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Stagnation despite ongoing innovation: Is R&D expenditure composition a missing link? An empirical analysis for the US (1948-2019)

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Stagnation despite ongoing innovation: Is R&D expenditure composition a missing link? An empirical analysis for the US (1948-2019)

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Abstract:

Among the explanations for prolonged economic stagnation in advanced economies we find those that highlight the role of technical progress and its weakening impact on potential growth. Several contributions stress the apparent paradox of technological development and innovation going hand in hand with slowing labour productivity growth. This discourse is in turn linked to numerous factors, among which the pattern of research productivity, that appears to be falling in the last decades. The contribution of this article is to analyse the role of innovation expenditures composition, and its effects on productivity. We study whether productivity stagnation can be (partially) explained by the continuously falling ratio between public and private expenditures in innovation in the USA. We carry out an SVAR analysis of the US case during the period 1948Q1-2019Q4. In the empirical exercise we estimate the effect of public expenditure in innovation on productivity, private R&D, and GDP, comparing the outcomes with those relative to private expenditure in innovation. According to our results, the public type of innovation spending exhibits a positive effect on productivity and GDP, and it has a greater effect than private expenditure in innovation. In addition to this, public expenditure in innovation exerts a strong crowding-in effect on private investment in R&D. Therefore, according to the evidence we find, we maintain that the focus on the prolonged and sustained fall of public expenditure in innovation in relation to private expenditure of the same type helps in explaining lasting stagnation.

Keywords: Secular Stagnation, public and private R&D, innovation policy, research productivity, productivity growth

JEL Codes: O47, O32, O40

1. Introduction

It is almost a decade since the search for the causes of lasting (secular) stagnation is up and running (Gordon 2015; Summers 2015; Teulings and Baldwin 2014). Among the main explanations for such a phenomenon we find those which stress the relevance of the supply side, pointing the attention towards the evolution of technical progress and its weakening impact on potential growth. This echoes the now rather distant, but still well-known Solow's (1987) paradox, who claimed that "[…]what everyone feels to have been a technological revolution, a drastic change in our productive lives, has been accompanied everywhere, including Japan, by a slowing-down of productivity growth, not by a step up. You can see the computer age everywhere but in the productivity statistics." Indeed, the issue of technological development going hand in hand with slowing labour productivity growth is still at the centre of the attention. For instance, Gordon (2018a, p. 2) stresses "the paradox that innovative activity as measured by patent issuance has been increasing while productivity growth has been slower in the past decade than in any decade of recorded American history". This discourse is in turn linked, among other things, to the worrisome pattern of research productivity, which is claimed to be falling in the last decades, bringing about concerns about the evolution of productivity and GDP growth (Bloom et al. 2020; Cauwels and Sornette 2022).

It is clear that such a far-reaching insight calls into question a long list of elements. Stagnation cannot obviously be attributed to a single, comprehensive element. The contribution of this article is to try to add one piece to the puzzle by analysing the element of innovation expenditures composition, and its effects on productivity. We want to study whether productivity stagnation can be (at least partially) explained by the fact that the ratio between public and private expenditures in innovation is continuously falling in the USA, as well as in general in advanced economies (Goel et al. 2008; Archibugi and Filippetti 2018). This is in turn linked to the increasing attention that the role of public research (and its tight link with basic research) is enjoying in the last years due to its wide-ranging beneficial effects to the economy (Akcigit et al. 2021; IMF 2021).

For this sake, we offer an SVAR analysis of the US case during the period (1948-2019). In the empirical exercise we try to estimate the effect of public expenditure in innovation on productivity, private R&D, and GDP. We also compare it to the effect of private expenditure in innovation on productivity, and to the effect of generic public expenditure on private R&D and GDP. By evaluating the presence of crowding-in of private R&D due to public R&D, we also contribute to the literature that tries to explain private research and development activity by means of publicly performed R&D. this literature is still relatively scant with respect to that devoted to other policy measures meant to stimulate business innovation (Bloom et al. 2019; Ziesemer 2021c). According to our results, the public type of innovation spending exhibits a positive, non-negligible effect on productivity, and together with generic public expenditure it has a greater effect than private expenditure in innovation. In addition to this, public expenditure in innovation exerts a strong crowding-in effect on private investment in R&D, remarkably stronger than generic public expenditure. Finally, public investment in innovation generates positive and high fiscal multipliers, thereby fostering GDP expansion much more than generic public expenditure. Therefore, according to the evidence we find, we maintain that a prolonged and sustained fall of public expenditure in innovation in relation to private expenditure of the same type helps in explaining stagnation.

The paper is organised as follows. Section 2 illustrates various strands of literature explaining Secular Stagnation from the supply-side. Section 3 reviews the contributions devoted to the study of the macroeconomic effects of innovation expenditures. Section 4 presents the empirical analysis on the macroeconomic impact of public R&D spending on labour productivity, private R&D, and GDP, and to compare this effects to those exerted on these indicators by private R&D and generic residual public expenditure, and Section 6 concludes.

2. (Secular) Stagnation and innovation

Two main strands of analysis have been investigating long-lasting stagnation in recent years. Summers (2014, 2015, 2018) demand-side Secular Stagnation theory retrieved Hansen (1939) gloomy prospects for major advanced economies to grapple with "sick recoveries which die in their infancy and depressions which feed on themselves and leave a hard and seemingly immovable core of unemployment". Summers's intuition grounds on the Wicksellian natural rate of interest and on the supposition for it to have become negative due to forces such as a shift away from major investments in physical capital, the fall of the price of capital goods *vis-à-vis* consumption goods, rising inequality, demography and ageing (Summers 2015; Eggertsson *et al*. 2019).[1] Gordon (2015, 2016, 2018a, 2018b) supply-side Secular Stagnation theory gives most prominence to supply-side elements. Indeed, Gordon (2015) theory is based on two fundamental elements: unfavourable demographic trends and the sluggish growth of total factor productivity. On the demographic side, population ageing and plummeting labour force participation rates are worrying trends. In this respect, the weakening effect of technical improvements on productivity growth and the diminishing returns from human capital accumulation are the main sources of preoccupation. In particular, "[t]he central argument is that the digital electronics revolution has begun to encounter diminishing returns" (ibid., p. 54). Obviously, the fact that Secular Stagnation cannot be simply ascribed to a one-sided explanation is well-understood by both sides of the debate. In this regard, Summers and Fatàs (2018) point out the adverse effect that prolonged demand shocks can have on capital accumulation and workers' skills. Moreover, Gordon (2015, p. 58) explicitly recognizes that "[i]n the end, secular

[1] The fact that the natural rate of interest can be negative in a long-run steady-state equilibrium generated several discussions (Bernanke 2015; Di Bucchianico 2020a, 2020b, 2021; Pagano and Sbracia 2014; Serrano *et al*. 2020; Von Weizsacker and Kramer 2021).

stagnation is not about just demand or supply but also about the interaction between demand and supply".[2] Given the focus of our enquiry, in what follows we will pursue in more details the discussion about the supply-side element constituted by technological innovation.

We start from the general picture offered by Pagano and Sbracia (2018), and then we will differentiate among the different strands present in this supply-side version of the literature on lasting stagnation. The two authors illustrate and comment on the patterns of the sources of growth in the US by presenting a conventional model of exogenous growth:

$$Y_t = A_t^{\sigma} \cdot K_t^{\alpha} \cdot H_t^{1-\alpha}$$

$$H_t = L_t \cdot h_t$$

$$h_t = e^{\theta s_t} \tag{1}$$

$$\frac{Y_t}{P_t} = \frac{L_t}{P_t} \cdot A_t^{\frac{\sigma}{1-\alpha}} \cdot \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} \cdot h_t \rightarrow$$

$$\rightarrow \dot{y} = \dot{e} + \frac{\sigma}{1-\alpha}\dot{a} + \frac{\alpha}{1-\alpha}\dot{k} + \dot{h}$$

In the first equation Y_t stands for output, A_t^{σ} for total factor productivity with $\sigma > 0$, K_t is the stock of physical capital, H_t the stock of human capital, α and $1-\alpha$ the respective shares of value added. Human capital is then developed as the product of total hours worked L_t times human capital per hour worked h_t. The latter element is in turn decomposed into the return to education $\theta > 0$ and the time period during which human capital accumulation takes place s_t. In the second equation, after rearranging the value added equation, inserting human capital specification and diving by total population P_t, we get GDP per capita. In this way, growth in GDP per capita $\dot{y}$ can be sorted in the rates of growth of four elements: employment ratio e, total factor productivity a, capital-output ratio k, and human capital per hour worked h (Pagano and Sbracia 2018, pp. 20-22).[3] The supply-side visions of Secular Stagnation are therefore all relatable to these elements. Obviously, each single vision puts greater weight on a different factor, or combination of factors.

[2] Eichengreen (2015, 2017) as well criticise one-sided supply-side views of Secular Stagnation. Albeit starting from a conception not distant from Summers (2014), he discusses at length the role of technological innovations.

[3] According to Fernald and Jones (2014), the bulk of US post-IIWW growth can be attributed to the exogenously given rate of growth of total factor productivity. The second place is occupied by human capital accumulation, the employment ratio shows a negligible contribution, and finally the capital-output ratio did not contribute at all.

