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Abstract. This paper aims to assess the macroeconomic and distributional impact of the Italian National Recovery and Resilience Plan (NRRP), which translates the Next Generation EU into action. We use a large-scale dynamic stochastic general equilibrium model adapted to capture the effects of the NRRP instruments. The plan is mapped onto the model using granular information available at the Ministry of Economy and Finance. Our results suggest a sizable impact on key macroeconomic variables mainly driven by investments. The impact on the functional distribution of income is initially adverse for profits, which decline in the early years because of the increase in labor and capital demand. However, profits suddenly move above their initial level after GDP increases. Overall, the selection and design of the public-investment programs emerge as a necessary condition for the plan's success.

Keywords: NRRP, macroeconomic impact, fiscal policies.

JEL Classification: C54, E62, E65, F54, F47.

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1. **Introduction**

The Next Generation EU (NGEU) is the primary European Union-wide response to the economic crisis triggered by the COVID-19 pandemic. It represents a never-before-seen fiscal spending effort that breaks away from the austerity policy adopted after the 2008 financial crisis. It provides about €807 billion in loans and grants distributed among EU member states. The National Recovery and Resilience Plans (NRRPs) translate the NGEU into action, defining a broad and ambitious package of investments and reforms.[1]

This paper aims to assess the macroeconomic and distributional impact of the Italian NRRP by using the QUEST-III R&D macro-model.[2] By using granular policy information available at the Italian Ministry of Economy and Finance, we map the policy actions of the NRRP into the model. In a nutshell, we grouped single expenditure items in five transmission channels: (i) public investments; (ii) incentives for business investments; (iii) government current expenditures; (iv) government transfers to households; (v) reductions of employer social security contributions (SSC). It is worth noting that our paper does not quantify the impact of structural reforms associated with the NRRP.[3]

Our findings show that GDP would grow steadily over 2021-2026, and in 2026 its level would be 3.4% higher compared to an alternative baseline scenario without the plan. In the short term, the NRRP boosts aggregate demand. As a result, demand for labor and capital factors increases. Considering a longer-term horizon, it boosts productivity mainly through the build-up of the public capital stock. It is worth noting that our assessment is based on the information from the NRRP published by the Italian government at the end of April 2021 and on the following updates.[4]

The plan's impact on the functional distribution of income is heterogenous in the first years, in which a trade-off emerges between different income categories. We find that incomes from wages, capital, and bonds increase at the cost of a reduction in the income from profits. However, in the medium term, this trade-off disappears, as the increasing fiscal stimulus allows for a generalized income increase except for unemployment benefits and transfers, which decrease because of employment improvements.

The assessment highlights the potential relevance of the NRRP for the Italian economy

[1] The NGEU is part of an ongoing change in the EU policy stance, whose nature in the long term still needs to be fully defined. See Buti and Messori (2021) and Buti and Papacostantinou (2021).

[2] QUEST-III R&D is a medium-scale DSGE model with a rich fiscal structure developed and estimated/calibrated by the European Commission for the Italian economy and available at the Treasury (Ministry of Economy and Finance) to analyze the effects of fiscal policies and structural reforms. The model is described in Roeger *et al.* (2008), D'Auria *et al.* (2009) in detail. See also Ratto *et al.* (2009), Coenen *et al.* (2012), Pfeiffer *et al.* (2020, 2021), and Roeger *et al.* (2021).

[3] See PCM (2021), Section 4, and MEF (2022) for an assessment of the main structural reforms. See also Buti and Messori (2021b), Messori (2021), and Corti and Núñez Ferrer (2021) on this point.

[4] It should be noted that the expenditure assumptions are not the same as those used in PCM (2021). therefore, the results of the two studies, even if related, are not strictly comparable.

in the medium and long term. However, it also highlights the risks involved. The plan's success is mainly linked to the efficiency of public investments and, consequently, to the ability to select, design, and implement tangible and intangible infrastructures – internalizing social externalities.

Our paper is significantly indebted to and related to Ramey (2021), who closely investigates the impact of infrastructure investment on output in the short and long run. Much of the expenditure associated with the NRRP consists in public investments, whose impact evaluation is formalized in a DSGE environment stressing the relevance of implementation delays – inherent in infrastructure projects – that reduce short-run multipliers even when government capital is productive.

This study is also connected to Bańkowski *et al.* (2021) and Pfeiffer *et al.* (2022), which assess the macroeconomic impact on the NGEU.

Bańkowski *et al.* (2021) study alternative uses of NGEU funds using the DSGE-EAGLE model from an aggregate perspective. They compare the potential effects of productive public investment, unproductive government spending, and the repayment of the existing sovereign debt. The work of Pfeiffer *et al.* (2022) is more closely related to our paper. They provide an assessment of a stylized recovery Plan focusing on fiscal spillovers. We share with them the approach and methodology.

Pfeiffer *et al.* (2022) suggest that a simple aggregation of the national effects of individual investment plans would substantially underestimate the impact of NGEU. As expected, the underestimation effects are considerable for small, more open-to-trade countries.[5] Pfeiffer *et al.* (2022) consider a stylized plan in which all expenditures are assumed to be public investments, abstracting from country-specific details of the NRRPs. Instead, considering different transmission channels, we map the plan into the model using granular policy information from the Italian Ministry of Economy and Finance. Although focused on Italy, following the insights of Pfeiffer *et al.* (2022), we account for the spillovers by introducing stylized plans for the other European countries.

Our paper somehow complements Di Bartolomeo *et al.* (2021), who evaluate the macroeconomic impact of the emergency fiscal measures introduced by the Italian government during the lockdown due to the COVID-19 pandemic in 2020. The economic policy response to COVID-19 has been swift and sizeable, preventing mass layoffs. In this respect, it also complements Pfeiffer *et al.* (2020), where policies to contain the effects of COVID-19 are also considered but at the aggregate European level. Di Bartolomeo *et al.* (2021) and Pfeiffer *et al.* (2020) focus on the immediate reaction to the lockdowns imposed by the emergency.[6] We instead look at the long-lasting response to the pandemic-induced economic crisis.

In evaluating the distributional impact of the plan, this paper borrows from Roeger *et al.* (2019), who use a different version of the QUEST model to evaluate the effects and trade-offs of structural reforms on the functional distribution of income in EU member countries. It is worth

[5] They suggest that the aggregate effects are around one third larger when explicitly accounting for the spillover effects from individual country plans.

[6] See also Cardani *et al.* (2022).

noting that empirical evidence on the distributional impacts of the COVID-19 pandemic suggests that inequality is likely to increase in the absence of decisive policy actions (Furceri *et al.*, 2021 and references therein).

The rest of the paper is organized as follows. The next section overviews the Italian NRRP and describes our classification of the expeditions associated with the plan based on the Treasury available-granular data. Section 3 describes the model and the equations related to the channels used to simulate the plan's impact. Section 4 provides some details on model parameters and gross ratios. Sections 5 and 6 illustrate our findings. The former focuses on the macroeconomic outcomes, the latter on the effects on the (functional) distribution. The final section concludes the paper.

2. The RRP in the administrative data

2.1 Plan overview

The Italian NRRP defines an ambitious package of investments and structural reforms to unleash Italian growth, promoting digitalization and innovation, social cohesion, and ecological transition. Overall, the plan mobilizes €222.1 billion, €191.5 from the NGEU Recovery and Resilience Facility (RRF), while €30.6 billion are from complementary national resources. An additional €13 billion are from the NGEU ReactEU; projects financed with this program complement those contained in the NRRP.[7]

The RRF facility aims to provide financial support to EU member states through grants and loans to cope with the enormous economic and social consequences of the COVID-19 crisis and give a strong and coordinated response, both at the Union and national levels. Beyond the short-term, RRF-funded investments and structural reforms should set the European economies on a path of sustained and sustainable economic growth in the medium and longer term, leveraging the opportunities of the green and digital transition (Buti and Messori, 2021b, 2021c). As previously mentioned, the complementary fund supplements the RRF funding with additional national resources.

The ReactEU program constitutes a bridge to the long-term recovery Plan, channeling additional grants to finance initiatives that supports job maintenance and creation, as well as measures to support the healthcare system and other crucial sectors to lay the basis of the recovery.

Along three strategic axes (digitalization and innovation; ecological transition; and social inclusion), the NRRP is distributed across six priority areas (or missions), which group 16 components. Funds are allocated for selected projects in digitalization, innovation, competitiveness, culture, and tourism; green revolution and ecological transition; infrastructure for sustainable mobility; education and research; inclusion and cohesion; and health. As per the

[7] The NGEU comprises additional programs not considered in this study, namely Horizon Europe, InvestEU, Rural Development, Just Transition Funds, and RescEU.

rules of RRF, the priority areas of green and digital transitions absorb about 38% and 25% of the funds, respectively.

The total endowment and source of financing for the simulations are summarized in Table 1. In our macro assessment, we only consider the additional resources, namely those funds that will finance additional projects concerning a scenario without the NGEU-related measures. Moreover, we focus on the period 2021-2026, which is the official time frame for the plan. According to our definition, additional funding amounts to €183.8 billion, corresponding to projects financed through RRF funds for new projects, the Complementary national fund, and the React-EU program. We also consider the RRF resources linked to the Development and Cohesion Fund (FSC) that, as outlined in the official plan, can be considered additional to a no-policy change scenario (PCM, 2021:247).

Table 1 – NRRP: Total and additional resources, €billion

RRF Grants	68.9
RRF Loans	122.6
Total RRF	**191.5**
New projects in RRF	124.6
Development and Cohesion Fund in RRF	15.6
Complementary Fund	30.6
React-EU	13.0
Total additional resources	**183.8**

Notes: Total additional resources are the sum of RRF funds for new projects, Complementary Fund, React-EU, and additional funding from the Development and Cohesion Fund (FSC).

2.2 Exploring the granular data

We map the plan into the model by using a dataset built on granular administrative data. The plan involves 25 central public administrations, 151 investment projects, 63 reforms, and a complex management system that processes a large flow of data to implement and monitor every project.[8] Information is contained in the NRRP Milestones and Targets Programming and Financial Framework datasets.[9] These data are complemented with additional information provided by the State General Accounting Department (RGS) and the legislation ruling the complementary national funds' allocations (Law No. 101/2021).

The NRRP is organized on milestones and targets (M&T), illustrating the reforms' planned progress and investments' results. Granular information on M&T is contained in the Milestones and Targets Programming administrative dataset. The milestones define, in general

[8] A list of the public administrations involved is reported in the NRRP Financial Framework dataset. See Appendix C.

[9] The data sources are described in Appendix C and can be retrieved from the Italian Government NRRP Portal "ItaliaDomani" (https://www.italiadomani.gov.it.)

terms, the relevant administrative and procedural steps. These are qualitative goals that identify critical phases for implementing the measures. The targets are the expected quantitative results of actions quantified by measurable indicators. The dataset associates each measure or sub-measure in the plan with its 1147 M&T. Each item provides qualitative and quantitative information about M&T and the administrations involved.

Information about the RRF expenditure items is contained in the Financial Framework dataset, while measures related to the Complementary Plan are described in Law No. 101/2021. As mentioned, these data are complemented with additional information provided by the State General Accounting Department on measures financed through the React-EU and on the expected annual timing of about 290 expenditure items related to the different sources of financing.

Table 2 summarizes the plan's projects related to the RRF facility. For each mission, it reports the expenditure, number of projects, and M&T. The overall number of projects is 134, which can be matched with 482 milestones and 665 targets.

Table 2 – NRRP: Missions, expenditures, and M&T

Mission	**# projects**	**Amount (€billion)**	**M**	**T**
Digitalization, innovation, competitiveness	29	40.29	146	262
Green revolution and ecological transition	45	59.46	118	111
Infrastructure for sustainable mobility	11	25.40	57	81
Education and research	24	30.88	65	84
Inclusion and cohesion	17	19.85	52	71
Health	8	15.63	44	56
Total	134	191.51	482	665

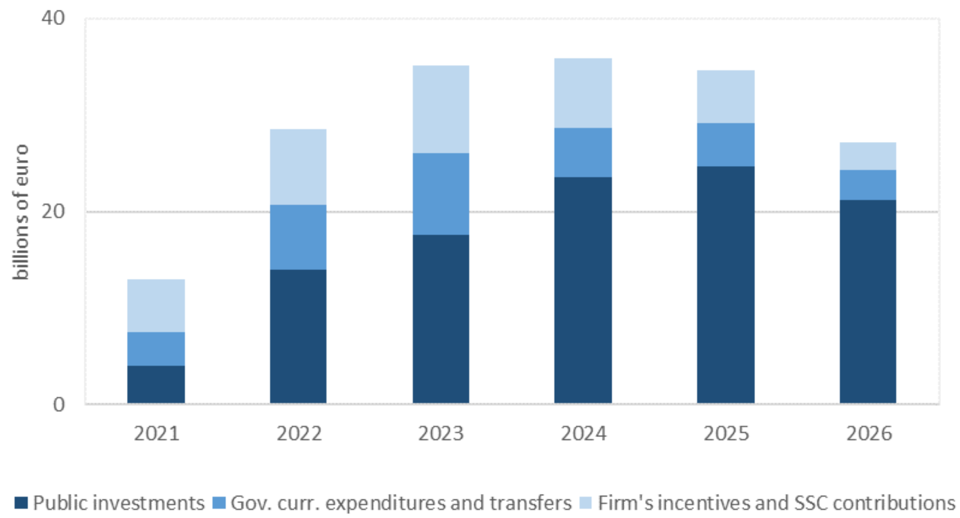
Source: ItaliaDomani (https://www.italiadomani.gov.it.)

The total amount for digitalization, innovation, competitiveness, and culture (Mission 1 alone) is €40.3 billion. The most important item in terms of allocation is the Transition 4.0 plan (€13.4 billion), which aims to boost business investment in R&D and skills. Considerable funds are also dedicated to developing superfast internet, i.e., broadband and 5G (€6.7 billion). Green revolution and ecological transition (Mission 2) absorb €59.5 billion; among these, the most significant part will subsidize energy efficiency improvements through €14 billion of tax credits to households ("ecobonus" and "sismabonus") and €1.4 billion to municipalities (for public buildings and guard against climate risks). In the remaining four missions, the government is making sizeable investments in high-speed railways (€13.2 billion), education, focusing on the early childhood education plan and redevelopment (€4.6 billion) and the safety plan for school buildings (€3.9 billion); job search and training services (€4.4 billion) for territorial cohesion and social inclusion; new technology and digitalization in hospitals (€4.1 billion) and healthcare and assistance at home, including telemedicine (€4 billion), which are the most important investment items in healthcare.

