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The Entrepreneurial State at Work: an Agent Based Exploration

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Abstract

In this report we explore the impact of alternative policies to support innovation and long-run economic growth. More specifically, building on the K+S model Dosi et al. (2010), we study a wide range of innovation policies including: (i) R&D subsidies to firms, (ii) discounts on investments in novel technologies, (iii) public hiring in non-productive activities, (iv) creation of public research-oriented firms diffusing technologies along specific "trajectories", (v) creation of National Research Labs conducting basic research that enlarges the set of technological opportunities and a variety of combinations. The model provides a concept-proof of the role of entrepreneurial state policies triggering the emergence of new technological paradigms vis-à-vis the role of disaggregated monetary incentives (e.g. subsidies and taxes). Further, the report provides details on the systemic, macroeconomic effects induced by mission-oriented and private-incentive innovation policies. Results strengthen the hypothesis that an entrepreneurial state actively engaging publicly funded research and diffusing technologies to private actors outperforms any policies based on disaggregated monetary incentives. Even though they come with the risk of deteriorating public finances, simulation experiments point to a significantly positive average impact of entrepreneurial state-like policies; further, the likelihood of success of these initiative increases with the size of government spending.

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Contents

1 Introduction

Countries around the world are seeking economic growth that is smart (innovation-led), inclusive and sustainable. Such ambitious goals might require re-thinking the role of government and public policy in the economy. The way the role of the State is conceived is crucial for determining growth's *pace* and - perhaps more relevantly - *direction*. In most parts of the world we are witnessing a massive withdrawal of the State, one that has been justified in terms of debt reduction and – even more systematically – in terms of rendering the economy more dynamic, competitive and innovative (Mazzucato, 2015b). Business is accepted as the innovative force, while the State is cast as inertial and necessary for the basics, but too large and heavy to be the dynamic engine. Mazzucato (2015a) has largely dismantled this view and showed that major, revolutionary technological changes had substantially benefited from an active role of the government (i) in directing and funding (on its own) the process of R&D and, on the other side, (ii) in taking the risk that private business alone had not be willing to sustain. There is little reason today to think that the role of the public government would be less important in solving contemporary major societal challenges and sustain value creation directly from the public sector. Indeed, innovation agencies around the world are increasingly considering socioeconomic and technological challenges that can be tackled through appropriate innovation policies.[1] The key question is thus determining which kind of government led innovation policy is more effective in sustaining growth and employment and, if possible, helping solve contemporary challenges as climate change, cancer and demographic ageing.

The present report examines a variety of innovation and research-support policies and systematically compare them across a variety of measures characterizing the performance of a modern economy. To accomplish the exercise we rely on the so-called *Schumpeter meeting Keynes* (K+S) macroeconomic agent based model, originally developed in (Dosi et al., 2010).[2] The model constitutes a flexible environment for simulation experiments and counter-factual analysis. It is mainly composed of two vertically related sectors, where heterogeneous firms non-trivially interact exchanging capital goods in a market with imperfect information. The dynamics of innovation and imitation laying behind the production of machines constitute the Schumpeterian engine of the model. In addition, a twofold Keynesian Keynesian engine shape aggregate demand

[1] The interested reader might want to look at the *EU Innovation Unit* or the *OECD Innovation Strategy*.

[2] We invite the interested reader to look at Dosi et al. (2006) for an antecedent of the model, to Dosi et al. (2016) for an overview and to Dosi et al. (2016), Dosi et al. (2015, 2017b) and Lamperti et al. (2018) for most recent developments.

via fiscal policies on one side, and investment decisions and workers consumption on the other. Under these premises, we believe the K+S model constitutes a good candidate to investigate innovation policies encompassing a variety of roles of the State.

In particular, we examine a set of five experiments (each corresponding to a different policy initiative) and a variety of possible combinations. Both direct policies, i.e. those that actively shape the innovation landscape and grant the government a direct role in selecting what and how much risk to bear, and indirect policies, i,e. those that passively provide monetary incentives to firms in the hope to stimulate private initiatives, are considered. Our results strongly point to the relevance of the entrepreneurial state. An active government publicly funding R&D within National Laboratories having the objective of enlarging the set of technological opportunities available to the public leads the economy towards a growth path of sustained growth, high employment and low deficits that other innovation policies cannot reach under comparable level of public spending. Relevantly, such evidence is robust to a number of model specifications. Further, we find that R&D subsidies outperform investment incentives in supporting growth and employment and - perhaps more interesting - they are synergic with Entrepreneurial state initiatives.

The rest of the report is organized as follows. Section 2 discusses the concept of entrepreneurial state and its linkages with innovation and fiscal policies. Section 3 briefly introduces the model and provides an overview of the policies we test in the corresponding experiments; section 4 discusses the main findings and, finally, section **??** concludes the report.

2 Innovation policy & the Entrepreneurial State

2.1 Policies for innovation and R&D

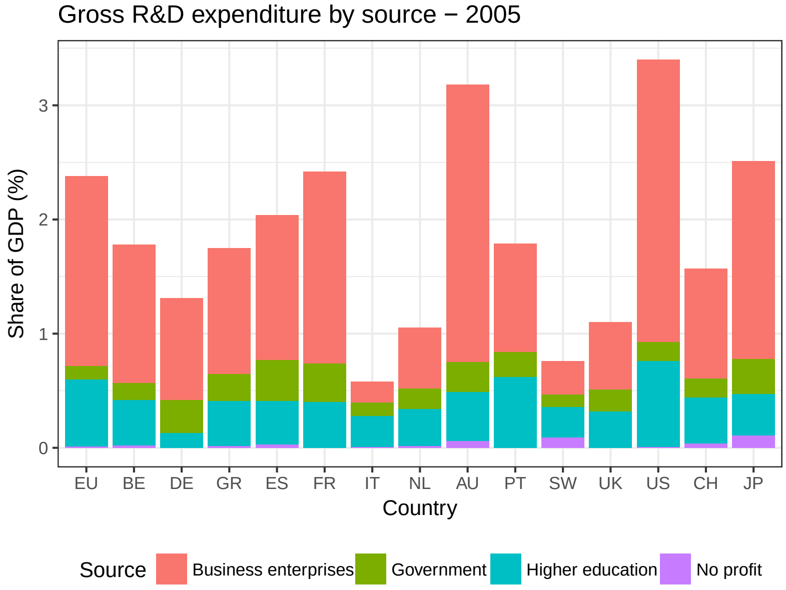
The assumption that R&D will help reach EU's long-term objectives is largely based on economic theory, which identifies technical change as the major source of long run economic growth. Despite relevant methodological and philosophical differences, such a central role of technical change is recognized both in the neoclassical (Solow, 1957; Romer, 1986; Aghion and Howitt, 1992) and evolutionary economic literature (Richard and Sidney, 1982; Dosi, 1988; Dosi et al., 1994). New production processes will allow firms to increase output per worker or unit of capital, or help reduce pollution, CO_2 emissions, and the consumption of fossil fuels and other non-renewable resources. New products will contribute to improving the living standard and well-being of consumers. Since the knowledge created through R&D is to some extent a public good, there may be additional benefits from positive externalities or spillovers from R&D. Further, the process of technical change fosters dynamic competition among firms, influences the processes of imitation and technological diffusion and finally affects the aggregate economic performance. Relevantly, the institutional setting plays a central role in all these dynamics. It might either promote or reduce the pace and direction of technological change and constitutes one of the precondition of economic growth (Winter, 1984; Breschi et al., 2000).