Gordon's supply-side analysis of US growth does not encompasses mechanisms hindering the realization of the full-employment output. Rather, potential output growth is considered to be on a much slower path than before, and it is also supposed to keep remaining on it for the foreseeable future due to several 'headwinds' the US economy is facing (Gordon 2012, 2014, 2016). Among those, we find: first, the progressive fading of a so-called 'demographic dividend' given by the baby-boom generation; second, the stasis reached by the diffusion of mandatory and higher education across US population;[4] third, the rise of inequality; fourth, the competition from countries featuring a much cheaper cost of labour; fifth, environmental concerns over climate change and global warming; sixth, mounting household and government debt levels. To such worrying patterns, Gordon (2015) adds the weak growth of total factor productivity. According to Gordon's reconstruction, the 1920-1972 period witnessed sustained total factor productivity growth, something that was not replicated in later decades. Indeed, the first two industrial revolutions delivered a long list of ground-breaking innovations, creating a favourable environment for the subsequent full-impact on productivity growth.[5] Gordon attributes the unsatisfactory productivity growth experienced in recent years to the supposition that the ramifications of the third revolution have already exhibited the bulk of their potential effect: "[m]ost of the economy has already benefitted from the Internet and web revolution, and methods of production have been little changed over the past decade" (ibid., p. 56).[6] This intuition can be found also in more recent works the author goes deeper in the analysis of the role of innovation in fostering productivity and economic growth (Gordon 2018a, 2018b). Gordon in fact singles out the paradoxical concomitance of fast innovation in terms of patenting and the slow growth of productivity. According to the author, again, the motive for this rests in the nature of the third industrial revolution, an episode that has brought about types of innovations that are not going to replicate the path-breaking pattern of past revolutions. Indeed, Gordon (2018b, pp. 16-17) maintains that "the Third (digital) Industrial Revolution generated a productivity boost of only a decade between 1996 and 2006, as contrasted to the five-decade (1920-70) interval of rapid productivity growth following the Second Industrial Revolution, because the earlier inventions had a more profound effect on every aspect of human existence". On the same footing, neither foreseeable forthcoming innovations in artificial intelligence, robots and biotechnologies will provide the type of stimulus needed to generate a new boost to

[4] This is reflected by the almost fully accomplished transition to a regime in which the bulk of the population completes its high school path, and a sizable share also attains college-level education.

[5] Among those, we find for example railroads during the first revolution, and electricity during the second. The third revolution was mainly about digital electronic, and it delivered among other things computers.

[6] According to Gordon, this can be ascertained by looking at many aspects of how business has evolved. After the introduction and diffusion of major digital innovations the technological frontier in the office work, in retailing, and in business organization seems not to have moved forward.

growth. In these contributions, Gordon thereby takes issue with the opinions which envisage an upcoming fourth industrial revolution, such as that of Mokyr (2018).

Recently, Ramey (2020) joined this strand of analysis by maintaining that the US is confronting an economic stagnation due to a ‘technological lull’. As also recalled by Gordon’s (2012) first headwind, Ramey points out the relevant role of the progressive retirement of the baby-boomers. In addition, the decline of labour productivity (measured as real output per hour worked) is entirely attributed to a decline in total factor productivity growth. Such a decline might be inherent to the type of general purpose large-scale disruptive waves of new technologies that drive development. Indeed, when a wave of this kind comes up, it can cause a phase of stagnation while the economy adapts to the novel technologies it brings about. Higher productivity growth may well follow after decades, and so a “technological revolution may not be perceived by most observers until years after its inception” (ibid., p 773).[7] Gordon and Ramey appear therefore to share much of their diagnosis about stagnation. However, there is a point made by Gordon (2018a, 2018b) that Ramey (2020) does not directly address: how to explain the sluggish rate of productivity expansion even in the face of intense innovation creation?

One must notice that such kind of predictions are a contested terrain among specialists of the topic. For example, as said, Mokyr (2018) questions the validity of those gloomy prospects, believing that, to the contrary, we may well be facing a prospect of continuous innovations capable of raising living standards on a sustained basis. Be this as it may, let us suppose Gordon’s concern to be well-founded. An alternative, different from Gordon’s accent on the comparison between the second and third industrial revolutions, is to consider the possibly rising cost of finding new major ideas. This possibility is briefly mentioned by Gordon (2018a, p. 9) but then he pursues the above-mentioned alternative route that assigns the brunt to the inner features of the contemporary technological innovations. Two contributions that explicit address this point are those of Fernald and Jones (2014) and Bloom *et al*. (2020). Fernald and Jones (2014) start from Romer (1990) endogenous growth model’s clue about the capability of ideas to generate increasing returns due to non-rivalry in their consumption. Grounding on this, they make recourse to an idea production function in which the number of available ideas is proportional to the number of researchers, the latter being in turn proportional to population. The production function of ideas, when combined with a standard Cobb-Douglas production function, delivers the following formula for growth accounting

[7] According to this view, possible solutions to a temporary technological lull are either waiting for the next wave of technical improvements or implementing public policies geared towards stimulating innovation. Among the possible policies, the author lists: government granting of subsidies to R&D activities, public infrastructural and human capital investments, and regulatory policies meant to foster innovation and target trusts.

$$\dot{y} \approx \left(\frac{K}{Y}\right)^{\beta} \cdot h \cdot (R\&D\ intensity) \cdot L^{\gamma} \tag{2}$$

The growth of GDP per capita and hence of labour productivity $\dot{y}$ is therefore driven by, in the respective order: the capital-output ratio, human capital per person, research intensity measured as the share of researchers over total workers), and total population. Research intensity is shown to have been the major contributor to productivity growth, followed by human capital and population. Given the fact that both educational attainments and research intensity cannot grow forever, and also considering the pattern of population ageing, the author express concerns about the prospects ahead for growth. Optimistic prospects are said to stem from the entrance of emerging countries into the global race for innovation and research, something that could help move the technological frontier forward. An agnostic judgement is left on what will the actual shape of the ideas production function in the future, another element that may considerably contribute to determine the future pace of innovation but that is difficult to accurately predict. In this sense, the authors appear less inclined to express a precise forecast, contrary to the (contrasting) takes of Mokyr (2018) and Gordon (2018a, 2018b).

Similarly to Fernald and Jones (2014), Bloom *et al*. (2020) use the following, very simple equation as the cornerstone of their analysis:

$$Economic\ growth = \downarrow research\ productivity \cdot \uparrow number\ of\ researchers \tag{3}$$

according to which the period of steady growth can be interpreted as the balancing of two opposed forces: on the one hand, the tendency for research productivity to dramatically fall, and on the other hand the increasing efforts spent to offset such pattern via incremental research activity. The authors recall the paradigmatic case of Moore's Law, predicting in principle that the transistors in a personal computer chip double every two years. To keep up with it in the face of falling productivity of research, the number of researcher engaged has increased enormously during the years. The same evidence is found in many other industries (such as agriculture and medicine), and it is valid at both the micro (industries) and the macro (aggregate economy) levels. In particular, the authors point out that research productivity at the aggregate level has been halving each 13-year span. This goes hand in hand with the conclusion that, given the primacy they attribute to the idea production function in steering growth, "just to sustain constant growth in GDP per person, the United States must double the amount of research effort every 13 years to offset the increased difficulty of finding new ideas" (Bloom et al. 2020, p. 1138). The fact that research productivity is witnessing a sustained fall over the decades is something that it is increasingly gathering evidence. Indeed, besides the work of Bloom et al. (2020), similar evidence is also presented by Link and Scott (2021), and Cauwels and Sornette (2022), who affirm that "the hypothesis that a slowdown in the rate of technological and scientific discoveries is taking place is now hotly debated, for its serious consequences for future productivity growth, economic development and policy implications".

The supply-side version of Secular Stagnation is not a monolithic theoretical body. In fact, despite the adherence of many economists to the vision that sees in supply-side elements the major drivers of economic growth, the framework of Gordon and Ramey is subject to criticisms. Among the most important authors who provide a different viewpoint, we find in particular various contributions by Acemoglu and Restrepo. Acemoglu and Restrepo (2017) discuss the interaction between the progressive adoption of new of technologies involving the deployment of robots and the ageing of population. As the authors show, there seems to be feeble evidence supporting the view predicting a negative impact of population aging on economic growth. What is more, they point the attention towards a positive relationship between the two.[8] In their line of reasoning, such a positive linkage can be rationalized by taking into account the innovative technological possibilities offered by the use of robots as a response to an ageing society. Indeed, a strong response in robots utilization as a consequence of ageing can more than outweigh the negative effects due to an increasingly elder population. However, Acemoglu and Restrepo (2018a) are careful not to lump together automation with labour- or capital-deepening technical change. According to them, in fact, automation leads to a direct replacement of workers in many tasks, and this leads – unless it causes huge productivity gains - to adverse effects on labour demand, the labour share of income and wages.[9] Although being careful not to set forth a causal link, Acemoglu and Restrepo (2017) also illustrate how the economies more subject to ageing are precisely those that are more aggressively undergoing robotization. A massive recourse to robots, albeit possibly ameliorating the situation in light of concerns over growth, can cause other issues. Indeed, as Acemoglu and Restrepo (2020a) recount, increasing automation in production may result in the displacement of workers.[10] The two economists pin down a particularly strong adverse effect of automation and robotization on the employment rate and workers' wages. At the aggregate level, Acemoglu and Restrepo find that an additional robot employed per thousand of labourers causes the employment-to-population ratio by 0.2% and wages by 0.42%. These effects might become larger as the process of robotization goes on, although the full effect of such trend is difficult to forecast due to the need to weight the effects on both workers' displacement and productivity gains. The potential adverse consequences on workers are also discussed in Acemoglu and Restrepo (2020b), where

[8] Besides the contributions we will present, other papers offered by the two economists are Acemoglu and Restrepo (2019, 2020c).