We built our dataset as follows. First, we collect information on the projects from the M&T Programming dataset and match them with the relevant administration in charge of realization. Second, information is then integrated with those from the Financial Framework dataset (on RRF expenditure items), Law No. 101/2021 (on the Complementary Plan), and additional information provided by the RGS Accounting Department (on measures financed through the React-EU facility.) Third, we employ data on the expected annual timing of about 290 expenditure items related to the different sources of financing (RRF, Complementary Fund, React-EU.) Finally, each expenditure item of the database was scrutinized and mapped into five different model categories: (i) public investments; (ii) incentives for business investments; (iii) government current expenditures; (iv) government transfers to households; (v) reductions of employer social security contributions on labor. Each model category corresponds to one of the model transmission channels described in the next section.

The aggregate result of our classification is summarized in Figure 1. It reports our classification of the distribution and yearly timing of the additional NRRP funds over the period 2021-2026, i.e., the time horizon of the official plan and the period in which the government plans to spend the resources stemming from the NGEU programs and most of the resources of the Complementary funds.[10] Our dataset is available upon request. The annual timing of each single expenditure item is confidential and should be requested to the Ministry of Economy and Finance. However, the replication of our results only requires the aggregate yearly data by category reported in Figure 1.

Figure 1 – Italian NRRP, additional resource allocation, €billion



Note: The figure reports the annual additional NRRP resource allocation by broad categories over 2021-2026 in €billions. Figures might differ from official statistics due to modeling definitions.

[10] Minor NGEU resources allocated to 2020 are assumed to affect 2021, while €9.5 billion from the Complementary funds are allocated to 2027-2030.

Most additional funds are allocated to financing public investments (62%). The remaining funds are allocated to encourage private investments (19%), reduce tax contributions on labor (2%), to current public expenditures (12%), and transfer (5%) to households.[11]

3. The model

The Plan assessment is performed using QUEST, i.e., the macroeconomic model developed at the Directorate General for Economic and Financial Affairs (DG ECFIN). Specifically, we used the large-scale multi-country R&D version calibrated for Italy, which is the standard reference for public investments and structural reform evaluations. It includes semi-endogenous technological changes, investment in tangibles and intangibles, and disaggregates employment into three skill categories. This section discusses some aspects of the model relevant to the NRRP evaluation. We refer to Roeger *et al*. (2008) and D'Auria *et al*. (2009) for the full description of the standard features.[12]

3.1 Overview

The multi-region model formalizes three economies: Italy, the rest of the euro area (REA), and the rest of the world. The structure for each of these three regions is as follows. The economy comprises households, non-financial firms operating either in the domestic market or in the import-export sector, R&D institutes, a government, and a central bank shared between Italy and the REA. Agents face nominal and real rigidities (i.e. price and wage stickiness and adjustment costs associated with employment and investment).

Households are of two types (two-agent New Keynesian, TANK, assumption).[13] Non-liquidity-constrained (Ricardian) households make decisions about consumption and labor supply. They have access to financial markets, accumulate physical capital subject to adjustment costs that rent out to the intermediate sector, and buy patents created by the R&D sector to license them to intermediate firms. Ricardian households receive revenues from wages, unemployment benefits, transfer income from the government, and interest income on bonds and capital. On the other side, liquidity-constrained households cannot access financial markets. They consume their current income from the labor net of taxes, unemployment benefits, and transfers. Members of both kinds of households offer low-, medium-, and high-skilled labor services indexed by $s \in (L, M, H)$.

Wage setting occurs under monopolistic competition, as workers supply differentiated labor in each skill group. A monopoly union acts as a wage setter, imposing a wage markup over the competitive wage. Nominal rigidities are imposed by assuming adjustment costs proportional

[11] The allocation of the total resources in the five categories might differ from official statistics due to the model's requirements.

[12] All equations of the baseline model and their descriptions are reported in Appendix A.

[13] See, among others, Galí *et al*. (2007), Bilbiie (2008, 2020), Colciago (2011), Motta and Tirelli (2012), and Bilbiie and Straub (2013).

to wage changes.

The model features three sectors on the production side. In the final-good sector, firms produce differentiated goods by combining intermediate inputs and a labor aggregate in a monopolistically competitive environment, allowing them to set a markup over the marginal costs. As we shall see in Section 3.5, the productivity-enhancing contribution of public investment is considered by introducing public capital in the production function as an additional and exogenous factor of production. After paying a fee to enter the market, monopolistically competitive intermediate firms rent physical capital designs produced by the R&D sector to transform each unit of capital into a single unit of an intermediate input, which they sell to final-good firms.

The R&D sector is assumed to be operated by a research institute. The latter employs high-skilled labor and produces intangible capital (designs) according to an ad-hoc rule where the stock of knowledge depends on the existing domestic and foreign stock. The first evolves according to the agent's optimization choices, while the latter is exogenous and depends on a calibrated growth rate.

Private and public consumption and investment combine domestic and foreign varieties of final goods aggregated through calibrated CES functions. Finally, government expenditures in steady state are based on simple rules and proportional to GDP. At the same time, the central bank follows a Taylor-type rule based on the observed deviation from the inflation target and the potential output.

3.2 Government transfers to households

Each household i aims to maximize a discounted intertemporal utility function defined by consumption (C_t^i) and leisure ($1 - L_t^{i,s}$):

(1) $$V_0^i = E_0 \sum_{t=0}^{\infty} \beta^t \left((1-\theta) log\left(C_t^i - \theta_C C_{t-1}\right) + \sum_s \frac{\omega_s}{1-k} (1 - L_t^{h,s})^{1-k} \right),$$

where β is the discount factor; instant utility from consumption accounts for habit persistence (θ_c), while a CES preference for leisure is assumed, which is based on a common labor supply elasticity ($1-k$), but skill-specific weights (ω_s).

The budget constraint of the representative Ricardian household i is:

(2a) $$(1 + t_t^c) P_t^C C_t^i + \Lambda_{F,t,t-1}^i + \Lambda_{R,t,t-1}^i = \Omega_L^{i,s} + PR_t^i + TR_t^i,$$

where C_t^i refers to real consumption, t_t^C are taxes on consumption, and P_t^C is the consumption utility deflator. In addition, $\Lambda_{F,t,t+1}^i$ and $\Lambda_{R,t,t+1}^i$ are the net financial and real investments between t and $(t-1)$, where the latter are subject to adjustment cost on real capital and capacity utilization; $\Omega_L^{i,s}$ is the after-tax labor income, which is obtained from all kinds of labor supplied, plus the unemployment benefits for households' unemployed members, net of the wage adjustment costs; PR_t^i are profits from final and intermediate firm ownerships, while TR_t^i are government transfers.

After-tax-real investments can be allocated to the acquisition of new tangible capital (J_t^i) or intangible ($J_t^{A,i}$) capital. Therefore, $\Lambda_{R,t,t-1}^i$ is the sum of two components:

(2b) $P_t^I\left(J_t^i + \Gamma_J(J_t^i)\right) - (1 - t_{t-1}^k)(i_{t-1}^K - rp_{t-1}^K - \xi_t^{rp})P_t^J K_{t-1}^i - t_{t-1}^K \delta^K P_t^I K_{t-1}^i - \tau^K P_t^I J_t^i,$

(2c) $P_t^A J_t^{A,i} - (1 - t_{t-1}^k)(i_{t-1}^A - rp_{t-1}^K)P_t^A A_{t-1}^i - t_{t-1}^K \delta^A P_t^A A_{t-1}^i - \tau^A P_t^A J_t^{A.i},$

where P_t^I and P_t^A are tangible and intangible capital prices; i_t^K and i_t^A are their rental rates; rp_{t-1}^K and rp_{t-1}^A are their risk premia; ξ_t^{rp} is an exogenous shock on the risk premium of tangible capital;[14] δ^K and δ^A are their depreciation rates; t_t^K is the capital tax, which is the same for both; τ^K and τ^A are tax credits received by households that invest in tangible and intangible capital. Accumulation of tangible (K_t^i) and intangible $\left(A_t^i\right)$ capital exhibit the following dynamics:

(3) $K_t^i = J_t^i + (1 - \delta^K)K_{t-1}^i,$

(4) $A_t^i = J_t^{A,i} + (1 - \delta^A)A_{t-1}^i,$

where J_t^i and $J_t^{A,i}$ are investments in physical and intangible capital and δ^K and δ^A are their depreciation rates.

The liquidity-constrained households do not own any financial wealth. Therefore, they do not smooth their consumption over time and consume all their disposable wage and transfer income in each period. The real consumption of each liquidity-constrained household is the net wage income plus transfers from the government. The real consumption of each liquidity-constrained household k is then:

(5) $C_t^k = \frac{\Omega_L^{k,s} + TR_t^k}{(1+t_t^c)P_t^C},$

where $\Omega_L^{k,s}$ is the after-tax labor income (which, as before, is obtained from all kinds of labor supplied, plus the unemployment benefits, net of the wage adjustment costs) and TR_t^k are transfers from the government. Total government transfers to households are thus the sum of TR_t^i and TR_t^k. Transfers enter in a lump-sum fashion in the budget constraint of households.

Transfers are used to simulate the NRRP measures related to scholarships and energy efficiency, and building requalification (ecobonus and sismabonus measures). Given that the bulk of the energy efficiency and building requalification measures is dedicated to housing and construction, we augmented the transfer simulation assuming an increase of private investments proportional to the resources allocated to these measures, which quickly transmit to the economy as the construction sector leads the cycle. This augmentation is obtained through an exogenous negative shock on risk premium on tangibles, as introduced

[14] Investors in tangible and intangible capital require premia to cover the increased risk on the return related to these assets.

in equation (2a).[15] Therefore, we considered a risk premium shock able to increase private investment as much as the additive resources allocated to energy efficiency and building requalification measures.

It is worth noting that the transfer/premium channel is very effective for mapping incentives, as timing and amounts of resources allocated can be precisely calibrated. In particular, measures related to energy efficiency and building requalification contained in the RRP have a peculiar timing. Investments must be made by 2023, while transfers from the government - in the form of a tax credit - take place five years after the work is completed, from 2022 to 2026.[16] A different solution would involve shocking tax credit on private investment (see the following subsection.) However, this channel would not be able to mimic the time mismatch between investments and transfers.[17]

3.3 Incentives for business investments

Non-Ricardian households maximize their utility function subject to their budget constraint and the laws of motion for tangible and intangible capital. Starting from the first-order conditions of the maximization problem, it is possible to show that investment evolves according to a standard Tobin's Q equation:

(6) $$Q_t^i = 1 + \gamma_K \left(\frac{J_t^i}{K_{t-1}^i} - \delta^K \right) + \gamma_I \left[\Delta J_t^i - E_t \left(\frac{\Delta J_{t+1}^i}{i_t - \pi_{t+1}^C} \right) \right] - \tau^K,$$

where Q_t^j represents the present discounted value of the rental rate of return from investing in physical capital; γ_K and γ_I are parameters governing the magnitude of investment and capital adjustment costs; $(i_t - \pi_{t+1}^C)$ is the rental rate of physical capital, with π_{t+1}^c being the expected inflation on investment goods; τ^K is a tax credit.

An increase in tax credits makes private investments cheaper, thus favoring the accumulation of physical capital. It makes projects with lower expected values profitable, positively affecting market entry and innovation. To see this, we need to briefly describe the production side of the model.

The final-good producer uses intermediate goods and labor aggregate, combining low-, medium-, and high-skilled labor inputs subject to fixed costs. Intermediate goods are produced in a monopolistically competitive intermediate sector, where firms enter the market by paying a fixed entry cost and renting tangible capital inputs and a design created by the R&D sector. After renting the design, firms can transform one unit of capital into a single unit of intermediate input. The R&D sector is based on a spillover augmented version of Jones (1995), the driving equation of the knowledge stock (A_t) evolves according to:

[15] The shock is introduced in a separate, ad-hoc simulation and added (linearly) to the main one.

[16] The measures also include the possibility of transferring the tax credit (e.g. to private banks) so that the transfer is received simultaneously. However, this transfer takes place within the private sector and would not affect the current model.

[17] Results obtained through this channel are quantitatively similar and available upon request.

(7) $$\Delta A_t = v A_{t-1}^{*\varpi} A_{t-1}^{\phi} L_{A,t}^{\lambda},$$

where ϖ and ϕ are parameters ruling the degree of foreign and domestic spillover from national (A_t) and foreign (A_t^*) knowledge stock; v is the total factor efficiency of the R&D sector, while λ is the elasticity to the number of researchers ($L_{A,t}$).

Under this setup, entry into the intermediate sector occurs when the present discounted value of profits of the intermediate sector (PR_t^x) is higher than the fixed-entry cost plus the net value of patents:

(8) $$PR_t^x > i_t^A P_t^A + (i_t^A + \pi_{t+1}^A) FC_A,$$

where i_t^A is the rental rate of intangible capital, P_t^A the price of one unit of intangible capital, π_{t+1}^A the related inflation, and FC_A is the fixed cost that intermediate firms pay to enter the market.

Introducing tax credits on private investments reduces firms' costs, increases profits, and induces higher entry. Moreover, given that one unit of capital is used to produce one unit of intermediate good, in equilibrium, the stock of knowledge is proportional to the stock of physical capital:

(9) $$\int_0^{A_t} x_{i,t}\, di = K_t,$$

where $x_{i,t}$ is the output of the *i*-th intermediate firm, and K_t is the stock of private capital.

3.4 Employer social security contributions

In the final goods sector, entrepreneurs combine the labor aggregate ($L_{Y,t}^j$) and varieties (A_t) of intermediate inputs *x* with an elasticity of substitution θ using Cobb-Douglas technology.

Each firm *j* produces a variety of the domestic good, which is an imperfect substitute for the varieties produced by other firms, as follows:

(10) $$Y_t^j = \left(L_{Y,t}^j - FC_L\right)^{\alpha} \left(\int_0^{A_t} (x_{i,t}^j)^{\theta} di\right)^{\frac{1-\alpha}{\theta}} KG_t^{1-\alpha_g} - FC_Y, \qquad 0 < \theta < 1$$

where a and a_g are production coefficients. The production is subject to fixed costs FC_Y and overhead labor FC_L. The latter includes fixed costs associated with bureaucracy. As we shall see in the following subsection, the introduction of the public capital stock (KG_t) in the production function for final goods can account for the productivity-enhancing features of public investment.

Labor ($L_{Y,t}^j$) is aggregated by a CES function:

(11) $$L_{Y,t} = \left(s_L^{\frac{1}{\sigma_L}} (e_L L_t^L)^{\frac{\sigma_L - 1}{\sigma_L}} + s_M^{\frac{1}{\sigma_L}} (e_M L_t^M)^{\frac{\sigma_L - 1}{\sigma_L}} + (s_H - s_A)^{\frac{1}{\sigma_L}} \left(e_H (L_t^H - L_{A,t})\right)^{\frac{\sigma_L - 1}{\sigma_L}} \right)^{\frac{\sigma_L}{\sigma_L - 1}},$$

where σ_L is the elasticity of substitution between different types of labor. Parameters s_L, s_M, s_H, s_A are the population shares of labor force in the low-, medium-, high-skilled, and in the R&D sector, which employs only high-skilled workers, while e_L, e_M, e_H are the corresponding efficiency unit.

