THE MEDIUM-TERM EFFECTS OF INVESTMENT STIMULUS

2024

BANCO DE ESPAÑA
Eurosistema

Documentos de Trabajo
N.º 2402

Rubén Domínguez-Díaz, Samuel Hurtado
and Carolina Menéndez

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Rubén Domínguez-Díaz [**]

BANCO DE ESPAÑA

Samuel Hurtado [***]

BANCO DE ESPAÑA

Carolina Menéndez [****]

BANCO DE ESPAÑA

(*) The views expressed in this paper are those of the authors and do not necessarily reflect those of the Banco de España or the Eurosystem.
(**) dominguezdiazruben@gmail.com.
(***) samuel.hurtado@bde.es.
(****) carolina.menendez@bde.es.

Documentos de Trabajo. N.º 2402

January 2024

https://doi.org/10.53479/35913

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ISSN: 1579-8666 (on line)

Abstract

This paper presents an endogenous growth general equilibrium model (EGGEM) of firm dynamics and innovative investment for the Spanish economy that allows the medium-term effects of economic policies and shocks to be better understood. The model is calibrated using both aggregate and firm-level data. It is then used to assess the medium-term macroeconomic consequences of the different components of the Next Generation EU (NGEU) programme, including public investment, private capital transfers and innovative investment transfers. According to our baseline simulation, the NGEU funds significantly foster economic activity by raising aggregate productivity, private investment and employment. As a result, annual GDP growth is increased by 0.17 percentage points on average over the period of NGEU disbursement. Among the different policy instruments considered, we find that innovation transfers have the largest impact on aggregate output, only matched by increases in the stock of public capital if it is highly efficient.

Keywords: productivity, public investment, endogenous growth, Next Generation EU.

JEL classification: O38, O52, O40, H54, E65.

Resumen

Este artículo presenta un modelo de equilibrio general y crecimiento endógeno (EGGEM) con dinámicas empresariales e inversión en innovación para la economía española, el cual permite una mejor comprensión de los efectos a medio plazo de políticas económicas y perturbaciones. El modelo se calibra usando datos agregados y datos a nivel de empresa. Una vez calibrado, se utiliza para evaluar los efectos macroeconómicos a medio plazo de los diferentes componentes de los fondos Next Generation EU (NGEU), incluyendo inversión pública, transferencias destinadas a la construcción de capital privado y transferencias dirigidas a la inversión en innovación. De acuerdo con nuestras principales simulaciones, los fondos NGEU estimularían la actividad económica significativamente, incrementando la productividad, la inversión privada y el empleo. En consecuencia, el crecimiento anual del PIB aumentaría de media en torno a 0,17 puntos porcentuales durante el período de gasto de los fondos NGEU. Entre los diferentes componentes que se consideran, se encuentra que las transferencias a la innovación tienen los mayores efectos en el *output* agregado, siendo estos solo comparables a la construcción de capital público si este es altamente eficiente.

Palabras clave: productividad, inversión pública, crecimiento endógeno, Next Generation EU.

Códigos JEL: O38, O52, O40, H54, E65.

1 Introduction

At least since Lucas (1987, 2003), it is well understood that economic policies and macroeconomic disturbances that have long-lasting effects on economic activity are of first-order importance for welfare. More recently, the last financial crisis together with the recent pandemic and energy crises have revived the interest on the persistent effects of shocks and of subsequent policy responses.[1] A prominent example is the the Next Generation EU (NGEU) program enacted by the European Commission in 2020, one the largest fiscal stimulus measures in the history of the European Union, aimed to fostering a long-lasting and structural recovery of member states after the pandemic crisis (European Council, 2020).

In this paper we introduce a dynamic general equilibrium model of endogenous growth (EGGEM) based on Atkeson and Burstein (2019) that allows us to explore the long-term effects of economic policies and economic events. We first extend the model along several dimensions, such as elastic labor supply and productivity-enhancing public capital, and we calibrate it to the Spanish economy using aggregate and firm-level data. We then use the model to study the aggregate consequences of three different broad components of the NGEU funds: public investment, private capital transfers, and innovation transfers. According to our results, the funds associated with the NGEU program can be expected to have significant effects on output over the medium term, driven by increases in capital accumulation, productivity, and hours worked. The average baseline fiscal multiplier of the NGEU is around unity, with the multiplier associated to innovation transfers standing out as particularly high.

More in detail, we consider a real model of firms dynamics for a closed-economy – with the exception of international transfers. Firms use physical capital and labor as production inputs. These are supplied elastically by households. In addition, firms engage in innovative investment: incumbent firms can invest to create new products (Romer, 1990)

[1] For example, Aikman et al. (2022) discusses the lasting effects on output of deep contractions, Jordà et al. (2022) document the persistent economic consequences of pandemics, Anzoategui et al. (2019) provide a model where weak aggregate demand leads to a slowdown of productivity growth, and Garcia-Macia (2017) shows that the interaction between financial frictions and intangible investment generate persistent slumps in a model calibrated to the Spanish economy.

or improve the productivity of their own existing products (Aghion and Howitt, 1992), while entering firms carry out innovative investment that leads to the creation of new products. As a result, aggregate productivity in this economy is endogenous to firms' innovative investment decisions, and hence to economy policy.

We calibrate the model to the Spanish economy using aggregate data from 2000 to 2019 and firm-level data from the Central Balance Sheet Data Office, maintained by Banco de España, to discipline the parameters driving the innovation process of firms.

We jointly consider three different policy instruments in this framework, following the breakdown of NGEU projects in Spain elaborated in Fernández-Cerezo et al. (2023). First, we introduce productivity-enhancing public physical capital, which allows firms to use their production inputs more efficiently (Baxter and King, 1993; Ramey, 2020). Second, we model two types of fiscal transfers to firms, one that is used to build physical capital, and one that is used to finance innovative investment. In line with the funding design of the NGEU program, we assume that these three policies are initially financed through international transfers that are later paid back, partially or totally, by the fiscal authority through a combination of labor income and consumption taxes. Our simulation assumes that the NGEU funds received by Spain are spent uniformly over time and split between the three different policy instruments in the proportions documented in Fernández-Cerezo et al. (2023).

Our quantitative findings are as follows. First, under our baseline simulation output growth increases by up to 0.17 percentage points per year over the duration of the NGEU program and output increases by up to 1.4% by the end of the program, relative to the a scenario without NGEU. We show that the stimulus to output is driven by improvements in all production inputs, including private physical capital accumulation and the increase in productivity that results from fiscal transfers to firms.

Next, we use the model as a laboratory to evaluate the effects of alternative allocations of funds. This allows us to investigate the relative effectiveness of different policy instruments in terms of fostering economic activity. We consider three different scenarios; in each of them all funds are allocated to just one of the policy instruments considered. We find that innovation transfers tend to deliver the largest effects on aggregate output, only comparable to the effects of public investment if we assume that public capital is highly efficient. Instead, allocating the funds to private capital transfers delivers smaller effects, albeit still meaningful and positive. The reason behind the more limited effects of private capital transfers is that these, by increasing the stock of capital, lead to a fall in the return of private capital. This discourages households savings, crowding-out the accumulation of physical capital financed with private resources. Therefore, physical capital increases less than one-to-one with transfers. A similar logic also applies to innovation transfers, but this policy still delivers higher effects because innovations that increase aggregate productivity increase aggregate output one-to-one, while the elasticity of output to either private or public capital is smaller than one.

Finally, we compute the fiscal multipliers associated with the baseline simulation of the NGEU program and with each of the alternative scenarios considered. We obtain that the cumulative fiscal multiplier in the baseline simulation is around 1. The fiscal multiplier associated with public investment ranges between 0.75 and 1.3, depending on the assumed efficiency of public capital. On the contrary, the fiscal multiplier associated with innovation transfers is consistently around 1, while the fiscal transfers to private capital deliver the lowest multiplier, around 0.46, in line with our previous discussion.

Related Literature. This paper contributes to several strands of the literature at the intersection of macroeconomic policies and their persistent effects on economic activity.

Considering firms' innovative investment in our framework allows the policies that we entertain to have a long-lived effect on aggregate productivity and output. In this regard, our work is related to Atkeson and Burstein (2019) or Bloom et al. (2002), who explore the effects on productivity of R&D subsidies. In a similar vein, Akcigit et al. (2021) show empirically, using cross-sectional data, that changes in corporate taxes tend to affect the innovation decisions of firms. Complementary, Cloyne et al. (2022) rely on aggregate data to show that corporate tax cuts boost R&D investment, leading to long-lasting effects of this policy. On the other hand, Antolin-Diaz and Surico (2022) document that military spending shifts public spending towards R&D, boosting aggregate output for longer than public consumption expenditures. In the context of the Spanish economy, Garcia-Macia

(2017) shows that transfers to young firms, which tend to be financially constrained, could have boosted intangible investment during the Great Recession, speeding up the recovery. Our work complements these papers by instead focusing on the joint role of fiscal transfers and public investment in boosting output and productivity over the medium term.

Our work also adds to the literature exploring the aggregate effects of public investment. Leeper et al. (2010) emphasizes the role played by implementation delays in a neoclassical growth model. Peri et al. (2023) show that public investment multipliers are amplified in a production network model with sticky prices. Ramey (2020) surveys the literature and explores the mechanisms underlying the propagation of public investment. Our paper complements this literature by also allowing productive-enhancing capital to spill over to the innovation investment decisions of firms.

Finally, a few papers have recently investigated the aggregate consequences of the NGEU program. Pfeiffer et al. (2022) study the effects of the NGEU funds in a New Keynesian multi-country model, finding that cross-country spillovers are an important source of amplification. This paper, however, only considers public investment and abstracts from fiscal transfers. More similar to us, Fernández-Cerezo et al. (2023) introduce a production network static model calibrated to the Spanish economy to analyze the aggregate and sector-level effects of the NGEU funds. We complement this work by also accounting for the endogenous movements in productivity in a dynamic framework.

Outline The remaining of the paper is structured as follows. We describe the model and related policies in section 2. Section 3 presents our calibration strategy. We present the results of the simulation exercises, including details of our mapping from the NGEU program to the model, in section 4 . A final section concludes.

2 Model

A fundamental goal of the NGEU funds is to foster economic growth over the medium and long term. In order to do so, funds have been allocated, for example, to public infrastructure and to transfers to firms designed to promote investment in physical capital and improve productivity (Fernández-Cerezo et al., 2023). Therefore, analyzing the macroeconomic consequences of the NGEU program requires a model that is able to capture the medium-term effects of economic policies and that allows for endogenous movements in productivity. Towards this end, we consider and extend the endogenous growth model of Atkeson and Burstein (2019).[2] The framework is a real model of a closed economy, with the exception of international fiscal transfers, that allows for accumulation of physical capital, productivity-enhancing public capital, fiscal transfers, and innovative investment (Aghion and Howitt, 1992; Romer, 1990). This means that, in our framework, aggregate productivity and economic growth are endogenous to firms' decision and therefore to economic policies such as public capital or fiscal transfers.

