t=0}^\infty$, where $b_{h,t+1}$ adjusts residually to close the government budget constraint.

In the above we use:

$$\delta_{f,t} = \delta_0 + \delta_1(u_{f,t} - 1) + \frac{\delta_2}{2}(u_{f,t} - 1)^2,$$

$$\frac{d\delta_{f,t}}{du_{f,t}} = \delta_1 + \delta_2(u_{f,t} - 1),$$

$$\delta_{i,t} = \delta_0 + \delta_1(u_{i,t} - 1) + \frac{\delta_2}{2}(u_{i,t} - 1)^2,$$

$$\frac{d\delta_{i,t}}{du_{i,t}} = \delta_1 + \delta_2(u_{i,t} - 1),$$

$$\pi_{f,t} = (1 - \tau_t^f)(y_{f,t} - w_t l_{f,t} - p_{i,t} x_{i,t}) - i_{f,t},$$

$$\pi_{i,t} = (1 - \tau_t^f)(p_{i.t} x_{i,t} - w_t l_{i,t}) - i_{i,t}.$$

Appendix F: Changes to the Base Model and Robustness

We next examine changes to the base model, focusing on long-run output multipliers by adjusting key parameters that are either not directly calibrated via the data or pinned down with data targets. In particular, we: (i) add half a year onto the time-to-build each type of public capital; (ii) use the higher and lower values for adjustment costs and habits discussed in the calibration section, i.e. 5.89 and 0.31 respectively; and (iii) increase the policy reaction coefficient from 0.05 to 0.075.

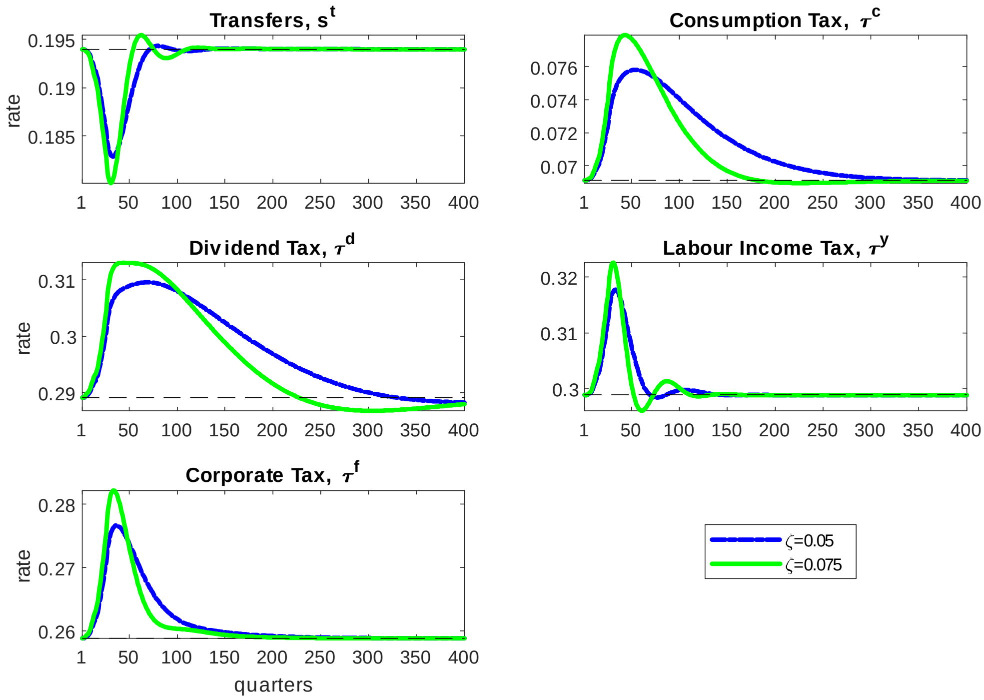
Table F1 shows that, relative to the base, increasing the time-to-build in row 2 lowers the multiplier for all public financing cases. This happens because, while the timing of costs remains the same, there is a delay in the benefits accruing to productive infrastructure. In contrast, higher adjustment costs and lower habits in rows 3 and 4 generally have a minimal effect on the long-run multiplier across instruments.