The final goods entrepreneur j maximizes profits:

(12) $$PR_t^{f,j} = P_t^j Y_t^j - \big((a + SSC_t^L) W_t^L L_t^{j,L} + (1 + SSC_t^M) W_t^M L_t^{j,M} + (1 + SSC_t^H) W_t^H L_t^{j,H}\big) - \int_0^{A_t} px_{i,t} x_{i.t}^j di,$$

where $px_{i,t}$ is the price of intermediate inputs, W_t^s is the nominal wages for each skill group $s \in (L, M, H)$, and SSC_t^S are the employer social security contributions. Solving the problem in a symmetric equilibrium yields the following demand for labor:[18]

(13) $$(1 + SSC_t^S) W_t^s = \alpha \frac{Y_t + FC_Y}{L_{Y,t} + FC_L} \left(\frac{L_{Y,t}}{L_t^S}\right)^{\frac{1}{\sigma_l}} s_S^{\frac{1}{\sigma_L}} e_S^{\frac{\sigma_L - 1}{\sigma_L}} \eta_t$$

where η_t is the wage inverse markup factor and L_t^s is the employment aggregate, which is an aggregate of the differentiated labor services supplied by households, i.e.

(14) $$L_t^s = \left[\int_0^1 \left(L_t^{s,h}\right)^{\frac{\sigma_S - 1}{\sigma_S}} dh\right]^{\frac{\sigma_S}{\sigma_S - 1}}$$

where $\sigma_S > 1$ refers to the degree of substitutability between different types of labor.

The reduction in SSC contributions foreseen in the plan is introduced through proportional change in SSC_t^S, which also enters in the Government budget constraint.

3.5 Public investments

Investments are the cornerstone of the NRRP. The resources allocated for public investment account for 62% of the total.

In the short term, the impact of public investment expenditure on GDP is determined through a change in labor as both public and private capital are relatively fixed. The impact depends mainly on how public expenditure interacts with the real and nominal rigidities present in the economy.[19] By contrast, production coefficients determine the impact of public investment expenditure in the long term as the medium to the long-term impact of public investment is transmitted through supply mechanisms.

The final goods sector combines the labor aggregate ($L_{Y,t}$), intermediate goods ($x_{m,t}$) and public capital ($K_{G,t}$) through a Cobb-Douglas production technology, subject to overhead labor costs (FC_L) and fixed costs (FC):

(15) $$Y_t = (L_{Y,t} - FC_L)^{\alpha} \left(\int_0^{A_t} x_{m,t}{}^{\theta} dm\right)^{\frac{1-\alpha}{\theta}} K_{G,t}{}^{1-\alpha_g} - FC,$$

where θ is the elasticity of substitution between intermediate inputs and a and a_g are production coefficients. The latter rules the impact of public investment on final output in the long run.

[18] As we considered the symmetric equilibrium, we removed the *j* subscript.

[19] The impact of public investment on macroeconomic variables in the short term depends mainly on how public expenditure interacts with the real and nominal rigidities present in the economy (see Ramey, 2021).

The stock of public capital is fueled by public investment (I_t^G). Formally, the public capital stock evolves according to the following motion law:

(16) $$K_t^G = \frac{1}{4}\sum_{i=1}^{4} I_{t-n}^G + (1-\delta^G)K_{t-1}^G.$$

The evolution of the public capital stock considers its depreciation (δ^G) and its gradual implementation according to a *time-to-build process* (Leeper *et al.*, 2010; Ramey, 2021).

In the context described above, everything equal, an increase in public investment has a direct impact on the potential output. However, it also has an indirect effect. A larger stock of public capital increases the productivity of other factors, encouraging companies to hire more workers and increase private investment.[20]

The direct impact of public investment, given the formalization introduced, crucially depends on the elasticity of output to the public capital stock ($\varepsilon_{Y,K^G} = 1 - a_g$) and the accumulated stock (K_t^G). Formally, the impact is given by the following expression:

(17) $$\frac{\partial Y_t}{\partial K_t^G} = \varepsilon_{Y.K^G}\frac{Y_t}{K_t^G}.$$

The direct effect of public investment, given the production function, will therefore depend negatively on the initial public investment stock (the higher the initial stock, the lower the marginal increase effect of investment) and positively on the elasticity of output relative to the public capital stock.

The elasticity of final output to the stock of public capital at the aggregate level is quite variable and depends on the type of public investment considered. Our calibration follows the detailed meta-analysis of Bom and Ligthart (2014). They conducted a meta-analysis on the elasticity. Collecting and comparing estimations in 68 studies, they found that, on average, the contemporaneous output elasticity of public capital is estimated to be 0.083. However, the estimates are sensible for the kind of public investment considered. Specifically, the estimates become larger, up to 0.19, when (i) public capital is installed at a regional/local level; (ii) core public capitals/infrastructures are considered; (iii) investments are on longer horizons.

We built a sort of confidence interval based on Bom and Ligthart (2014) and we consider a mean output elasticity of 0.12. This value is higher for core (high efficiency) public capital, with an elasticity of 0.17. High-efficiency investments aim at constructing roads, motorways, airports, water systems (core infrastructure), and, more generally, investments directly and indirectly linked to the production activities of the various economic sectors. Additionally, we consider a value of the output elasticity equal to 0.07 when public capital accumulates through low-efficiency investments.[21] Our confidence interval captures the uncertainty of the effects of public

[20] A change in the stock of public capital has a positive impact on capital and labor productivity to the extent that the direct effect is positive ($\partial Y_t/\partial K_t^G > 0$).

[21] Our assumptions align with the European Commission (2020), where average, high, and low-efficiency investments are associated with output elasticities equal to 0.12, 0.17, and 0.07, respectively. The IMF (2014) also uses a value of 0.17 for core infrastructure. A slightly different calibration is contained in in 't Veld (2016), where elasticities equal to 0.09 and 0.17 are associated with average and high-efficiency scenarios, respectively. Our assumptions are also

investments (see below) and the success of their implementation.

Here, a series of issues related to calibrating the output elasticity to public capital is worth mentioning.[22] First, the elasticities considered in the literature are average values that reflect industrialized economies. Using specific values for Italy, based on ad-hoc empirical studies, would contribute to a more precise quantification of the effects of short- and long-term public investment. In this case, the elasticities should be built up considering the composition of public investment and its regional location (Guarascio and Zezza, 2022). Second, measuring the stock of public capital is another problematic aspect. The existing data are not of good quality, and the approach followed is, therefore, to induct backward, i.e. the stock is reconstructed from the public investments observed or an average of these. In very simplified terms, given the average value observed over a certain period for investment (I^G), the stock of public capital will be equal to $K^G = I^G/\delta^G$. Given the variability from public investment, the average value observed in the long term can be used for calibration. A calibration based on the average share of investments is consistent with the stationary properties of the model.[23]

Finally, it should be noted that several other factors influence the multipliers of public investment. Specifically, in our model, the impact multiplier of public investment tends to decrease with the degree of openness of the economy due to the positive impact on relative prices and, consequently, on international trade. A coordinated stimulus at the European Union level tends to eliminate these effects, favoring the positive impact of public investment on GDP.[24]

3.6 Government current expenditures and monetary policy setup

The government and the central bank manage fiscal and monetary policies, respectively. The systematic component of public policies is modeled according to simple rules, assuming that in steady state government consumption (G_t) government investment (I_t^G) and transfers are proportional to GDP, while unemployment benefits (BEN_t) are indexed to wages and consumer prices. As partially outlined in the previous sections, the government also provides subsidies (S_t)

supported by the rich analysis recently developed by Zezza and Guarascio (2022) on Italian regional data (Conti Pubblici Territoriali.)

[22] See Ercolani (2021) for a more detailed critical review of the literature on the macroeconomic effects of public infrastructure investment associated with the main underlying transmission channels.

[23] It should be noted that this compensates for a mismatch between model calibration and national accounting data (where the share of public investment is that observed in the current year and not the average). In this case, a proportional correction would be required to consider the deviation between the average and observed value to report the data to the national accounts.

[24] As previously mentioned, the model includes semi-endogenous growth and the possibility of introducing exogenous shocks to intangible investments in R&D through tax credits and wage subsidies. However, incentives to intangibles would generate a skill trade-off, as high-skilled workers would move from production to R&D, reducing GDP in the short term. Given the nature of the measures under analysis, which do not imply workers' reallocation but productivity improvements, we consider incentives to simulate R&D investments simply as public investment or incentives to private investments, with positive short-term demand effects and long-term supply-side improvements.

on physical capital and R&D investments in the form of tax credits and depreciation allowances:

(18) $$S_t = t_{t-1}^k\left(\delta^K P_t^I K_{t-1}^i + \delta^K P_t^I A_{t-1}^i\right) + \tau^K P_t^I J_t^i + \tau^A P_t^A J_t^{i,A}\ ,$$

where t_t^k are taxes on capital, P_t^I and P_t^A are the tangible capital and R&D price deflators, respectively, while τ^A are tax credit on R&D investment.

On the revenues (R_t^G) side, the government collects resources through taxes on consumption, capital, and labor income. Accordingly, government debt (B_t) evolves according to the following equation:

(19) $$B_t = (1 + r_t)B_{t-1} + P_t^C(G_t + I_t^G) + TR_t + BEN_t + S_t - R_t^G - T_t^{LS},$$

where T_t^{LS} are lump-sum taxes. Increases in government consumption are introduced into the model by simply adding an erogenous i.i.d. shock to the endogenous variable G_T.

Finally, the European Central Bank adopts a Taylor-kind rule; thus, the monetary authorities respond to changes in expected inflation and output gap at the EU level.

4. Calibration

The QUEST model is used for policy assessments of member countries by the European Commission. The calibration for every country is obtained from a mix of estimation and matching approaches.[25] The model consists of about 500 equations/variables and 187 parameters. Therefore, this section can only briefly summarize the calibration. More details on the methodology and the values of calibrated/estimated parameters can be deepened by reading D'Auria *et al.* (2009), Ratto *et al.* (2009), and Rogers *et al.* (2022).[26] However, it is worth noting that the model is widely used, and its calibration is extensively documented. Leaving the details to Rogers *et al.* (2022) and other mentioned works, we here emphasize the main aspects of the model calibration.

The model is calibrated to match the great ratios for Italy: a consumption-to-GDP ratio equal to 0.58 and an investment-to-GDP ratio equal to 0.19. The model is also calibrated to match the shares of the government's consumption (0.22), investment (0.02), and transfers (0.22), which are obtained from Eurostat and updated in the 2018 figures. Similarly, effective tax rates on labor, capital, and consumption are obtained from Eurostat and used to determine government revenues.[27]

The parameters of the utility function, including habits and the frictional parameters, are

[25] The model parameters are estimated by applying a Bayesian approach to the model (e.g., Schorfheide, 2000; Smets and Wouters, 2003) and externally by using micro estimations. Calibration is also routinely updated by the Commission. Our assessment is based on the 2018 update.

[26] See also Coenen *et al.* (2012), Pfeiffer *et al.* (2020, 2021a, 2021b), and Roeger *et al.* (2008., 2021).

[27] By using AMECO data, tangible and intangible private capital to GDP ratios are also matched. The same occurs for the labor participation and employment figures.

calibrated by using information from the estimation of the core QUEST III model (Ratto *et al.*, 2009). The monetary policy parameters are those estimated by Ratto *et al.* (2009). Core inflation is about 2% on an annual basis.

Sectoral markup estimates are instead obtained from EU KLEMS data. The aggregate markup is around 13% in the final goods sector and 10% in the intermediate production sector - markups pin down the elasticity of substitutions. Estimated aggregate entry barriers rely on Djankov *et al.* (2002). Finally, fixed costs are set to reconcile markups with observed profit rates.

The steady-state rental rate of capital matches a capital-output ratio of 3 and an R&D share of 2% to GDP. Output elasticities of R&D production and subsidies to R&D investments are obtained from Bottazzi and Peri (2007) and Warda (2006, 2009). The growth rate of ideas is based on Pessoa (2005), assuming an obsolescence rate of 5%. Data on the R&D share of labor and intensity are taken from Eurostat. Import shares are calibrated on information from Eurostat COMEX. Trade price elasticity is estimated (Ratto *et al.*, 2009).

Skill shares are calibrated using the information provided by Eurostat and wage premia. The elasticity of substitution between skilled labor and unskilled labor is calibrated at 1.7, following Acemoglu and Autor (2011), who updated Katz and Murphy (1992). Price and wage adjustment cost parameters are estimated following Ratto *et al.* (2009) and are equal to 19.7 for prices and 120 for wages, without differences across skills.

5. Macroeconomic impact of the plan

Our results must be read in light of the implementation assumptions. Therefore, the transposition of the plan into the model is a crucial part of our exercise. As previously mentioned, the planned expenses are mapped into the five categories described using granular data on every measure.

Our assumption about the distribution and timing of the additional NRRP funds over the period 2021-2026 are descried in Section 2 (see Figure 1 for a summary.) To account for the positive spillovers stemming from the NGEU program, we assumed that RRF grants allocated to other EU countries are used for average-efficiency public investments over six years with a constant path of spending.

We also assume that the European Central Bank responds according to a standard Taylor rule. While we do not expect the ECB to increase rates in the first periods of the simulation, we cannot exclude a slowdown of non-conventional policies. This would be captured by an increase in the interest rates in the model, which would partially move as a shadow rate. Moreover, leaving the ECB standard (Taylor) rule reaction function allows the production of some conservative estimates in the short run.[28]

[28] A study of the optimal policy mix is beyond the scope of the present paper.

We assumed a reduction of debt financing costs for obligations arising from RRF-loans-financed measures. To consider the different impacts of grants- and loans-financed measures on public finance variables, grants-financed measures were deducted through the introduction of an exogenous variable on the deficit and debt equations. These latter assumptions have no significant impact on the macroeconomic variables we will discuss later.

The critical assumption underlining the NRRP simulations is that all public investments contained in the plan are those with high efficiency. Accordingly, we use a GDP elasticity to public capital $(1 - a_g)$ equal to 0.17 for the reference simulations (see Section 3.5).

It is worth noting that the simulation does not consider the impact of structural reforms. However, most current expenditures are considered, and, to a lesser extent, public investments are linked or directly financed by the reforms described in the NRRP.

Our results are summarized in Table 3, reporting the impact evaluation of the NRRP on selected macroeconomic variables over 2021-2026, the expected time horizon of the plan. GDP grows steadily over the period under analysis and is estimated to be 3.4% higher in 2026 compared to a no-policy change baseline scenario. The positive impact on GDP over the first three years is driven by a substantial increase in total investment while dampening the slowdown of consumption and exports.

The model's logic explains the negative impact on private consumption. The massive increase in public investment increases the expected returns on capital investments. Consequently, Ricardian households tend to reduce consumption to save and invest in the first periods because of higher consumption levels in the future. This reduction in consumption could be partially avoided by assuming a more expansionary stance of the monetary authority, assumed to follow a standard Taylor rule for the motivations previously outlined.