[9] According to their view, the worst type of new technologies in terms of detrimental effects on labourers are those which are convenient to adopt, but that do not give rise to noticeable productivity gains. Moreover, going beyond factor-augmenting progress, what must be tackled is the analysis of which tasks are transferred to machines and whether it is possible to create new tasks in which labourers possess a comparative advantage that makes them less liable to fall victim of task-reallocation towards robots.

[10] See Acemoglu and Restrepo (2018b) for a theoretical analysis of similar issues.

the two economists recall the far-reaching impact of artificial intelligence development. As mentioned in the other reviewed works, the ensuing reorganization of the production process might bring about both labour displacement in already established tasks but also make room for new incoming tasks where to employ labour. Yet, the type of transformation we have been witnessing has been decidedly steered towards the former kind of effect, and Acemoglu and Restrepo highlight that if this road is pursued further the social consequences of automation might be disappointing.

A similar approach is taken by Lee and Mason (2010). Indeed, when discussing the role of population ageing, Lee and Mason come to a conclusion close to Acemoglu and Restrepo's, namely that ageing might not be something to fear in terms of economic growth. They stress the long-run adverse effect of both decreasing mortality and fertility on support ratios, making the latter fall. This notwithstanding, the two authors maintain that such pattern can as well give rise to gains in productivity and per capita income. This is turn is explained by resorting to the enhancing effect on physical and human capital accumulation that would bring about a higher capital per worker level throughout the economy. However, one can notice that such a result is driven by a more conventional route, that of fostered capital accumulation, and not of robotization, something that Acemoglu and Restrepo (2018a), as mentioned, prefer to treat as a different phenomenon.[11]

Eichengreen (2015, 2017) as well joins the group of those who criticise one-sided supply-side views of Secular Stagnation. His views are particularly interesting because, albeit starting from a conception not distant from Summers (2014), he discusses at length the role of technological innovations. In actual fact, the author states that he thinks of Secular Stagnation as a "downward tendency of the real interest rate, reflecting an excess of desired saving over desired investment, and resulting in a persistent output gap and/or slow rate of economic growth" (Eichengreen 2015, p. 66). Behind this tendency, he envisages the effect of four elements: rising global savings rates, shrinking investment opportunities together with the falling relative price of investment goods, and slowing population growth rates. Focusing on why attractive investment choices are disappearing, the author recalls the vision of Gordon (2012, 2014) and agrees on the historical evidence therein presented. Nonetheless, Eichengreen introduces into the discourse the differentiation between 'range of applicability' and 'range of adaptation' of new technologies. The former concerns the extent, in terms of application in a number of sectors, that a path-breaking innovation is going to cover. The latter instead concerns the degree of reorganization that the economy must undergo to allow innovations to exert their full potential impact. This means that evaluations on the likely future impacts of novel technologies must weight how large is their field of application, as well as how much initial disruption into existing setups they are going to bring about. Attached to this latter consideration it comes the possibility for future productivity growth to accelerate once the momentary phase of reorganization arrives to completion,

[11] For other contributions stressing the role of ageing, see Eggertsson, Lancastre and Summers (2019).

as we saw in Ramey (2020). Therefore, current predicaments might be "a harbinger of better things to come". This kind of view also implies that, in accordance with Pagano and Sbracia (2018), although the spectre of stagnation is often feared in the aftermath of major recessions, this is at least partly due to the underestimation of the potential of the technologies that are currently still in the course of being fully applied, or in those that are about to be applied. To further characterize its distance from pure supply-inspired theories, Eichengreen (2017) also points the attention to the necessity of the implementation of expansionary fiscal policies during the phases in which the disruptive effects of new technologies is mostly felt, to allow the economy not to suffer from the slowdown that is involved by the wave of reorganizations.

As we can see, the literature on the supply-side origins of Secular Stagnation is very rich and it encompasses several viewpoints that stress various aspects as crucial to understand long-term economic predicaments. In what follows, we will address one single point, namely the issue of whether the relationship between R&D activities and macroeconomic variables such as productivity and GDP can be - partially - shaped and influenced by the type of innovation activity (public or private) operated in an economy.

3. Public vs private R&D: A possible explanation?

The focus of our investigation is to understand whether the explanations that points the attention to the pattern of the productivity of research, and its effect on long-term economic growth, have uncovered a plausible factor behind stagnation. Bloom *et al.* (2020, p. 1138) list some possible explanations for the gloomy trend of research productivity: the necessity to increase more and more research inputs (something that has not been done in recent decades), the fact that innovations of the 'follow on' kind have less impact than their originators, and the decline of basic, publicly funded research. In fact, the issue related to the composition of research expenditure is increasingly stimulating researchers to understand whether this can provide a key to also rationalize the dynamics of innovation, productivity, and growth. Indeed, Archibugi and Filippetti (2018), after showing international data about the progressive retreat of the public sector from research funding and implementing, ask whether the place in which research activity is carried out (universities or private business) affects its outcomes.[12] In the authors' opinion such a structural change is going to exert relevant effects on future innovation and long-term growth given that current research outcomes are among the most important inputs of future research. The fundamental reasons for such a prediction rests in the different features that the two types of research enjoy.

[12] As the authors show, in recent decades the share of (gross) privately-funded research activity in OECD countries, relevant differences among countries notwithstanding, has been continuously rising at the expense of (gross) publicly-funded research. This trend is also related to a remarkable decrease of military spending in advanced economies; indeed, defense spending is usually associated with R&D through public procurement.

First, research guided by the private sector may not pursue targets that are beneficial from a social point of view. Second, privately-generated research is much more characterized by rivalry in consumption and excludability in production with respect to public research.[13] Third, path-breaking scientific innovations are usually provided by public research, and the authors mention the cases of electricity, chemicals, ICT, pharmaceuticals, GPS, and the internet. The progressive shift towards private-led research is also linked to the longer-term prospects for the economy, as the authors recall the preoccupations of Gordon concerning the worrying pace of innovation creation and technological development. On a similar footing, Van Reenen (2020; see also Van Reenen 2021) points out that "Private and government R&D are not interchangeable. Government R&D tends to fund higher-risk basic research that private investors are often reluctant to take on […]. Therefore, public R&D investment tends to produce higher value, as well as high spillover inventions over a longer period of time. It is concerning that federal R&D as a share of GDP fell from 1.86 percent in 1964 to 0.62 percent in 2018. In addition, despite this decline in government R&D funding, the private sector has invested *less* in basic research over time".

Relevantly to our analysis, the plunging pattern of public and basic research can be argued to have detrimental effects in the long-run on the growth rate of productivity. For instance, Archibugi et al. (2020) pose the emphasis on the primary role to be assigned to public investment in innovation (to be understood both as R&D and physical investment). According to their view, such kind of investment is liable to generate a return in terms of output which exceeds the basic multiplier. This because these expenditures have a wide scope for creating new markets and stimulating more productive sectors at once (see also Mazzucato 2018).[14] As we will see later with the empirical findings of, among others, Goel et al. (2008), Deleidi and Mazzucato (2021), and Ziesemer (2021a), this insight is confirmed on empirical grounds. In addition to this, it can also be pointed out how, in close connection with the concerns about falling public-to-private R&D ratios the literature stresses the presence of a similar pattern for the basic-to-applied R&D ratios. Very recently, in fact, various contributions launched the warning regarding the adverse economic and social consequences of basic research underfunding. The IMF (2021), pointing the attention in particular to the case of mRNA vaccines meant to contrast the Covid-19 pandemic, has published a report in which R&D expenditures are linked to long-run economic growth. The international institution singles out the presence in the data of an alleged paradox which they frame in terms similar to those used by Gordon (2018a, 2018b, p. 65): "Productivity growth has slowed, even amid increased spending on research and development[…]. This apparent conflict with leading theories makes formulating policies to boost long-term growth

[13] Setting aside relevant aspects that often does not allow to neatly separate the two type of research in terms of these two characteristics.

[14] The authors carry out their assessment of policies meant to stimulate precisely this type of expenditure, and the institutional changes that should accompany the implementation of well-designed fiscal interventions, to address the issue of long-lasting European stagnation.

rather difficult". The possible explanation that the IMF researchers set forth grounds on the pattern of basic research, that, as we have said for public research, is shown to be on a downward trend against applied research. Analogously to what Archibugi and Filippetti (2018) contend, IMF (2021) points out the intrinsic characteristics of basic R&D to be a key to understand why it may matter so much in light of long-run economic growth. In particular, by recalling the seminal work of Nelson (1959), the report stresses the potentially high social returns to basic R&D which however are difficult for private firms to fully capture, thereby leading to a likely scenario in which the most important type of research is underprovided.[15] According to the empirical outcomes obtained, basic research matters for long-run productivity growth. Indeed, the authors estimate that a domestic basic R&D increase of 10 percent would lead to an increase in productivity of 0.3 percent. Given the possibility for basic research outcomes to smoothly spill over at the international level, the same percentage increase, this time in foreign basic R&D, would cause an increase in domestic productivity of double the size for that conducted internally. Such extensive empirical evidence is rationalized by the authors also by referring to the relevant theoretical work of Akcigit et al. (2021), who devise an endogenous growth model in which basic and applied research are explicitly sorted apart. Within it the authors pinpoint the fact that a likely equilibrium scenario is one in which there is too much applied research relative to basic, and therefore public intervention is needed to address such inefficiencies. Moreover, tackling this suboptimal situation via uniform research subsidies may worsen the equilibrium inefficiency. Together with this, the authors contend that the policymakers should also take into account the strong complementarity existing between public basic research and private applied research.