Table F1: Long-Run Output Multipliers

	s^t	τ^c	τ^d	τ^y	τ^f
	Base calibration				
Frisch elasticity=0.72	2.13	1.54	1.47	1.04	0.58
	Changes from Base				
$\uparrow$ time-to-build	2.04	1.45	1.38	0.96	0.50
$\uparrow$ adjustment costs (ψ)	2.13	1.55	1.50	1.04	0.59
$\downarrow$ habits (ξ)	2.17	1.59	1.52	1.12	0.60
$\uparrow$ policy reaction (ζ)	2.12	1.61	1.80	0.99	0.70

Finally, a rise in the policy reaction coefficient in row 5 increases the multiplier for all tax financing cases, except the labour income tax rate, which falls slightly. These findings relate to the inter-temporal trade-off between whether the higher taxes required due to the increased reaction coefficient take place over a shorter time (front-loaded) versus a longer time (back-loaded). A benefit from back-loading is that the cost is spread out over more years so that the economy does not suffer much in the short term, where the latter has a higher weight in the present discounted value of the long-run multiplier. In contrast, a cost from back-loading is that the anticipation of higher taxes for a more extended period hurts incentives, especially investment decisions, more persistently.

Figure F.1: Paths of Fiscal Instruments Over Reaction Coefficients, ζ



Here, our results for the consumption, dividend and corporate taxes show that it is better to front-load the fiscal adjustment, at least when we use feedback policy coefficients within the range used by the literature. Figure F.1 above further illustrates this point by plotting the dynamic reaction of each fiscal instrument as it responds to increasing debt due to higher infrastructure spending. All plots for $\zeta = 0.05$ and $\zeta = 0.075$ start at the steady-state for each policy instrument. The figures for the consumption tax, the dividend tax and the corporate income tax clearly show that despite initial higher distortionary increases in the respective rates for the $\zeta = 0.075$ case, all of these rates fall faster than in the $\zeta = 0.05$. Thus, in terms of the output multipliers, the benefits of lower taxes for a longer time outweigh the costs of higher taxes for a shorter time.

Appendix G: Social Planner's Problem

The social planner maximizes:

$$\sum_{t=0}^{\infty} \beta^t u\left(c_{h,t}, l_{f,t} + l_{i,t}\right), \tag{G.1}$$

where:

$$u\left(c_{h,t}, u_{h,t}\right) = \log(c_{h,t} - \xi c_{t-1}) - \mu \frac{(l_{f,t} + l_{i,t})^{1+\frac{1}{\nu}}}{1 + \frac{1}{\nu}}, \tag{G.2}$$

subject to:

$$y_{f,t} = A\left[(u_{f,t}k_{f,t})^{\alpha} l_{f,t}^{1-a}\right]^{1-\sigma} \left[x_{i,t}\right]^{\sigma} \left[k_{1,t}^{g}\right]^{\gamma_{f,1}} \left[k_{2,t}^{g}\right]^{\gamma_{f,2}} \left[k_{3,t}^{g}\right]^{\gamma_{f,3}}, \tag{G.3}$$

$$x_{i,t} = A\left[(u_{i,t}k_{i,t})^{\alpha} l_{i,t}^{1-a}\right] \left[k_{1,t}^{g}\right]^{\gamma_{i,1}} \left[k_{2,t}^{g}\right]^{\gamma_{i,2}} \left[k_{3,t}^{g}\right]^{\gamma_{i,3}}, \tag{G.4}$$

$$k_{f,t+1} = (1 - \delta_{f,t})k_{f,t} + \left[1 - \frac{\psi}{2}\left(\frac{i_{f,t}}{i_{f,t-1}} - 1\right)^2\right] i_{f,t}, \tag{G.5}$$

$$k_{i,t+1} = (1 - \delta_{i,t})k_{i,t} + \left[1 - \frac{\psi}{2}\left(\frac{i_{i,t}}{i_{i,t-1}} - 1\right)^2\right] i_{i,t}, \tag{G.6}$$