The negative dynamic for exports is due to the inflationary pressure on the prices of exported goods. The NRRP increases the demand for investment goods with positive effects on the costs faced by firms, which are also rebated on export prices. The improvement in terms of trade has adverse effects on the dynamic of exports in the first periods, where demand-side effects prevail. In the medium term, however, the accumulation of public capital, a factor of production, improves the economy's supply capacity, posing negative pressure on firms' costs and export prices. As it is clear from Table 3, the supply-side effect prevails in the medium term. In 2026, exports are 2.3% higher concerning a no-policy change baseline scenario. However, export improvement is not enough to avoid a deterioration of the current account.

It should be noted that the plan under analysis does not fully consider the spillover effects of implementing NRRPs in other countries.[29] In the latter case, the increase in foreign demand would also set more substantial positive pressure on exports in the short term, possibly compensating for the described deterioration of the current account.

Table 3 – Impact of the NRRP on selected macroeconomic variables

	2021	2022	2023	2024	2025	2026
GDP	0.5	1.0	1.4	2.1	2.8	3.4
Private consumption	-0.4	-0.7	-0.5	-0.1	0.7	1.6
Total investment	2.9	7.0	8.4	10.9	11.7	11.0
Import	0.2	0.8	1.4	2.2	3.1	3.8
Export	-0.1	-0.4	-0.2	0.4	1.3	2.3

Note: This table reports the impact evaluation of the plan on selected macroeconomic variables. Results are annual percent deviations from a no-policy change (baseline) scenario.

To better understand the previous results, Figure 2 reports the relative contribution of the different NRRP policy measures on GDP. We consider the five transmission channels introduced in Section 2, grouped into three main categories; moreover, we consider the spillover arising from public investment in the REA.

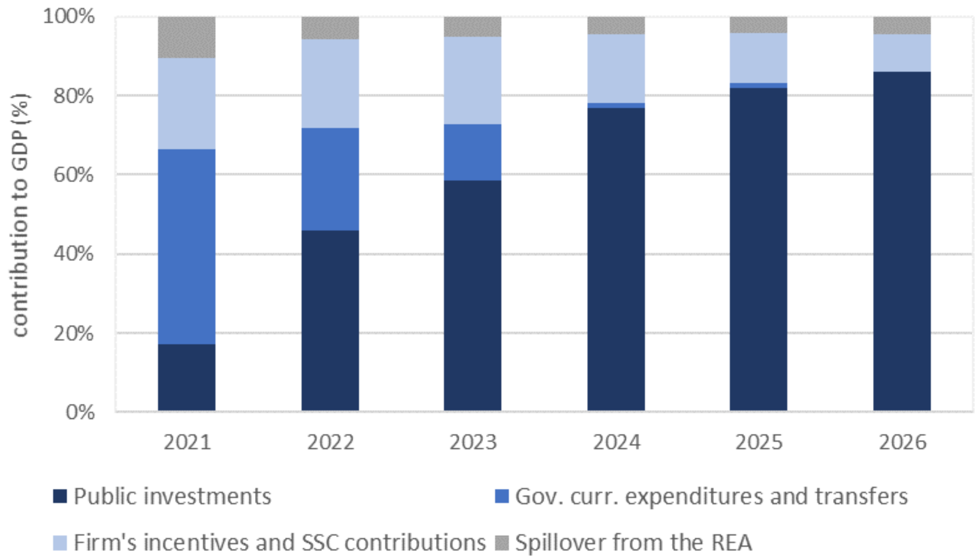
During the first two years, the contribution to the simulated GDP deviation from the baseline is distributed across current public expenditures, investments, and incentives to firms. Public investment becomes the leading channel behind the GDP dynamic, followed by a decreasing but persistent role of firms' incentives. A somewhat limited and steady role stems from the positive spillover effects of investments in the REA.

The results of our simulations hinge on the assumption that public capital stock has a high efficiency concerning its impact on output. To investigate the uncertainty surrounding our findings, Table 4 reports the result of the same simulation considering two additional scenarios. Following the discussion in Section 3.5, the first is an "average" scenario, in which we consider investments with efficiency concerning GDP corresponding to the average estimate found in the empirical literature. The second is a "low" scenario, in which public investments with lower effectiveness are financed, i.e., those with a lower impact in terms of potential GDP growth.[30]

[29] See Pfeiffer *et al.* (2022).

[30] The impact of public investments is subjected to great uncertainty as this depends on the kind of investment, its implementation design, and the institutional framing conditions (see, among others, Albrizio and Geli, 2021; Avellán *et al.*, 2021; Cacciatore *et al.*, 2021). Focusing on multipliers of ERDF spending, Canova and Pappa (2021) provide evidence on the great country and regional heterogeneity.

Figure 2 – Relative contributions to GDP by policy measures



Note: The figure reports the relative contribution of the different policy measures on the GDP deviation from the no-policy change (baseline) scenario. The transmission channels considered are public investments, incentives for firms' investments, reductions of SSC contributions on labor, current government expenditure, government transfers, and spillovers from public investment in the rest of the euro area.

As previously outlined in the model, the scenarios differ regarding the elasticity of final output to public capital stock. We assume that the elasticity is 0.12 in the average scenario and 0.07 in the low scenario (in the reference "high" scenario is 0.17.) Investments associated with the low scenario might include projects involving the unproductive distribution of the resources allocated to investment. This case occurs, for example, when there are errors in the selection, planning, and implementation of investments. In the latter case, the initial demand effect is not followed by significant long-term effects on the potential growth of the product. This category might also include investments that suffer significant delays in their implementation, where projects become obsolete due to the delay in their implementation.

During the first and second years, the impact of public investment is similar in the three scenarios. As already outlined, in the short term, the effects of investment primarily depend on their impact through aggregate demand, which is broadly equivalent across different scenarios. Moreover, the efficiency of public investment plays a crucial role in the medium term. For example, the GDP levels increase in the simulation's final year compared with the baseline no-policy scenario, equaling 1.8% in the low scenario compared with 3.4% when high-efficiency investments are assumed.

Table 4 – Impact of the NRRP on GDP, different public capital efficiency

Efficiency	2021	2022	2023	2024	2025	2026
High	0.5	1.0	1.4	2.1	2.8	3.4
Average	0.5	1.0	1.2	1.7	2.2	2.6
Low	0.5	0.9	1.0	1.3	1.6	1.8

Note: This table reports the impact evaluation of the plan on real GDP, conditional on different public capital efficiency. The output elasticity of public capital equals 0.07 in the Low, 0.12 in the Average, and 0.17 in the High scenario. Results are annual percent deviations from a no-policy change (baseline) scenario.

Similar conclusions to those stemming from Table 4 are reached if these results are analyzed from a different perspective, namely calculating the cumulative multiplier of the measures in 2026, the end-year of the program. The latter is the sum of the year-by-year GDP deviation from baseline over 2021-2026 and the same sum for the NGEU funds (Ramey, 2021). Using a cumulative multiplier as a synthetic measurement of the plan's impact has the advantage of capturing investments' dynamic medium- and longer-term effects.[31]

At the end of the simulation horizon, the cumulative multiplier equals 0.7 in the low scenario, 0.9 in the average scenario, and 1.1 in the high one. As expected, variations in the output elasticity to the capital stock parameter significantly affect the returns from public investments and the cumulative multipliers. It follows that, as already emerged in the current debate, much of the success of the NRRP is connected to the policymakers' ability to select, design, and implement public investment programs.[32]

6. Distributional impacts

The NNRP will unquestionably contribute to the growth of the Italian economy in the coming years. However, the positive effect on GDP might hide heterogeneous and possibly adverse dynamics across income earners and categories. Against this background, this section investigates the plan's impact on different income categories by analyzing the model-based functional income distribution.[33] The methodology is borrowed from Roeger *et al.* (2021), who focus on the distributional impact of labor market reforms.

6.1 Impact by income category and income share

As outlined in Section 3, households in the model receive income from labor, capital, profits, financial wealth, unemployment benefits, and transfers. Accordingly, we analyze the

[31] The same definition is also contained in Pfeiffer *et al.* (2022), where authors look at longer-term horizons.

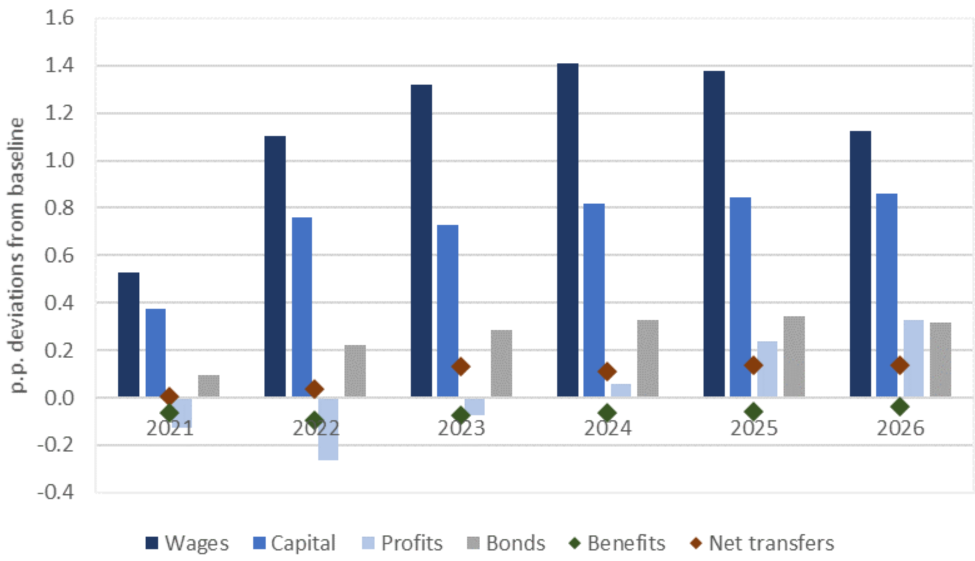
[32] See, e.g., Alcidi *et al.* (2020) for a discussion on the risks related to the implementation of large investment plans.

[33] The epidemics of the last two decades have always been followed by increases in inequality (IMF, 2020; Furceri, 2020; 2021). Therefore, the plan's impact on the distribution cannot be ignored, even if, in this context, within the limits of the functional distribution of income.

plan's impact on these income categories in absolute terms and relative share of National Disposable Income (NDI).[34] Our results are described in Figures 3, 4, and 5.

Figure 3 reports the plan's impact on the income categories in deviations from the no-policy change scenario in p.p. of GDP. Incomes from the capital, labor, and financial wealth appear to be mainly driven by demand factors; therefore, they roughly follow the total expenditure path, which steadily increases in the first years.

Figure 3 – Impact by income category, change in absolute values, p.p. of GDP



Note: This figure shows total net income from wages, capital, profits, bond, government benefits, and transfers as p.p. of GDP deviation from a no-policy change (baseline) scenario.

Interestingly, profits decline in the early years, driven by the increase of labor and capital incomes, which, everything equal, are negatively correlated with profits. However, the result is reversed in the last three years, where profits moved above their initial level following the increase in GDP and productivity enabled by the accumulation of public and private investment. Finally, net transfer dynamics follow our assumptions on the disbursement timing. As expected, unemployment benefits fall over the period under analysis, following the overall improvement in economic activity.

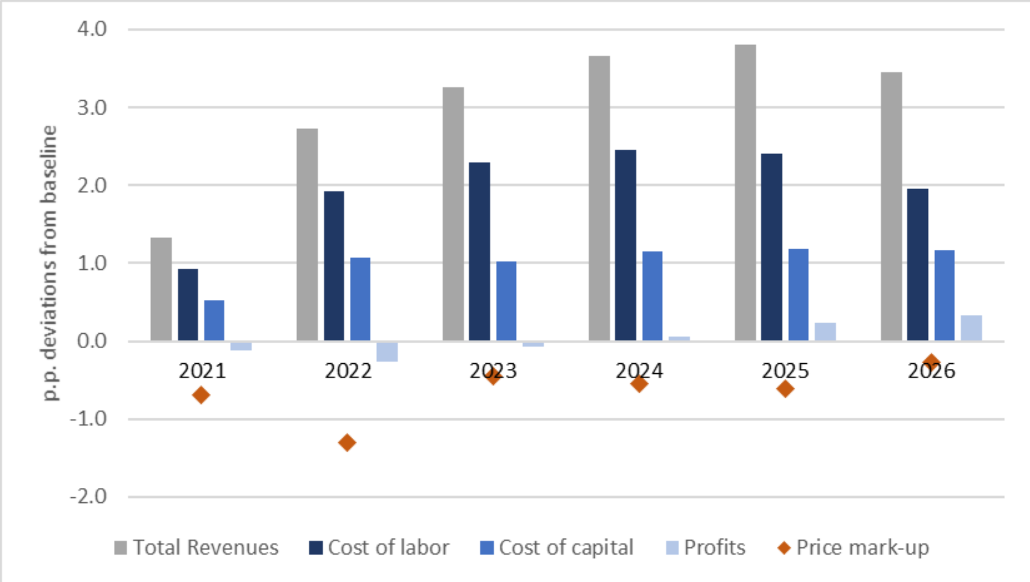
To better understand the drivers behind the profit dynamic, in Figure 4, we break it up into the following three components: total revenues and (minus) the cost of labor and capital.[35] In

[34] The model-based NDI is defined as the sum of net income from labor, capital, profits, financial wealth, and government transfers.

[35] Formally, profit income is the sum of profits from final, intermediate, and R&D sector. Following Roeger *et al.* (2019), profit income can be expressed in compact form as $P_t^Y Y_t - W_t L_{Y,t} - P_t^x K_t + (1-\lambda) P_t^A \Delta A_t$, where P_t^Y and P_t^x are output and intermediate prices, W_t the aggregate nominal wage, and λ the elasticity of R&D production with respect to the number of researchers. The four blocks in the equation can be described as total revenues from the

addition, we also report the price markup dynamics.[36]

Figure 4 – Impact on profits, profits' components, and price markup, p.p.



Note: This figure shows total net income from profits and its components (total revenues, cost of labor, cost of capital) as p.p. of GDP in deviation from a no-policy change (baseline) scenario. Price markup is expressed as p.p. from a no-policy change (baseline) scenario.

The evolution of revenues and costs seems to explain the overall dynamic of profits. In the plan's first three years, the increase in revenues is not enough to cover the increasing labor and capital costs, driven by increasing wages, employment, capital stock, and interest rate, while the contrary occurs from 2024 onwards. As a result, the price markup is constantly below its baseline value, with negative deviations between 0.7 and 1.3 p.p. The negative impact on price markup arises from the inflationary pressure of the plan and the fact that because of adjustment costs, a fraction of firms cannot index their prices to the expected inflation.