The relative contribution of public and private institutions to basic research is overall a point which is gaining relevance if one considers together the above-mentioned worrisome trend of publicly-funded research which, as just seen in the last contributions, is also likely to bring with it a decline of basic research. The picture gets even more gloomy when one considers that also in privately-funded research the share of basic research and its overall contribution to scientific progress is steadily waning (Arora et al. 2018, 2019; Arora et al. 2020). Obviously, the choice of what type of research must be financed and conduced is not only informed by economic but also political considerations. Indeed, Filippetti and Vezzani (2022) maintain that investing in public research is in itself a political decision heavily shaped by institutions and politics. By means of an empirical study on 41 countries, the authors find out a tight positive association between public R&D and institutions such as parliamentary government arrangements, proportional electoral systems and bicameralism. Moreover, intermediate social organizations such as unions and collective groups contribute to create a

[15] As Van Reenen (2021) aptly puts it, "[t]he good news is that we have abundant empirical evidence that faster technological innovation boosts productivity growth. The bad news is that we also know that the private sector will not provide enough research and development (R&D) if left to itself".

favourable environment for public research. This in turn can contribute to foster long-run growth via the discovery of far-reaching innovations (and in this respect the authors mention the ground-breaking work of Dosi 1982).

Let us now focus more in detail on recent evidence concerning the macroeconomic impacts of the public and private innovation expenditures. For instance, Van Elk et al. (2019) examine the macroeconomic impact, in particular on productivity, of public R&D expenditures in a panel of 22 OECD countries during the period 1963-2011 using a variety of models based on production functions. The first model they employ is based on a standard Cobb-Douglas production functions with constant returns to scale. The model encompasses also the stocks of public, private and foreign R&D. The next steps involve the use of translog models that permit the inclusion of more factors into the analysis besides those employed in the initial basic scenario, and also to better account for country-specific issues that may cause results to differ among nations. The outcomes that Van Elk et al. obtain do not consistently support the thesis of a robust effect of public R&D on productivity growth. The evidence provided is indeed mixed and subject to vary considerably according to the particular specification in use.
In fact, while the models based on the Cobb-Douglas specification generally do not exhibit statistically significant effects, models based on translog functions do, but generally show a negative impact. Finally, when the latter type of model is augmented via the addition of other factors (for example, public capital, foreign direct investment, trade in high-tech), the estimated effect turns out to be generally positive, albeit small. This kind of evidence leads the authors to conclude that public R&D is not a warranted type of expenditure that leads to faster productivity growth. Nonetheless, subject to country-specific contexts and in conjunction with other factors, it can lead to beneficial effects. In recent years the study of the macroeconomic impact of R&D expenditures in a comparative international perspective is witnessing a relative boom. Researching on this subject, Soete et al. (2022) specifically address the impact of public R&D expenditures on a macroeconomic level by studying a panel of 17 OECD countries during the 1975-2014 period by means of a VECM analysis. In particular, the authors wish to quantify the effect of both public and private R&D stocks on TFP. By using country-specific VECM estimations, they are also able to take into account peculiar characteristics of countries, that are liable to shape the relations of interest in different ways with respect to other contexts. According to their estimates, public R&D in most cases shows a positive effect on TFP. Moreover, the authors discover tight complementarity between public and private R&D. Therefore, it is possible to interpret these results also as a possibility to incentivize the investment in R&D by the private sector by increasing the amount of publicly-performed R&D, given that in the majority of the cases this does not discourage firms to follow-up, but rather the contrary. Another contribution to this literature comes from Herzer (2021), who however employs a different indicator for research and development than the stocks of R&D expenditure. Herzer maintains that the number of researchers employed in research in both the public and private sectors are better indicators for the research effort in their respective fields.

He then estimates the impact of such indicator on TFP in a panel of countries, finding evidence of strong impact of both public and private researchers on TFP. In addition to this, the further interesting piece of evidence offered in the paper concerns the comparison between the two sectors in which research is conducted: researcher employed in the public sector impart a stronger positive boost to TFP.

In the spirit of investigating the macroeconomic impact of R&D expenditure on a country-specific basis instead, there are also contributions that separately investigate single case studies. Among them, we can find the cases of the Netherlands and of Japan. For what concerns the Netherlands, Soete et al. (2020) study the period 1968-2014 by using, as before, a VECM strategy. The object of the analysis is again the relationship among public and private R&D stocks (both domestic and foreign), TFP and GDP. According to the outcomes of the study, additional R&D exerts a positive effect on both TFP and GDP, and there is complementarity between the two types of R&D (although when calling into question the domestic-foreign dichotomy, at least in the shorter-term foreign R&D appears to be deemed as a partial substitute to internal R&D). In the case of Japan results do not seem to be at odds with what we hitherto saw. In fact, Ziesemer (2020) follows the same strategy to tackle the case of Japan during the period 1963-2017. The beneficial effect of public R&D on TFP is found to be stronger than that of private R&D, and also stimulates private R&D itself (both domestic and foreign). In addition to this, Ziesemer finds that when there is a transitory change in GDP, public R&D behaves counter-cyclically while private R&D behaves pro-cyclically. All these studies, which as seen rely on a VECM econometric specification when conducted, generally lack a well-defined theoretical framework in order to be put in perspective via a unified framework. Ziesemer (2021b) does so by setting forth growth models in the semi-endogenous tradition where R&D expenditures are explicitly inserted. As in the applied literature, the author distinguishes the various types of R&D according to two main categorizations: public vs private, and domestic vs foreign. Ziesemer also makes use of alternative types of production functions such as Cobb-Douglas and VES. The parameters derived from the theoretical models are then linked to the VECM estimations carried out in the empirical literature, thereby showing the possibility to connect the latter type of evidence to theoretical models.

The studies on the impact on macroeconomic variables do not always take public R&D as a single category, for it is a complex grouping of different activities. One of particular interest in recent years is the type of R&D and innovation activity related to the so-called ‘mission-oriented’ type of public intervention (Mazzucato 2018). Let us therefore briefly review some studies that focus more specifically on particular types of public innovation expenditures, linked to objectives that are of utmost interest to the government’s eyes. Goel et al. (2008) investigate through an empirical analysis what is the effect of different types of R&D expenditures on economic growth in the United States during the period 1953-2000. They stress the apparent relative behaviour of different kinds of R&D in the post-war period. In particular, they single out the plunging pattern of federal R&D over total R&D performed in the US. This means that privately-conducted research and development activities tended to gain more and more space out of total resources devoted to it. Within such a general landscape, Goel et al. also highlight the plummeting course of defense R&D out of both federal and total R&D spending. Consequently, they base their empirical exercise on a disaggregated analysis that takes into account the different types of R&D expenditures we just mentioned, and by means of an ARDL strategy found two different results. First, the comparison between the effect on growth of federal and non-federal R&D turns out to give prominence to the former: federal R&D has a stronger positive effect on economic growth. Second, when the comparison is made between generic federal expenditures and defense-related expenditures, the latter exhibits a stronger impact on growth with respect to the former. Therefore, the authors advocate, the descriptive patterns concerning the comparative trends in different R&D expenditures can be assessed to be detrimental in light of long-run economic growth: a continuously falling share of resources devoted to federal (and defense) R&D contributes to impart a weakening stimulus to growth. This dynamics, Goel et al. comments, shall be revised and changed through economic policy actions informed by the results they obtained. Deleidi and Mazzucato (2021) agree with Goel et al. (2008) for what concerns the need to evaluate the various outcomes of different types of expenditures. In this case, the authors wish to discern the comparative effects of generic government expenditure against a 'mission-oriented' type aimed at bringing about structural change. In this article, that kind of mission-oriented expenditures are taken to be best represented by defense R&D. The authors carry out an SVAR analysis on a quarterly dataset for the US (1947-2018). The comparison between generic public expenditure and the mission-oriented type neatly shows the higher impact that the latter kind has on both GDP and private R&D, thereby demonstrating the considerable effectiveness of those public policies in terms of output expansion and crowding-in of private investment in research and development. More precisely, according to the estimates presented by Deleidi and Mazzucato, mission-oriented expenditures innovation policies cause at impact a multiplier of 24 and a crowding-in of private R&D equal to 0.7. The respective peaks show a magnitude of 55 and 6. The authors advocate that such results cannot but strongly recast the attention of public authorities towards well-planned active fiscal policy meant not only to solve contingent market failures but rather target broader social challenges. The magnitude of the impact that these direct policies can have is indeed so wide-ranging that it cannot be neglected.

In actual fact, the class of expenditures that fall within the scope of defense-related R&D is enjoying a broad attention in recent years. The empirical literature increasingly offers confirmation about the potentiality of this class of public expenditures from various standpoints. Obviously, the focus about the impact of mission-oriented R&D expenditures is not limited to the effects on GDP but also on productivity, as in Moretti et al. (2019) who study the issue on both country and firm-level. The authors investigate whether government R&D crowds in private R&D, and what its final impact on productivity is. To do so, they employ, similarly to Deleidi and Mazzucato (2021), defense-related R&D as a proxy for exogenous variations in government decision to implement far-reaching investment plans. An interesting consideration made by Moretti and co-authors is that the magnitude of the federal budget destined to such kind of R&D expenditures is much higher than that of any other type of innovation policy in the US. Similar considerations apply also to other cases, such as those of UK and France. This can be contrasted with the reviews offered by Becker (2015) and Ziesemer (2021c), where the literature is shown to have concentrated the attention much more on other types of policies, based for example on subsidies to research activity. Their increasing recognition by researcher in the innovation field is testified by the inclusion by Bloom et al. (2019) in the list of innovation policies that can be useful to implement. In the empirical analysis Moretti et al. find strong evidence of crowding-in of private R&D caused by public R&D. Furthermore, the authors find also relevant positive spillover effects among countries across borders. At last, additional evidence is presented for what concerns the impact on productivity measure both as TFP and output per worker. Predicted defense R&D is used as an instrument to handle endogeneity. The effect is estimated to be positive but not strong. Therefore, they conclude that while crowding-in of private R&D is clearly visible and such result can be safely used for policy recommendations, the effect on productivity is not so neat so as to justify firm policy conclusions on the necessity of increasing defense-related R&D to boost productivity.