2.1 Households

The economy is populated by an infinitely lived representative household with time-separable preferences over per capita consumption C_t/H_t and hours worked:

$$\max_{C_t, K_{t+1}, B_{t+1}, L_t^p, L_t^r} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t H_t \left(\log\left(\frac{C_t}{H_t}\right) - \kappa \frac{\left(\frac{L_t^r + L_t^p}{H_t}\right)^{1+\varphi}}{1+\varphi} \right) \quad \text{s.t.} \tag{1}$$

$$\begin{aligned} (1+\tau_t^C)C_t + I_t + B_{t+1} = (1-\tau_t^L)(W_t^p L_t^p + W_t^r L_t^r) + r_t^k K_t + (1+R_{t-1})B_t \\ + D_t - \Xi^L(L_t^p, L_t^r, L_{t-1}^p, L_{t-1}^r), \end{aligned} \tag{2}$$

$$K_{t+1} = (1-\delta_K)K_t + I_t + T_t^K - \Xi^I(I_t, K_t), \tag{3}$$

where $\beta \in (0,1)$ and H_t denotes population, which grows at an exogenous rate g_H. The household can save in physical capital K_t , which rents to firms at rental rate r_t^k , and in government bonds B_t, with risk-free return R_t. Additionally, the household derives labor income from supplying production working hours L_t^p, paid at wage rate W_t^p, and research working hours L_t^r with wage rate W_t^r. Here, τ_t^L marks the labor income tax rate, and τ_t^C the consumption tax. We assume that labor is subject to adjustment costs

[2] We follow the exposition of Atkeson and Burstein (2019) where there is overlay in the description of the model. A detailed descriptions of model equations can be found in appendix A.

$\Xi^L(L_t^p, L_t^r, L_{t-1}^p, L_{t-1}^r)$. Finally, economy-wide firms' profits D_t are rebated lump-sum to the household.

The capital accumulation equation is given by (3), where δ_K marks the depreciation rate of private physical capital and $\Xi^I(I_t, K_t)$ denotes capital adjustment costs. Capital accumulates over time due to two main forces. First, through the investment expenditures that the household finances with her own market income, I_t. Second, we consider government transfers that the household can only use to build physical capital. T_t^K.[3]

We note that although we assume that the household has to spend government transfers T_t^K on building private capital, this does not mean that transfers do not distort the investment made by the household with the non-transfer income, I_t. Namely, under the production function we consider in section 2.2, the extra capital built with government transfers may come, in equilibrium, with a fall in the capital return r_t^k. Such fall in the return to household savings can potentially crowd-out investment I_t.

2.2 Production Sector

The production sector of the economy consists of three sub-sectors: First, a final good producer that bundles intermediate goods. Second, intermediate goods producers that engage in innovative investment and use physical capital and production labor as productions inputs. As we specify in more detail below, intermediate goods producer finance innovative investment through their own resources and also through government transfers that have to be spent on innovative activities, similar to the case of capital transfers. Third, a research good producer that uses research labor as factor input.

2.2.1 Final Good Producer

A competitive final good producer combines a continuum of differentiated intermediate goods using a constant elasticity of substitution (CES) production function to produce a final good Y_t:

[3] In the data, transfers to build private capital are given to firms rather than to households. Alternatively, one could introduce in the model a firm that takes the role of a capital good producer and let the government give the transfers to such firm. However, since the representative household is the ultimate owner of all firms in this economy, that formulation and the one we consider here are equivalent.

$$\max_{y_t(z)} \quad Y_t - \sum_z p_t(z) y_t(z) M_t(z) \quad \text{s.t.} \quad Y_t = \left[\sum_z M_t(z) y_t(z)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{4}$$

with $\rho > 1$. Above, $y_t(z)$ denotes the output of an intermediate producer with productivity index z, which has a price $p_t(z)$. $M_t(z)$ denotes the mass of intermediate goods with productivity index z at time t.

2.2.2 Intermediate Good Producers

There is a continuum of intermediate good producers that produce differentiated goods y using production labor l^p and physical capital k. We summarize the technology that is used in the production of an intermediate good at time t by its productivity index z. Moreover, we assume that public capital K_t^G improves the use of private resources by firms with efficiency χ, such that the production function is given by:

$$y_t(z) = z \left(K_t^G \right)^{\chi} k_t(z)^{\alpha} l_t^p(z)^{1-\alpha}, \tag{5}$$

with $\alpha \in (0,1)$. As in Atkeson and Burstein (2019), we assume that z has a countable support with grid elements z_n, and refer to the highest element in the grid for each intermediate good as the frontier technology for that good. Since capital and labor are flexible at the firm-level, the optimal allocation of production inputs maximizes per-period firms' variable profits, defined as:

$$\pi_t(z) \equiv \left(p_t(z) y_t(z) - W_t^p l_t^p(z) - r_t^k k_t(z) \right). \tag{6}$$

Intermediate good producers can engage innovative investment, which requires the purchase of a research good. Innovative investment results in the creation of a new product in the economy, as in Romer (1990), or in efficiency improvements of already existing products. As we show later, this leads to changes in aggregate productivity.

We allow both incumbent firms, those that produce at time t and were also producing at time $t-1$, and new entrants (that did not produce at time $t-1$) to invest in innovation. Innovative investment by entrants can only lead to the creation of products that are new to society.[4] Incumbent firms, additionally, can also improve the efficiency of the products that they already own. Furthermore, we assume that an exogenous fraction δ_0 of goods produced by incumbent firms exits the market each period. We describe the innovation process of incumbents and entering firms next.

Innovative investment by entering firms. We denote by M^e_{t+1} the measure of enters that invest in innovation at time t. Each of these firms obtains at $t+1$ a frontier technology to produce a new intermediate good with productivity index z'. As in Atkeson and Burstein (2019), and similar to Luttmer (2007), we assume that z' is drawn from a distribution such that $\mathbb{E}_t z'^{\rho-1} = \eta_e Z_t^{\rho-1}/M_t$, where Z_t denotes aggregate productivity and M_t marks the total measure of products available. More precisely, these are defined as:

$$Z_t = \left(\sum_z z^{\rho-1} M_t(z)\right)^{\frac{1}{\rho-1}} \tag{7}$$

$$M_t = \sum_z M_t(z). \tag{8}$$

Finally, we assume that an entering firm has to purchase $1/M_t$ units of the research good at time t to create a new firm with one product at time $t+1$. We denote by x^e_t the total amount of research goods purchased by M^e_{t+1} entering firms at time t. Note that this implies that $x^e_t = M^e_{t+1}/M_t$.

Denoting by $V_t(z)$ the value of an intermediate-good firm with productivity index z at time t, the free-entry condition is given by:

$$\frac{1}{M_t} P^r_t = \mathbb{E}_t \frac{1}{1+R_t} V_{t+1}(z'), \tag{9}$$

where P^r_t marks the price of the research good at time t. The left hand side in (9) is the marginal cost of investing one additional unit in innovation $x^e_t(z)$, since this has a cost $P^e_t M_t^{-1}$ for an entering firm. The right hand size is the expected discounted value of ob-

[4]The model could also be also easily adapted to include business stealing as is standard in quality ladder models (Klette and Kortum, 2004). See, for example, Atkeson and Burstein (2019).

taining a product with productivity z' at time $t+1$ as result of that innovative investment decision.

Innovative investment by incumbent firms. Incumbent firms can purchase research goods to create products that are new society, as entering firms, or to improve the efficiency of the products that they already own.

First, consider the former case. An incumbent firm has the opportunity to invest $x_t^m(z)$ units of the research good at time t to create a new product at time $t+1$ with probability $h\left(x_t^m(z)/s_t(z)\right)$, where $s_t(z)$ is given by:

$$s_t(z) \equiv \left(\frac{z}{Z_t}\right)^{\rho-1}. \tag{10}$$

Similar to the case of entering firms, we assume that the productivity index of the new product created by an incumbent firms is drawn from a distribution such that $\mathbb{E}z'^{\rho-1} = \eta_m z^{\rho-1}$. Similarly, the aggregate quantity of research goods purchased by incumbent firms to create new products is given by $x_t^m = \sum_z M_t(z) x_t^m(z)$.

Second, consider the case of an incumbent firm that wishes to improve the productivity of a product with productivity index z that it already produces. Such firm purchases $x_t^c(z)$ units of the research good at time t and draws a new productivity index z' for its existing product – conditional on not exiting the market – from a distribution such that $\mathbb{E}z'^{\rho-1} = \zeta\left(x_t^c(z)/s_t(z)\right) z^{\rho-1}$. In a similar fashion to the previous cases, we define the aggregate quantity of this class of innovative investment $x_t^c = \sum_z M_t(z) x_t^c(z)$.

Under the previous assumptions, we can write the intertemporal problem of an incumbent firm with productivity index z as:

$$V_t(z) = \max_{x_t^c(z), x_t^m(z)} (1-\tau_t^{\text{Corp}})\pi_t(z) - P_t^r\left(x_t^m(z) + x_t^c(z)\right) + T_t^{R,c} + T_t^{R,m} + \mathbb{E}_t \frac{1}{1+R_t} V_{t+1}(z'), \tag{11}$$

where $\pi_t(z)$ are per period variable profits as defined in (6) and τ_t^{Corp} is a coporate tax rate. $T_t^{R,m}$ and $T_t^{R,c}$ are fiscal transfers for innovative investment provided by the government. We discuss these next.

Fiscal transfers to innovation. The fiscal authority provides intermediate good producers with transfers that have be spent on innovative investment, similar to the case of fiscal transfer to be used for capital accumulation. Namely, we consider that the total amount of research good purchased for a type of innovative investment, $\{x_t^e, x_t^m, x_t^c\}$, consists on the amount of goods that firms purchase using its resources $\tilde{x}_t^j$ plus the the amount of goods purchased using fiscal transfers $T_t^{R,j}$:

$$P_t^r x_t^j = P_t^r \tilde{x}_t^j + T_t^{R,j}, \quad \text{with} \quad j \in \{e, m, c\} \tag{12}$$

In line with the case of fiscal transfers, we also note here that fiscal transfers $T_t^{R,j}$ can distort firms' innovative investment decisions in equilibrium. This follows since a greater demand for research goods arising from an increase in transfers may lead to an increase in the price of the research good, leading to a fall in the amount that firms spend on innovative investment using their own resources.

2.2.3 Research Good Producer

A representative research good producer hires research labor L_t^r to produce the research good used in the innovation process according to:

$$Y_t^r = A_t^r \left(K_t^G\right)^{\chi} Z_t^{\phi-1} L_t^r. \tag{13}$$

Above, A_t^r can be interpreted as a stock of freely available scientific progress, which we assume to grow at an exogenous rate g_{A_r}. Moreover, as in the case of the production of intermediate goods, we assume that public capital K_t^G improves the efficiency with which research labor is used. Finally, the term $Z_t^{\phi-1}$, with $\phi \leq 1$, follows Jones (2002). It represents intertemporal knowledge spillovers. Namely, since $\phi \leq 1$, increases in aggregate productivity Z_t reduce the efficiency of research labor, capturing the notion outlined in Bloom et al. (2020) that "ideas are getting harder to find".