6.2 Impact on liquidity-constrained and non-liquidity-constrained households

As outlined in Section 3.2, households in the model are of two types. Ricardian households have access to financial markets, accumulate physical capital, and can thus smooth their consumption over time. Liquidity-constrained households, instead, cannot access financial markets. Hence, they consume all their current income from the labor net of taxes, unemployment benefits, and transfers. In this respect, from a policy perspective, it is of great interest to understand the differential impact of the plan on these two classes of households. Table 5 reports the

final goods sector, gross wages, the stock of capital priced as intermediate goods, and profits from the R&D sector. At the cost of oversimplifying, in the text we refer to $P_t^Y Y_t + (1-\lambda) P_t^A \Delta A_t$ as total revenues, $W_t L_{Y,t}$ as the cost the of labor, and $P_t^x K_t$ as the cost of capital.

[36] Fluctuations of the price mark-up are due to price adjustment costs and the partial indexing of prices to inflation. See Roeger *et al.* (2008), Section 1.2.1 on this point.

consumption dynamics of the two groups together with the aggregate consumption.

Table 5 – Impact on liquidity- and non-liquidity-constrained households

Private Consumption	2021	2022	2023	2024	2025	2026
Aggregate	-0.4	-0.7	-0.5	-0.1	0.7	1.6
Liquidity-Constrained	0.1	0.2	0.6	1.0	1.6	2.1
Non-Liquidity-Constrained	-0.6	-1.2	-1.1	-0.6	0.2	1.3

Note: This table reports the impact evaluation of the plan on (aggregate) private consumption, liquidity-constrained households' consumption, and non-liquidity-constrained households' consumption. Results are annual percent deviations from a no-policy change (baseline) scenario.

As expected, the reduction of aggregate consumption registered in the first periods of the plan is due to the consumption smoothing of Ricardian households, which chose to save and invest during the first years of the plan to capture a share of the expected increases in (future) capital income. On the contrary, the dynamic of liquidity-constrained households roughly follows the time allocations of public funds.

Considering the income dynamics for liquidity-constrained and non-liquidity-constrained households, it is helpful to recall here that both liquidity-constrained and non-liquidity-constrained households offer low-, medium-, and high-skilled labor services in the model. Consequently, the household income gap is not affected by skill-specific wage heterogeneity. On the contrary, the different income sources in the model drive the income gap. As shown in Figure 5, the plan positively impacts income from profits, capital, and bonds, which are a source of revenues for the Ricardian, but not for the liquidity-constrained households.

It is important to underline here that the latter result is mainly a by-product of the model characteristics and simulation assumptions rather than the actual impact of the plan on the two types of households. First, households' characteristics in the model are (necessarily) simplified and do not map one-to-one to the distribution of income and skills in the actual economy. Second, the model does not allow for the targeting of the NRRP measures to different groups of households, while actual policies often target the most economically (and socially) vulnerable people. Third, structural reforms, not considered in this exercise, often aim to support vulnerable groups.

As a final caveat, the current model setup does not allow for an analysis of the plan's impact on income distribution but only on the functional distribution between different income categories. A possible way to assess this critical point would be to use the QUEST output to feed microsimulation or micro-econometric models.[37] We leave the exploration of this to future research.

[37] See, for example, Barrios *et al.* (2019).

7. Conclusions

This paper has assessed the NRRP's impact on the Italian economy. Using granular information available at the Italian Ministry of Economy and Finance, we mapped the plan onto a large dynamic stochastic general equilibrium model built to capture the transmission channels associated with the NRRP instruments. Using Italy as a case study, we concentrate on the effects of national fiscal measures, complementing the existing literature that focuses on aggregate data or spillovers with simplified expenditure assumptions.

Our results show a sizable NRRP impact on the Italian economy. The plan involves a GDP growth between 1.8 and 3.4 percent in the medium term, depending on the efficiency of public investment. In the short run, GDP growth is driven by aggregate demand, while in the long run, the NRRP boosts productivity and GDP through the build-up of public capital stock. However, the magnitude and persistence of the effect depend on the efficiency of public investment financed, i.e. how much financed public investments contribute to the development of infrastructures that internalize production externalities. In this respect, the NRRP challenges the country's institutional capacity to select and execute viable and productive public projects.

We find that the plan's impact on the functional income distribution is adverse for profits in the plan's early years. They decline because of the increase in labor and capital demand. A trade-off is observed: incomes from wages, capital, and bonds increase at the expense of profits. In the medium term, this trade-off disappears as the increasing fiscal stimulus allows a generalized income increase. When GDP increases, profits move above their initial level.

As a final word of caution in evaluating the realism of the simulations, it is worth noting that it is necessary to consider various structural factors that influence the effectiveness of public investments. Various studies agree, for example, on the positive relationship between the efficiency of public administrations and the stock and quality of public capital. Moreover, the timing, effectiveness, and sustainability of public investments depend substantially on the regulatory regime and its implementation. The effectiveness of public investment also requires strong coordination between different levels of government. In Italy, investments by local authorities account for well over half of public investments.

The appropriate *scenario* for the simulation depends on the type of investments selected. Nevertheless, it also depends (if not mostly) on the context in which they will be made. Hence, creating the conditions for the success of a vast investment plan is one of the critical challenges that Italy will face. On these grounds, the planned structural reforms would play a crucial role. However, an investigation of their effects and interaction with the plan is beyond the scope of the present paper.

Our assessment is based on the planned expenditures. In this respect, inflationary dynamics could reduce the macroeconomic investment impact. The plan was designed when the average expected inflation was below 2%. However, the current expected values are much higher.[38] Since the financial plan is defined in nominal terms, without additional funding, this would imply lower investments in real terms, which could preclude the effectiveness of the projects considered.[39] To deal with this issue, the Italian Government has already allocated substantial additional resources to offset the effects of the unanticipated inflation.

[38] The December 2022 Eurosystem staff projections foresee that inflation will drop sharply, from 8.4% in 2022 to 3.6% by the end of 2023, mainly reflecting lower energy prices. But it will then stay at around 3.4% in 2024 and will reach 2% only in the third quarter of 2025.

[39] For a discussion on the point, see Pfeiffer *et al.* (2023).

References

Albrizio, S. and J. F. Geli (2021), "Scaling up NGEU: Institutions matter!" Banco de España, mimeo. Paper presented at the QUEST-R&D Users' Group workshop, October 2021.

Alcidi, C., D. Gros, and F. Corti (2020), "Who will really benefit from the Next Generation EU funds?" CEPS Policy Insight, No. 05.

Acemoglu, D. and D. Autor (2011), "Skills, tasks and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, Vol. 4, Part B, edited by O. Ashenfelter and D. Card, 1043-1171. Amsterdam: Elsevier.

Avellán, L., A. Galindo, and J. León-Díaz (2020), "The role of institutional quality on the effects of fiscal stimulus," IDB Working Paper Series No. 1113.

Bańkowski, K., M. Ferdinandusse, S. Hauptmeier, P. Jacquinot, and V. Valenta (2021), "The macroeconomic impact of the Next Generation EU instrument on the euro area," Occasional Paper Series No. 255, European Central Bank, Frankfurt, Germany.

Barrios, S, M. Dolls, A. Maftei, A. Peichl, S. Riscado, J. Varga, and C. Wittneben (2019), "Dynamic scoring of tax reforms in the European Union," *Journal of Policy Analysis and Management*, 38(1): 239-262.

Bilbiie, F. O. (2008), "Limited asset markets participation, monetary policy and (inverted) aggregate demand logic," *Journal of Economic Theory*, 140(1): 162-196.

Bilbiie, F. O. (2020), "The New Keynesian cross," *Journal of Monetary Economics*, 114(C): 90-108.

Bilbiie, F. O. and R. Straub (2013), "Asset market participation, monetary policy rules, and the Great Inflation," *The Review of Economics and Statistics*, 95(2): 377-392.

Bom, P. R. D. and J. E. Ligthart (2014), "What have we learned from three decades of research on the productivity of public capital?" *Journal of Economic Surveys*, 28(5): 889-916.

Bottazzi, L. and G. Peri (2007), "The international dynamics of R&D and innovation in the long run and in the short run," *The Economics Journal*, 117(3): 486-511.

Buti, M. and M. Messori (2021a), "Euro area policy mix: From horizontal to vertical coordination," CEPR Policy Insight No. 113.

Buti, M. and M. Messori (2021b), "Implementing the Recovery and Resilience Plans: The case of Italy," in Messori M., Recovery Pathways: The difficult Italian convergence in the Euro Area, Bocconi University Press, Milan, Italy: 237-245.

Buti, M. and M. Messori (2021c), "Next Generation EU: An interpretative guide," in Messori M., Recovery Pathways: The difficult Italian convergence in the Euro Area, Bocconi University Press, Milan, Italy: 215-226.

Buti, M. and G Papacostantinou (2021), "The Legacy of the Pandemic: How Covid-19 is reshaping economic policy in the EU," CEPR Policy Insight No. 109.

Cacciatore, M., R. Duval, D. Furceri, and A. Zdzienicka (2021), "Fiscal multipliers and job-protection regulation," *European Economic Review*, 132(C).

Canova, F. and E. Pappa (2021), "What are the likely macroeconomic effects of the EU Recovery Plan?" CEPR Discussion Paper No. 16669.

Cardani, R. O. Croitorov, M. Giovannini, P. Pfeiffer, M. Ratto, and L. Vogel (2022) "The euro area's pandemic recession: A DSGE-based interpretation," *Journal of Economic Dynamics and Control*, 143, 104512.

Coenen, G., C. Erceg, C. Freedman, D. Furceri, M. Kumhof, R. Lalonde, D. Laxton, J. Linde, A. Mourougane, D. Muir, S. Mursula, C. de Resende, J. Roberts, W. Roeger, S. Snudden. M. Trabandt, and J. in 't Veld (2012), "Effects of fiscal stimulus in structural models," *American Economic Journal Macroeconomics*, 4: 22-68.

Colciago, A. (2011), "Rule-of-thumb consumers meet sticky wages," *Journal of Money, Credit and Banking*, 43(2-3): 325-353.

Corti, F. and J. Núñez Ferrer (2021), "Assessing reforms in the National Recovery and Resilience Plans: Italy," Recovery and Resilience Reflection Papers, CEPS, Brussels, Belgium.

D'Auria, F., A. Pagano, M. Ratto, and J. Varga (2009), "A comparison of structural reform scenarios across the EU member states: Simulation-based analysis using the QUEST model with endogenous growth," Economic Papers, No. 392, European Commission Directorate-General for Economic and Financial Affairs.

Djankov, S., R. L. Porta, F. Lopez-De-Silanes, and A. Shleifer (2002), "The regulation of entry," *Quarterly Journal of Economics*, 117(1): 1-37.

Di Bartolomeo, G., P. D'Imperio, and F. Felici (2021), "The fiscal response to the Italian COVID-19 crisis: A counterfactual analysis," Ministry of Economy and Finance, Department of the Treasury, Working Paper. Forthcoming in *Journal of Macroeconomics*.

Ercolani, V. (2021), "The macroeconomic impact of infrastructure investment: a review of channels," Occasional Papers, No. 613, Bank of Italy.

European Commission (2020), "Country report Italy 2020," SWD (2020) 511 final.

Furceri, D., P. Loungani, J. D. Ostry, and P. Pizzuto (2020), "Will COVID-19 affect inequality? Evidence from past pandemics," *COVID Economics*, 12: 138-157.

Furceri, D., P. Loungani, J. D. Ostry, and P. Pizzuto (2021), "The rise in inequality after pandemics: can fiscal support play a mitigating role?" *Industrial and Corporate Change*, 30: 445-457.

Galí J., J. D. López-Salido, and J. Vallés (2007), "Understanding the effects of government spending on consumption," *Journal of the European Economic Association*, 5(1): 227-270.

IMF (2014), "Is it time for an infrastructure push? The macroeconomic effects of public investment," World Economic Outlook 2014, IMF, Washington D.C.

IMF (2020), *Fiscal Monitor,* International Monetary Fund, Washington D.C.

in 't Veld, J. (2016), "Public investment stimulus in surplus countries and their Euro Area spillovers," European Commission Economic Brief, 16.

Leeper, E. M., T. B. Walker, and S.-C. S. Yang (2010), "Government Investment and Fiscal Stimulus," *Journal of Monetary Economics*, 57: 1000-1012.

Katz, L. F. and K. M. Murphy (1992), "Changes in relative wages, 1963-1987: Supply and demand factors," *Quarterly Journal of Economics*, 107(1): 35-78.

MEF [Italian Ministry of Economy and Finance] (2022), "Document of Economics and Finance – National Reform Programme".

Messori, M. (2021), "The Next Generation–EU breakthrough: Opportunities and risks for Italy," in Messori M., Recovery Pathways: The difficult Italian convergence in the Euro Area, Bocconi University Press, Milan, Italy: 229-235.

Motta G. and P. Tirelli (2012), "Optimal simple monetary and fiscal rules under limited asset market participation," *Journal of Money, Credit and Banking*, 44(7): 1351-1374.

PCM [Italian Presidency of the Council of Ministers] (2021), "The Recovery and Resilience Plan: Next Generation Italia," Presidency of the Council of Ministers.

Pessoa, A. (2005), "Ideas driven growth: The OECD evidence," *Portuguese Economic Journal*, 4: 46-67.

Pfeiffer, P., W. Roeger, and J. in 't Veld (2020), "The COVID19-pandemic in the EU: Macroeconomic transmission and economic policy response," European Economy, Discussion Paper No. 127.

Pfeiffer, P., J. Varga, and J. in 't Veld (2022), "Quantifying spillovers of Next Generation EU investment," *Macroeconomic Dynamics,* 1-23.

Pfeiffer, P., J. Varga, and J. in 't Veld (2023), "QUEST simulations of Next Generation EU: An update," paper presented at the QUEST User Workshop 2023, European Commission, DG ECFIN.

Ramey, V. A. (2021), "The macroeconomic consequences of infrastructure investment," in E. L. Glaeser and J. M. Poterba (eds.), *Economic Analysis and Infrastructure Investment*, University of Chicago Press.

Ratto, M., W. Roeger W., and J. in 't Veld (2009), "QUEST III: An estimated open-economy DSGE model of the euro area with fiscal and monetary policy," *Economic Modelling*, 26: 222-233.

Roeger, W., J. Varga, J. and in 't Veld (2008), "Structural reforms in the EU: A simulation-based analysis using the QUEST model with endogenous growth," European Economy Economic Paper, n. 351, European Commission, Brussels.

Roeger, W., J. Varga, J. in 't Veld, and L. Vogel (2021), "The distributional impact of labor market reforms: A model-based assessment," *European Economic Review*, 131(C).

Roeger, W., J. Varga, and J. in 't Veld (2022), "The QUEST III R&D model," in U. Akcigit, C. Benedetti Fasil, G. Impullitti, O. Licandro, M. Sanchez-Martinez (eds.), *Macroeconomic Modelling of R&D and Innovation Policies,* Palgrave Macmillan, Cham, Switzerland.

Schorfheide, F. (2000), "Loss function-based evaluation of DSGE models," *Journal of Applied Econometrics*, 15: 645-670.