Pallante et al. (2021) and Petach (2021) further contribute to such strand of literature by directing the attention towards macro-regional analyses whose focus is on the US case. Pallante et al. (2021) employ a strategy based on a panel of US States to estimate the elasticity of private R&D with respect to defense-related R&D. Also in their case, defense-related R&D appears to feature considerable crowding-in impact, and this is also shown to cause positive effects on employment (in particular of high-skilled labour force such as engineers). Petach (2021) adds to this by reconstructing the role of spatial Keynesianism policies that were carried out in the US for decades. Once this policy-course was abandoned in recent times, in favour of a decentralised schema, the author argues, a decline in the convergence among US states occurred, thereby demonstrating the necessity to resort to government direct intervention not only to stimulate R&D expenditures and innovation but also to foster income levels convergence among different regions.

At last, Ziesemer (2021a) takes a broader perspective on what can be included in the mission-oriented kind of spending, going beyond the more narrow viewpoint of the studies hitherto seen. The author studies the relationship in a selected group of EU countries among, on the one hand, the stocks of mission-oriented R&D, domestic and foreign private R&D, domestic and foreign public R&D, and on the other hand TFP and GDP. In the paper the author's stance is to define sectors such as defense, environment, energy, health, and space those in which the R&D is of a 'mission' type.[16] The mission-

[16] In these fields, the author contends, it is not sufficient to correct market imperfections due to the presence of externalities and natural monopolies. Rather, direct intervention by the government sector via public investment and R&D plans is needed.

oriented type of R&D is found to have a long-run beneficial effects on several macroeconomic variables. More specifically, Ziesemer (2021a) finds considerable positive impacts of mission-oriented R&D on public and private R&D, TFP, and GDP. According to the author, the beneficial effects could stem from the prevalence of research complementarities between the private and public sectors, and from the fact that although some parts of these public expenditures actually take the form of public consumption spending, this does not impinge on growth.

Obviously, we are here neglecting the fact that publicly-performed R&D and its effects on private R&D and macroeconomic indicators are only one possible channel through which the government can interact with the private sector for what concerns innovation. A much broader classification can be found in Bloom et al. (2019). In addition to this, the issue has been subjected to extensive literature reviews several times. For instance, Becker (2015) provides a comprehensive survey about the impact of R&D policies on private R&D. The paper casts particular attention on three types of policies: R&D tax credits and subsidies, support of university research, and support of R&D cooperation programs. One of the most relevant takeaways is that empirical research is steadily changing general opinion on the broad effectiveness of R&D policies. Recent contributions are in fact said to consistently display crowding-in effects of the mentioned types of R&D policy. More recently, Ziesemer (2021c) offers another review that encompasses studies on topics such as the effects of public R&D on private R&D, the presence of crowding-in or out effects, the strategies to incentive private R&D. The author conveys a long list of takeaways to be got from extant studies. Among those, we see the presence of incomplete crowding-out of public research with respect to private research, complementarity between the two types when the policies of tax credits and subsidies are analysed, and the fact that research and development activities carried out at the universities unambiguously exert a beneficial impact on both business R&D and productivity.

Given the empirical evidence from the extant literature, and the link with the literature on long-term stagnation, the next step is to carry out an analysis of what has happened in the post-WWII period in the United States. This case study consents to investigate the relationship between public and private R&D, and their effects on GDP and productivity, in the single most important OECD economy.

4. Empirical analysis

Gordon's (2018a, 2018b) preoccupation concerning the divergence in the pace of innovation (described by patenting dynamics) and labour productivity is well-grounded in empirical evidence. In fact, as recalled by the American economist, patenting in the US does not seem to experience a deceleration. Rather, as we can see in Fig. 1, patents applications and patents granted both appear to be on a rising trend especially from the late Eighties/beginning of the Nineties.

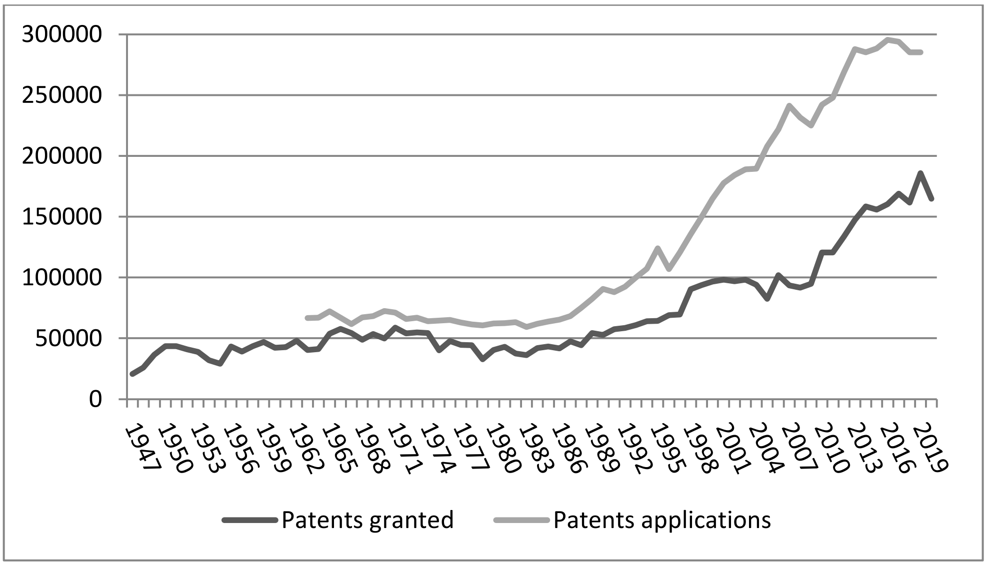

Figure 1 – The number of patents applications of (1963-2019), and patents granted (1947-2020) to US residents (yearly data). *Source*: USPTO.

An altogether different path is exhibited by labour productivity growth. Indeed, as it is ascertainable by having a glance at Fig. 2 and Fig. 3, the growth rate of labour productivity have been continuously decreasing on average through time over the decades. The exception is constituted by the so-called ‘growth revival’ of the Nineties (Gordon 2015), which temporarily and partially reversed what can be seen to be a long-term issue in the US economy.

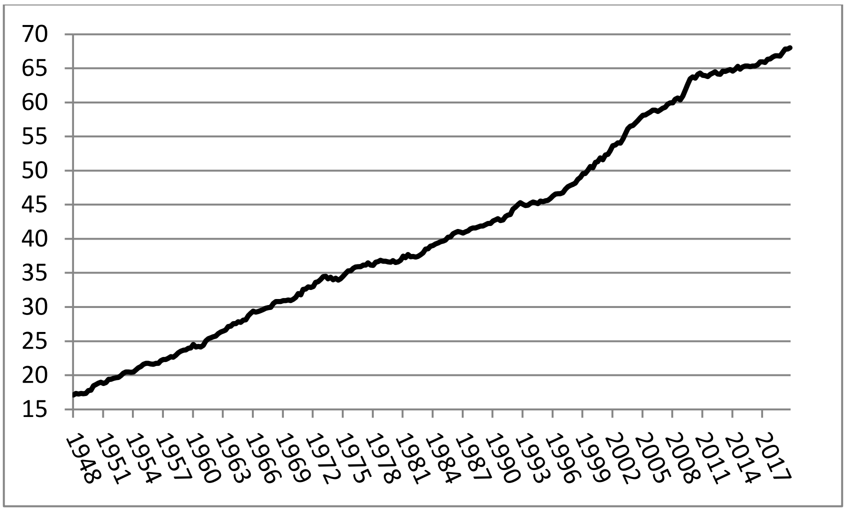

Figure 2 – Labour productivity calculated as real GDP divided by hours worked, quarterly (US, 1948Q1-2019Q4). *Source*: FRED and Bureau of Labor Statistics.

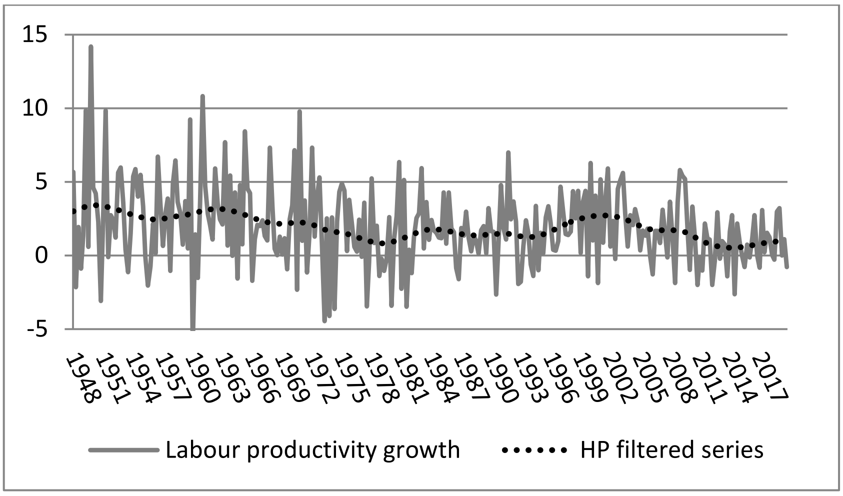

Figure 3 – Growth rates of labour productivity, percent change at an annual rate, quarterly (US, 1948Q1-2019Q4). *Source*: FRED and Bureau of Labor Statistics.