Much of innovation policy is aimed at measures inducing the private sector to increase its investments in innovation. Countries are largely heterogeneous in terms of GDP shares spent in R&D and such a variety obviously reflects some differences in the type of policy initiatives put forward by the different governments. Figure 1 reports gross R&D expenditures for a number of OECD countries and brakes the share into different sources of funding (panel a. shows data relative to 2005, while panel b. those relative to 2015). Even though a slight increase in total spending for research activities is generally visible within a decade since the financial crisis, the size of government funding appears rather stationary and, in general, averages around 0.20-0.25% of GDP for European countries and 0.30 for the US.

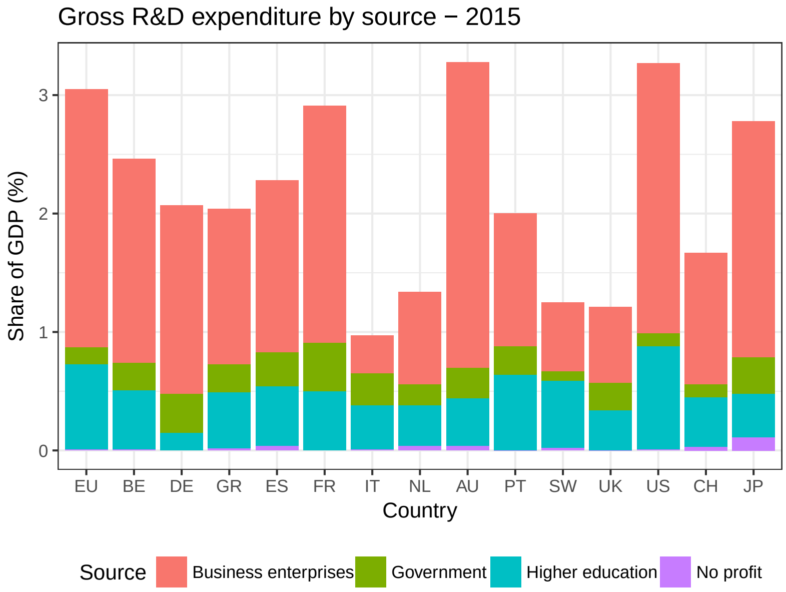
In addition, as stressed by Mazzucato (2017), measures are often too indirect, assuming that all that is needed are incentives (see figure 2). To the contrary, evidence suggests that business tends to invest seriously in innovation only when market and technological opportunities are in sight. And the latter are strongly correlated with direct (not indirect) government investments in new areas characterised by high capital intensity and high technological and market risks. More specifically, direct investments that create new technological and industrial landscapes tend to crowd-in private investment more than indirect tax incentives. These investments have not been driven by the need to fix narrow market failures, but by the mission to solve societal and technological challenges (Mazzucato, 2015a).

2.2 The government as a dynamic agent: the entrepreneurial state

The role the state in the economy has always been crucial, both in the EU and the US (see e.g. Block, 2008). However, too often it is perceived as the one that simply "administer", "fixes", "regulates", and at best "facilitates" and "de-risks" the private sector. Market failure theory has increasingly argued for public intervention in the economy if only if it is geared toward fixing situations in which markets fail to efficiently allocate resources (Arrow, 1951). Indeed, such an



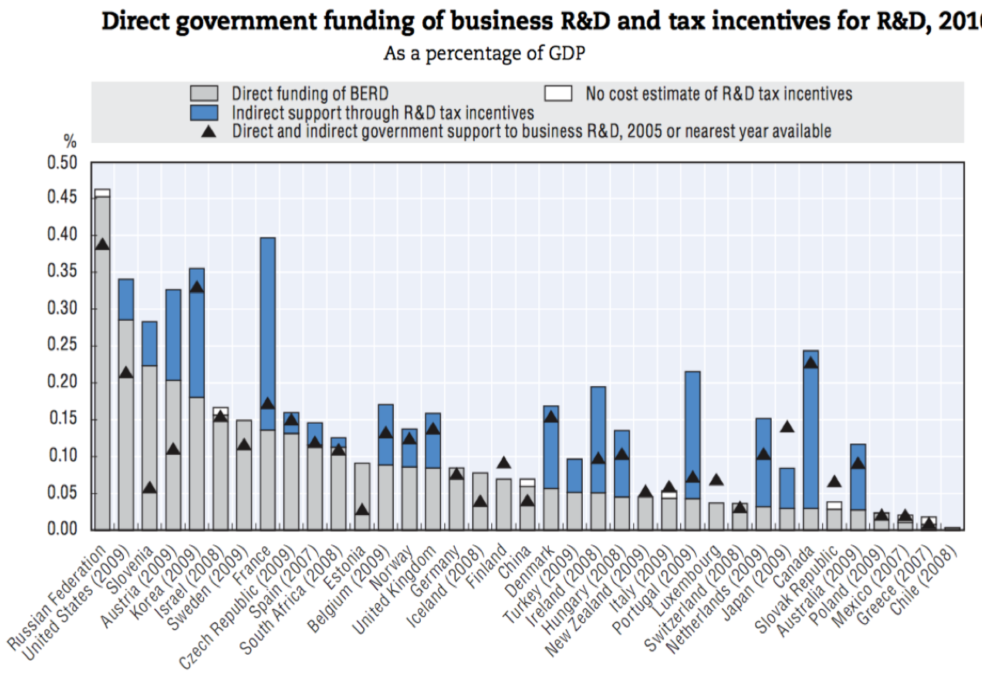
(a) 2005



(b) 2015

Figure 1: R&D expenditures (as share of GDP) by source of funding in EU. Source: Eurostat.

approach suggests that governments intervene to fix markets by investing in areas characterized by positive or negative externalities. As emphasized in Mazzucato (2016), it prevents from thinking creatively about how to allow public sector vision, risk-taking, and investment to lead and structure the necessary transformational changes. One impact of public choice theory has been to undermine faith in the positive power of public institutions. This has provided the justification



Source: OECD 2012 http://www.oecd.org/sti/sti-outlook-2012-financing-business-rd.pdf

Figure 2: Government spending in business R&D by type of instrument. Source: OECD.

for a reduction in public sector investments in its internal capabilities and competencies which are essential to guide such change (and has led to a rise in outsourcing Crouch, 2016 which only compounds the problem).

While market failure theory has provided interesting insights on the potential role of an extremely well function market system and have proved to be of some utility for describing a steady-state scenario in which public policy aims to put patches on existing trajectories of economic development (e.g. on the under-provision of goods with positive externalities). It is less useful when policy is required to dynamically create and shape markets and the competition landscape of industries and firms. We find it difficult to use a market failure approach to explain innovation-fuelled and government-led phenomena like the "race to moon" or the development of the nuclear bomb, which had sound repercussions on the technological and competitive environment of firms. More to the point, it cannot explain the kinds of transformative, catalytic, mission-oriented public investments (Nelson, 1977; Foray et al., 2012) that created new technologies and sectors that did not previously exist. This includes the emergence of the Internet, the nanotechnology sector, the biotechnology sector, and the emerging clean-tech sector (Block and Keller, 2015; Sampat, 2012). Such mission-oriented investments coordinated public and private initiatives, built new networks, and drove the entire techno-economic process. In all such cases, the State has taken the lead and created or actively supported research institutions. In no such cases, the State has limited to providing tax discounts or subsidies.