Smets, F. and R. Wouters (2003), "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European Economic Association*, 1: 1123-1175.

Taylor, J. B. (1999), "A historical analysis of monetary policy rules," in J. B. Taylor, ed., Monetary policy rules. Chicago: University of Chicago Press: 319-341.

Warda, J. (2006), "Tax treatment of business investments in intellectual assets: An international comparison," OECD Science, Technology and Industry Working Papers 2006/4, OECD, Paris.

Warda, J. (2009), "An update of R&D tax treatment in OECD countries and selected emerging economies, 2008–2009," OECD, mimeo.

Zezza, F. and D. Guarascio (2022), "Fiscal policy, public investment, and structural change: A P-SVAR analysis on Italian regions," Working Papers in Public Economics No. 226, University of Rome La Sapienza, Department of Economics and Law.

Appendix A – Model details

As outlined in the main text, the model features three interacting economies: Italy, the rest of the euro area (EA), and the rest of the world (ROW). Two types of households populate each economy: Ricardian $R \in [0, 1-\epsilon]$, and non-Ricardian households $N \in (1-\epsilon, 1]$. The latter are liquidity-constrained households and thus cannot trade in financial and physical assets. The members of both types of households offer labor services, which are differentiated into three skill levels indexed by $s \in \{L, M, H\}$, namely low (L), medium (M), and high (H). A union sets the wage for each skill level in monopolistically competitive labor markets. The unions pool wage income and distribute it equally among their members. Nominal rigidities arise because of adjustment costs proportional to wage changes.

Firms produce intermediate goods or final goods in monopolistic competition. Intermediate goods producers enter the market by paying a fee to overcome administrative barriers and rent physical capital designs from the R&D sector (Jones, 1995, 2005). They sell their products to final goods producers, each of which produces a variety of domestic goods that are imperfect substitutes for the final goods produced by other firms (Dixit and Stiglitz, 1977). Final goods producers combine intermediate goods and labor and fix the final price by setting a markup over the marginal cost.

The R&D sector hires only high-skilled labor to discover a new variety of producer durables. The stock of new knowledge evolves based on domestic and foreign existing knowledge. The first depends on the agent's optimization choices, while the latter is exogenous and based on a calibrated growth rate.

Combined domestic and foreign varieties of final goods are aggregated through calibrated CES functions to obtain private and government consumption and investment. To conclude, government expenditures (consumption, transfers, and investment) are proportional to GDP, while revenues derive from taxes on consumption, labor, and capital income. Debt is issued accordingly. The central bank follows a Taylor-type rule that allows the smoothing of the interest rate based on deviations from the inflation target and the potential output.

In the following, we describe the structure of the model. Although we limit our description to the domestic country (Italy), a similar structure holds for the rest of the EA and the ROW block.

A.1 Entrepreneur

In the final goods sector, entrepreneurs combine the labor aggregate and A_t varieties of intermediate inputs x with an elasticity of substitution $\theta \in (0,1)$ using a Cobb-Douglas technology. Each firm j produces a variety of the domestic good, which is an imperfect substitute for the varieties produced by other firms, as follows:

$$Y_t^j = \left(L_{Y,t}^j - FC_L\right)^{\alpha} \left(\int_0^{A_t} (x_{i,t}^j)^{\theta} di\right)^{\frac{1-\alpha}{\theta}} KG_t^{1-\alpha_g} - FC_Y, \tag{A.1}$$

and it is subject to fixed costs FC_Y and overhead labor FC_L. The latter includes fixed costs associated with bureaucracy. In the same equation KG_t is the level of public capital, while α and α_g are production coefficients.

The CES labor aggregate in the production of the final good function (A.1) combines the three skill categories:

$$L_{Y,t}^{j} = (S_L^{\frac{1}{\sigma_L}}\left(ef_L L_t^{j,L}\right)^{\frac{\sigma_L-1}{\sigma_L}} + S_M^{\frac{1}{\sigma_L}}\left(ef_M L_t^{j,M}\right)^{\frac{\sigma_L-1}{\sigma_L}} + S_{H,Y}^{\frac{1}{\sigma_L}}\left(ef_H L_t^{j,H}\right)^{\frac{\sigma_L-1}{\sigma_L}})^{\frac{\sigma_L}{\sigma_L-1}}, \tag{A.2}$$

where S_s is the population share of each labor-force subgroup, $L_t^{j,s}$ corresponds to their employment levels, and ef_s to their efficiency. High-skilled workers can be employed in the final goods and the R&D sector, so we index those allocated in the sector producing the final goods by L_t^H and those in R&D by L_t^A. The parameter σ_L measures the elasticity of substitution between labor types, fixed across different labor types.

The final good entrepreneur j maximizes profits:

$$PR_t^{f,j} = P_t^j Y_t^j - \left(W_t^L L_t^{j,L} + W_t^M L_t^{j,M} + W_t^H L_t^{j,HY}\right) - \int_0^{A_t} px_{i,t} x_{i,t}^j di, \tag{A.3}$$

where $px_{i,t}$ is the price of intermediate inputs $x_{i,t}^j$ and W_t^s is the wage index of each CES aggregate $L_t^{j,s}$.

Solving the problem in a symmetric equilibrium yields the following demand for labor[40]

$$W_t^s = \alpha \frac{Y_t + FC_Y}{L_{Y,t} + FC_L}\left(\frac{L_{Y,t}}{L_t^s}\right)^{\frac{1}{\sigma_L}} S_s^{\frac{1}{\sigma_L}} ef_s^{\frac{\sigma_L-1}{\sigma_L}} \eta_t^p \tag{A.4}$$

and for intermediate inputs

$$px_{i,t} = \eta_t^p (1-\alpha) \frac{Y_t + FC_Y}{K_t} x_{i,t}^{\theta-1} \tag{A.5}$$

where in steady state $\eta_p = 1 - \frac{1}{\sigma^d}$ and σ^d is the price elasticity of the demand function of final goods producers. Moreover, the following identity applies $K_t = \int_0^{A_t} (x_{i,t}^j)^\theta di$.

In the intermediate goods sector, entrepreneurs license a design from domestic households and rent tangible capital at a rental rate i^k. Monopolistically competitive firms must pay an initial fixed cost FC_A (entry cost) to enter the market. They can transform each capital unit into a single unit of an intermediate input $x_{i,t}$ and sell products to final goods producers, whose inverse demand function has been developed in equation (A.5).

Each entrepreneur i maximizes profits:

[40] As we considered the symmetric equilibrium, we removed the *j* subscript.

$$PR_{i,t}^{x} = \max_{x_{i,t}}\{px_{i,t}x_{i,t} - i_t^K P_t^C K_{i,t} - i_t^A P_t^A - FC_A\}, \tag{A.6}$$

where P^C is the price of tangible capital, i^A is the rental rate (user's cost) of intangible capital whose price is P^A. Entrepreneurs are subject to a linear technology able to transform one unit of effective capital ($K_{i,t}ucap_t$) in one unit of intermediate input:

$$x_{i,t} = K_{i,t}ucap_t, \tag{A.7}$$

where $ucap_t$ is the utilization capacity of the existing capital stock.[41]

By solving the producer's problem, the resulting first-order condition is

$$i_t^K P_t^C = \theta\eta_t^p(1-\alpha)(Y_t + FC_Y)(\int_0^{A_t}(x_{i,t}^j)^\theta di)^{-1}(x_{i,t})^{\theta-1}. \tag{A.8}$$

The price of intermediate goods is thus set as a gross markup (θ^{-1}) on the marginal cost, i.e.,

$$PX_t = px_{i,t} = \frac{1}{\theta} i_t^K P_t^C. \tag{A.9}$$

Finally, each intermediate firm x can enter the market until the present discounted value of its profits (PR_t^x) reimburses the initial fixed costs and the net value of patents, i.e.,

$$\sum_{\tau=0}^{\infty}\prod_{j=0}^{\tau}\left(\frac{1}{1+r_{t+j}}\right)PR_{t+\tau}^{x} = P_t^A\frac{1}{1-t_t^K(1-\delta^A)+\tau^A} + FC^A\,, \tag{A.10}$$

because of the no-arbitrage condition

$$PR_{i,t}^{x} = PR_t^x = i_t^A P_t^A + (i_t^A + \pi_t^A)FC_A, \quad \forall i. \tag{A.11}$$

In equations (A.10) and (A.11), r_t is the real interest rate, t^K represents capital income taxes, δ^A is the depreciation rate of intangibles, τ^A is a tax credit on intangibles, and π^A is the gross price change of intangibles. Fixed entry costs enter (A.11) directly, while tax credits do so indirectly by the user's cost of intangible capital.

The R&D sector hires high-skilled (R&D research) labor (L_A) at their market wage and faces an adjustment cost of hiring new employees. It generates new designs according to the following production function:

$$\Delta A_t = \nu A_{t-1}^{\varphi} L_{A,t}^{\lambda}, \tag{A.12}$$

where the parameter ν can be interpreted as the total factor efficiency of R&D production, while λ measures the elasticity of R&D production to the number of researchers (L_A). The parameter (φ) measures the spillover effect from the aggregate domestic stock of knowledge A_t.[42] Note that $\varphi = 1$ would imply the strong scale effect feature of fully endogenous growth models

[41] The capacity is changed by considering an adjustment cost governed by two parameters that capture its slope and curvature.

[42] Positive values for these parameters refer to the *standing-on-shoulders effect* and imply positive research spillovers. In contrast, negative values can be interpreted as the *fishing out effect*, i.e., when innovation decreases with the level of knowledge.

concerning A_t. The international stock of knowledge grows exogenously at the rate g_{A^w}.

The R&D maximizes the discounted profit stream:

$$\max_{L_{A,t}} \sum_{t=0}^{\infty} d_t \left(P_t^A \Delta A_t - W_t^H L_{A,t} - \frac{\gamma_A}{2} W_t^H \Delta L_{A,t}^2\right), \tag{A.13}$$

where d_t is the discount factor and γ_A represents the adjustment costs parameter on R&D labor demand. In equilibrium, high-skilled workers are paid the same wages across sectors. The first-order condition associated with the R&D sector is as follows:

$$\lambda P_t^A \frac{\Delta A_t}{L_{,t}} = W_t^H + \gamma_A\left(W_t^H \Delta L_{A,t} - d_t W_{t+1}^H \Delta L_{A,t+1}\right). \tag{A.14}$$

A short-run employment trade-off between R&D and output is worth to be noted, as allocating more high-skilled to R&D decreases the share of high-skilled available for final goods production.

A.2 Employment, labor market participation, and work skills

Both Ricardian and non-Ricardian households receive after-tax wage incomes and unemployment benefits. The skill-specific wage is set by trade unions, which charge a markup of $1/\eta_t^W$, which depends on the intra-temporal elasticity of substitution between skill types σ_{sk}, over the reservation wage. Similarly to the price markup, in steady state $\eta^W = 1 - 1/\sigma_{sk}$.

Formally, unions set wages as:

$$\frac{W_t^s(1-t_t^{W,s}-b_t^s(1-\mathrm{csrc}_t))}{(1+t_t^C)P_t^C} = \frac{1}{\eta_t^W}\frac{U_{1-L,t}^{h,s}}{U_{C,t}^h} \quad \text{for } h \in \{R,N\} \tag{A.15}$$

i.e., the real gross wage adjusted for labor taxes (t_t^W) and unemployment benefits (l.h.s.) is set as a markup on the ratio of the marginal utility of leisure to the marginal utility of consumption (reservation wage, r.h.s.). Note that benefits are treated as a subsidy to leisure, but they are scaled according to the cost of searching for a job ($csrc_t$). Any increase in the marginal cost of the search thus reduces the reservation wage and, consequently, unemployment. It is worth noting that the wage markup is time-varying because of indexation.

Unemployment benefits (BEN_t) enter the household budget constraint and are considered an expenditure on the government side. Therefore, in the government budget, they are aggregated as:

$$BEN_t = \sum_s b_t^s W_t^s (1 - NP_t^s - L_t^s). \tag{A.16}$$

Unemployment benefits are not paid to the share of employed L_t^s and the inactive share of the population NP_t^s. The benefit-replacement rate b_t^s is proportional to wages.

The total number of employees is calculated as follows:

$$L_t = S_L L_t^l + S_M L_t^M + S_H L_t^H. \tag{A.17}$$

Similarly, unemployed are obtained from the following aggregation:

$$UN_t = \sum_s S_s (1 - NP_t^s - L_t^s). \tag{A.18}$$

Finally, the unemployment rate (un_t) is defined as the ratio of unemployed over the labor force. Therefore, from equations (A.17) and (A.18), we obtain:

$$un_t = \frac{UN_t}{UN_t + L_t}. \tag{A.19}$$

A.3 Households

Each Ricardian household (indexed by R) maximizes an intertemporal utility function separable in consumption and leisure.

$$u_t^i = E_0 \sum_{t=0}^{\infty} \beta^t \big(U(C_t^R) + \sum_s V(1 - L_t^{R,s}) \big). \tag{A.20}$$

We assume:

$$U(C_t^r) = (1-h)\, log(C_t^R - hC_{t-1});$$

$$V(1 - L_t^{R,s}) = \frac{\omega_s}{1-\kappa}(1 - L_t^{R,s})^{1-\kappa},$$

where the parameter $\kappa > 0$ is linked to the skill-specific Frisch elasticity of labor supply.[43]

The utility function is additively separable in consumption (C_t^R) and leisure ($1 - L_t^{R,s}$) and allows for habit persistence (measured by h). The CES preferences for leisure exhibit a common labor supply elasticity but a skill-specific weight (ω_s) on leisure to capture differences in employment levels across skill groups.

Ricardian households have access to financial markets where they can buy and sell domestic and foreign assets (government bonds), accumulate physical capital, and buy patents of designs produced by the R&D sector. Then they rent physical capital and license patents to the intermediate goods-producing firms. As already explained, the members of the households offer low-, medium- and high-skilled labor services.

Non-liquidity-constrained households own all tangible (K_t^R) and intangible capital (A_t^R), which evolve according to the following law of motions:

$$K_t^R = J_t^R + (1 - \delta^K) K_{t-1}^R, \tag{A.21}$$

$$A_t^R = J_t^{A,R} + (1 - \delta^A) A_{t-1}^R, \tag{A.22}$$

where J_t^r and $J_t^{A,R}$ are investments in tangible and intangible capital, δ^K and δ^A are their depreciation rates.

Ricardian households receive wage income (WI_t^R), unemployment benefits and transfer income from the government (BT_t^R), and interest income from the tangible (IK_t^R) and intangible (IA_t^R) capital services as well as financial assets (FA_t^R) they hold, and profits (PR_t^R). They choose how much to consume (C_t^R), their labor supply (L_t^R), financial investments into domestic and foreign assets (B_t^R and $B_t^{F,R}$), the purchase of the investment good (J_t^R), to rent their physical

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[43] The κ parameter is common across the skill groups. The skill-specific Frisch elasticity can be obtained by multiplying κ times the ratio between the employed and the unemployed in each skill group (Roeger *et al.*, 2021).

capital stock (K_t^R), the purchase of new patents from R&D firms ($J_t^{A,R}$), the licensing of existing patents (A_t^R), and the capital utilization ($ucap_t^R$).