As Goel et al. (2008) pointed out, a comparison among different measures of R&D flows clearly shows a continuous decreasing pattern of the government component of research. This is true for both generic government R&D and for defence R&D, which is the most important component of government-funded research in the US (Moretti et al. 2019).

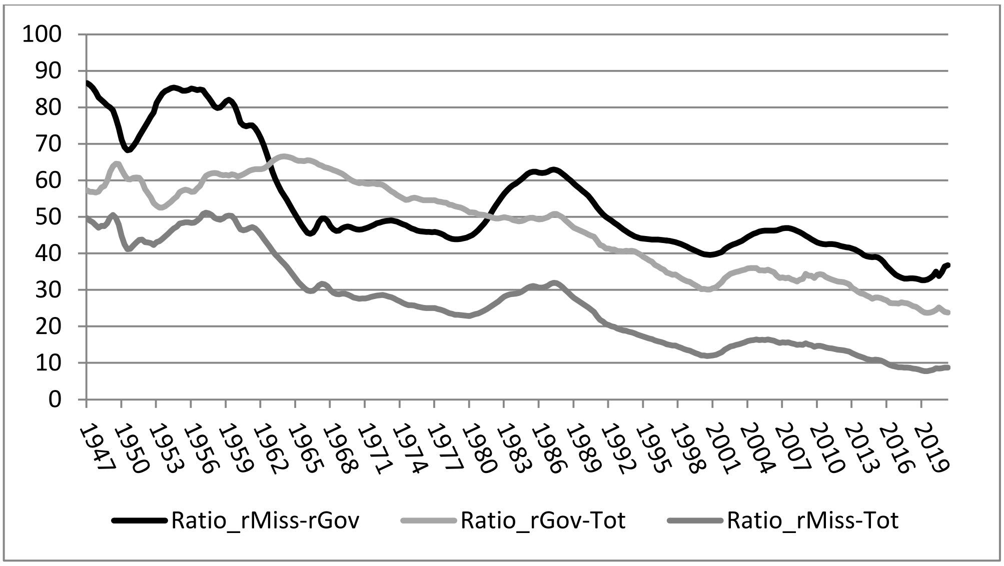

Figure 4 – Ratios between the (quarterly, real) R&D flows of: mission over government, government over total (government plus private), mission over total (US, 1947Q1-2020Q2). *Source*: Bureau of Economic Analysis.

As we can see, after a peak in the early Sixties, government R&D over total constantly declined over the decades by plummeting towards levels just above one-fifth in most recent years. This means that the private share of R&D is now the bulk of US research. Although this is not always directly linkable one for one to the behaviour of basic research, such patterns clearly go hand in hand with a sustained fall of basic research vis-à-vis applied research, and more generally with an overall content of research in which scientific discovery enjoys less attention (as already discussed before in the contributions of IMF 2021, Arora et al. 2018). Such trends are not confined to the US but can be shown to feature now many advanced economies as well (Ziesemer 2021; Archibugi e Filippetti 2018). Indeed, this evidence is consistent with that of Filippetti and Vezzani (2022, p. 2), when showing data for 41 countries from the 1981 to 2017 on public- and business-funded R&D as shares of GDP comment on the remarkable "reduction of aggregate public R&D coupled with an increase of business R&D, with the gap among the two steadily increasing over the past four decades".

In what follows we will try to investigate systematically whether these descriptive trends can be all linked together for the sake of pointing out one possible cause of the unsatisfactory behaviour of labour productivity in recent years. To do this, we make use of quarterly data for the US economy provided by the Bureau of Economic Analysis (BEA), United States Patent and Trademark Office (USPTO), Bureau of Labor Statistics (BLS) and Federal Reserve Economic Data (FRED) for the 1948-2019 period. Specifically, the number of patents (*PAT*), public investment in R&D (*G_IN*), government expenditures net of G_IN (*G_R*), private research and development expenditure (*R&D*), the gross domestic product (*Y*), labour productivity (*PROD*) and total factor productivity (*TFP*) are the variables included in the dataset. Details on the construction of the variables and data sources are provided in Table 1.

Variable	***Description***	***Source***
PAT	Sum of the patents granted to US residents minus patents granted to foreign residents, from annual to quarterly (Denton interpolation).	USPTO
G_IN	Government gross investment: Research and development, billions of dollars, quarterly, seasonally adjusted annual rate. Deflated by DEFL.	BEA
G_R	Government consumption expenditures and gross investment, billions of dollars, quarterly, seasonally adjusted annual rate, minus G_IN. Deflated by DEFL.	BEA
R&D	Gross private domestic investment: Research and development, billions of dollars, quarterly, seasonally adjusted annual rate. Deflated by DEFL.	BEA
GDP	Gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate. Deflated by DEFL.	BEA
PROD	Ratio between GDP and H.	BEA, BLS
TFP	Level of TFP obtained from business sector TFP growth rates, quarterly, variable in percentage change at an annual rate.	FRED

H	Hours worked in total U.S. economy, billions, seasonally adjusted.	BLS
DEFL	Gross domestic product: Implicit price deflator, quarterly index, 2012=100, seasonally adjusted.	BEA

Table 1 – List of variables used in the empirical analysis, and their description.

The empirical analysis tries to investigate whether the paradox highlighted by Gordon (2018a, 2018b) can be understood, at least partially, as a consequence of the shifting composition of R&D expenditures. Indeed, as we will better see when describing the identification strategy, the intuition behind our empirical exercise grounds on Gordon's story. The number of patents offers a measure of the dynamics of innovation, but at the same time the inclusion of different types of R&D expenditures (federal and non-federal) allows to understand what their relative effect on measures of productivity is. As main variable of interest we use labour productivity, which is taken as real GDP per hour worked. In line with the literature, we also run robustness checks by using total factor productivity (Soete et al. 2020, Moretti et al. 2019, Herzer 2021).[17] The inclusion of generic public expenditure allows also for a comparison of the effects of public innovation expenditures and generic public spending on GDP and private R&D (Deleidi and Mazzucato 2021). This permits to ascertain, in the former case, which type of fiscal policy has the greatest impact on the dynamics of GDP and hence to calculate the associated fiscal multipliers. In the other case, we can assess the relative effect on private R&D so as to evaluate the presence and the size of crowding-in effects on private expenditures in innovation, instead.

The overall structure of the work grounds on two premises. First, we use the flows of R&D expenditure instead of the stocks built by means of the perpetual inventory method, as the literature generally does. This is due to the fact that such a method produces series that are usually integrated, and with our data the stocks take up orders of integration higher than one. This does not allow the inclusion of such series in an SVAR analysis. Therefore, in this respect, we are closer to the type of analysis carried out by Goel et al. (2008), Deleidi and Mazzucato (2021), as we use the flows of R&D. Second, that the US can be treated as a relatively closed system. Such assumption is supported by empirical evidence and this point is relevant as in fact it is common practice to address in this fields of studies the cross-border spillovers effects stemming from international R&D (van Elk et al. 2019). As Ziesemer (2022) reports, the literature on international R&D spillovers on the US economy generally found them not to be relevant. Among others, no spillovers are found by Bernstein and Mohnen (1998) when analysing the direction running from Japan to the US find no spillovers, and Atukeren (2007) again finds no spillovers effects from the EU to the US. While Luintel and Khan

[17] However, we prefer labour productivity as an indicator of the productivity pattern given the interpretative difficulties that the use of TFP entails (Felipe and McCombie 2007; Storm 2017).

(2004) found zero or negative international spillovers, a later paper displays that international R&D exerts a positive effect on US patents and productivity (Luintel and Khan 2009). Ziesemer (2022) adds to this literature by analysing the effect of EU, Japan, and Canada's stocks of public and private R&D stocks on the US during the period 1963-2017. According to his outcomes, international public and private R&D shows a positive effect on the US economy for what concerns public R&D, while the effect on private R&D is more mixed. Although the author interprets these results as a possible indication of the presence of spillovers to the US, he also adds that "we cannot exclude the possibility that there are no spillovers, and the reactions are completely strategical in the spirit of oligopolistic reaction curves" (ibid., p. 13). Therefore, while the literature is seeing a new flow of contributions, it still broadly supports the hypothesis of no spillovers, hence making the US a relatively closed system for what concerns the relations of our interest.

In order to detect the effect of different types of R&D expenditures on GDP and productivity, we use SVAR models (Kilian and Lütkepohl, 2017). An SVAR is represented as follows in equation (4):

$$B_0 y_t = a + \sum_{i=1}^{p} B_i \, y_{t-p} + w_t \tag{4}$$

Where y_t is the $k \; x \; 1$ vector of considered variables, a is the constant term, B_i is the $k \; x \; k$ matrix of autoregressive slope coefficients, and w_t is the vector of structural shocks. To obtain structural shocks, an identification strategy needs to be implemented by imposing restrcitions in B_0 that represents the matrix of contemporaneous relationships among considered variables.[18] Once restrictions are imposed in B_0 and structural shocks are estimated, impulse response functions (IRFs) are computed to assess and evaluate the effect produced by identified shocks on variables included in the model. Standard errors are estimated through Hall's studentized bootstrap (1000 repetitions) and IRFs are reported with one-standard error bands, namely considering a 68% confidence interval.[19]

A fundamental step is the identification of the structural shocks. For such sake, we make use of both short-run zero exclusion restrictions and a Cholesky factorisation. This is shown through the identification presented in (5).