Governments willing to implement innovation policies that generate real additionality, rather than enhancing the profitability of existing innovations, should act as an investor of first resort in new ones, absorbing the high degree of uncertainty during early stages of innovation and possibly welcoming failures when they happens (Mazzucato, 2016).

3 The model and the experiments

3.1 The *Schumpeter meeting Keynes* model

Our simple economy is composed of a machine-producing sector made of F_1 firms, a consumption-good sector made of F_2 firms, LS consumers/workers, and a public sector. Capital-good firms invest in R&D and produce heterogeneous machines. Consumption-good firms combine machine tools bought by capital-good firms and labour in order to produce a final product for consumers. The public sector levies taxes on firms' profits, pay unemployment benefits and, eventually, implement the selected innovation policy. In the baseline configuration we assume innovation policy is absent and the government just concentrates on fiscal policy. However, innovations are undoubtedly endogenous to our economy. It is the uncertain outcome of the search efforts of the producers of capital equipment and exerts its impact throughout the economy via both the lowering of the production costs of such equipment and its diffusion in the downstream consumption-good sector.

Capital and consumption good firms.

Firms in the capital-good industry produce machine-tools using labour. The technology of the machines of vintage τ is captured by a couple of coefficients $(A_{i,\tau}, B_{i,\tau})$, where the former represents the productivity of machines employed in the consumption-good industry, while the latter indicates the productivity of the production technique needed to manufacture the machine. Given the monetary wage, $w(t)$, paid to workers, the unitary cost of production for capital-good firm i is given by:

$$c_i^{cap}(t) = \frac{w(t)}{B_{i,\tau}}. \quad (1)$$

Similarly, the unitary production cost of a consumption-good firm j is:

$$c_j^{con}(t) = \frac{w(t)}{A_{i,\tau}}. \tag{2}$$

Firms in the capital-good industry adaptively strive to increase market shares and profits trying to improve their technology via innovation and imitation. They are both costly processes: firms invest in R&D a fraction of their past sales in the attempt to discover new technology or to imitate more advanced competitors. As in Dosi et al. (2010), both innovation and imitation are modelled as two step processes. The first step captures the stochastic nature of technical change and determines whether a firm successfully innovates or imitates through a draw from a Bernoulli distribution, where the (real) amount invested in R&D, that is, ultimately, number of people devoted to search, affects the likelihood of success. The second step determines the size of the technological advance via an additional stochastic processes:

$$A_{i,\tau+1}^k = A_{i,\tau}^k(1+\chi_{A,i}) \tag{3}$$

$$B_{i,\tau+1}^k = B_{i,\tau}^k(1+\chi_{B,i}) \tag{4}$$

where $\chi_{A,i}$ and $\chi_{B,i}$ are independent draws from $Beta(\alpha^k, \beta^k)$ distributions over the interval $[\underline{x}, \overline{x}]$. The support of each distribution defines the potential size of the technological opportunity along the corresponding dimension (Dosi, 1988). Specifically, in case of successful innovation, the new vintage of capital-goods will be characterized by a novel labour productivity.

Beyond innovation, imitation might also take place at each round. Specifically successful imitators (i.e. those who obtain a success from the corresponding Bernoulli trial) have the opportunity to copy the technology of the closest competitors in the technological space.[3]

Firms in the *consumption-good industry* produce a homogeneous good using their stock of machines under constant returns to scale. They face a demand created by the expenditures of workers, and plan their production according to (adaptive) expectations over such a demand, [4] desired inventories, and their stock of inventories. Whenever the capital stock is not sufficient to produce the desired amount, firms invest in order to expand their production capacity.

Further, firms invest to replace current machines with more technologically advanced ones.

[3]The technological space is modelled as a 2-dimensional Euclidean space where ℓ^2 is chosen as the metric determining distance between couples of points. Each point represents a technology.

[4]In the benchmark setup, expectations are myopic. The results are robust for different expectation formation mechanisms. More on that in Dosi et al. (2006) and Dosi et al. (2017a).

In particular, given the set of all vintages of machines owned by firm j at time t, the machine of vintage τ is replaced with a new one if

$$\frac{p^{new}}{c_j^{con}(t) - c^{new}} = \frac{p^{new}}{\left[\frac{w(t)}{A_{i,\tau}^{LP}}\right] - c_j^{new}} \leq b \tag{5}$$

where p^{new} and c^{new} are the price and unitary cost of production associated to the new machine and b is a pay-back parameter determining firms' "patience" in obtaining net returns on their investments.[5] Gross investment of each firm is the sum of expansion and replacement investments. Aggregate investment just sums over the investments of all consumption good firms.

Consumption-good firms choose their capital-good supplier comparing price and productivity of the currently manufactured machine tools they are aware of. Indeed, as the capital-good market is characterized by imperfect information, consumption-good firms can directly buy from a subset of machine-tool producers. Machine production is a time-consuming process: consumption-good firms receive the ordered machines at the end of the period.[6]

Firms sets the price of their final good applying a variable mark-up (μ_j) on their unit cost of production:

$$p_j^{con}(t) = c_j^{con}(t)[1 + \mu_j(t)]. \tag{6}$$

The mark-up change over time according to the evolution of firm's market share, f_j (in line with a lot of evolutionary literature and also with "customer market" models originally described by Phelps and Winter, 1970):

$$\mu_j(t) = \mu_j(t-1)\left[1 + \upsilon \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right] \tag{7}$$

with $0 \leq \upsilon \leq 1$.

Consumers have imperfect information regarding the final product (see Rotemberg, 2008 for a survey on consumers' imperfect price knowledge) which prevents them from instantaneously switching to the most competitive producer. Still, a firm's competitiveness $(E_j(t))$ is directly determined by its price, but also by the amount of past unfilled demand $l_j(t)$:

[5] We notice that our assumptions are in line with a large body of empirical literature showing that replacement investment is typically not proportional to the capital stock (e.g. Feldstein and Foot, 1971; Eisner, 1972; Goolsbee, 1998).

[6] These assumptions finds all in line with large bodies of literature; see, e.g., Rotemberg (2008) for details on pricing, imperfect information and behavioural attitudes of consumers and Boca et al. (2008) for presence of gestation lag effects in firms' investments.

$$E_j(t) = -\omega_1 p_j(t) - \omega_2 I_j(t), \tag{8}$$

where $w_{1,2} \geq 0$.[7] At the aggregate level, the average competitiveness of the consumption-good sector is computed averaging the competitiveness of each consumption-good firm weighted by its past market share, f_j. Market shares are finally linked to their competitiveness through a "quasi" replicator dynamics:

$$f_j(t) = f_{j,t-1}\left(1 + \chi \frac{E_j(t) - \bar{E}_t}{\bar{E}_t}\right), \tag{9}$$

where $\chi > 0$ and $\bar{E}_t$ is the average competitiveness of the consumption good sector.