The investment decisions are subject to convex adjustment costs:

$$\Gamma_J(J_t^R) = \frac{\gamma_K}{2}\frac{\left(J_t^R\right)^2}{K_{t-1}^R} + \frac{\gamma_I}{2}(\Delta J_t^R)^2, \tag{A.23}$$

where γ_K and γ_I are positive parameters that measure the adjustment costs.

The budget constraint is as follows:[44]

$$WI_t^R + BT_t^R + IK_t^R + IA_t^R + FA_t^R + PR_t^R =$$

$$= (1+t_t^c)P_t^C C_t^R + B_t^R + E_t B_t^{F,R} + P_t^I\left(J_t^R + \Gamma_J(J_t^R)\right) + P_t^A J_t^{A,R} \tag{A.24}$$

where:

$$WI_t^R = \sum_s\left\{(1-t_t^{w,s})W_t^{R,s}L_t^{R,s} + \frac{\gamma_W L_t^{R,s}}{2}\frac{\left(\Delta W_t^{R,s}\right)^2}{W_{t-1}^{R,s}}\right\};$$

$$BT_t^R = \sum_s\left\{b_t^s W_t^{R,s}(1 - NP_t^{R,s} - L_t^{R,s})\right\} + TR_t^R;$$

$$IK_t^R = (1-t_{t-1}^K)(i_{t-1}^K - rp_{t-1}^K)P_{t-1}^K K_{t-1}^R + t_{t-1}^K\delta^K P_t^K K_{t-1}^R + \tau^K P_t^K J_t^{K,R}$$

$$IA_t^R = (1-t_{t-1}^K)(i_{t-1}^A - rp_{t-1}^A)P_{t-1}^A A_{t-1}^R + t_{t-1}^K\delta^A P_t^A A_{t-1}^R + \tau^A P_t^A J_t^{A,R};$$

$$FA_t^R = (1+r_{t-1})B_{t-1}^R + \left(1 + r_{t-1}^F - \Gamma_{B^F}\left(\frac{e_t B_{t-1}^F}{Y_{t-1}}\right)\right)e_t B_{t-1}^{F,R};$$

$$PR_t^R = \int_0^n PR_{j,t}^{f,R}\,dj + \int_0^{A_t} PR_{j,t}^{x,R}\,dj.$$

Labor income, WI_t^r, includes convex wage adjustment costs formally given by $\Gamma_W(W_t^{R,s}) = \sum_s(\gamma_W L_t^{R,s})/2\left(\Delta W_t^{R,s}\right)^2/W_{t-1}^{R,s}$ with γ_W>0. Physical (IK_t^R) and non-tangible (IA_t^R) asset income depends on investment into tangible and intangible capital (which leads to premia rp_t^K and rp_t^A to cover the increased risk on the return related to these assets) and include tax credits on tangible (τ^K) and non-tangible investments (τ^A). Considering the financial asset income, FA_t^R, there is no perfect arbitrage. Interest rates on domestic and foreign bonds are denoted by r_t and r_t^F, respectively. In taking a position in the international bond market, the household faces a financial intermediation premium $\Gamma_{B^F}(.)$ that depends on the economy-wide net holdings of internationally traded bonds. Regarding profit income (PR_t^R), all firms are owned by non-liquidity-constrained households who thus share the total profit of the n final ($\int_0^n PR_{j,t}^{f,R}\,dj$) and

[44] The budget constraints are written in real terms with all prices and wages normalised with P_t, the price of final domestic goods.

the A_t intermediate sector firms ($\int_0^{A_t} PR_{j,t}^{x,R}\, dj$).

The model has a rich fiscal structure: all households pay t_t^w wage income taxes and t_t^K capital income taxes minus tax credits and depreciation allowances ($t_t^K \delta^K$ and $t_t^K \delta^A$) after their earnings on physical capital and patents. Note also that consumption and investment are aggregates of domestic and foreign varieties of final goods, with preferences expressed by a CES utility function. We denote with P_t^C the corresponding utility-based deflator for them (note that $P_t^I = P_t^C$).

Maximizing the utility subject to the budget constraint, the capital law of motions, and the adjustment costs concerning consumption, financial and real assets, it is possible to obtain the household's first-order conditions:

$$\frac{\partial U(C_t^R)}{\partial C_t^R} - \lambda_t^R (1+t_t^c) P_t^C = 0, \tag{A.25}$$

$$-\lambda_t^R + \beta E_t\left(\lambda_{t+1}^R (1+r_t)\right) = 0, \tag{A.26}$$

$$-\lambda_t^R + \beta E_t\left(\lambda_{t+1}^R \left(1 + r_t^F - \Gamma_{B^F}\left(\frac{e_t B_t^F}{Y_t}\right)\right)\frac{e_{t+1}}{e_t}\right) = 0, \tag{A.27}$$

$$E_t\left(\frac{\lambda_{t+1}^R \xi_{t+1}^R}{\lambda_t^R}\beta(1-\delta) - \xi_t^R + \frac{\lambda_{t+1}^R}{\lambda_t^R}\beta[(1-t_t^K)(i_t^K ucap_t^R - rp_t^K - \Gamma_U(ucap_t^R)) + t_t^K \delta^K] P_{t+1}^C\right) = 0, \tag{A.28}$$

$$-\lambda_t^R P_t^C \left(1 + \gamma_K\left(\frac{J_t^R}{K_{t-1}^R}\right) + \gamma_I \Delta J_t^R - \tau^K\right) + \beta E_t(\lambda_{t+1}^R P_{t+1}^C \gamma_I \Delta J_{t+1}^R) + \lambda_t^R \xi_t^R = 0, \tag{A.29}$$

where λ_t^R are the Lagrange multipliers, $\Gamma_U(ucap_t^R)$ adjustment costs linked to capital utilization, and e_t is the nominal exchange rate. The real interest rate r_t is equal to the nominal interest rate minus expected inflation: $r_t = i_t - E_t(\pi_{t+1})$. All arbitrage conditions are standard except for trading frictions ($\Gamma_{B^F}(.)$) on foreign bonds, modeled as a function of the ratio of assets to GDP.

Using the arbitrage conditions and neglecting the second-order terms, investment is given as a function of the variable $Q_t = \xi_t / P_t^C$:

$$Q_t - 1 = \gamma_K\left(\frac{J_t^R}{K_{t-1}^R}\right) + \gamma_I \Delta J_t^R - \tau^K - \gamma_I E_t\left(\frac{\Delta J_{t+1}^R}{1+i_t-\pi_{t+1}^C}\right), \tag{A.30}$$

where Q_t is the present discounted value of the rental rate of return from investing in real assets

$$Q_t = E_t\left(\frac{1-\delta}{1+i_t-\pi_{t+1}^C} Q_{t+1} + \frac{(1-t_t^K)(i_t^K ucap_t^R - rp_t^K - \Gamma_U(ucap_t^R)) + t_t^K \delta^K}{1+i_t-\pi_{t+1}^C}\right). \tag{A.31}$$

Note that the relevant discount factor for the investor is the nominal interest rate adjusted by the trading friction minus the expected inflation of investment goods (π_{t+1}^C).

Ricardian households buy new patents for designs produced by the R&D sector (I_t^A) and rent their total stock of designs (A_t) at the rental rate i_t^A to intermediate goods producers in period

t. Households pay income tax at a rate t_t^K on the period return of intangibles, and they receive tax subsidies at the rate τ^A. Hence, the first-order conditions concerning R&D investments are given by:

$$E_t\left(\lambda_{t+1}^R\beta\left(\psi_{t+1}^R(1-\delta^A)+\left((1-t_t^K)(i_t^A-rp_t^A)+t_t^K\delta^A\right)P_{t+1}^A\right)\right)-\lambda_t^R\psi_t^R=0, \tag{A.32}$$

$$-P_t^A(1-\tau^A)+\psi_t^R=0. \tag{A.33}$$

The rental rate of intangible capital can be obtained by combining the above expressions with the first-order condition for domestic bond holdings. After neglecting the second-order terms, it follows:

$$i_t^A \approx \frac{1}{1-t_t^K}\left[(1-\tau^A)E_t(i_t-\pi_{t+1}^A+\delta^A)-t_t^K\delta^A\right]+rp_t^A. \tag{A.34}$$

Ricardian households require a rate of return on intangible capital which is equal to the nominal interest rate minus the rate of change of the value of intangible assets, covering the cost of depreciation, plus a risk premium (rp_t^A).[45]

Non-Ricardian households cannot trade in financial and physical assets and consume their disposable income each period. As for Ricardian households, they offer low-, medium- and high-skilled labor services. Their consumption in real terms is thus determined by the net wage income plus net transfers, i.e.,

$$C_t^N=\frac{\sum_s\left((1-t_t^{w,s})W_t^{N,s}L_t^{N,s}+b_t^sW_t^{N,s}\left(1-NP_t^{N,s}-L_t^{N,s}\right)-\frac{\gamma_W}{2}\frac{L_t^{N,s}\left(\Delta W_t^{N,s}\right)^2}{W_{t-1}^{N,s}}\right)}{(1+t_t^c)P_t^C}+\frac{TR_t^N}{(1+t_t^c)P_t^C} \tag{A.35}$$

Aggregate consumption is obtained by integration. Remembering that the share of the non-Ricardian household is ε, it follows that $C_t=(1-\varepsilon)C_t^R+\varepsilon C_t^N$. Labor is aggregated similarly, and physical capital and patents are as well. However, physical capital and patents are aggregated only among Ricardian households.

A.4 Trade and international financial flows

The economies trade their final goods. Aggregate imports are given by

$$IM_t=s^M\left(\frac{P_t^C}{P_t^{IM}}\right)^{\sigma_{IM}}(C_t+I_t+G_t), \tag{A.36}$$

where σ_{IM} is the elasticity of substitution between bundles of domestic and foreign goods, s^M is a parameter governing the calibrated openness of the country towards foreign economies, and $P_t^{IM}=e_tP_t^*$ are producer prices of imports (IM_t) with P_t^* denoting foreign prices.

The net foreign assets (B_t^F) evolve according to the following equation:

[45] The government can thus affect investment decisions in intangible capital by giving tax incentives in the form of tax credits and depreciation allowances or by lowering the tax on the return from patents.

$$e_t B_t^F = (1 + r_t^F) e_t B_{t-1}^F + P_t^{EX} EX_t - P_t^{IM} IM_t, \tag{A.37}$$

where ${P_t}^{EX} = P_t$ are producer prices of exports (EX_t). Note that foreign assets are denoted in foreign currency.

A.5 Government

On the expenditure side, we assume that government consumption, transfers, and investment are proportional to GDP, and unemployment benefits are partially indexed to inflation.

The government also provides subsidies (S_t) on physical capital and R&D investments in the form of tax credits and depreciation allowances, i.e.,

$$S_t = t_{t-1}^K \left(\delta^K P_t^I K_{t-1}^{i,H} + \delta^A P_t^A A_{t-1}^{i,H}\right) + \tau^K P_t^I J_t^{i,H} + \tau^A P_t^A J_t^{A,i,H}. \tag{A.38}$$

The stock of public capital is fueled by public investment (I_t^G). Formally, the public capital stock evolves according to:

$$K_t^G = \frac{1}{4} \sum_{i=1}^{4} I_{t-n}^G + (1 - \delta^G) K_{t-1}^G. \tag{A.39}$$

The evolution of the public capital stock considers its depreciation (δ^G) and its gradual implementation according to a *time-to-build process* (Leeper *et al.*, 2010; Ramey, 2020). Everything equal, an increase in public investment directly impacts the potential output. However, it also has an indirect effect. A positive shock of public capital increases the productivity of other factors, encouraging companies to hire more workers and increase private investment.[46] The direct impact of public investment, given the formalization introduced, crucially depends on the elasticity of output to the public capital stock ($1 - a_g$) and the accumulated stock (K_t^G). Formally, the impact is given by the following expression: $\frac{\partial Y_t}{\partial K_t^G} = (1 - a_g) \frac{Y_t}{K_t^G}$. The direct effect of public investment, given the production function, will therefore depend negatively on the initial public investment stock (the higher the initial stock, the lower the marginal increase effect of investment) and positively on the elasticity of output relative to the public capital stock (Di Bartolomeo and D'Imperio, 2022.)

Government revenues, R_t^G, are made up of taxes on consumption and capital and labor income. Government debt (B_t) evolves according to

$$B_t = (1 + r_t) B_{t-1} + P_t^C G_t + TR_t + BEN_t + S_t - R_t^G - T_t^{LS}. \tag{A.40}$$

There is a lump-sum tax (T_t^{LS}) used for controlling the debt-to-GDP ratio according to the following rule:

$$\Delta T_t^{LS} = \tau^B \left(\frac{B_{t-1}}{Y_{t-1} P_{t-1}} - b^T\right) + \tau^{DEF} \Delta \left(\frac{B_t}{Y_t P_t}\right), \tag{A.41}$$

where b^T is the government debt target. The two parameters τ^B and τ^{DEF} rule the response of

[46] A change in the stock of public capital has a positive impact on capital and labor productivity to the extent that the direct effect is positive ($\partial Y_t / \partial K_t^G > 0$.)

lump-sum taxes to deviations of public debt from the debt target and the growth rate of the public debt stock, respectively.

The European Central Bank adopts a Taylor-kind rule. The domestic monetary authority thus responds to changes in expected inflation and output gap at the euro-area level according to the following Taylor rule:

$$i_t = \tau_{lag}^{INOM} i_{(t-1)} + \left(1 - \tau_{lag}^{INOM}\right)\left[r^{EQ} + \pi^T + \tau_{\pi}^{INOM}(\pi_t^C - \pi^T) + \tau_{y,1}^{INOM} ygap_t\right]. \quad \text{(A.42)}$$

Equation (A.41) features some smoothness in response to the deviation of inflation (π_t^C) concerning the inflation target (π_t^C) and to the output gap ($ygap_{t-1}$). In equation (A.42), r^{EQ} is the real interest rate in the steady state while τ_{lag}^{INOM}, τ_{π}^{INOM}, and τ_{y}^{INOM} are parameters ruling the interest rate smoothness, the response of the central bank to inflation, and the response to the output gap. A similar rule is adopted for describing the monetary policy behavior in the rest of the world. Finally, the output gap definition approximates the standard practice of output gap calculation used for fiscal surveillance and monetary policy. A production function approach defines the output gap as the deviation of capital and labor utilization from their long-run trends.