[18] The covariance matrix of structural errors is normalized: $\mathbb{E}(\mathrm{w_t w_t'}) = \sum_{\mathrm{w}} = \mathrm{I_K}$.

[19] The choice of 68% error bands is used in several contributions (see, for instance, Blanchard and Perotti, 2002; Caldara and Kamps, 2017). Moreover, error bands corresponding to 0.68 probability allow for more precise estimation of the true coverage probability than 0.95 bands (Sims and Zha 1999; Giordano et al. 2007).

$$B_0 y_t = \begin{bmatrix} - & 0 & 0 & 0 & 0 & 0 \\ - & - & 0 & 0 & 0 & 0 \\ - & - & - & 0 & 0 & 0 \\ - & - & - & - & 0 & 0 \\ - & - & - & - & - & 0 \\ - & - & - & - & - & - \end{bmatrix} \begin{bmatrix} PAT_t \\ G\_IN_t \\ G\_R_t \\ R\&D_t \\ GDP_t \\ PROD_t \end{bmatrix} \tag{5}$$

where '−' indicates an unrestricted parameter and '0' represents a zero restriction. In the identification strategy, we assume that PAT, the number of patents granted in each period to US residents, is the most exogenous variable in the contemporaneous relationships. PAT is affected neither by output dynamics nor the other variables included in the model. The basic assumption is that patenting activity, from the initial filing to the final concession, takes more than one quarter to be granted. Indeed, as underlined by Bottazzi and Peri (2007) and Jaffe and Trajtenberg (2002, Ch. 13), the process of obtaining a patent is slow and takes several years. This is also confirmed by recent data on patenting showing that the patent needs several months on average to be granted. Specifically, "Patent average first action pendency was 14.8 months at the end of FY 2020, and average total pendency was 23.3 months. Average first action pendency measures the time from when an application is filed until it receives an initial determination of patentability by the patent examiner. Average total pendency measures the time from filing until an application is either issued as a patent or abandoned" (USPTO 2020, p. 60).[20] From the second equation to the fifth equation, we follow the identification strategy implemented by Deleidi and Mazzucato (2021). G_IN is the second ordered variable. Within the quarter, G_IN is independent of changes in G_R, R&D, Y, and PROD. Changes in government R&D expenditures can be considered as exogenous variations reflecting political priorities that are independent of GDP and productivity shocks (Mowery, 2010, 2012; Moretti et al., 2019). Indeed, government R&D spending, in particular in the US where it is also largely tied to the defense sector, is carried out in light of considerations that "are largely independent of productivity shocks in different domestic industries" (Moretti et al. 2019, p. 2). G_R is the third ordered variable as considered less strategically relevant than G_IN. This is supported by the empirical literature on fiscal multipliers, in which the order of fiscal variables depends also on the policy relevance of considered spending components (e.g., Auerbach and Gorodnichenko, 2012; Deleidi et al. 2021a, 2021c). The fourth variable is private R&D investment. Such variable is supposed to be liable to be affected within the quarter by G_R and G_IN, but not by GDP. Such choice is driven by the consideration that firms, before deciding to change their investments in R&D, must at first perceive changes in the level of GDP as persistent. This strategic change cannot be based on

[20] Ahmad (2021) employs a different strategy to identify a structural VAR model to study the pro- or counter-cyclicality of R&D activities. In that contribution patents are considered among the most endogenous variables. This, in our view, neglects the important issue of the considerable time-lags involved in patenting activity, thereby our different strategy. Ahmad and Zheng (2022) use instead a SEM empirical strategy to handle similar issues.

events that happen only within the quarter. The fifth variable is the GDP which is influenced by all spending variables within the quarter, while the last ordered variable is labour productivity (PROD). PROD is the most endogenous variable that can be affected by different government spending components and output dynamics following the Kaldorian tradition (e.g., Kaldor 1961, 1978) and the recent more empirically-based literature (McCombie and Spreafico 2016), also using SVAR modelling (e.g., Deleidi et al. 2021b; Bachmann and Sims 2012; Jørgensen and Ravn 2022). Furthermore, productivity dynamics may be influenced by also more supply-side variables, such as private R&D and patenting activities. Therefore, by assuming labour productivity as endogenous, we suppose that innovation processes may be determined both by supply and demand factors. While the demand factors are those related to government expenditures and GDP, supply factors are expressed via the inclusion of patents and private R&D. As a robustness check the same model is also estimated by using total factor productivity (TFP) as most endogenous variable (Romero and Britto 2017).
Our benchmark model (Model 1) has thus the following vector of endogenous variable (y_t):

$$y_t = \left[PAT_t\ , G_{IN_t}, G_{R_t}, R\&D_t, GDP_t, PROD_t,\right]'$$

Each model specification is estimated both for the whole sample (1948Q1-2019Q4), and excluding the post-crisis period (1948Q1-2007Q4). This is made in order to understand whether the results are robust to a change in the time span covered by the dataset.

We now show the results of our benchmark model (Model 1). Specifically, we display both the estimated IRFs as well as the cumulative responses of our variables of interest. Figure 5 shows the estimated IRFs of Model 1 for the whole period (1948Q1-2019Q4), whereas Figure 6 shows the estimated IRFs of Model 1 over a shorter time horizon that stops before the unraveling of the Great Recession (1948Q1-2007Q4).

Figure 5 – The impulse-response functions obtained from the SVAR estimation on Model 1 for the period 1948Q1-2019Q4. Dotted lines are 68% confidence bands estimated through a Bootstrapping procedure (1,000 repetitions). *Source*: author's elaboration.

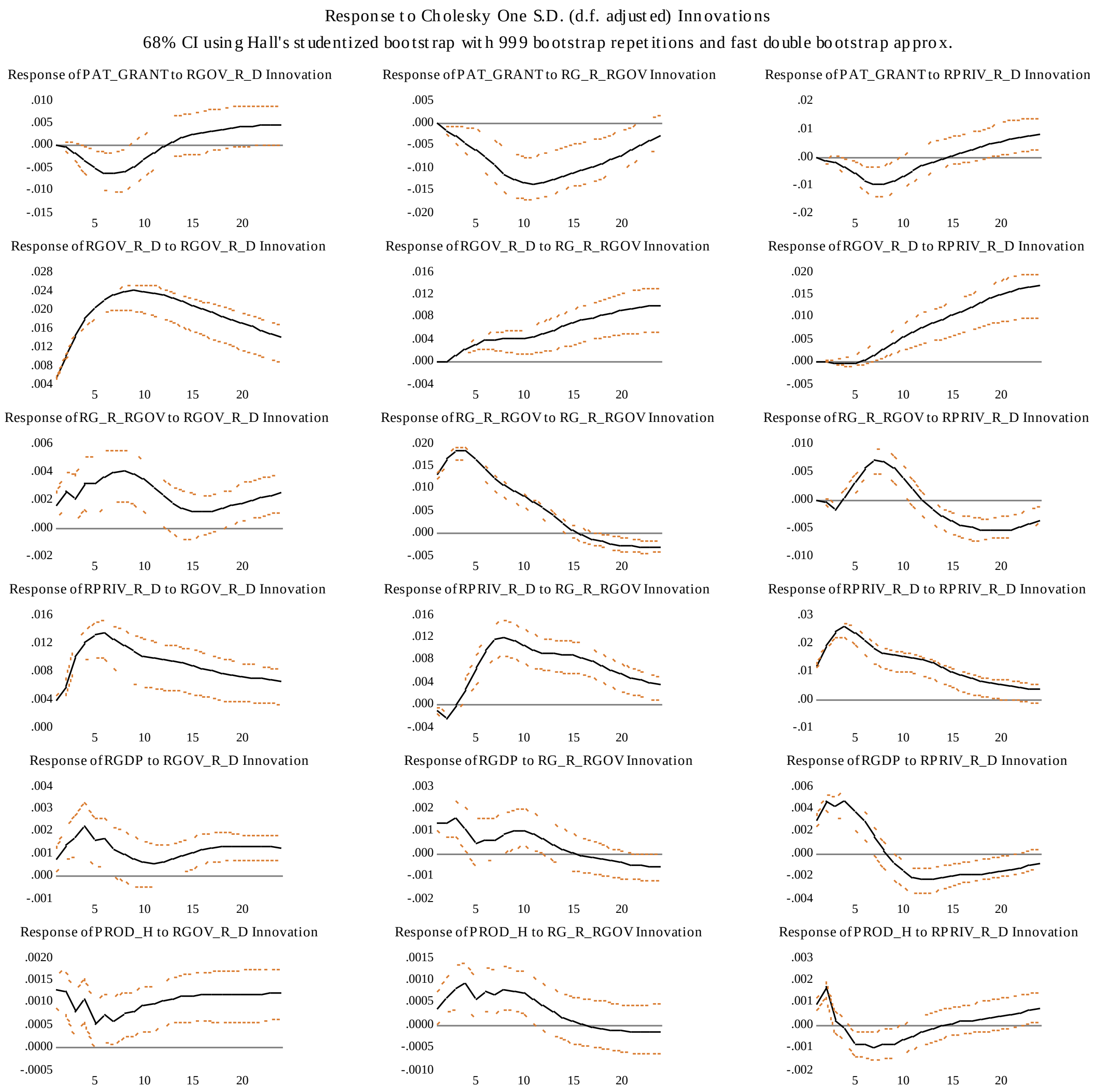

Figure 6 – The impulse response functions IRFs) obtained from the SVAR estimation on Model 1 for the period 1948Q1-2007Q4. Dotted lines are 68% confidence bands estimated through a Bootstrapping procedure (1,000 repetitions). *Source*: author's elaboration.