Entry and exit.

At the end of each period we let firms with (quasi) zero market shares or negative net assets die and we allow a new breed of firms to enter the markets. We keep the number of firms fixed, hence any dead firm is replaced by a new one. In line with the empirical literature on firm entry Bartelsman et al. (2005), we assume that entrants are on average smaller than incumbents, with the stock of capital of new consumption-good firms and the stock of liquid assets of entrants in both sectors being a fraction of the average stocks of the incumbents. Concerning the technology of entrants, new consumption-good firms select amongst the newest vintages of machines, according to the "brochure mechanism" described above. The process- and product-related knowledge of new capital-good firms is drawn from a Beta distribution. In fact, the distribution of opportunities for entrants vis-à-vis incumbents is a crucial characteristics of different sectoral technological regimes and finds somewhat in line with the distance from the technological frontier of entrants modelled in Aghion and Howitt (2006). However, contrarily to Dosi et al. (2010) we leave entrants and incumbents with the same set of technological opportunities. Indeed, in this paper it is up to the innovative effort of public and private actors to "discover new paradigms" that would re-define the set of available technologies in the economy.

Government, wages and labour.

The public sector levies taxes on firm profits and worker wages and pays to unemployed workers

[7] Such unfilled demand is due to the difference between expected and actual demand. Firms set their production according to the expected demand. If a firms is not able to satisfy the actual demand, its competitiveness is accordingly reduced. On the contrary, if expected demand is higher than actual one, inventories accumulate.

a subsidy, which corresponds to a fraction of the current market wage. Taxes and subsidies are the fiscal leverages that contribute to the aggregate demand management regimes. Aggregate consumption (C) is computed by summing up over the income of both employed and unemployed workers:

$$C(t) = w(t)L^D(t) + w^U[L^D(t) - L^S(t)], \tag{10}$$

where w represent wages, w^U the unemployment subsidy and L^D and L^S labour demand and labour supply respectively.

The model satisfies the standard national account identities: the sum of value added of capital- and consumption goods firms equals their aggregate production since in our simplified economy there are no intermediate goods, and that in turn coincides with the sum of aggregate consumption, investment and change in inventories.

Wages are linked to the dynamics of productivity, prices and unemployment rate:

$$w(t) = w(t-1)\left[1 + \psi_1 \frac{\Delta \bar{AB}(t)}{\bar{AB}(t-1)} + \psi_2 \frac{\Delta cpi(t)}{cpi(t-1)} + \psi_3 \frac{\Delta U(t)}{U(t-1)}\right], \tag{11}$$

where $\bar{AB}$ indicates the average productivity in the economy, cpi is the consumer price index and, intuitively, U stands for unemployment rate. In fact, taxes and subsidies are the fiscal instruments that contribute to the aggregate demand management (see Dosi et al., 2010, for additional details). All wages and subsidies are consumed: the aggregate consumption (C_t) is the sum of income of both employed and unemployed workers. We notice that consumption, in this model, does not directly entail production of emissions. The model satisfies the standard national account identities: the sum of value added of capital- and consumption-goods firms (Y_t) equals their aggregate production since in our simplified economy there are no intermediate goods, and that in turn coincides with the sum of aggregate consumption, investment ($I_t = EI_t + RI_t$) and change in inventories (ΔN):

$$\sum_{i=1} Q_i(t) + \sum_j Q_j(t) = Y_t \equiv C_t + I_t + \Delta N. \tag{12}$$

3.2 Model dynamics and the baseline configuration

The baseline configuration of the model is rather simple. Parameters are chosen to replicate a wide array of microeconomic and macroeconomic stylized facts (see appendix A) and to generate a behaviour of self-sustained economic growth where crises are - however - not infrequent. The unemployment rate fluctuates around 6-7% and deficit on GDP is relatively contained (5% in the average period). We assume that fiscal policy is active and relatively balanced, in the sense that the tax rate on individual income is equal to the unemployment rate (see appendix B for additional details). Finally, no innovation policy is implemented. All firms face identical technological opportunities and invest in R&D the same fraction (4%) of their sales; such a share of proceedings are then equally split towards innovation and imitation activities.

Table 1: Summary statistics for the main variables in the baseline scenario.

Variable	**Mean**	**St. Dev**	**Variable**	**Mean**	**St. Dev**
GDP growth	0.0244	0.0016	Unemployment	0.0714	0.0327
GDP volatility	0.0789	0.0007	Productivity growth	0.2506	0.0015
Deficit on GDP	0.0510	0.0530	HHI Cap. Good sector	0.6280	0.0512
Likelihood of crises	0.171	0.0415	HHI Cons Good sector	0.0029	0.0001

Simulations of the baseline model configuration show - see Table 1 and Figures 3 and 4 - an economy in good shape. The model robustly generates endogenous self-sustained growth patterns characterized by the presence of persistent fluctuations. Deficit moves around reasonable levels (4-6%) for a Western economy and does not exhibit trending behaviours. To the contrary, output, labour productivity and wages behave as typical unit-root processes; further, they appear sharing a long run trend, indicating that in an economy under a balanced growth where wages are indexed to fundamentals of the economy, productivity-wage gaps do not tend to increase. From a "micro" perspective the behaviour of the Hirschman-Herfindall indexes of the capital- and consumption-good sectors indicate that market concentration varies during the simulation as a consequence imperfect competition and Schumpeterian entry and exit; in general, we observe higher dynamism in the upstream sector, where high concentration is more likely to emerge, even though dominant positions are rapidly eroded.

Summing up, our baseline configuration shows a growing economy with endogenous and possibly severe crises, which are escaped mainly through innovation activities and fiscal policy. Unemployment tends to keep at low levels yet spiking during downturns and inflation evolves approximately constant with a slightly positive long run average (1.6%).

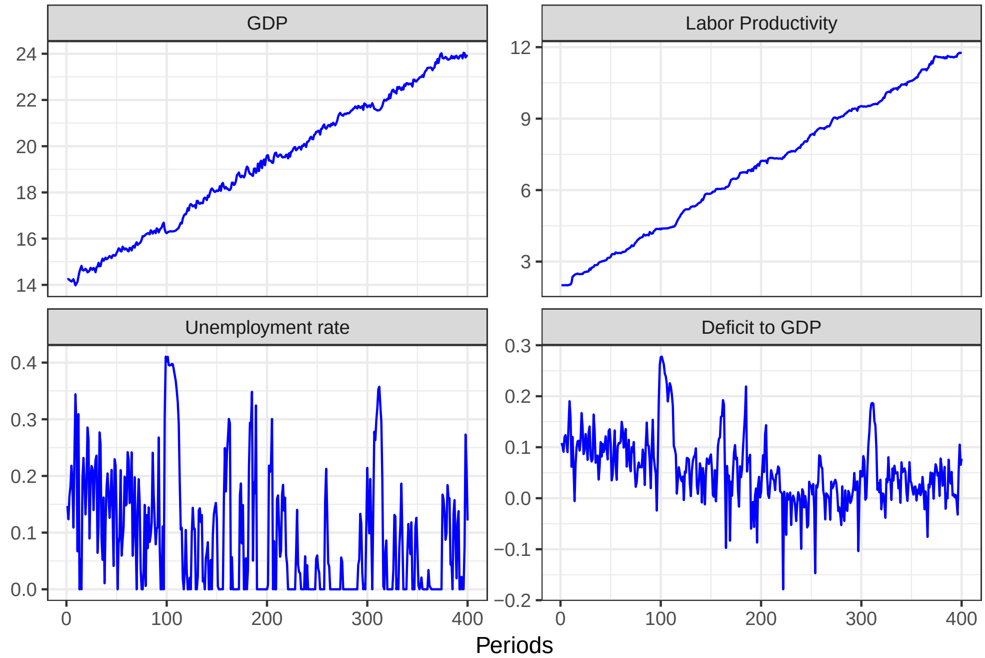


Figure 3: Model behaviour in the baseline setting for a randomly selected run. GDP and Labor Productivity are in log.