Appendix B – Model calibration

The QUEST model is widely used by the European Commission and its Member States mainly as a policy evaluation tool. The calibration for every country is obtained from a mix of estimation and matching approaches. We summarize the quantitative calibration aspects for the model's parameters and steady states in this Appendix. Note that the model consists of about 500 equations/variables and 187 parameters. Therefore, this Appendix summarizes the calibration. The methodology employed to set the parameter values can be deepened by reading D'Auria *et al.* (2009), Ratto *et al.* (2009), and Rogers *et al.* (2022). Calibration is also routinely updated by the Commission. Our assessment is based on the 2018 update.

A summary of the parameter calibration is provided in Table C.1. QUEST III R&D is calibrated using a mix of different methodologies. First, some parameters are estimated using a Bayesian approach.[47] These are labeled as "Ratto *et al.* (2009)." Others are calibrated by using external study micro-estimations or statistical matchings. In such a case, we indicate the source, i.e., the relevant study or dataset. Finally, a last group of parameters is set to match the steady-state-great ratio described in Table C.2 or specific shares reported in Table C.1.[48] We refer to these parameters by the label "Calibration." Likewise, calibration is also used to refer to parameters set to match the theoretical restrictions of the model in equilibrium.

[47] The model parameters are estimated by applying a Bayesian approach to the model (e.g., Schorfheide, 2000; Smets and Wouters, 2003) and externally by using micro estimations.

[48] See Ratto *et al.* (2009). It is worth noting that these are estimated by the "average" version of QUEST, so they are assumed to be the same in different areas.

Table C.1(a) – Parameter calibration: R&D sector[49]

Parameter	Symbol	Italy	EA	ROW	Source
Elasticity of R&D w.r.t. labor	λ	0.53	0.52	0.52	Bottazzi and Peri (2007)
Elasticity of R&D w.r.t. domestic ideas	φ	0.49	0.51	0.51	Bottazzi and Peri (2007)
R&D efficiency parameter	ν	0.59	0.43	0.41	Calibration
Adjustment (quadratic) cost on R&D	γ_A	1563.90	1115.32	1526.14	Calibration
Depreciation rate of ideas (%)	δ^A	2.5	2.5	2.5	Pessoa (2005)
Growth rate of ideas (%)	g_{A^w}	1.15	1.15	1.15	Pessoa (2005)
Selected variables matched					
R&D (% GDP)		1.48	2.40	1.81	Eurostat
Researchers (% employment)	L_t^A	0.55	0.86	0.93	Eurostat

Table C.1(b) – Parameter calibration: Intermediate and final good sectors

Parameter name	Symbol	Italy	EA	ROW	Source
Net markup (%) intermediate sector	$1/\theta - 1$	10.0	10.0	10.0	EUKLEMS
Entry cost in the intermediate sector	FC_A	0.15	0.06	0.03	WB Doing Business*
Risk premium on intangibles (%)	rp^A	1.54	0.43	1.72	Calibration
Depreciation rate of capital (%)	δ^K	1.50	1.50	1.50	Calibration
Depreciation rate of public capital (%)	δ^G	1.25	1.25	1.25	Calibration
Net markup (%) final good sector	$1/\eta^p - 1$	11.41	12.86	10.99	EUKLEMS
Overhead labor costs (final good sector)	FC_L	0.01	0.02	0.02	Calibration
Fixed costs in the final good sector	FC_Y	0.01	0.03	0.03	Calibration
Elasticity of labor (final good sector)	α	0.65	0.65	0.65	Calibration
Elasticity of public capital	$1 - \alpha_g$	0.12	0.12	0.12	Bom and Ligthart (2014)
Selected variables matched					
Capital utilization	*ucap*	1.00	1.00	1.00	Normalized

(*) See Djankov *et al.* (2002) for details.

[49] Calibration of the R&D sector is qualitatively well-described by Roeger *et al.* (2022) and Benedetti Fasil *et al.* (2022).

Table C.1(c) – Parameter calibration: Labor market

Parameter name	Symbol	Italy	EA	ROW	Source
Low-skilled population share (%)	s_L	39.07	25.80	19.86	Eurostat
Medium-skilled population share (%)	s_M	56.67	66.55	73.35	Eurostat
High-skilled population share (%)	s_H	4.24	7.65	6.79	Eurostat
Labor skill elasticity of substitution	σ_L	1.7	1.7	1.7	Acemoglu and Autor (2011)
Low-skilled efficiency level	ef_L	0.31	0.19	0.22	Calibration
Medium-skilled efficiency level	ef_M	0.50	0.42	0.35	Calibration
High-skilled efficiency level	ef_H	1.33	1.40	0.65	Calibration
Low-skilled non-participation rate	NP^L	39.55	34.76	32.04	Eurostat
Medium-skilled non-participation rate	NP^M	22.41	18.63	17.27	Eurostat
High-skilled non-participation rate	NP^H	14.00	10.79	12.12	Eurostat
Low-skilled leisure parameter	ω_L	0.43	0.52	0.71	Calibration
Medium-skilled leisure parameter	ω_M	0.14	0.11	0.09	Calibration
High-skilled leisure parameter	ω_H	1.74	1.01	0.98	Calibration
Wage adjustment costs	γ_w	120	120	120	Ratto *et al.* (2009)
Low-skilled benefit replacement rate (%)	b^L	17.97	31.46	16.05	Calibration*
Medium-skilled benefit replacement rate (%)	b^M	21.79	44.14	19.60	Calibration*
High-skilled benefit replacement rate (%)	b^H	32.49	72.41	25.20	Calibration*
Net wage markup (%)	$1/\eta^w$	20.00	20.00	20.00	EUKLEMS
Selected variables matched					
Employment	L	65.27	73.03	79.32	Ameco
Low-skilled employment (%)	L^L	51.79	55.05	64.26	Eurostat
Medium-skilled employment (%)	L^M	73.41	78.67	82.80	Eurostat
High-skilled employment (%)	L^H	80.63	84.62	85.76	Eurostat

(*) Calibration from benefit replacement rate used in Ratto *et al.* (2009).

Table C.1(d) – Parameter calibration: Households

Parameter name	Symbol	Italy	EA	ROW	Source
Habits	h	0.7	0.7	0.7	Ratto *et al.* (2009)
Share of Ricardians	ε	0.60	0.60	0.60	Calibration
Inverse elasticity of labor supply	k	2.45	2.20	2.20	Calibration
Capital adjustment costs	γ_K	20	20	20	Ratto *et al.* (2009)
Investment adjustment costs	γ_I	75	75	75	Ratto *et al.* (2009)
Cost of search	$csrc_t$	0.70	0.70	0.70	Calibration
Openness share	s^M	0.16	0.14	0.02	Calibration
Elasticity domestic-foreign bundle of goods	σ_{IM}	0.10	0.10	0.10	Calibration
Selected variables matched					
Import share (%) from Italy		-	9	12	ECFIN, comex
Import share (%) from EA		46	-	88	ECFIN, comex
Import share (%) from RoW		54	91	-	ECFIN, comex

Table C.1(e) – Parameter calibration: Public sector

Parameter name	Symbol	Italy	EA	ROW	Source
Taxes/subsidies					
Tax credit on intangibles (%)	τ^{A}	2.99	4.68	2.51	OECD
Tax rate on capital income (%)	t^{K}	27.80	24.05	19.00	DG TAXAUD
Consumption tax rate (%)	t^{C}	22.56	25.83	21.43	DG TAXAUD
Labor tax rate (%)	t^{L}	42.60	38.38	25.73	DG TAXAUD
Fiscal rule					
Debt target	τ^{B}	0.01	0.01	0.01	Calibration
Deficit	τ^{DEF}	0.00	0.00	0.00	Calibration
Monetary rule					
Inflation weight	τ_{π}^{INOM}	-	1.5	1.5	Taylor (1999)
Output gap weight	$\tau_{y,1}^{INOM}$	-	0.05	0.05	Taylor (1999)
Lagged interest rate	τ_{lag}^{INOM}	-	0.81	0.81	D'Auria *et al.* (2009)
Inflation target (annualized)	π^{T}	-	2.00	2.00	Calibration
Real interest rate (annualized)	r^{EQ}	-	1.29	1.29	Calibration
Selected variables matched					
Quarterly debt on GDP*	B	6.06	4.02	4.62	Ameco
Public transfer share	TR	22.98	18.94	15.63	Ameco
Inflation rate (%) (annualized)	π	2.00	2.00	2.00	Ameco

(*) General government consolidated gross nominal debt

Table C.2 – Steady states, main variables (great ratios)

Selected variables	Italy	EA	ROW	Source
Private consumption (% GDP)	58	55	63	Ameco
Public consumption (% GDP)	22	23	15	Ameco
Investment (% GDP)	18	19	19	Ameco
Public investment (% GDP)	2	3	3	Ameco
Imports (% GDP)	28	25	5	Ameco
Exports (% GDP)	28	25	5	Ameco
GDP (% world GDP)	3	15	82	Ameco

Notes: Values rounded to the nearest integer.

Finally, calibrations are also based on the world population and total factor productivity growth rates set at 0.0005 and 0.00375, respectively (Source: EUKLEMS.)

Appendix C – Data sources

Simulations are based on the Italian NRRP, described in the following documents:

- Presidency of the Council of Ministers (2021), *National Recovery and Resilience Plan*, Presidency of the Council of Ministers, Italian Government, Rome, Italy;
- European Commission (2021), "Revised annex to the council implementing decision on the approval of the assessment of the recovery and resilience Plan for Italy," Brussels, 8 July 2021.

Additionally, our dataset is based on detailed information on the NRRP measures and sub-measures contained in the following datasets:

- **Milestones and Targets programming of the NRRP dataset.** The dataset associates each measure or sub-measure in the Plan with its milestones and targets (M&T). For each measure/sub-measure, the dataset reports a description and identification codes that allow its identification, the description and identification code of the mission and component, and the administration that owns the intervention. Measures and sub-measures are associated with the unique identification code of the milestone or target, the type (investment/reforms), the detailed description of the milestone/target, the national or European relevance, and the quarter and year of the planned achievement. For each milestones the dataset contains a description of the linked qualitative indicators; for targets, it contains the quantitative starting and target values as well as their unit of measurement. Further information on verification mechanisms is provided for M&T of European relevance.
- **The monitoring of NRRP measures through sustainable development indicators (SDGs) and Agenda 2030 dataset.** The dataset contains a detailed mapping between the NRRP measures and the Sustainable Development Goals (SDGs) and targets of the 2030 Agenda for Sustainable Development.
- **NRRP Financial Framework.** The dataset contains information on the measures and sub-measures of the Plan financed through the RRF facility. For each measure/sub-measure the dataset contains a description, the codes that enable identification on the various reference systems, the description and identification code of the mission and of the component, the total amount of financing. Furthermore, the measures and sub-measures are associated with the administration holding the intervention, the amounts allocated that pertain to the "Development and Cohesion Fund 2021-2027". Projects are also categorized as existing projects or new projects, as identified by the Decree of the Minister of the Economy of August 6, 2021, and subsequent amendments. Data contained in the NRRP Financial Framework are complemented with the legislation ruling the complementary national funds' allocations (Law No. 101/2021) and additional information provided by the RGS Accounting Department on measures financed through the React-EU.

The above datasets can be retrieved from: http://italiadomani.gov.it/en (Italian Government Portal on the RRP.) Our dataset is available upon request. Note that we provide information about the aggregate annual timing by category used in the assessment. The annual timing of each single expenditure measure is confidential and should be requested to the Italian Ministry of Economy and Finance. However, it is worth noting that the replication of our results only requires aggregate yearly information.

Appendix references

Acemoglu, D. and D. Autor (2011), "Skills, tasks and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, Vol. 4, Part B, edited by O. Ashenfelter and D. Card, 1043-1171. Amsterdam: Elsevier.

Benedetti Fasil C., M. Sanchez-Martinez, and J. Ravet (2022), "Other innovation policies and alternative modelling approaches," in U. Akcigit, C. Benedetti Fasil, G. Impullitti, O. Licandro, M. Sanchez-Martinez (eds.), *Macroeconomic Modelling of R&D and Innovation Policies*, Palgrave Macmillan, Cham, Switzerland.

Bom, P. R. D. and J. E. Ligthart (2014), "What have we learned from three decades of research on the productivity of public capital?" Journal of Economic Surveys, 28(5): 889-916.

Bottazzi, L. and G. Peri (2007), "The international dynamics of R&D and innovation in the long run and in the short run," *The Economics Journal*, 117(3): 486-511.

D'Auria, F., A. Pagano, M. Ratto, and J. Varga (2009), "A comparison of structural reform scenarios across the EU member states: Simulation-based analysis using the QUEST model with endogenous growth," Economic Papers, No. 392, European Commission Directorate-General for Economic and Financial Affairs.

Di Bartolomeo, G. and P. D'Imperio (2022), "A macroeconomic assessment of the Italian National Recovery and Resilience Plan," Ministry of Economy and Finance, Department of the Treasury, Working Paper No 2/2022.

Dixit, A. K., and J. E. Stiglitz (1977) "Monopolistic competition and optimum product diversity," *The American economic review*, 67(3), 297-308.

Djankov, S., R. L. Porta, F. Lopez-De-Silanes, and A. Shleifer (2002), "The regulation of entry," *Quarterly Journal of Economics*, 117(1): 1-37.

Jones, C. I. (1995), "R&D-based models of economic growth," *Journal of Political Economy*, 103(4): 759-784.

Jones, C. I. (2005), "Growth and ideas," in P. Aghion and S. Durlauf (eds.), *Handbook of Economic Growth*, Amsterdam, North-Holland, Volume 1, Chapter 17: 1063-1111.

Leeper, E. M., T.B. Walker, and S. C. S. Yang (2010), "Government investment and fiscal stimulus. Journal of monetary Economics," 57(8) 1000-1012.

Pessoa, A. (2005), "Ideas driven growth: The OECD evidence," *Portuguese Economic Journal*, 4:

46-67.

Ramey, V. A. (2020). "The macroeconomic consequences of infrastructure investment," NBER Working Papers No. 27625, National Bureau of Economic Research.

Ratto, M., W. Roeger W., and J. in 't Veld (2009), "QUEST III: An estimated open-economy DSGE model of the euro area with fiscal and monetary policy," *Economic Modelling*, 26: 222-233.

Roeger, W., J. Varga, J. in 't Veld, and L. Vogel (2021), "The distributional impact of labor market reforms: A model-based assessment," *European Economic Review*, 131(C).

Roeger, W., J. Varga, and J. in 't Veld (2022), "The QUEST III R&D model," in U. Akcigit, C. Benedetti Fasil, G. Impullitti, O. Licandro, M. Sanchez-Martinez (eds.), *Macroeconomic Modelling of R&D and Innovation Policies*, Palgrave Macmillan, Cham, Switzerland.

Schorfheide, F. (2000), "Loss function-based evaluation of DSGE models," *Journal of Applied Econometrics*, 15: 645-670.

Smets, F. and R. Wouters (2003), "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European Economic Association*, 1: 1123-1175.

Taylor, J. B. (1999), "A historical analysis of monetary policy rules," in *Monetary policy rules*, University of Chicago Press: 319-348.