$$\delta_{f,t} = \delta_0 + \delta_1(u_{f,t} - 1) + \frac{\delta_2}{2}(u_{f,t} - 1)^2, \tag{G.7}$$

$$\delta_{i,t} = \delta_0 + \delta_1(u_{i,t} - 1) + \frac{\delta_2}{2}(u_{i,t} - 1)^2, \tag{G.8}$$

$$k_{j,t+1}^{g} = (1 - \delta_j^{g})k_{j,t}^{g} + g_{j,t}^{g}, \tag{G.9}$$

$$c_{h,t} + i_{f,t} + i_{i,t} + g_t^c + \sum_{j=1}^{3} g_{j,t}^{g} = y_{f,t}, \tag{G.10}$$

where $j = 1, 2, 3$.

The first-order conditions for $c_{h,t}$, $l_{f,t}$, $l_{i,t}$, $i_{f,t}$, $i_{i,t}$, $k_{f,t+1}$, $k_{i,t+1}$, $u_{f,t}$, $u_{i,t}$, are respectively (as in the decentralized economy, we do not internalize consumption habits):

$$\frac{1}{(c_{h,t} - \xi c_{h,t-1})} = \lambda_t, \tag{G.11}$$

$$\mu\left(l_{f,t}+l_{i,t}\right)^{\frac{1}{\nu}} = \frac{\lambda_t(1-\sigma)(1-a)y_{f,t}}{l_{f,t}}, \tag{G.12}$$

$$\mu\left(l_{f,t}+l_{i,t}\right)^{\frac{1}{\nu}} = \frac{\lambda_t\sigma(1-a)y_{f,t}}{l_{i,t}}, \tag{G.13}$$

$$\begin{aligned} \lambda_t &= \nu_t\left[1-\tfrac{\psi}{2}\left(\tfrac{i_{f,t}}{i_{f,t-1}}-1\right)^2\right]-\nu_t\psi\left(\tfrac{i_{f,t}}{i_{f,t-1}}-1\right)\tfrac{i_{f,t}}{i_{f,t-1}}+ \\ &+\beta\nu_{t+1}\psi\left(\tfrac{i_{f,t+1}}{i_{f,t}}-1\right)\left(\tfrac{i_{f,t+1}}{i_{f,t}}\right)^2, \end{aligned} \tag{G.14}$$

$$\begin{aligned} \lambda_t &= \xi_t\left[1-\tfrac{\psi}{2}\left(\tfrac{i_{i,t}}{i_{i,t-1}}-1\right)^2\right]-\xi_t\psi\left(\tfrac{i_{i,t}}{i_{i,t-1}}-1\right)\tfrac{i_{i,t}}{i_{i,t-1}}+ \\ &+\beta\xi_{t+1}\psi\left(\tfrac{i_{i,t+1}}{i_{i,t}}-1\right)\left(\tfrac{i_{i,t+1}}{i_{i,t}}\right)^2, \end{aligned} \tag{G.15}$$

$$\nu_t = \beta\left[\nu_{t+1}(1-\delta_{f,t+1})+\frac{\lambda_{t+1}(1-\sigma)\alpha y_{f,t+1}}{k_{f,t+1}}\right], \tag{G.16}$$

$$\xi_t = \beta\left[\xi_{t+1}(1-\delta_{i,t+1})+\frac{\lambda_{t+1}\sigma\alpha y_{f,t+1}}{k_{i,t+1}}\right], \tag{G.17}$$

$$\nu_t k_{f,t}[\delta_1+\delta_2(u_{f,t}-1)] = \frac{\lambda_t(1-\sigma)\alpha y_{f,t}}{u_{f,t}}, \tag{G.18}$$

$$\xi_t k_{i,t}[\delta_1+\delta_2(u_{i,t}-1)] = \frac{\lambda_t\sigma\alpha y_{f,t}}{u_{i,t}}, \tag{G.19}$$

and, to the extent that the planner also chooses public investment and public capital optimally, we also have the first-order conditions for $g^g_{j,t}$ and $k^g_{j,t+1}$:

$$\lambda_t = \varphi_{j,t}, \tag{G.20}$$

$$\varphi_{j,t} = \beta\left[\varphi_{j,t+1}(1-\delta^g_j)+\frac{(\gamma_{f,j}+\sigma\gamma_{i,j})\lambda_{t+1}y_{f,t+1}}{k^g_{j,t+1}}\right], \tag{G.21}$$

where $j=1,2,3$; λ_t is the multiplier associated with the resource constraint in (G.10); ν_t is the multiplier associated with the motion of private capital in the final good sector in (G.5); ξ_t is the multiplier associated with the motion of private capital in the intermediate good sector in (G.6); and $\varphi_{j,t}$ is the multiplier associated with the motion of public capital j in (G.9).

Thus, for $j=1,2,3$ we have 25 equations in 25 variables $\{c_{h,t}$, $l_{f,t}$, $l_{i,t}$, $k_{f,t+1}$, $i_{f,t}$, $\delta_{f,t}$, $u_{f,t}$, $k_{i,t+1}$, $i_{i,t}$, $\delta_{i,t}$, $u_{i,t}$, $y_{f,t}$, $x_{i,t}$, λ_t, ν_t, ξ_t, $g^g_{j,t}$, $k^g_{j,t+1}$, $\varphi_{j,t}\}_{t=0}^{\infty}$ with given $\{g^c_t\}_{t=0}^{\infty}$.

Steady state capital shares

At the steady-state, (G.20) and (G.21) imply for $j = 1, 2, 3$:

$$1 = \beta \left[1 - \delta_j^g + \frac{(\gamma_{f,j} + \sigma\gamma_{i,j}) y_f}{k_j^g} \right], \tag{G.22}$$

so that we have:

$$\frac{k_j^g}{y_f} = \frac{\beta(\gamma_{f,j} + \sigma\gamma_{i,j})}{1 - \beta(1 - \delta_j^g)}, \tag{G.23}$$

and

$$\frac{K^g}{y_f} = \sum_{j=1}^{3} \frac{k_j^g}{y_f}. \tag{G.24}$$

Also for socially optimal private capital in the two sectors we have from (G.14)-(G.17):

$$\frac{k_f}{y_f} = \frac{\beta(1-\sigma)\alpha}{1 - \beta(1 - \delta_f)}, \tag{G.25}$$

$$\frac{k_i}{y_f} = \frac{\beta\sigma\alpha}{1 - \beta(1 - \delta_i)}, \tag{G.26}$$

$$\frac{K}{y_f} = \frac{k_f + k_i}{y_f}, \tag{G.27}$$

where, with the utilization rate equal to 1, $\delta_f = \delta_i = \delta_0$.

Appendix H: Self Financing Rate

A simple version of our model

If we start by defining total tax revenue, T, as the product of the tax rate, τ, and output, Y:

$$T = \tau Y, \tag{H.1}$$

then:

$$\frac{dT}{d\tau} = Y \left(1 + \frac{\partial Y}{\partial \tau} \frac{\tau}{Y} \right), \tag{H.2}$$

which is the slope of the standard Laffer curve in the $(T : \tau)$ space. Moreover the elasticity of tax revenues with respect to the tax rate is defined as:

$$e_{T,\tau} = \frac{dT}{d\tau} \frac{\tau}{T} = \left(1 + \frac{\partial Y}{\partial \tau} \frac{\tau}{Y} \right). \tag{H.3}$$

If we next define tax revenue as in a stylised version of our model:

$$T = \tau(p)Y(\tau(p), p), \tag{H.4}$$

where p is public spending, then:

$$\frac{dT}{dp} = \tau\frac{\partial Y}{\partial p} + Y\left(1 + \frac{\partial Y}{\partial \tau}\frac{\tau}{Y}\right)\frac{\partial \tau}{\partial p}. \tag{H.5}$$