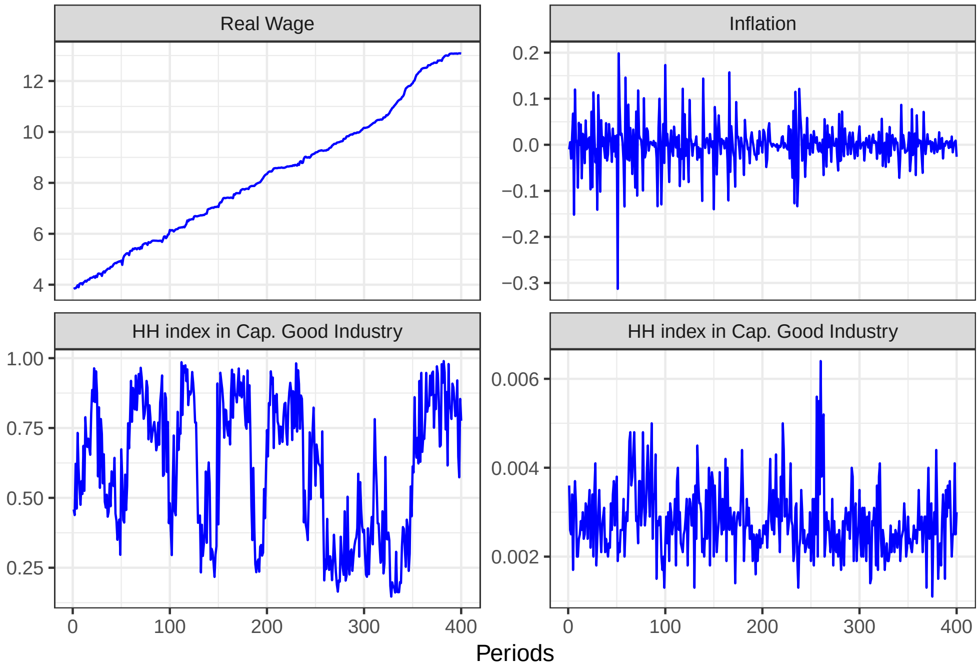


Figure 4: Model behaviour in the baseline setting for a randomly selected run. Real wage is in log.

3.3 Policy experiments

Against the baseline configuration introduced in the previous section, we test and compare a series of innovation policy regimes. The aim of such exercises is to show how the aggregate behaviour of the economy is substantially shaped by the intervention of the government, which can move towards entrepreneurial-like policies, or simply stick to disaggregated monetary incentives to firms, yet of different type. To ensure full comparability of results we design policy intervention in a way that the amount of resources the public authority can spend in its policy program are equal after controlling for the size of the economy. In other words, the fiscal cost of the different policies is identical in terms of GDP share. Such a spending is financed through taxes and, eventually, public debt. Here it follows a brief description of the various policy regimes we consider.

Experiment I: R&D subsidies.

This is the most common innovation policy tool in support of R&D. The Government provides a generic subsidy to increase firms' research effort in the hope it will increase its chances of discovering a novel product, a novel process or it will successfully imitate the technology of a close competitor. In our model, we assume that $\alpha > 0$ is a parameter controlling for the size of the subsidy. Under policy intervention, consumption good firm i's spending in R&D is

$$RD(t)_i = (1 + \alpha)RD^B(t)_i \tag{13}$$

where the apex B is used to indicate R&D under the baseline. Obviously, larger firms will obtain larger subsidies in monetary terms.

Experiment II: discounts on investments.

The second experiment we consider mimics the typical example of *indirect* policy introduced earlier in this report. In this regime, firms obtain a government-financed discount on their investments in novel capital goods. Recall that consumption good firms invest to replace current machines with more technologically advanced ones. Their decision about what machines to buy is governed by a pay-back period routine, where firms evaluate their costs across the horizon they plan to use the capital good. In particular, under the current policy regime, consumption-good firm j buy the new machine if and only if

$$\frac{p^{new,B} * (1-\beta)}{c_j^{con}(t) - c^{new}} \leq b, \tag{14}$$

where $\beta > 0$ represents the size of the discount expressed as a share of the price and, again, B indicates the baseline.

Experiment III: support of non-productive activities.

The third experiment mimics government spending in support of non-productive activities whose social value is also difficult to establish economically. Such scenario would like to capture forms of public hiring that do not directly contribute to the production side of the economy nor facilitates it. In a sense, we would like to characterize those activities that, for example in Italy, recently went under plans of "spending-review". They can be roughly defined as tasks whose removal would allow to reduce public spending keeping constant the level of public services offered to citizens. In this experiment we assume that the government increases the expenses for non-productive public servants rather than reducing them.

Experiment IV: publicly-owned firms diffusing knowledge.

The very concept of entrepreneurial state encompasses the creation of public entities (agencies as well publicly financed firms) whose aim is to actively shape the innovation landscape by engaging and coordinating research in given fields and diffusing the relevant knowledge to facilitate technological progress. Even though the model described in section 3 falls short of capturing precise directions of technical change, we can test a first approximation of an entrepreneurial state policy where the government creates and funds public firms in the capital good sector that (i) devote all their profits to research activities, (ii) freely diffuse knowledge to *technologically close* private firms who are interested in the developments the public firms may obtain. With respect to all other features but (i) and (ii), the public firm is identical to all its competitors. In such an experiment the role of the state is to finance new (public) capital good-firms, absorb eventual losses to prevent bankruptcy and fund their research activities.

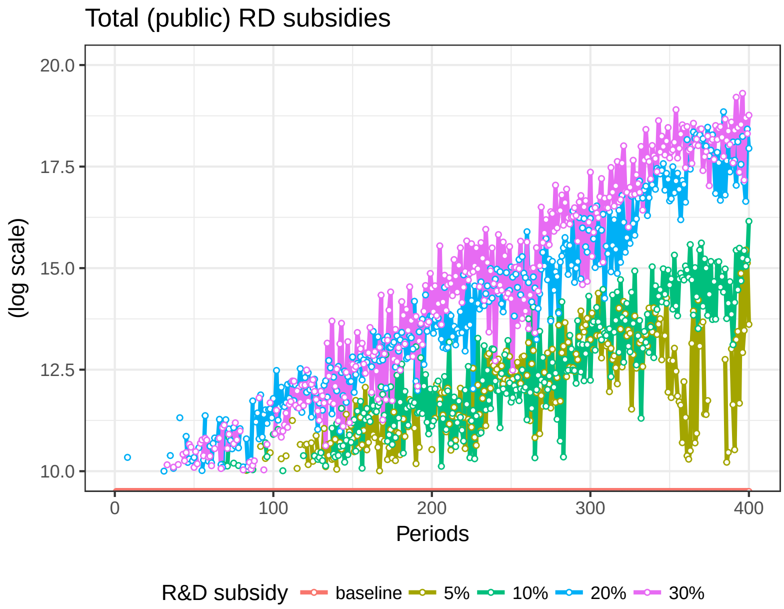
Experiment III: national research laboratories.