The research good is sold at price P_t^r to intermediate good produces engaging in innovative investment, such that the research good producer solves the following intratemporal problem:

$$\max_{L_t^r} \quad P_t^r Y_t^r - W_t^r L_t^r \quad \text{s.t.} \quad Y_t^r = A_t^r \left(K_t^G\right)^{\chi} Z_t^{\phi-1} L_t^r \tag{14}$$

2.3 Government

The government consists of a fiscal authority. The government raises revenue from labor income taxes, consumption taxes and corporate taxes. In addition we allow for the possibility that the government receives international transfers T_t^{EU}. It uses the revenue and government debt B_{t+1} to finance interest payments on public debt and expenditures. Government expenditures consists of public investment I_t^G and transfers to firms dedicated to either purchase physical capital T_t^K or research goods $T_t^{R,j}$. Therefore, the budget constraint of the government is given by:

$$\begin{aligned} I_t^G + B_t(1+R_{t-1}) + T_t^{R,e} + T_t^{R,m} + T_t^{R,c} + T_t^K = B_{t+1} + \tau_t^L(W_t^r L_t^r + W_t^p L_t^p) \\ + \tau_t^C C_t + \tau_t^{\text{Corp}} \sum_z M_t(z)\pi_t(z) + T_t^{\text{EU}}, \end{aligned} \tag{15}$$

$$\text{with} \quad I_t^G = K_{t+1}^G - (1-\delta^G)K_t^G,$$

where δ^G marks the depreciation rate of physical capital.

2.4 Equilibrium, Market Clearing, and Productivity Dynamics

A *competitive equilibrium* is a sequence of consumption and hours $\{C_t, L_t^r, L_t^p\}_t$, private and innovative investment $\{I_t, x_t^e, x_t^m, x_t^c\}_t$, such that given prices $\{W_t^r, W_t^p, P_t^r, r_t^k, R_t, q_t\}_t$ and a sequence for public capital $\{K_t^G\}_t$ and transfers $\{T_t^{\text{EU}}, T_t^K, T_t^R\}$ such that households a firms optimize and markers clear:

1. The labor market clears if $L_t^p = \sum_z M_t(z) l_t^p(z)$ and the amount of research hours supplied by the household equals the research ours demanded by the research good producer.

2. The capital market clears if $K_t = \sum_z M_t(z) k_t(z)$

3. The market for research goods clears if the innovative investment by entering firms and incumbent firms equals the production of the research good:

$$Y_t^r = x_t^e + x_t^m + x_t^c \tag{16}$$

4. The market for the final good clears if the total ouput is used either for private consumption or for public or private investment:

$$C_t + I_t + I_t^G = Y_t \tag{17}$$

5. The market for intermediate good producers clears by Walra's law.

Similarly, we define a *Balanced Growth Path* (BGP) as a competitive equilibrium where all variables grow at constant rates. In appendix A.5 we provide a detailed description of detrended variables and associated equilibrium conditions in terms of stationary variables.

2.5 Aggregation and Productivity Dynamics

In appendix A.3 we show that in equilibrium, under the assumptions made on the innovation process of firms together with constant markups, aggregate output can be written as:

$$Y_t = Z_t (K_t^G)^{\chi} (K_t)^{\alpha} \left(L_t^p\right)^{1-\alpha}, \tag{18}$$

where aggregate productivity Z_t is defined in (7).

The expression for aggregate output (18), together with expression for Z_t, makes clear that firm-level innovative investment – and policies that affect it – lead to endogenous changes into aggregate productivity Z_t, and hence on output Y_t.

We can see this point more clearly by deriving an expression for the dynamics of aggregate productivity following Atkeson and Burstein (2019). First, we consider the dynamics for the total measure of products available, M_t, which is given by:

$$M_{t+1} = (1 - \delta_0) M_t + x_t^e M_t + h\left(x_t^m\right) M_t. \tag{19}$$

The above expression states that the total measure of products available in $t+1$, M_{t+1}, is governed by three forces. The first one – the first term on the right hand side of (19) –

corresponds to the exogenous exit of products from the market. That is, only a fraction $1-\delta_0$ of existing products in t survive to the next period. The second force – second term in equation (19) – corresponds to the mass of entering firms, $M^e_{t+1}=x^e_t M_t$, which engage in innovative investment at time t to create a new product at time $t+1$. Similarly, the last term corresponds to the fraction of incumbent firms that engage in innovative investment to create new products.

Following a similar logic, we can derive the dynamics of aggregate productivity Z_t, given by:

$$Z_{t+1}^{\rho-1}=(1-\delta_0)\zeta(x_t^c)M_t\frac{Z_t^{\rho-1}}{M_t}+\eta_m h(x_t^m)M_t\frac{Z_t^{\rho-1}}{M_t}+\eta_e x_t^e M_t\frac{Z_t^{\rho-1}}{M_t} \tag{20}$$

The level of productivity next period, Z_{t+1}, depends on three terms determined by the innovative investment of incumbents and entrants. The first term on the right hand side of equation (20) is the average productivity $t+1$ of products that were already produced at time t by incumbent firms that did no exit the market. The second term, corresponds to the average productivity of new products at time $t+1$ that results from innovative investment incurred by incumbent firms at time t. The final term in equation (20) is the average productivity of new products in the economy resulting from innovative investment of entering firms.

Taking logs in equation (20) and rearranging we can then express aggregate productivity growth, $g_{Z,t}\equiv\log Z_{t+1}-\log Z_t$, as:

$$g_{Z,t}=\frac{1}{\rho-1}\log\left((1-\delta_0)\zeta(x_t^c)+\eta_m h(x_t^m)+\eta_e x_t^e\right), \tag{21}$$

which makes explicit the dependence of productivity growth on innovative investment decisions of incumbent and entering firms.

3 Calibration

We calibrate the model to the Spanish economy. The calibration sample is 2000-2019, starting shortly after the creation of Euro area and ending right before the COVID-19 crisis. One period in the model corresponds to one year. We draw from two data sources to calibrate the model. First, we obtain aggregate data from the National Statistical Office of Spain (Instituto Nacional de Estadística, INE). Second, we rely on Central Balance Sheet Data Office (Central de Balances), maintained by Banco de España, to obtain the firm-level data used in the calibration of the innovation process of firms.

3.1 Household Sector

We set the inverse of the Frish elasticity φ to be equal to one, in the range of the estimates provided in Chetty et al. (2011). The parameter governing the disutility from labor, κ, is set to match an average unemployment rate of 16% over the period. We set the time-discount factor, β, to target an annualized interest rate of 2.5% at the steady state. The population growth, g_H, is set to 0.6%, in line with the average population growth in Spain over the sample period.

As regards of the parameters affecting the capital accumulation process, we first assume a functional form for the capital adjustment costs $\Xi^I(I_t, I_{t-1}, K_t)$ similar to Christiano et al. (2011):

$$\Xi^I(I_t, K_t) = \frac{\sigma_I}{2}\left(\frac{I_t}{K_t} - (\delta_K + \exp(g_Y) - 1)\right)^2 K_t, \tag{22}$$

where g_Y marks the constant growth rate of output at the BGP. We set σ_I equal to 17, in line with the estimates of Eberly et al. (2008), and the depreciation rate of private physical capital, δ_K, to be 5.5% annually, in line with the estimates of Arencibia Pareja et al. (2018).

We assume that labor adjustment costs have a similar functional form:

$$\Xi^L(L_t^p, L_t^r, L_{t-1}^p, L_{t-1}^r) = \frac{\sigma_L}{2}\left(\log(\frac{L_t^r/H_t}{L_{t-1}^r/H_{t-1}})^2 + \log(\frac{L_t^p/H_t}{L_{t-1}^p/H_{t-1}})^2\right). \tag{23}$$

We calibrate the parameter governing the labor adjustment costs, σ_L, such that it is equal to 4.5% of the quarterly wage rate at the BGP, which is line with the vacancy-posting costs estimates of Silva and Toledo (2009). This results in $\sigma_L = 0.23$.

3.2 Government

We assume that the stock of public capital depreciates at the same rate as the private capital, meaning that $\delta_G = 5.5\%$. The range of estimates of the efficiency of public capital, χ, is rather wide (cf. Bom and Ligthart, 2014). Therefore, in our simulations we will consider two possible values for this parameter, $\chi \in \{0.05, 0.15\}$, which are towards the lower end and upper end of available estimates, respectively.

Regarding tax rates we proceed as follows. We first normalize the consumption tax rate to 0.[5] We then set the corporate tax rate to target a ratio of firms' tax payments to

Table 1: Calibration

Parameter	Description	Value	Target / Source
Households			
κ	Disutility from labor	1.14	$L/H = 0.84$
φ	Frisch elasticity	1	Chetty et al. (2011)
β	Discount factor	0.99	$R = 2.5\%$
g_H	Growth rate Pop.	0.6%	INE
δ_K	Depreciation capital	5.5%	Arencibia Pareja et al. (2018)
σ_I	Capital adj. cost	17	Eberly et al. (2008)
σ_L	Labor adj. cost	0.23	Silva and Toledo (2009)
Government			
τ^l	Labor income tax rate	0.04	$I^G/Y = 3.5\%$
τ^{Corp}	Corporate profit tax rate	0.42	Firms' taxes / profits = 9.18%
δ_G	Depreciation public capital	5.5%	Same as δ_K
χ	Efficiency public capital	$\{0.05, 015\}$	Bom and Ligthart (2014)
Production			
ρ	Elasticity Substitution	4	Broda and Weinstein (2006)
ϕ	Intertemp. Externatility	-1.6	Fernald and Jones (2014)
g_{Ar}	Exogenous Prod. Growth	0.06%	$g_Y = 1.6\%$
α	Capital share	0.43	$K/Y = 4.23$
Innovation			
δ_0	Exit rate	0.05	
η_e	Prod. step entrant	1.6	
η_m	Prod. step incumb.	0.74	See text for a discussion
$\{h_0, h_1\}$	Fct. innov. new prod. incumb.	$\{0.4, 0.5\}$	
$\{\zeta_0, \zeta_1, \zeta_2\}$	Fct. innov. exist. prod. incumb.	$\{0.9, 0.6, 0.5\}$	

Notes: List of calibrated parameters. See text for a discussion on targets, values, and data used.