Thus, combining (H.3) and (H.5) gives:

$$\begin{aligned} \tfrac{dT}{dp} &= \tau\tfrac{\partial Y}{\partial p} + \tfrac{dT}{d\tau}\tfrac{\partial \tau}{\partial p}, \\ &= \tau\tfrac{\partial Y}{\partial p} + e_{T,\tau}Y\tfrac{\partial \tau}{\partial p}. \end{aligned} \tag{H.6}$$

which is the total change in tax revenue when spending changes. In other words (H.6) is the slope of the spending Laffer curve. The first term on the RHS is the self-financing part since it denotes the additional revenue, $\tau\frac{\partial Y}{\partial p}$, due to the increase in the tax base, ∂Y, resulting from the change in spending, ∂p. The second term on the RHS is the part of tax revenue generated by discretionary rises in the tax rate, which are also driven by changes in public spending. Thus, the self-financing rate can be defined as:

$$sf = \frac{\tau\frac{\partial Y}{\partial p}}{\frac{dT}{dp}}, \tag{H.7}$$

and understood as follows:

1. If $\frac{\partial \tau}{\partial p} = 0$, $sf = 100\%$. This case occurs when higher spending does not trigger an increase in the tax rate so that the required extra government revenue is generated by a larger tax base only. The self-financing rate is also 100% when $\frac{dT}{d\tau} = e_{T,\tau} = 0$ or equivalently when $\frac{\partial Y}{\partial \tau}\frac{\tau}{Y} = -1$. Intuitively, when an increase in spending triggers a rise in the tax rate, but the latter leads to a fall in the tax base in the same proportion, the change in the tax revenue is zero. This happens, by definition, at the peak of the standard Laffer curve.

2. On the upward-sloping part of the standard Laffer curve, $\frac{dT}{d\tau}, e_{T,\tau} > 0$ so that $sf < 1$. In other words, both a more extensive tax base and a rise in the tax rate contribute to the required increase in the tax revenue due to the fiscal stimulus.

3. On the downward-sloping part of the standard Laffer curve, $\frac{dT}{d\tau}, e_{T,\tau} < 0$ so that $sf > 1$. In this case, an increase in the tax rate leads, other things equal, to a fall in tax revenues. Thus, the self-financing rate has to be higher than 100%. The tax revenue generated by the direct beneficial effect on real activity compensates for the loss in tax revenues due to higher tax rates.

4. If there is no direct beneficial effect on real activity from higher spending, namely $\frac{\partial Y}{\partial p} = 0$, then obviously $sf = 0$. Notice that sf can even become negative if the increase in spending is counter-productive, $\frac{\partial Y}{\partial p} < 0$. In this case, an increase in tax revenue achieved by the rise in the tax rate has to make up for the strong crowding-out of real economic activity and the associated loss in tax revenue. This occurs, for example, if the extra public spending is in the form of transfers that distort labour incentives and result in negative output multipliers.

Our model

In our model, recall that the government budget constraint is:

$$\begin{aligned} g_t^c + g_t^t + \textstyle\sum_{j=1}^{3} g_{j,t}^g + (1+r_t^b)b_{h,t} \equiv\ & \tau_t^c c_{h,t} + \tau_t^y w_t(l_{f,t} + l_{i,t}) + \\ & +\tau_t^f[(y_{f,t} - w_t l_{f,t} - p_{i,t}x_{i,t}) + (p_{i,t}x_{i,t} - w_t l_{i,t})] + \\ & +\tau_t^d(\pi_{f,t} + \pi_{i,t}) + b_{h,t+1}, \end{aligned} \tag{H.8}$$

so that the total tax revenue in our model is:

$$T_t \equiv \tau_t^c c_{h,t} + \tau_t^y w_t l_t + \tau_t^f(y_{f,t} - w_t l_t) + \tau_t^d \pi_t, \tag{H.9}$$

where $g_t^g = \sum_{j=1}^{3} g_{j,t}^g$, $l_t = (l_{f,t} + l_{i,t})$ and $\pi_t = (\pi_{f,t} + \pi_{i,t})$.