Finally, in this fifth innovation policy regime we aim at capturing the other soul of an entrepreneurial state, i.e. the voluntary action of creating institutional bodies supporting the creation of novel technological opportunities, funding primary research where private business lack initiative, bearing the risks of such projects. In our simplified model, we translate such a policy scenario in the creation of a National Research Lab that (i) uniquely conducts research and, hence, do not produce; (ii) tries to enlarge the set of technological opportunities available in the economy (i.e. the support of the Beta distributions described in section 3.1) across a variety of possible directions. Being the NRL a novel agent in our model, we briefly describe its behaviour. At each time step in the simulation the NRL receive funding from the government to perform its research activities. The outcome of these activities results from a two-step process. First, the NRL is subject to a Bernoulli trial whose probability of success depends from the value of a logistic transformation of the economy's cumulative R&D intensity (i.e. summing private and public spending). In particular, the following logistic is chosen $f\left(\frac{cumRD}{GDP}\right) = \frac{1}{1+e^{2(x-0.5)}}$, which implies that the probability of expanding the technological opportunities reaches 50% when 50% of GDP is spent in R&D. The second step entails a gain in the upper support representing the set of technological opportunities by a (multiplicative) factor extracted from a uniform $[\theta_L, \theta_U]$. When the set of technological opportunities is expanded, we assume that each successfully innovating firm can enjoy such a new stock of knowledge. The latter assumption is crucial and implies the existence of a private cost to obtain the publicly discovered new technologies that was absent in experiment III.

3.4 Implementation

Here we briefly describe the simulation settings chosen to perform the experiments I-V discussed above. The model is then run for 400 periods and, being stochastic in its essence, each configuration is tested in a Monte Carlo (MC) exercise of size 200 to wash out individual-run heterogeneity.

As previously anticipated, we compare experiments against a common baseline scenario and assuming a comparable size of public spending for the innovation policy selected. To determine the share of GDP to be spent for such policy we start performing experiments I (R&D subsidies) and II (discounts on investments). There, we run the model setting α and β equal to $\{5\%, 10\%, 20\%, 30\%\}$. Then, we compute the average fiscal cost (in terms of GDP share) of such two policies and use such value to compute the amount of resources spent implementing policy regimes (III, IV and V). Figures 5 and 6 show the behaviour of different quantities of interest in experiments I and II. In particular, they point to a different nature of the intervention. Spending - much higher in absolute terms for R&D subsidies under the chosen parametrizations - exhibits an almost log-linear dynamics in both cases. To the contrary it appears rather constant in terms of output share over the simulations what in experiment I, while rather spiky in experiments II, thereby reflecting the nature of investments.



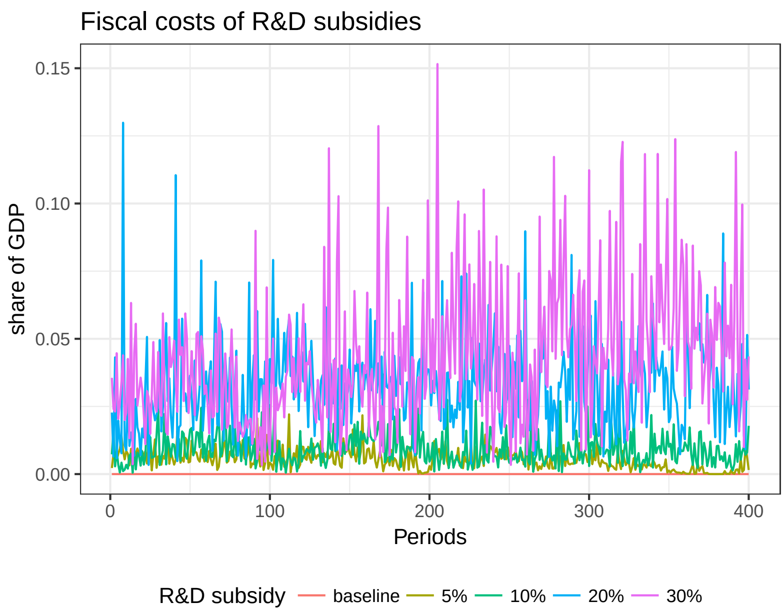


Figure 5: R&D subsidies, typical run.

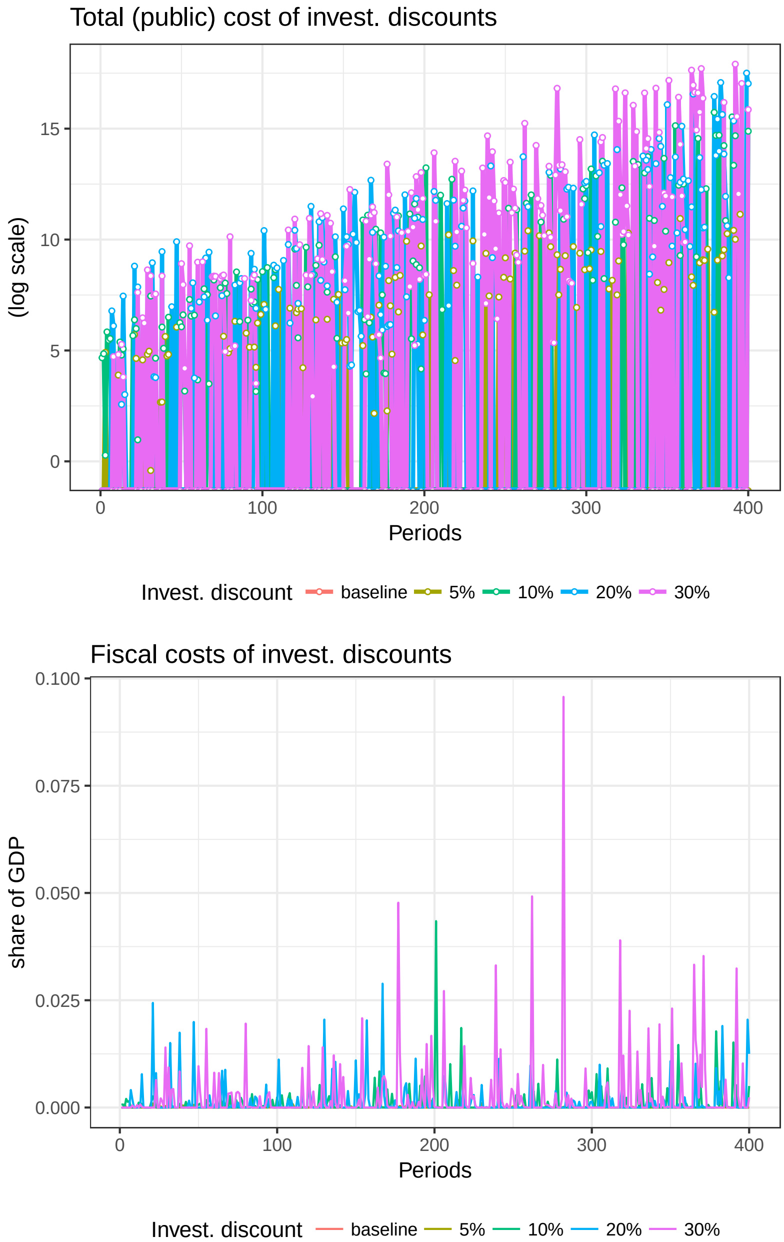


Figure 6: Investment discounts, typical run.