[5] All tax rates are constant in the BGP. Therefore, the only first-order condition where the consumption tax is in the intratemporal condition characterizing labor supply. It does so in a symmetric way to the labor income tax, such that increasing one is equivalent to decreasing the other.

profits equal to 9.18%, which is achieved with $\tau^{\text{Corp}} = 0.42$. Next, we set international transfers, transfers to firms, and public debt equal to zero at the BGP. Finally, we set the tax rate on labor income, τ^L, to target a share of public investment over GDP of 3.5%.

3.3 Production and Innovation

We set the elasticity of substitution across intermediate goods equal to 4, in line with the estimates of Broda and Weinstein (2006). The parameter governing the intertemporal externality of technological progress in (13), ϕ, is set to -1.6 following Fernald and Jones (2014). Next, we set exogenous growth rate of A equal to 0.06% to target an annual growth rate of output of 1.6% at the BGP, the average growth rate GDP in our sample period. The capital share α in the model is set to target a capital-to-output ratio of 4.23, as in Arencibia Pareja et al. (2018).

Our calibration strategy for the innovation process of firms closely follows Atkeson and Burstein (2019) whenever possible. Namely, we next posit the following functional forms for the innovation functions of incumbents for new products, $h(x_t^m)$, and for existing products, $\zeta(x_t^c)$:

$$h(x_t^m) = h_0 (x_t^m)^{h_1} \tag{24}$$

$$\zeta(x_t^c) = \zeta_0 + \zeta_1 (x_t^c)^{\zeta_2}. \tag{25}$$

Therefore, there are eight remaining parameters to be calibrated. We need to calibrate the productivity steps of new products for entrants and incumbents, η_e and η_m; the exogenous exit rate of products from the economy, δ_0; and the parameters governing the innovation function for new products (h_0 and h_1) and for continuing products (ζ_0, ζ_1, and ζ_2). We calibrate these parameters following the same strategy derived in Atkeson and Burstein (2019). Namely, we start by setting ζ_2 equal to 0.5, which is the mid point of admissible values for this parameter according to Atkeson and Burstein (2019). Next, we set the remaining seven parameters to target the following firm-level moments obtained from Central Balance Sheet Data Office: the growth rate of the number of firms (1%); the share of production that corresponds to new firms (0.02), to the growth of incumbent firms (0.04), and to previous levels of production of incumbent firms (0.94); the share of employment that corresponds to new firms (0.03), to the growth of incumbent firms (0.03), and to previous levels of employment of incumbent firms (0.94). [6]

4 Simulation Exercises

We next use the model to assess the aggregate impact of the NGEU program on the Spanish economy, considering alternative allocations of funds, and compute the implied fiscal multipliers associated with the fiscal program. We compute the transition paths that follow the implementation of the NGEU program within our model under the assumption of perfect foresight. We first describe the mapping between the data on NGEU funds and the model and our assumptions regarding the funding on the program, and later present our main quantitative results and counterfactuals.

4.1 Mapping the NGEU funds to the model

We focus on the the key instrument of the NGEU program, the Recovery and Resilience Facility (RRF), approved by the European Union in 2020 to foster a persistent recovery of EU member states. In this context, Spain has been allocated funds equivalent to roughly 6.4% of 2019 GDP in form of grants. In order to channel these funds to the economy, the Spanish Government has enacted the Recovery, Transformation, and Resilience Plan (Plan the Recuperación, Transformación, y Resilencia, or PRTR). [7] In our framework, the reception of grants from the NGEU program takes the form of international transfers T_t^{EU}, incorporated into the budget constraint of the government (15).

We map the different projects included in the PRTR to the instruments available in the model following the breakdown provided in Fernández-Cerezo et al. (2023). Of the

[6] Atkeson and Burstein (2019) use data on employment and the number of establishments. Since our data set only contains information at the firm level but not at establishment level, we instead use production. Yet, we obtain data moments are close to the moments computed by these authors, as presented in Table 3 of the online appendix of that paper.

[7] The original allocation of grants to Spain amounted to €69.5 bn (5.9% of 2019 GDP), which was later increased by an additional €7.7 bn after revising the magnitude of the pandemic recession in Spain and by roughly €2.6 bn as consequence of the Ukraine war. Furthermore, a similar amount of funds is available for Spain to be requested in form of loans. We abstract from these potential funds in this paper.

overall size of the program, 13% of the funds are allocated to public consumption expenditures; we abstract from this share of the funds, since our focus is on policies that directly affect output over the medium term through the supply side of the economy. The remaining 87% of the funds is allocated between public investment to build infrastructures (47%) – in our model, I_t^G – and transfers to private firms (40%), which in turn, are split in roughly equal amounts between transfers targeted to build private physical capital (T_t^K) and transfers targeted to improve the technology with which firms operate (T_t^R). Regarding the latter, we assume that transfers for innovation investment are equally split between the three different types ($T_t^{R,e} = T_t^{R,m} = T_t^{R,c}$). Finally, as regards of the shape and time of the spending paths, we assume for simplicity that funds are received and spent uniformly over an eight-year period, starting in 2021 and ending in 2028.[8] [9]

We plot in Figure 1 the implied path for transfers and expenditures in the model, as a percentage of 2019 Spanish GDP. International transfers (panel a) amount to nearly 0.7% of GDP per year. The bulk of these transfers is used to increase public investment (panel b). Note that transfers expire in 2028, but public investment remains permanently higher than in 2019; this happens because we assume that once the new public capital has been built between 2021 and 2028, when the NGEU program is finished, the government raises investment as to cover the depreciation costs of the newly built capital.[10] The remaining funds are equally split between transfers to build physical capital (panel c) and transfers to increase innovative investment (panel d).

In our simulations, the NGEU grants are repaid partially and indirectly. There's no explicit repayment, but EU member states must contribute to the union-wide budget according to their share of GDP, which is then used by the EU to pay back the debt issued to finance the NGEU funds between 2028 and 2058.[11] The share of union-wide NGEU

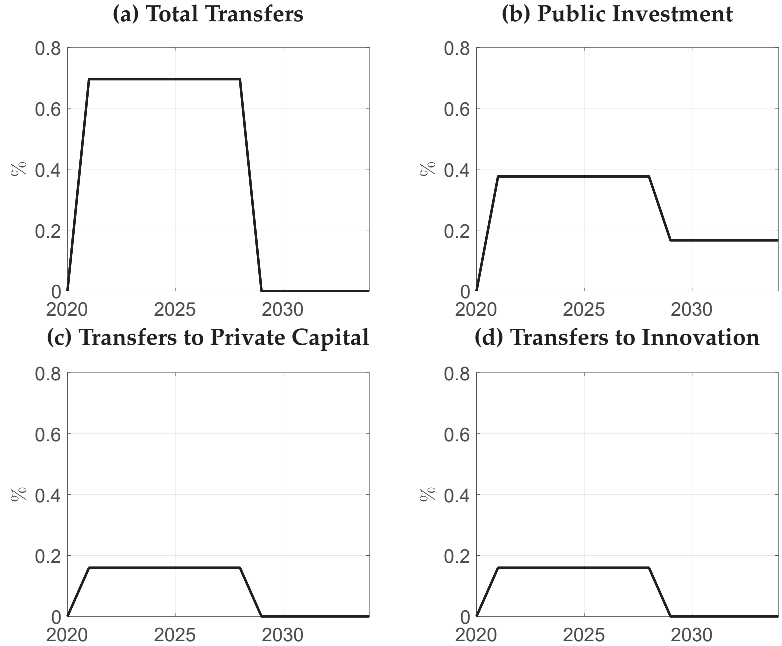
[8]The NGEU funds are initially designed to finish in 2026. However, some programs under the umbrella of the PRTR have been already extended to 2028. See, for example, the case of the funds designated to the design and production of electric vehicles https://www.lainformacion.com/clima/gobierno-extiende-2028-plazo-perte-vec/2881737/

[9]In Appendix B we consider the effects of the NGEU program under alternative spending profiles. There, we show that the main results of our baseline specification remain robust to considering increasing or decreasing spending paths, with only marginal effects on the shape of the transition.

[10]We deem this assumption as natural. It says, for example, that if the government build new railroads of highways it does not let them rot until they become obsolete once the NGEU program ends.

[11]See $https://commission.europa.eu/strategy-and-policy/eu-budget/eu-borrower-investor-relations/nextgenerationeu_en$

Figure 1: Fiscal Mix



Notes: This figure shows the path for policy variables in our simulation of the NGEU program.

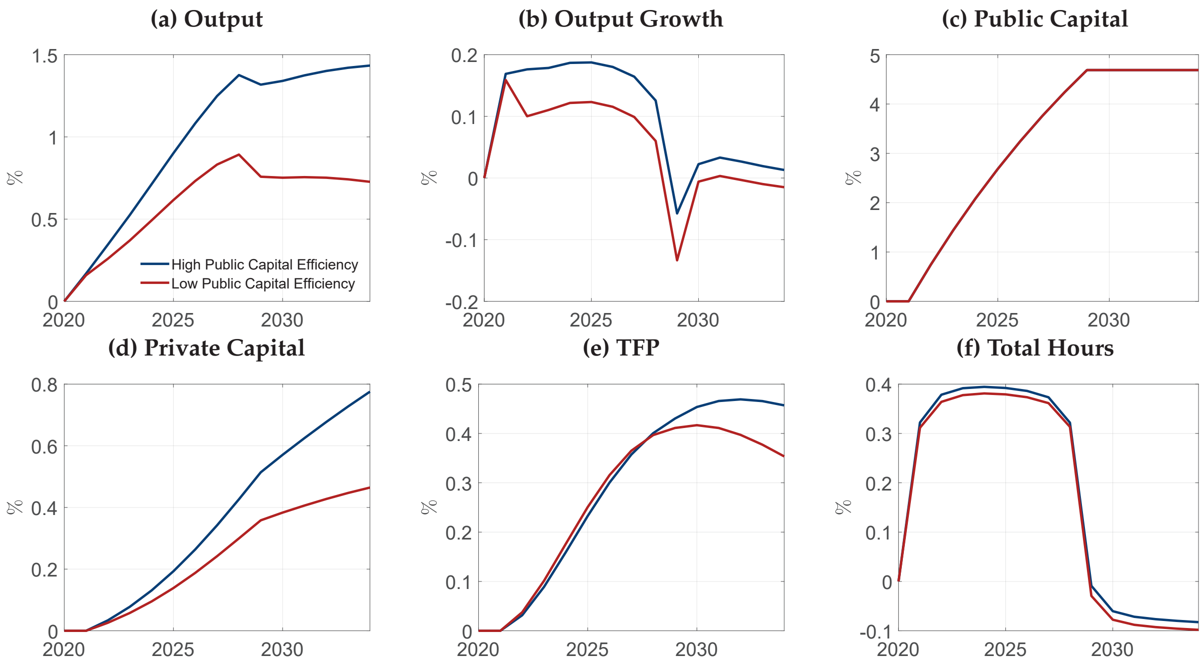
grants received by Spain is roughly 20%, while the Spanish economy represents approximately 10% the EU GDP. Therefore, in our simulations we assume that between 2028 and 2058 half of the international transfers received are paid back by raising both labor income taxes and consumption taxes.[12] We also assume that the government raises these same tax rates to finance the additional public investment required to cover the depreciation costs of the newly built public capital (see panel b, Figure 1).