In equilibrium, changes in endogenous variables are driven by changes in the level of infrastructure spending denoted as dg^g. Recall that infrastructure spending can change both because of the assumed shock and any resulting changes in the level of output that affect the spending-to-GDP ratio, as specified in subsection 2.4 in the main text. Since the tax bases are functions of g^g and their own tax rate, the total derivative of the tax revenue is:

$$\begin{aligned} \frac{dT}{dg^g} =\ & \tau^c \frac{\partial c_h}{\partial g^g} + \tau^y\left(w\frac{\partial l}{\partial g^g} + l\frac{\partial w}{\partial g^g}\right) + \tau^f\left(\frac{\partial y_f}{\partial g^g} - w\frac{\partial l}{\partial g^g} - l\frac{\partial w}{\partial g^g}\right) + \tau^d\frac{\partial \pi}{\partial g^g} + \\ & +c_h\left(1 + \frac{\partial c_h}{\partial \tau^c}\frac{\tau^c}{c_h}\right)\frac{\partial \tau^c}{\partial g^g} + wl\left(1 + \frac{\partial w}{\partial \tau^y}\frac{\tau^y}{w} + \frac{\partial l}{\partial \tau^y}\frac{\tau^y}{l}\right)\frac{\partial \tau^y}{\partial g^g} + \\ & +y_f\left(1 + \frac{\partial y_f}{\partial \tau^f}\frac{\tau^f}{y_f}\right)\frac{\partial \tau^f}{\partial g^g} - wl\left(1 + \frac{\partial w}{\partial \tau^f}\frac{\tau^f}{w} + \frac{\partial l}{\partial \tau^f}\frac{\tau^f}{l}\right)\frac{\partial \tau^f}{\partial g^g} + \\ & +\pi\left(1 + \frac{\partial \pi}{\partial \tau^d}\frac{\tau^d}{\pi}\right)\frac{\partial \tau^d}{\partial g^g}, \end{aligned} \tag{H.10}$$

where the first line of the RHS is, as above, the part of tax revenues generated by changes in the tax bases for given tax rates or the self-financing component, while the other terms capture changes in tax revenues generated by higher tax rates. Thus, the self-financing rate is:

$$sf = \frac{\tau^c \frac{\partial c_h}{\partial g^g} + \tau^y \left(w \frac{\partial l}{\partial g^g} + l \frac{\partial w}{\partial g^g} \right) + \tau^f \left(\frac{\partial y_f}{\partial g^g} - w \frac{\partial l}{\partial g^g} - l \frac{\partial w}{\partial g^g} \right) + \tau^d \frac{\partial \pi}{\partial g^g}}{\frac{dT}{dg^g}}, \tag{H.11}$$

where, as in e.g. Trabandt and Uhlig (2011, section 4.1), the partial derivatives are approximated numerically as:

$$\begin{aligned}
\frac{\partial c_h}{\partial g^g} &\approx \frac{c_h(g^g \cdot (1+\epsilon)) - c_h(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)}, \\
\frac{\partial l}{\partial g^g} &\approx \frac{l(g^g \cdot (1+\epsilon)) - l(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)}, \\
\frac{\partial w}{\partial g^g} &\approx \frac{w(g^g \cdot (1+\epsilon)) - w(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)}, \\
\frac{\partial y_f}{\partial g^g} &\approx \frac{y_f(g^g \cdot (1+\epsilon)) - y_f(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)}, \\
\frac{\partial \pi}{\partial g^g} &\approx \frac{\pi(g^g \cdot (1+\epsilon)) - \pi(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)}, \\
\frac{dT}{dg^g} &\approx \frac{T(g^g \cdot (1+\epsilon)) - T(g^g \cdot (1-\epsilon))}{g^g \cdot (1+\epsilon) - g^g \cdot (1-\epsilon)},
\end{aligned} \tag{H.12}$$

and, recall from above, $g^g = \sum_{j=1}^{3} g_j^g$ and $g_j^g = s_j^g y_f$.

Finally, note that in the transition analysis (see section 6 in the main text), the above differences are with respect to the initial 2019 steady-state values so that, for any variable x, $dx_t = x_t - x$ where x is the initial steady-state value of the variable in question.

Appendix I: Dividend tax, Frisch elasticity and labour supply

We use a simple version of our model that allows for an analytical solution.