4 Results and discussion

Table 2 reports the results from the first two set of experiments (R&D subsidies and investment discounts) relative to the baseline across a number of macroeconomic measures of performances. Just to clarify, a value of 1.10 in the table indicates that the performance under scrutiny is, on average, 10% higher than in the baseline. The asterisk is used to mark a statistically significant (0.05 level) difference with the baseline.

Table 2: Policy experiments involving R&D subsidies and discount on investments.

	GDP growth	**GDP volatility**	**Unemployment**	**Periods full empl.**	**Deficit (% GDP)**	**Fiscal cost (% GDP)**
Baseline	2.4%	0.08	7.1%	24%	5.1%	0
Experiments:						
I - R&D subsidies						
5%	1.04	1.01	0.98	1.04	1.25	0.9%
10%	1.08 *	1.02	0.98	1.08	1.39 *	2.2% *
20%	1.11 *	0.98	0.96	1.21 *	1.16 *	4.8% *
30%	1.18 *	0.99	0.95	1.37 *	0.94	6.4% *
II - Discount on invest.						
5%	1.01	1.15 *	0.99	1.04	1.21 *	0.5%
10%	1.03	1.17 *	0.98	1.36 *	1.25 *	0.8% *
20%	1.07	1.22 *	0.97	1.38 *	1.34 *	2.1% *
30%	1.10 *	1.26 *	0.97	1.41 *	1.19	3.0% *

Notes: all values refer to averages over a Monte Carlo exercise of size 100. For all the experiments values are reported as the ratio with respect to the baseline but for fiscal costs, which are expressed in levels. * indicates a significant (0.05 level) difference between the experiment and the baseline. Fiscal costs are measured as the public costs borne by the government to implement the policy scheme indicated in the corresponding experiment. In the baseline fiscal costs are set to zero as no policy is implemented (apart from income taxation and unemployment benefits, which are kept constant across all the experiments).

First, our results show that R&D subsidies are more effective than investment discounts. Under comparable size of the policy intervention (around 2% of GDP), subsidies produce a statistically higher GDP growth than in the baseline, while investment discount fail to impact on the long run pace of the economy. To the contrary, they significantly increase the volatility of output (measured as square root of growth rates' variance). Such result reflects the microeconomics of firms, which has largely documented that investment tend to be lumpy Doms and Dunne (1998). Investment discounts allow firms to invest more at the margin, but do not push them to do what they would have done - at least partially - anyway. The slight increase in investment generates larger aggregate demand, whose effects are visible on the number of periods of full employment, but not on the average unemployment rate of the economy.

R&D subsidies stimulates growth conditional on the strength of the policy. When a sufficiently high amount of resources are channelled towards firm's R&D, the economy grows at larger paces, unemployment falls (even though not significantly) and also public finances benefit from the higher trajectory of the economy, with a deficit to GDP ratio that is approximately equal to the baseline even though 6.4 percentage points of GDP are spent into innovation policy. Contrarily, investment discounts deteriorate the primary surplus in the long run. The difference between experiments I and II arise from the degree of "directness" of the policy. While subsidies are either fully spent in the search for new technologies or in the effort to successfully imitate a competitor, discounts act the margin; they might induce some firms to substitute their machines, but they often just translate into additional profits.

Experiment III, where the government channels funds towards non profitable activities, provides the worst economic performance across all the different experiments (see Table 3). Almost no impact is observed on growth, employment rate and volatility, while the deficit over GDP ratio rises and overcome its baseline counterpart by 20% (with the difference that is statistically significant at 0.05 level). Some positive effect from such a policy can be retrieved on the share of full employment periods, as an higher number of workers raises consumption, but not enough to stimulate growth. In a nutshell, experiment III shows that public spending should be carefully channelled to productive activities with an high multiplier effects. The feedback loop effect on demand is found to be too weak to be profitable just to spend. Paraphrasing one of the authors, "direction of public spending is amongst the first and most relevant things that should be set".

Accordingly, our results underline that entrepreneurial state-like policies successfully kick-start growth and reduce employment in the long run. Experiment V, where innovation policy creates a National Research Lab fuelling the economy with novel technological opportunities, provides the benchmark scenario in terms of economic performance. The creation of a public firm diffusing technologies along specific (though not better defined) "trajectories" clearly shows a larger pace of growth than in the baseline, but fails to overcome experiment V. Despite such evidences, we also find a downside of entrepreneurial state policies. First, the average volatility of the economy is substantially larger than in the baseline (with statistically significant difference for both experiment IV and V) and largely depends on whether publicly discovered technologies manage to diffuse among private firms or not. Remarkably, we find that cases where the government directly spends resources and intervene to reshape the innovation landscape but support projects that do not crowd-in the interest of private businesses. Under such a scenario, the economic impact of *direct* policy intervention (experiments IV and V) turns out to be negligible and, further, risks to significantly dampen the health of public finances raising deficits and, in turn, debt (Figure 7). However, would a government be ready to bear such risks, the average behaviour clearly points to the effectiveness of entrepreneurial state policies, which increase both growth and unemployment.

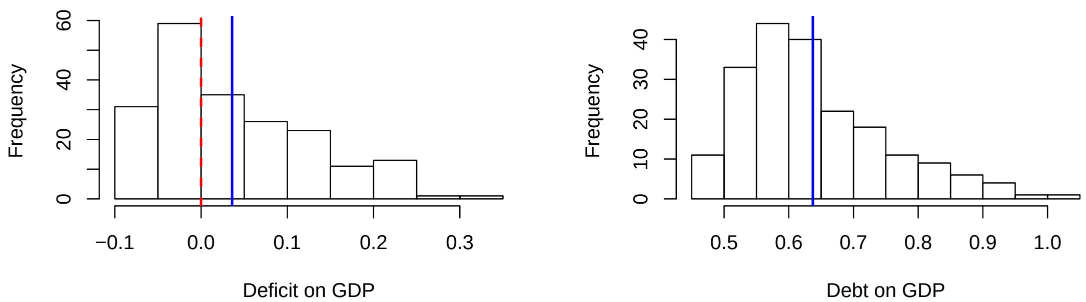


Figure 7: Histogram showing frequencies of (average) deficit and debt to GDP ratios over the MC exercise for experiment V (creation of National Research Lab). Red dashed line indicates the zero; blue solid line indicates the average. Debt reported when different from zero.