4.2 Aggregate Consequences of the NGEU funds

Figure 2 plots the responses of aggregate variables to the NGEU funds in our model, implemented as described in the previous section . Since public investment accounts for an important share of the program, we provide responses with the two different values of the public capital efficiency in terms of increasing private productivity. The blue lines show the case with a relatively high efficiency of public capital, $\chi = 0.15$. This would be

[12]See Pfeiffer et al. (2022) for a similar assumption. Contrary to that paper, however, we assume that the additional revenue required to pay back grants is raised through distortionary taxation, rather than through lump-sum taxes.

Figure 2: Aggregate Consequences of the NGEU funds



Notes: Impulse response functions to the path of the NGEU program, described in detail in section 4.1. Blue lines plot the path under a high efficiency of public capital, $\chi = 0.15$, and red lines under a lower efficiency of public capital, $\chi = 0.05$.

our baseline simulation. The red lines display the responses with a lower efficiency of public capital, $\chi = 0.05$.

Panels (a) and (b) show that the NGEU funds have a quantitatively relevant effect on the level of output and on output growth. In panel (a) we can observe that by 2028, when transfers expire in our simulation, output is between 0.9% and 1.4% higher relative to the baseline without NGEU funds. The average growth rate of output over that period increases by roughly $0.11 - 0.17$ percentage points (panel b). These results from our model line up well with previous estimates of the effects of NGEU program (cf. Fernández-Cerezo et al., 2023; Pfeiffer et al., 2022). The increase in output does not stop in 2028, despite the fact that fiscal variables remain constant thereafter, but it continues to be higher for several more years until output stabilizes at a new level.[13]

Panels from (c) to (f) display the evolution of the different production inputs. Public capital (panel c) increases slowly over time as a result of higher public investment, stabi-

[13] There are permanent effects on the level of output since we consider that the government does not let the newly built public capital depreciate, recall Figure 1.

lizing after 2028 at a new level that is permanently higher. Private capital (panel d) builds up much more slowly and takes a longer time to stabilize to new levels, as households generate savings at a slower pace to ensure a smooth consumption path. We observe here that the assumed efficiency of public capital has a non-negligible effect on the path of private capital. Namely, a more productive public capital allows firms to use their private resources more efficiently, increasing firm's demand for capital and resulting in a higher accumulation of capital.

Aggregate productivity Z_t is displayed in panel (e). In both cases it increases steadily until 2028 and by a similar amount to the response of private capital. This highlights the relevance of accounting for the endogenous response of productivity to economic policy, which could be as relevant as the the build up of capital itself. Furthermore, we observe that in this case the blue and red line closely track each other until the end of the our simulated NGEU program, suggesting that fiscal transfers destined to innovative uses are one of the main drivers of the change in productivity, with public capital having a more limited role on this variable.

Finally, panel (f) shows the response of total hours worked. Households work more as long as the NGEU program is in place, because higher productivity and capital increase firms' labor demand and hence wages. After the end of the program, hours remain temporarily higher but to a lesser extent; the reason for this is that from 2028 onward, the government increases labor income taxes to pay back international transfers and to sustain the higher level of investment required to maintain the new stock of public capital.

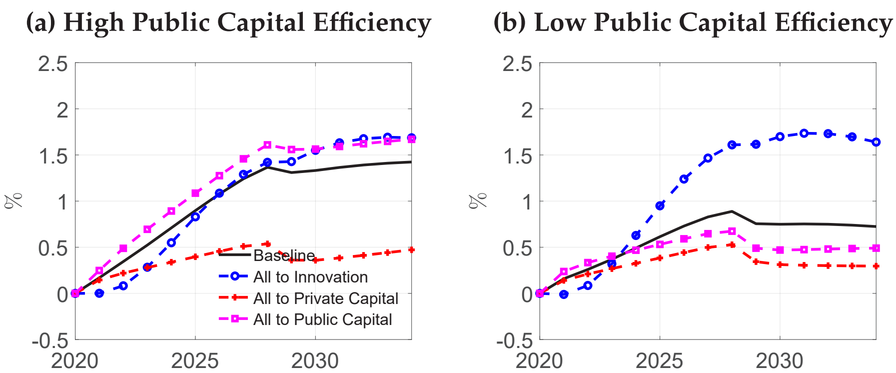
In sum, the aggregate consequences for output of the programs associated with the NGEU funds are quantitatively meaningful: in our baseline simulation, annual GDP growth is increased by 0.17 percentage points on average over the period of NGEU funds disbursement, and effects persist afterwards. Furthermore, as the evolution of the different production inputs presented in Figure 2 makes clear, these positive aggregate effects are not driven by a single component in isolation, but instead by the joint combination of different forces, including productivity.

4.3 Alternative Allocation of NGEU funds

The previous section has shown that the current allocation of NGEU funds within the context of the Spanish economy can be expected to have significant positive effects on economic activity. We next use the model as laboratory to explore counterfactual simulations that provide some hindsight about which of the components of the NGEU is more effective in raising output and how the economy would fare under alternative allocations of the funds.

We consider three counterfactual allocations of the NGEU funds. Namely, instead of our baseline allocation of funds, we next assume that all transfers displayed in panel (a) of Figure 1 are allocated to one of the three policy instruments that we consider: either (i) public capital, (ii) transfers to fund an increase of private physical capital, or (iii) transfers towards innovative investment.[14]

Figure 3: Alternative allocations of NGEU funds



Notes: Path for output under alternative allocations of the NGEU funds. The left panel shows the effects with high efficiency of public capital, $\chi = 0.15$, and the right panel for a lower efficiency of public capital, $\chi = 0.05$. The black lines display our baseline simulation, see section 4.2. The remaining lines consider counterfactual simulations, where all NGEU funds are allocated to either public capital (pink line, squares), innovation transfers (blue line, circles), or private capital transfers (red line, circles).

We show the response of output in each of these scenarios in Figure 3, where the left panel shows the responses of output for the case of a high efficiency of public capital, and the right panel displays the case of a lower efficiency of public capital. In both panels we show with black lines our baseline allocation of funds. Pink lines with squares shows

[14]As to make sure that these counterfactuals are comparable to our baseline, in all these alternative scenarios we assume that once transfers end, the fiscal authority keeps the same path for public investment as plotted in panel (b) of Figure 1.

the path for output under the alternative allocation where all funds are used for public capital. Blue lines with circles show the output response when all funds go to finance innovate investment. Finally, red lines with circles display the output path under the assumption that all transfers are used to build private physical capital.

Consider first the case where all transfers are allocated to the provision of public capital. In this scenario, we observe that the implied response of output is relatively close to the path under the baseline allocation of funds (the pink lines are similar to the black lines). This is true for both levels of public capital efficiency. Therefore, it seems that moving from the current allocation of NGEU funds to the alternative where all transfers are used for public investment would not significantly change the effects on aggregate output.

Next, focus on the case where all transfers are allocated to fund innovative investment (blue lines with circles). With a high level of public capital efficiency (left panel), the output effects of this policy are very close to the baseline but slightly lower than the effects observed under the policy that allocates all the funds to public capital. This ranking, however, sharply changes when the efficiency of public capital is low (right panel); in this case, the output effects of transfers to innovative investment would be clearly larger than in the baseline and in the case of the allocation of all funds to public capital. In other words, according to our model, a high productivity of public capital is required for that investment to mirror the output effects of stimulating innovative investment.

This is not just a consequence of the fact that changes in aggregate productivity Z increase one-to-one aggregate output Y, while the elasticity of output to public capital is controlled by its efficiency χ. The reason for this is two-fold. First, since the outcomes of innovation at the firm level are uncertain, changes in innovative investment – which is what fiscal transfers stimulate – do not necessarily translate one-to-one into changes in aggregate productivity. One can also see this more clearly by considering the dynamics of aggregate productivity in equation (21), which relates innovative investment to productivity. Second, transfers do not increase innovative investment one-to-one since the increase in the price of the research good leads to a crowding out of the innovative investment that firms undertake with their own resources.

Finally, consider the scenario where all funds are allocated to transfers to fund the accumulation of private physical capital (red lines). In this counterfactual we observe, for both high and low public investment efficiency, that the output increase is clearly smaller than in the baseline and than in the previous counterfactuals. The reason for this result is the combination of two forces. First, as in the case of innovation transfers, there is a crowding out of private capital accumulation financed via private resources, which explains why transfers to private capital have smaller effects on output than when funds are allocated towards public investment. Second, the elasticity of output to private capital, α, is smaller than one, contrary to the case of aggregate productivity, which explains why the output response here is smaller than when funds go to fund innovative investment.

In sum, the alternative scenarios considered in this section highlight the difficulty in discerning what is the allocation on funds that maximizes output gains. In general, our results point towards relatively large effects of transfers that encourage innovative investment, which can be only compared to the build up of a public capital when this is highly productive. On the other hand, the gains from transfers allocated to build private physical are positive but more limited than the other options considered here.

4.4 Fiscal Multipliers

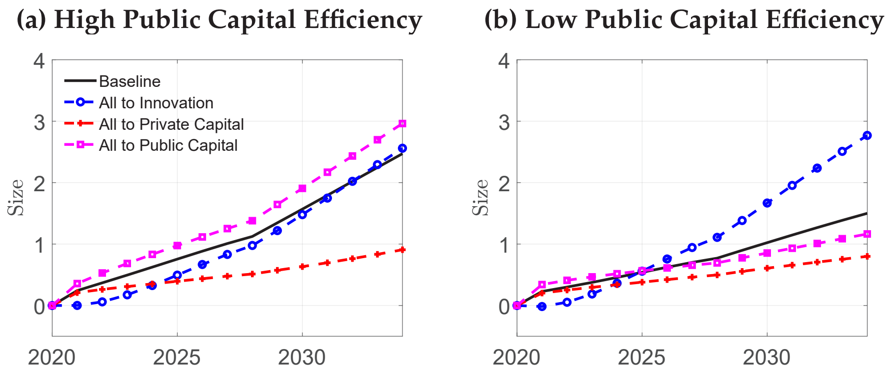
In previous sections we have explored the aggregate consequences of the current allocation of NGEU transfers, and we have investigated the effects of alternative fiscal arrangements. In this section we summarize those results by computing cumulative fiscal multipliers, which can serve a useful summary statistic for the effects of the NGEU program. More precisely, we define the cumulative output multiplier associated with the NGEU transfers at horizon h as:

$$\mathcal{M}_h = \frac{\sum_{j=0}^{h} \beta^j (Y_{t+j} - Y_{t-1})}{\sum_{j=0}^{h} \beta^j (T_{t+j}^{EU} - T_{t-1}^{EU})}, \tag{26}$$

where $t-1$ is time period before NGEU transfers start to take place.