Household

Say that the household maximises as in the main paper:

$$\ln c - \mu \frac{l^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}}, \tag{I.1}$$

subject to the budget constraint:

$$c = (1-\tau^y) wl + (1-\tau^d)\pi. \tag{I.2}$$

The first-order condition for labour is as in the main paper:

$$\mu l^{\frac{1}{\nu}} = \frac{(1-\tau^y) w}{c}. \tag{I.3}$$

Combining the above two conditions, we have:

$$1 = \mu l^{\frac{1}{\nu}} \left[l + \frac{(1-\tau^d)\pi}{(1-\tau^y)w} \right]. \tag{I.4}$$

Totally differentiating this equation implies that work hours, l, increase with the dividend tax rate, τ^d, and the gross wage rate, w, while they decrease with the income tax rate, τ^y, and gross profits, π. Also, all these comparative static effects become stronger quantitatively as the value of the Frisch elasticity, ν, becomes larger. Below we show that the same properties carry over to general equilibrium where the wage rate and profits are endogenised. As discussed in the main text, the intuition behind the adverse effect of the net-of-dividend-tax profit relative to the net-of-income-tax wage rate is as in, e.g. Fang and Rogerson (2011, p. 168). The former works like a transfer, and this distorts the labour supply decision. However, at the same time, an increase in τ^d reduces the size of this transfer and hence the distortion.

Firm

Say that the firm maximises:

$$\pi = l^\alpha - wl. \tag{I.5}$$

The standard optimality condition is:

$$w = al^{\alpha-1}. \tag{I.6}$$

Equilibrium

Combining all the above, we have in equilibrium (given policy):

$$l = \left[\frac{1}{\mu\left(1 + \frac{(1-\tau^d)(1-\alpha)}{(1-\tau^y)\alpha}\right)} \right]^{\frac{1}{1+\frac{1}{\nu}}}. \tag{I.7}$$

That is, l increases with τ^d and decreases with τ^y as in the partial equilibrium analysis above.

Appendix J: Social Welfare

To calculate social welfare, V_t, we work as in, e.g. Schmitt-Grohé and Uribe (2007) and Sims and Wolff (2018), by adding the recursive specification of welfare to our equilibrium conditions:

$$V_t = u_t + \beta V_{t+1}, \tag{J.1}$$

where, u_t is the period utility function in equation (2). By forward substitution, starting at $t = 0$, we have $V_0 = \sum_{t=0}^{T} \beta^t u_t$ which is the present discounted value (PDV) of the household's lifetime utilities.

For our quantitative analysis, we define the pre-spending welfare as the PDV of lifetime utilities had we stayed forever in the pre-Covid 2019 steady-state (ss), i.e. $V_{ss} = \frac{u^{ss}}{1-\beta}$. In contrast, to assess the welfare accruing from the agreed public infrastructure shocks starting in period 1, we calculate the path of $\{V_t\}_{t=0}^{\infty}$ and use its value at $t = 1$, V_1, to measure the welfare due to the fiscal stimulus. Then, working as in the related literature, we define a permanent and constant consumption subsidy, χ, that solves $V_{ss} = V_1$, i.e.,

$$\begin{aligned} V_1 &= \frac{\ln[(1+\chi)c_{ss} - \xi(1+\chi)c_{ss}] - \mu\frac{(l_{ss})^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}}}{1-\beta}, \\ &= \frac{\ln(1+\chi) + \ln(c_{ss} - \xi c_{ss}) - \mu\frac{(l_{ss})^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}}}{1-\beta}. \end{aligned} \tag{J.2}$$

Solving (J.2) for χ gives:

$$\chi = (e^{(1-\beta)(V_1 - V_{ss})} - 1) \times 100, \tag{J.3}$$

where $\frac{\ln(c_{ss} - \xi c_{ss}) - \mu\frac{(l_{ss})^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}}}{1-\beta} = \frac{u^{ss}}{1-\beta} = V_{ss}$. In other words, χ is the subsidy that should be given to the household in 2019 to make it as well off as after the increase in public infrastructure. A positive subsidy, $\chi > 0$, implies a welfare gain from higher public infrastructure, and vice versa if $\chi < 0$.