Finally, we notice that there exist complementarity across the different types of innovation policy. A fully fledged entrepreneurial state implementing both a NRL and a public firms diffusing technologies to the public provides, by far, the best economic returns. On the other side, we notice the complementarity between experiment V and R&D subsidies: when the economy as a whole is relatively more engaged in research activities, the chances of creating public-private virtuous cycles increase and well as the likelihood of successfully enlarging the set of technological opportunities available to firms. Contrarily, unproductive spending and discounts on investments tend to the decrease the effectiveness of entrepreneurial state initiatives by diverting resources from R&D.

5 Conclusion

In this report we have proposed a comparative analysis of a variety of innovation policies, ranging from R&D subsidies to the creation of National Research Labs. Our results strengthen the hypothesis that an entrepreneurial state actively engaging publicly funded research and diffusing technologies to private actors outperforms any policies based on disaggregated monetary incentives. Under comparable size of the government intervention, we find evidence that the creation of National Research Labs conducting research focused on enlarging technological opportunities available to private firms is a requirement to shift the economy toward sustained growth trajectories characterized by low unemployment and high productivity. Such an initiative is found to be complementary with the creation of public firms diffusing technologies along selected direction of technological change and - to a less extent - with the use of R&D subsidies increasing the private sector spending in innovative activities. These policy initiatives comes with the risk of deteriorating public finances in those cases where the publicly-discovered technologies do not manage to diffuse and private business do not get in line with research directions of public bodies. However, would the government be willing to sustain such risks, we find that - on average - the entrepreneurial state's strategy delivers significantly better aggregate performances. On the other side, investment discounts and spending into non-productive activities turn out to be self-defeating.

Table 3: Complete set of policy experiments and comparison with the baseline.

	GDP growth	**GDP volatility**	**Unemployment**	**Periods full empl.**	**Deficit (% GDP)**	**Fiscal cost (% GDP)**
Baseline	2.4%	0.08	7.1%	24%	5.1%	0
Experiments:						
III - Non productive activities	1.05	0.98	0.89	1.37*	1.22*	2.6%
IV - Entr state diffusing tech.	1.27*	1.53*	0.88*	1.28*	1.19*	2.6%
V - National Lab	1.65*	2.32*	0.71*	1.68*	0.88*	2.6%
IV+I	1.16*	1.12*	0.94*	1.32*	1.27*	2.6%
IV+II	1.12*	1.40*	0.96	1.49*	1.34*	2.6%
V+I	1.49*	2.05*	0.84*	1.46*	0.85*	2.6%
V+II	1.38*	1.98*	0.92*	1.53*	0.96	2.6%
IV+V	1.87*	3.21*	0.65*	1.78*	0.78*	2.6%
Experiments:						
I	1.13*	0.98	0.95	1.25*	1.17*	5%
II	1.12*	1.25*	0.97	1.43*	1.20 *	5%
III	1.03	0.98	0.73*	1.51*	1.97*	5%
IV	1.35*	2.02*	0.81*	1.79*	1.11*	5%
V	1.80*	2.79*	0.65*	1.91*	0.65*	5%
IV+I	1.40*	1.88*	0.79*	1.82*	1.06	5%
IV+II	1.30*	2.31*	0.85*	1.64*	1.08	5%
V+I	1.91*	2.54*	0.76*	1.84*	0.92*	5%
V+II	1.85*	2.68*	0.80*	1.73*	0.98	5%
IV+V	1.96*	3.21*	0.62*	1.90*	0.47*	5%

Notes: all values refer to averages over a Monte Carlo exercise of size 100. For all the experiments values are reported as the ratio with respect to the baseline but for fiscal costs, which are expressed in levels. * indicates a significant (0.05 level) difference between the experiment and the baseline. Fiscal costs are measured as the public costs borne by the government to implement the policy scheme indicated in the corresponding experiment. In the baseline fiscal costs are set to zero as no policy is implemented (apart from income taxation and unemployment benefits, which are kept constant across all the experiments). Fiscal costs of 2.6% are imposed to ensure comparability and come from the average cost of the experiments reported in table 2. Fiscal costs of 5% are studied as additional scenario and exogenously chosen.

A Appendix - Stylized facts replicated by the model

Table 4: Main empirical stylized facts replicated by the DSK model.

Stylized facts	Empirical studies (among others)
Macroeconomic stylized facts	
SF1 Endogenous self-sustained growth	Burns and Mitchell (1946); Kuznets and Murphy (1966)
with persistent fluctuations	Zarnowitz (1985); Stock and Watson (1999)
SF2 Fat-tailed GDP growth-rate distribution	Fagiolo et al. (2008); Castaldi and Dosi (2009); Lamperti and Mattei (2016)
SF3 Recession duration exponentially distributed	Ausloos et al. (2004); Wright (2005)
SF4 Relative volatility of GDP, consumption and investments	Stock and Watson (1999); Napoletano et al. (2006)
SF5 Cross-correlations of macro variables	Stock and Watson (1999); Napoletano et al. (2006)
SF6 Pro-cyclical aggregate R&D investment	Wälde and Woitek (2004)
Microeconomic stylized facts	
SF12 Firm (log) size distribution is right-skewed	Dosi (2007)
SF13 Fat-tailed firm growth-rate distribution	Bottazzi and Secchi (2003, 2006)
SF14 Productivity heterogeneity across firms	Bartelsman and Doms (2000); Dosi (2007)
SF15 Persistent productivity differential across firms	Bartelsman and Doms (2000); Dosi (2007)
SF16 Lumpy investment rates at firm-level	Doms and Dunne (1998)

B Appendix - Model Parameters

Table 5: Main parameters and initial conditions in the economic system. For previous parametrization of some sub-portions of the model and for model sensitivity to key parameters see Dosi et al. (2006, 2010, 2013).

Description	Symbol	Value
Monte Carlo replications	MC	200
Time steps in economic system	T	400
Number of firms in capital-good industry	F_1	50
Number of firms in consumption-good industry	F_2	200
Capital-good firms' mark-up	μ_1	0.04
Consumption-good firm initial mark-up	$\bar{\mu}_0$	0.28
Uniform distribution supports	$[\varphi_1, \varphi_2]$	$[0.10, 0.90]$
Wage setting $\Delta \bar{AB}$ weight	ψ_1	1
Wage setting Δcpi weight	ψ_2	0
Wage setting ΔU weight	ψ_3	0
R&D investment propensity (industrial)	ν	0.04
R&D allocation to innovative search	ξ	0.5
Firm search capabilities parameters	$\zeta_{1,2}$	0.3
R&D investment propensity (energy)	ξ_e	0.01
R&D share investment in green tech.	$\eta_g e$	0.4
Beta distribution parameters (innovation)	(α_1, β_1)	$(3, 3)$
Beta distribution support (innovation)	$[\chi_1, \bar{\chi}_1]$	$[-0.15, 0.15]$
New customer sample parameter	$\bar{\omega}$	0.5
Desired inventories	l	0.1
Physical scrapping age	η	20
Payback period	b	3
Tax rate	τ	0.2
Unemployment subsidy	w^U	0.2
Lower support technological opp. advancement	θ_L	0.01
Upper support technological opp. advancement	θ_U	0.03

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