Figure 4 shows the cumulative fiscal multipliers for the baseline simulation, as well as for the each of the alternative allocation of funds considered in section 4.3. As before, the

Figure 4: Fiscal Multipliers



Notes: Dynamic cumulative fiscal multipliers, computed as in equation (26). The left panel shows the effects with high efficiency of public capital, $\chi = 0.15$, and the right panel for a lower efficiency of public capital, $\chi = 0.05$. The black lines display our baseline simulation, see section 4.2. The remaining lines consider the counterfactual simulations, where all NGEU funds are allocated to either public capital (pink line, squares), innovation transfers (blue line, circles), or private capital transfers (red line, circles).

left panel shows the case of high efficiency of public capital and the right panel considers the calibration with a lower efficiency of public capital.

Fiscal multipliers in the baseline simulation range between 1.10 and 0.77 in the year after the NGEU program expires. This means that, according to our simulation, for each euro of NGEU transfers output would increase on average by roughly 0.94 euros. This lines up well with previous estimates of public investment multipliers (Ilzetzki et al., 2013) and government spending multipliers (Ramey, 2019).

Comparing the fiscal multipliers associated with each of the alternative scenarios considered we observe that main messages of the previous section hold when results are presented in these terms. The fiscal multipliers for public capital ranges between 1.4 (high public capital efficiency) and 0.7 (low public capital efficiency). The average fiscal multiplier associated with the counterfactual where all transfers go into innovative investment is around 1, close to the baseline multipliers. On the contrary, the fiscal multiplier associated with transfers to private physical capital falls to roughly 0.50, summarizing the smaller effects on output described in the previous section.

The multipliers grow at longer horizons, as the benefits of the increased investment continue after the end of the NGEU expenditure. Computing a present-discounted-value version of these fiscal multipliers allows the analysis to take these long-term benefits into effect.

Table 2: Long-run Cumulative Multipliers

	Baseline	All to Pub. Inv.	All to Innovation	All to Priv. Inv.
High Effi. Pub. Capital	6.6	7.2	6.4	5.2
Low Effi. Pub. Capital	2.4	2.3	3.2	1.9

Notes: Discounted cumulative multipliers computed as in equation (27). First row shows the case for a high efficiency of public capital, and the second row for a low efficiency. Each column displays the results under each alternative allocation of the NGEU funds considered.

$$\mathcal{M}_{pdv} = \frac{\sum_{j=0}^{\infty} \beta^j (Y_{t+j} - Y_{t-1})}{\sum_{j=0}^{\infty} \beta^j (T_{t+j} - T_{t-1})}. \tag{27}$$

In this case, since we focus on the long run, the denominator includes both the transfers from the NGEU program and also the increase in fiscal expenditures required to later maintain the new stock of public capital built with the NGEU funds.

Table 2 shows the results in these terms. As can be observed, multipliers can be significantly higher than unity when the long run is included in the analysis and the fiscal expenditure is successful in increasing potential output. Again, the table shows our previous point that increasing innovative investment tend to deliver the higher returns in terms output, unless that the public stock of capital built is highly efficient.

These results showcase fact that an increase in public expenditure or transfers, with multipliers close to unity in the short term, can have a much bigger impact in the long run if it is able to successfully leverage improvements in innovation and productivity. Comparing the multipliers across different levels of public investment productivity shows that a careful design of the investment package is key to achieve a high impact on output in long run.

5 Conclusion

In this paper we have introduced an endogenous growth model of firm dynamics based on Atkeson and Burstein (2019), extended with elastic labor supply, productivity-enhancing public capital, and fiscal transfers to fund innovation and private capital. Calibrating the model to the Spanish economy, we have used the framework to assess the aggregate effects of the different elements of the NGEU program on output and its components, including productivity.

We have found that under current allocation of funds in the NGEU program in Spain, in the baseline calibration of our model, aggregate output growth would be boosted by 0.17 percentage points per year during the duration of the program and at the end of this period the output level would be roughly 1.4% higher. Using the model as a laboratory to build counterfactuals, we have shown that transfers to innovative investment are particularly effective, only matched by increases in a stock of public capital when this is highly efficient. On the contrary, private capital transfers are less effective due to crowding-out effects. Although they are close to unity in the medium term, we find very high fiscal multipliers in the long run, with values ranging from 2.4 to 6.6 in terms of present discounted value, as the positive effects of these interventions outlast most of their costs. For this theoretical result to be achieved in practice, though, it is important that the design of the fiscal package actually succeeds in improving innovation and productivity.

In future work it would be interesting to extend our current framework to a multi-country model, as in Pfeiffer et al. (2022), to explore the cross-country spillovers of the NGEU funds. Since the model is particularly well suited to analyze long-term effects of shocks and policies, it could also be used to assess the long-term consequences of changes in population growth (Jones, 2022) or be extended to assess climate change policies within an endogenous growth framework (Hassler et al., 2021). Finally, it would be of particular interest to enrich the model to assess the effects of transfers on capital and productivity when firms face financial frictions, along the lines of Moll (2014) and Garcia-Macia (2017).

References

Aghion, Philippe, and Peter Howitt. (1992). "A model of growth through creative destruction". *Econometrica (1986-1998)*, 60(2), p. 323. https://doi.org/10.2307/2951599

Aikman, David, Mathias Drehmann, Mikael Juselius and Xiaochuan Xing. (2022). "The scarring effects of deep contractions". BIS Working Papers, 1043, Bank for International Settlements. https://ideas.repec.org/p/bis/biswps/1043.html

Akcigit, Ufuk, John Grigsby, Tom Nicholas and Stefanie Stantcheva. (2021). "Taxation and Innovation in the Twentieth Century*". *The Quarterly Journal of Economics*, 137(1), pp. 329-385. https://doi.org/10.1093/qje/qjab022

Antolin-Diaz, J., and Paolo Surico. (2022). "The long-run effects of government spending". CEPR Discussion Papers, 17433. https://cepr.org/publications/dp17433

Anzoategui, Diego, Diego Comin, Mark Gertler and Joseba Martinez. (2019). "Endogenous technology adoption and r&d as sources of business cycle persistence". *American Economic Journal: Macroeconomics*, 11(3), pp. 67-110. https://doi.org/10.1257/mac.20170269

Arencibia Pareja, Ana, Samuel Hurtado López, Mercedes de Luis López and Eva Ortega Eslava. (2018). "New version of the Quarterly Model of Banco de España (MTBE)". Documentos Ocasionales, 1709, Banco de España. https://repositorio.bde.es/handle/123456789/6390

Atkeson, Andrew, and Ariel Burstein. (2019). "Aggregate implications of innovation policy". *Journal of Political Economy*, 127(6), pp. 2625-2683. https://doi.org/10.1086/701823

Baxter, Marianne, and Robert G. King. (1993). "Fiscal policy in general equilibrium". *The American Economic Review*, 83(3), pp. 315-334. http://www.jstor.org/stable/2117521

Bloom, Nicholas, Charles I. Jones, John Van Reenen and Michael Webb. (2020). "Are ideas getting harder to find?". *American Economic Review*, 110(4), pp. 1104-1144. https://doi.org/10.1257/aer.20180338

Bloom, Nick, Rachel Griffith and John Van Reenen. (2002). "Do r&d tax credits work? Evidence from a panel of countries 1979-1997". *Journal of Public Economics*, 85(1), pp. 1-31. https://doi.org/https://doi.org/10.1016/S0047-2727(01)00086-X

Bom, Pedro R. D., and Jenny E. Ligthart. (2014). "What have we learned from three decades of research on the productivity of public capital?". *Journal of Economic Surveys*, 28(5), pp. 889-916. https://doi.org/10.1111/joes.12037

Broda, Christian, and David E. Weinstein. (2006). "Globalization and the Gains From Variety*". *The Quarterly Journal of Economics*, 121(2), pp. 541-585. https://doi.org/10.1162/qjec.2006.121.2.541

Chetty, Raj, Adam Guren, Day Manoli and Andrea Weber. (2011). "Are micro and macro labor supply elasticities consistent? A review of evidence on the intensive and extensive margins". *American Economic Review*, 101(3), pp. 471-475. https://doi.org/10.1257/aer.101.3.471

Christiano, Lawrence, Martin Eichenbaum and Sergio Rebelo. (2011). "When is the government spending multiplier large?". *Journal of Political Economy*, 119(1), pp. 78-121. https://doi.org/10.1086/659312

Cloyne, James, Joseba Martinez, Haroon Mumtaz and Paolo Surico. (2022). "Short-term tax cuts, long-term stimulus". Working Paper, 30246, National Bureau of Economic Research. https://doi.org/10.3386/w30246

Eberly, Janice, Sergio Rebelo and Nicolas Vincent. (2008). "Investment and value: A neoclassical benchmark". Working Paper, 13866, National Bureau of Economic Research. https://doi.org/10.3386/w13866

European Council. (2020). "European Council conclusions, 17-21 July 2020". Tech. rep., European Council. https://www.consilium.europa.eu/en/press/press-releases/2020/07/21/european-council-conclusions-17-21-july-2020/

Fernald, John G., and Charles I. Jones. (2014). "The future of US economic growth". *American Economic Review*, 104(5), pp. 44-49. https://doi.org/10.1257/aer.104.5.44

Fernández-Cerezo, Alejandro, Enrique Moral-Benito and Javier Quintana González. (2023). "A production network model for the Spanish economy with an application to the impact of NGEU funds". Documentos de Trabajo, 2305, Banco de España. https://doi.org/10.53479/27333

Garcia-Macia, Daniel. (2017). "The financing of ideas and the great deviation". IMF Working Paper, 17/176, IMF. https://doi.org/http://dx.doi.org/10.5089/9781484311134.001

Hassler, John, Per Krusell and Conny Olovsson. (2021). "Directed technical change as a response to natural resource scarcity". *Journal of Political Economy*, 129(11), pp. 3039-3072. https://doi.org/10.1086/715849

Ilzetzki, Ethan, Enrique G. Mendoza and Carlos A. Végh. (2013). "How big (small?) are fiscal multipliers?". *Journal of Monetary Economics*, 60(2), pp. 239-254. https://doi.org/https://doi.org/10.1016/j.jmoneco.2012.10.011

Jones, Charles I. (2002). "Sources of U.S. economic growth in a world of ideas". *American Economic Review*, 92(1), pp. 220-239. https://doi.org/10.1257/000282802760015685

Jones, Charles I. (2022). "The end of economic growth? Unintended consequences of a declining population". *American Economic Review*, 112(11), pp. 3489-3527. https://doi.org/10.1257/aer.20201605

Jordà, Òscar, Sanjay R. Singh and Alan M. Taylor. (2022). "Longer-Run Economic Consequences of Pandemics". *The Review of Economics and Statistics*, 104(1), pp. 166-175. https://doi.org/10.1162/rest_a_01042

Klette, Tor Jakob, and Samuel Kortum. (2004). "Innovating firms and aggregate innovation". *Journal of Political Economy*, 112(5), pp. 986-1018. https://doi.org/10.1086/422563

Leeper, Eric M., Todd B. Walker and Shu-Chun S. Yang. (2010). "Government investment and fiscal stimulus". *Journal of Monetary Economics*, 57(8), pp. 1000-1012. https://doi.org/https://doi.org/10.1016/j.jmoneco.2010.09.002

Lucas, Jr., Robert E. (2003). "Macroeconomic priorities". *American Economic Review*, 93(1), pp. 1-14. https://doi.org/10.1257/000282803321455133

Lucas, R. E. (1987). *Models of business cycles.* Blackwell.

Luttmer, Erzo G. J. (2007). "Selection, Growth, and the Size Distribution of Firms*". *The Quarterly Journal of Economics*, 122(3), pp. 1103-1144. https://doi.org/10.1162/qjec.122.3.1103

Moll, Benjamin. (2014). “Productivity losses from financial frictions: Can self-financing undo capital misallocation?”. *American Economic Review*, 104(10), pp. 3186-3221. https://doi.org/10.1257/aer.104.10.3186

Peri, Alessandro, Omar Rachedi and Iacopo Varotto. (2023). “The public investment multiplier in a production network”. Documentos de Trabajo, 2311, Banco de España. https://doi.org/10.53479/29825

Pfeiffer, Philipp, Janos Varga and Jan in ’t Veld. (2022). “Quantifying spillovers of coordinated investment stimulus in the EU”. *Macroeconomic Dynamics*, pp. 1-23. https://doi.org/10.1017/S1365100522000487

Ramey, Valerie A. (2019). “Ten years after the financial crisis: What have we learned from the renaissance in fiscal research?”. *Journal of Economic Perspectives*, 33(2), pp. 89-114. https://doi.org/10.1257/jep.33.2.89

Ramey, Valerie A. (2020). “The macroeconomic consequences of infrastructure investment”. Working Paper, 27625, National Bureau of Economic Research. https://doi.org/10.3386/w27625

Romer, Paul M. (1990). “Endogenous technological change”. *Journal of Political Economy*, 98(5, Part 2), pp. S71-S102. https://doi.org/10.1086/261725

Silva, José Ignacio, and Manuel Toledo. (2009). “Labor turnover costs and the cyclical behavior of vacancies and unemployment”. *Macroeconomic Dynamics*, 13(S1), pp. 76-96. https://doi.org/10.1017/S1365100509080122

A Model Appendix

In this appendix we provide the details of the model outlined in the main text, including the first order conditions associated with the optimization problems of agents.

A.1 Households

The solution to the household problem outlined in the main text and described by equations (1), (2), and (3), satisfies the following optimality conditions:

$$\frac{1}{C_t/H_t} = \mathbb{E}_t \beta (1+R_t) \frac{1+\tau_t^C}{1+\tau_{t+1}^C} \frac{1}{C_{t+1}/H_{t+1}}, \tag{28}$$

$$\frac{1}{C_t/H_t} = \mathbb{E}_t \beta \frac{1+\tau_t^C}{1+\tau_{t+1}^C} \frac{1}{C_{t+1}/H_{t+1}} \frac{1}{q_t} \left(r_{t+1}^k + q_{t+1} \left(1 - \delta_K - \frac{\partial \Xi^I(I_{t+1}, K_{t+1})}{\partial K_{t+1}} \right) \right), \tag{29}$$

$$\frac{1}{q_t} = 1 - \frac{\partial \Xi^I(I_t, K_t)}{\partial I_t}, \tag{30}$$

$$\begin{aligned} \kappa \left(\frac{L_t^P + L_t^R}{H_t} \right)^{\varphi} (1+\tau_t^C) \frac{C_t}{H_t} =& (1-\tau_t^L) W_t^R - \frac{\partial \Xi^L(L_t^R, L_{t-1}^R, L_t^P, L_{t-1}^P)}{\partial L_t^R} \\ & - \mathbb{E}_t \frac{1}{1+R_t} \frac{\partial (L_{t+1}^R, L_t^R, L_{t+1}^P, L_t^P)}{\partial L_t^R}, \end{aligned} \tag{31}$$

$$\begin{aligned} \kappa \left(\frac{L_t^P + L_t^R}{H_t} \right)^{\varphi} (1+\tau_t^C) \frac{C_t}{H_t} =& (1-\tau_t^L) W_t^P - \frac{\partial \Xi^L(L_t^R, L_{t-1}^R, L_t^P, L_{t-1}^P)}{\partial L_t^P} \\ & - \mathbb{E}_t \frac{1}{1+R_t} \frac{\partial (L_{t+1}^R, L_t^R, L_{t+1}^P, L_t^P)}{\partial L_t^P}, \end{aligned} \tag{32}$$

Equations (28) and (29) are the Euler equations for risk-free bonds and capital, respectively. q_t above marks Tobins's q – the marginal value of capital in terms of consumption units – and is given in equation (30). The final two equations summarize the labor supply of research and production labor of the household.

A.2 Firms

A.2.1 Final Good Producer

The solution to the final good producer's problem (4) delivers the following system of demand equations for intermediate goods:

$$y_t(z) = p_t(z)^{-\rho} Y_t, \tag{33}$$

A.2.2 Intermediate Good Producers

We divide the problem solved by intermediate good producers in two problems. A first one is a static problem where firms optimally choose production inputs and prices. The second problem is a dynamic problem where firms decide how much to invest in innovation.

Static Problem. The static problem of a firm with productivity index z consists on choosing labor $l^p(z)$, capital $k(z)$, and prices $p(z)$ to maximize variable profits (6), subject to the demand equation (33) and the production technology (5). The solution to that problem is characterized by the following equations:

$$\frac{k_t(z)}{l_t^p(z)} = \frac{\alpha}{1-\alpha} \frac{W_t^P}{r_t^k}, \tag{34}$$

$$W_t^P = \lambda_t(z)(1-\alpha)\frac{y_t(z)}{l_t^p(z)}, \tag{35}$$

$$\lambda_t(z) = \max\left\{0, \frac{1}{z}\mathrm{MC}_t\right\}, \tag{36}$$

$$p_t(z) = \mu \frac{1}{z} MC_t, \tag{37}$$

$$\mu = \min\{\frac{\rho}{\rho-1}, \bar{\mu}\}, \tag{38}$$

$$\text{MC}_t \equiv \frac{1}{(K_t^G)^\chi}\left(\frac{W_t^P}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^k}{\alpha}\right)^\alpha \tag{39}$$

Equation (34) shows that the capital-to-labor ratio chosen by intermediate good firms is independent of the idiosyncratic productivity index z, albeit the levels of this variables does not need to be. Equation (35) is the equation that defines labor demand for production work of a firms with productivity index z, where $\lambda_t(z)$ is the Lagrange multiplier as given by (36).[15]

Equation (37) states that intermediate good producers charge a constant markup μ over marginal costs MC_t/z, defined in (39). As in Atkeson and Burstein (2019), we assume that the markup is given by the minimum between the monopoly markup $\rho/\rho-1$ and the technology gap with respect to the second most productive firm producing the same product with productivity index $z/\bar{\mu}$.

Dynamic Problem. The dynamic problem of an incumbent firms consists on choosing innovative investment to maximize:

$$V_t(z) = \max_{\tilde{x}_t^m(z),\tilde{x}_t^c(z)} \pi_t(z)(1-\tau_t^{\text{Corp}}) - P_t^r(\tilde{x}_t^m(z)+\tilde{x}_t^c(z)) + \mathbb{E}_t \frac{V_{t+1}(z')}{1+R_t}\left((1-\delta_0)+h\left(\frac{\tilde{x}_t^m(z)}{s_t(z)}\right)\right), \tag{40}$$

where variable profits $\pi_t(z)$ are defined in (6). The continuation value of the firm $V_{t+1}(z')$ is weighted by two terms. The first of them $1-\delta_0$ corresponds to the probability of keeping an existing product. The second term $h(\tilde{x}_t^m(z)/s_{(z)})$ is the probability of having the opportunity to invest in a new product.

We solve the problem (40) following the same steps as in Atkeson and Burstein (2019). Namely, one first can easily show that variable profits scale with $s_t(z)$, that is $\pi_t(z) = s_t(z)(1-\tau_t^{\text{Corp}})\frac{\mu-1}{\mu}Y_t$. Second, one can show that innovative investment scales with $s_t(z)$ as well – $x_t^j(z) = s_t(z)x_t^m$ for $j \in \{c, m, e\}$. This leads to $V_t(z) = V_t s_t(z)$, where V_t is given by:

[15] The complementary slackness conditions is given by $\lambda_t(z)\left(y_t(z) - z(K_t^G)^\chi k_t(z)^\alpha l_t^p(z)^{1-\alpha}\right) = 0$.

$$V_t = \max_{\tilde{x}_t^m, \tilde{x}_t^c} (1-\tau_t^{\text{Corp}}) \frac{\mu - 1}{\mu} Y_t - P_t^r(\tilde{x}_t^m + \tilde{x}_t^c) + \mathbb{E}_t \frac{V_{t+1}}{1+R_t} \left((1-\delta_0)\zeta(x_t^c) + \eta_m h(x_t^m)\right) \frac{Z_t^{\rho-1}}{Z_{t+1}^{\rho-1}} \tag{41}$$

The first order conditions for innovative investment for incumbent firms and the free-entry conditions for new entrants are therefore given by:

$$x_t^m : \quad P_t^r = \frac{1}{1+R_t} V_{t+1} \eta_m h'(x_t^m) \left(\frac{Z_t}{Z_{t+1}}\right)^{\rho-1} \tag{42}$$

$$x_t^c : \quad P_t^r = \frac{1-\delta_0}{1+R_t} V_{t+1} \xi'(x_t^c) \left(\frac{Z_t}{Z_{t+1}}\right)^{\rho-1} \tag{43}$$

$$\text{Free-entry} : \quad P_t^r = \frac{1}{1+R_t} V_{t+1} \eta_e \left(\frac{Z_t}{Z_{t+1}}\right)^{\rho-1} \tag{44}$$

A.2.3 Research Good Producer

The maximization problem of the research good producer (14) deliver the following first order conditions for demand of research labor:

$$P_t^R A_t^R \left(K_t^G\right)^{\chi} Z_t^{\phi-1} = W_t^R \tag{45}$$

A.3 Aggregation

In this section we show that aggregate output Y_t can be written as:

$$Y_t = Z_t (K_t^G)^{\chi} (K_t)^{\alpha} \left(L_t^p\right)^{1-\alpha}. \tag{46}$$

We first start by noting that using (34) and (37) the demand for intermediate goods (33) can be written as:

$$\left(K_t^G\right)^{\chi} \left(\frac{K_t}{L_t^P}\right)^{\alpha} l_t^p(z) = (\mu \text{MC}_t)^{-\rho} Y_t z^{\rho-1}. \tag{47}$$

Next, using the definition of the Lagrange multiplier (36) together with the pricing condition (37), we can write the return on labor (35) as a function of aggregate output and aggregate production work:

$$W_t^p = \frac{1-\alpha}{\mu}\frac{Y_t}{L_t^p}, \tag{48}$$

and similarly for the return on private physical capital:

$$r_t^k = \frac{\alpha}{\mu}\frac{Y_t}{K_t}, \tag{49}$$

Equations (48) and (49) allows us to write marginal costs MC_t in equation (39) as:

$$\mu \text{MC}_t = \frac{Y_t}{(K_t^G)^{\chi}\,(K_t)^{\alpha}\left(L_t^p\right)^{1-\alpha}} \tag{50}$$

Using (50) into (47) and aggregating over z gives us:

$$\left((K_t)^{\alpha}\left(L_t^p\right)^{1-\alpha}\right)^{1-\rho} = Y_t^{1-\rho}\sum_z M_t(z) Z^{\rho-1} \tag{51}$$

Rearranging (51) and defining Z_t as in (7) gives us the desired result.

A.4 Equilibrium

An equilibrium consists on a path for fiscal variables $\{B_t, \tau_t^C, \tau_t^L, \tau^{\text{Corp}}, T_t^K, T_t^R, T_t^{\text{EU}}, I_t^G\}$, quantities $\{Z_t, K_t, L_t^R, L_t^P, C_t, Y_t, Y_t^R, x_t^m, x_t^c, x_t^e\}$, and prices $\{P_t^r, q_t, R_t, r_t^k, W_t^P, W_t^R, V_t\}$ such that the optimality conditions for the household (28) - (32) hold, the first order conditions for firms (42) - (44), (45), (48), (49) hold, the value of an incumbent firm is given by (40), final output and research output are given by (46) and (13), the law of motion for aggregate productivity follows (20), and the market clearing conditions (17) and (16) hold. This forms a system of 17 equations for 17 variables, given a path for fiscal policy.

A.5 Balanced Growth Path

Our economy features endogenous growth. Therefore we detrend the equilibrium variables by their constant balanced-growth-path (BGP) growth rates to obtain an stationary equilibrium.

At the BGP we have that $\{Y_t, C_t, K_t, P_t^r, V_t\}$ grow at the growth rate of output g_Y. Productivity Z_t grows at g_z, given by (21). Hours worked $\{L_t^R, L_t^P\}$ grow at the same rate as population, g_H. Wages $\{W_t^R, W_t^P\}$ grow at the growth rate per capita output $g_Y - g_H$. Asset returns $\{q_t, R_t, r_t^k\}$ are already stationary. Furthermore, as in Atkeson and Burstein (2019), we restrict out attention to the a BGP where innovative investment $\{x_t^e, x_t^m, x_t^c\}$, and hence production of research good Y_t^r is constant. Finally we also let public capital K_t^G to grow at the same rate as output, g_Y, as to have a constant public-investment-to-output ratio at the BGP, and assume that tax rates are constant at the BGP.

We denote by small-case letters detrended variables. That is, for a variable X_t we have that $x_t \equiv X_t/\exp(tg_x)$, where g_x is the constant growth rate of X_t at the BGP, is constant at the BGP. Following this notation we can write the system of equilibrium equations in terms of stationary variables as:

$$\frac{1}{c_t} = \mathbb{E}_t \beta(1+R_t)\frac{1+\tau_t^C}{1+\tau_{t+1}^C}\exp(g_Y - g_H)\frac{1}{c_{t+1}} \tag{52}$$

$$\frac{1}{c_t} = \mathbb{E}_t \exp(g_Y - g_H)\frac{1+\tau_t^C}{1+\tau_{t+1}^C}\frac{1}{c_{t+1}}\frac{1}{q_t}\left(r_{t+1}^k + q_{t+1}\left(1 - \delta_K - \frac{\partial \Xi^I(i_{t+1}, k_{t+1})}{\partial k_{t+1}}\right)\right) \tag{53}$$

$$\frac{1}{q_t} = 1 - \frac{\partial \Xi^I(i_t, k_t)}{\partial i_t}, \tag{54}$$

$$\begin{aligned} \kappa\left(\frac{l_t^P + l_t^R}{h_t}\right)^{\varphi}(1+\tau_t^C)\frac{c_t}{h_t}\exp(g_Y - g_H) =& (1-\tau_t^L)w_t^R\exp(g_Y - g_H) - \frac{\partial \Xi^L(l_t^R, l_{t-1}^R, l_t^P, l_{t-1}^P)}{\partial l_t^R} \\ & - \mathbb{E}_t \frac{1}{1+R_t}\frac{\partial(l_{t+1}^R, l_t^R, l_{t+1}^P, l_t^P)}{\partial l_t^R}, \end{aligned} \tag{55}$$

$$\begin{aligned} \kappa\left(\frac{l_t^P + l_t^R}{h_t}\right)^{\varphi}(1+\tau_t^C)\frac{c_t}{h_t}\exp(g_Y - g_H) =& (1-\tau_t^L)w_t^P\exp(g_Y - g_H) - \frac{\partial \Xi^L(l_t^R, l_{t-1}^R, l_t^P, l_{t-1}^P)}{\partial l_t^P} \\ & - \mathbb{E}_t \frac{1}{1+R_t}\frac{\partial(l_{t+1}^R, l_t^R, l_{t+1}^P, l_t^P)}{\partial l_t^P}, \end{aligned} \tag{56}$$

$$p_t^r = \frac{\exp(g_Y - (\rho-1)g_Z)}{1+R_t} v_{t+1}\eta_m h'(x_t^m)\left(\frac{z_t}{z_{t+1}}\right)^{\rho-1} \tag{57}$$

$$p_t^r = \frac{\exp(g_Y - (\rho-1)g_Z)}{1+R_t} v_{t+1}(1-\delta_0)\xi'(x_t^c)\left(\frac{z_t}{z_{t+1}}\right)^{\rho-1} \tag{58}$$

$$p_t^r = \frac{\exp(g_Y - (\rho-1)g_Z)}{1+R_t} v_{t+1}\eta_e\left(\frac{z_t}{z_{t+1}}\right)^{\rho-1} \tag{59}$$

$$p_t^R Y_t^R = w_t^R l_t^R \tag{60}$$

$$w_t^p = \frac{1-\alpha}{\mu}\frac{y_t}{l_t^p}, \tag{61}$$

$$r_t^k = \frac{\alpha}{\mu}\frac{y_t}{k_t}, \tag{62}$$

$$\begin{aligned} v_t = &\max_{\tilde{x}_t^m, \tilde{x}_t^c} (1-\tau_t^{\text{Corp}})\frac{\mu-1}{\mu} y_t - p_t^r(\tilde{x}_t^m + \tilde{x}_t^c) \\ &+ \mathbb{E}_t \exp(g_Y - (\rho-1)g_Z)\frac{v_{t+1}}{1+R_t}\left((1-\delta_0)\zeta(x_t^c) + \eta_m h(x_t^m)\right)\frac{z_t^{\rho-1}}{z_{t+1}^{\rho-1}} \end{aligned} \tag{63}$$

$$y_t = z_t (k_t^G)^\chi (k_t)^\alpha \left(l_t^p\right)^{1-\alpha}. \tag{64}$$

$$Y_t^r = \left(k_t^G\right)^\chi z_t^{\phi-1} l_t^r. \tag{65}$$

$$\left(\frac{\exp(g_Z) z_{t+1}}{z_t}\right)^{\rho-1} = (1-\delta_0)\zeta(x_t^c) + \eta_m h(x_t^m) + \eta_e x_t^e \tag{66}$$

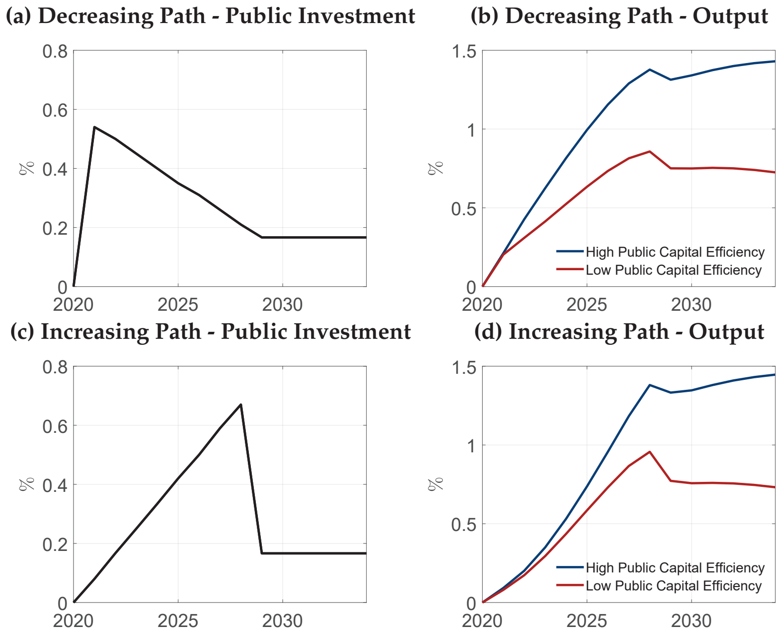
$$Y_t^r = x_t^e + x_t^m + x_t^c \tag{67}$$

$$c_t + i_t + i_t^G = y_t \tag{68}$$

B Alternative spending paths

Out baseline spending path for NGEU spending considers a uniform disbursement of funds, as described in Section 4.1. In this appendix we evaluate the consequences for output of alternative paths for disbursement of funds, which could of interest given potential delays in the implementation of the NGEU program.

Figure B.1: Alternative Spending Paths



Notes: This figure shows the output effects under alternative paths for public investment. The top row considers a decreasing path for public investment (panel a) and the corresponding effects on output (panel b). The bottom row considers a decreasing path for public investment (panel c), and panel (d) shows the corresponding path for output.

We consider two alternative paths for public investment, the largest component of the NGEU funds according to our baseline. Namely, we entertain an decreasing path for public investment, as depicted in panel (a) of Figure B.1, and an increasing path for public investment, shown in panel (c).

In the medium run, the total effects on aggregate output of the different spending paths are quite similar, compare panels (b) and (d) of Figure B.1. This should not come as a surprise given that in all scenarios we maintain fixed the overall size of the program, as well as the allocation of funds to the different fiscal instruments. Indeed, the average effect on GDP growth (not shown here) remains the same under these alternative paths as under our baseline flat spending profile. The timing of the stimulus differs across the different spending paths, however. A decreasing path for public investment (bottom row, Figure B.1) implies an output effect that is more front-loaded than in our baseline, while the stimulus to output under the increasing profile (top row, Figure B.1) is more back-loaded.

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