Once we have estimated the IRFs we move on to obtain the results of our interest. In fact, what we calculate from the IRFs are the elasticities for three types of factors. First, the elasticities of labour productivity with respect to three different types of expenditure: government R&D (G_IN), generic public expenditure (G_R), and private R&D (R&D). In this case, given that we are not interested in getting a proper multiplier in consideration of the fact that labour productivity is more akin to a technical variable, the calculation of the elasticities does suffice. In the cases of the effects of public expenditure on private R&D and GDP things are different, because in these instances we want to get a multiplier which tells us how much additional private research and development expenditure, and how much additional output we obtain given one more dollar spent by the government. The elasticities $\mathcal{E}$ can then be used to get multipliers m by following the simple calculation:

$$
\begin{aligned}
\mathcal{E}_{cr} &= \frac{\Delta R\&D}{\Delta G\_IN} \cdot \frac{G\_IN}{R\&D} \;\rightarrow m_{cr} = \frac{\Delta R\&D}{\Delta G\_IN} = \mathcal{E}_{cr} \cdot \frac{R\&D}{G\_IN} \\
\mathcal{E}_{cr} &= \frac{\Delta R\&D}{\Delta G\_R} \cdot \frac{G\_R}{R\&D} \;\rightarrow m_{cr} = \frac{\Delta R\&D}{\Delta G\_R} = \mathcal{E}_{cr} \cdot \frac{R\&D}{G\_R} \\
\mathcal{E}_{GDP} &= \frac{\Delta GDP}{\Delta G\_IN} \cdot \frac{G\_IN}{GDP} \;\rightarrow m_{GDP} = \frac{\Delta GDP}{\Delta G\_IN} = \mathcal{E}_{GDP} \cdot \frac{GDP}{G\_IN} \\
\mathcal{E}_{GDP} &= \frac{\Delta GDP}{\Delta G\_R} \cdot \frac{G\_R}{GDP} \;\rightarrow m_{GDP} = \frac{\Delta GDP}{\Delta G\_R} = \mathcal{E}_{GDP} \cdot \frac{GDP}{G\_R}
\end{aligned}
\qquad (6)
$$

Hence, by multiplying the respective elasticity by its associated ratio between expenditures as an average over the sample. Let us explain the procedure for the first and third case in (6). The multiplier m_{cr} meant to express the crowding-in effect of public expenditure in innovation on private R&D is obtained by multiplying the elasticity $\mathcal{E}_{cr}$ we got before by the ratio between private R&D and government spending in innovation. The latter ratio is obtained by averaging over the total sample the two observed series. The multiplier m_{GDP} meant to express the multiplier effect of public expenditure in innovation on GDP is obtained by multiplying the elasticity $\mathcal{E}_{GDP}$ we got before by the ratio between private R&D and government spending in innovation. The latter ratio is obtained by averaging over the total sample the two observed series. Following the recent literature on fiscal multipliers we estimate the cumulative response (Ramey and Zubairy, 2018). The cumulative effect is estimated by dividing the cumulative change in the variable of interest $\Delta y_{i,t+h}$ by the cumulative change in the selected fiscal expenditure $\Delta x_{i,t+h}$. Specifically, we have:

$$
\beta_{cum}^{h} = \frac{\sum_{h=0}^{n} \Delta y_{i,t+h}}{\sum_{h=0}^{n} \Delta x_{i,t+h}} \qquad (7)
$$

Using this method, we can calculate the response of our variable of interest per unit of spending. We show the results we got in the following tables.

	Cumulative Elasticities (PROD)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 1 (1948-2019)								
G_IN	**0.22**	**0.09**	**0.07**	**0.07**	**0.08**	**0.09**	0.22 (1)	0.09
G_R	**0.06**	**0.06**	**0.08**	**0.10**	0.13	0.16	0.16 (25)	0.10
R&D	**0.08**	0.01	-0.01	-0.01	0.00	0.01	0.08 (1)	0.01
Model 1 (1948-2007)								
G_IN	**0.24**	**0.07**	**0.05**	**0.05**	**0.05**	**0.06**	0.24 (1)	0.07
G_R	**0.03**	**0.04**	**0.05**	0.05	0.06	0.06	0.06 (17)	0.05
R&D	**0.08**	0.02	-0.01	-0.01	-0.01	**0.00**	0.08 (1)	0.00

Table 2 – The cumulative elasticities of labour productivity with respect to government R&D, generic public expenditure and private R&D (25 quarters), obtained from Model 1 (1948Q1-2019Q4) and Model 1 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak elasticities and average elasticities are shown. *Source*: author's elaboration.

	Cumulative Multipliers (R&D Crowding-in)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 1 (1948-2019)								
G_IN	**0.78**	**0.73**	**0.65**	**0.61**	**0.61**	**0.63**	0.78 (1)	0.65
G_R	**0.00**	**0.00**	**0.02**	**0.03**	**0.04**	**0.05**	0.05 (25)	0.02
Model 1 (1948-2007)								
G_IN	**0.79**	**0.71**	**0.60**	0.55	**0.52**	**0.52**	0.79 (1)	0.60
G_R	**0.00**	**0.00**	**0.03**	**0.04**	**0.06**	**0.08**	0.08 (25)	0.04

Table 3 – The cumulative crowding-in multipliers of private R&D with respect to government R&D and generic public expenditure (25 quarters), obtained from Model 1 (1948Q1-2019Q4) and Model 1 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak crowding-in multipliers and average crowding-in multipliers are shown. *Source*: author's elaboration.

	Cumulative Multipliers (GDP)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 1								
(1948-2019)								
G_IN	**13.27**	**14.06**	11.05	**10.73**	**11.79**	**13.10**	14.94 (4)	12.20
G_R	**0.64**	0.31	0.12	0.02	-0.04	-0.08	0.64 (1)	0.12
Model 1								
(1948-2007)								
G_IN	12.60	10.32	6.40	5.19	5.44	5.84	12.63 (2)	7.21
G_R	**0.54**	0.36	**0.37**	0.39	0.37	0.31	0.54 (1)	0.38

Table 4 – The cumulative multipliers of government R&D and generic public expenditure (25 quarters), obtained from Model 1 (1948Q1-2019Q4) and Model 1 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak multipliers and average multipliers are shown. *Source*: author's elaboration.

The main change that we operate when estimating Model 2 rests in replacing labour productivity with total factor productivity (TFP).[21] We therefore show a robustness check conducted by changing the measure of productivity adopted as the most endogenous variable to be included in identification (5). As well as in the other analysis, we will check whether changing the time span by stopping before the unraveling of the Great Recession makes a difference in terms of the results we get. Figure 7 shows the IRFs of Model 2 for the whole period (1948Q1-2007Q4), while Figure 8 shows the IRFs of Model 2 excluding the Recession period (1948Q1-2007Q4). As in the previous case, we calculate: first, the elasticities of total factor productivity with respect to public spending in innovation, generic residual public expenditure, and private expenditure in innovation (Table 5). The next step is to see if in this model public expenditure in innovation and generic residual public expenditure crowd-in private expenditure in innovation, and we can see the results in Table 6. At last, we assess the size of the fiscal multipliers associated with public expenditure in innovation and generic residual public expenditure (Table 7).

For what concerns the cumulative elasticity of total factor productivity, as we can see the main result is not different from what we saw earlier. The public expenditure in innovation and generic residual public spending exhibit a positive effect, higher than that of private expenditure in innovation. Nonetheless, two differences arise. First, in this model the magnitude of the elasticities is higher than before. As an example, the

[21] There are analyses pointing out the theoretical and empirical issues involved when using such measure (Felipe and McCombie 2007; Storm 2017). However, given its extensive use in the literature we are dealing with, we use it to check whether our previous results hold also with a different variable.

average elasticity with respect to public expenditure in innovation in the full-length model amounts to 0.60, while in Table 2 when labour productivity was employed it was equal to 0.09. Second, while before we had a substantial equality in the magnitude of the response to public innovation and generic public expenditures, now there is neat evidence showing a remarkably higher positive effect associated with public spending in innovation. Only in the final part of the sample stopping before the Great Recession we can see how the two types of expenditure reach the same value, but they still largely differ in the average values over the sample.

Results are broadly confirmed also in the case of the crowding-in effect. There is indeed again a stark difference between the effect on private investment in research and development when we separately analyse the two types of public spending. As before, the public expenditure devoted to innovation features a much higher crowding-in effect, and the size of the estimated effect is roughly equal to what we saw earlier. The same holds for the mild effect that is imparted to private R&D spending by generic residual public expenditure.

At last, we comment on the fiscal multipliers. Again, the evidence does not change the scenario we saw earlier. Public innovation spending generates a greater multiplier with respect to generic residual expenditure. In this case, the average values of the multiplier exceed those seen in the first model, both in the case of the full sample and in the case of the shorter time horizon. Generic public expenditure features a much lower multiplier, and in the full sample case the latter takes up even a slightly negative value. There is therefore room to contend once again for the very high impact that public innovation expenditures can have on GDP.

Figure 7 – The impulse-response functions obtained from the SVAR estimation on Model 2 for the period 1948Q1-2019Q4. Dotted lines are 68% confidence bands estimated through a Bootstrapping procedure (1,000 repetitions). *Source*: author's elaboration.

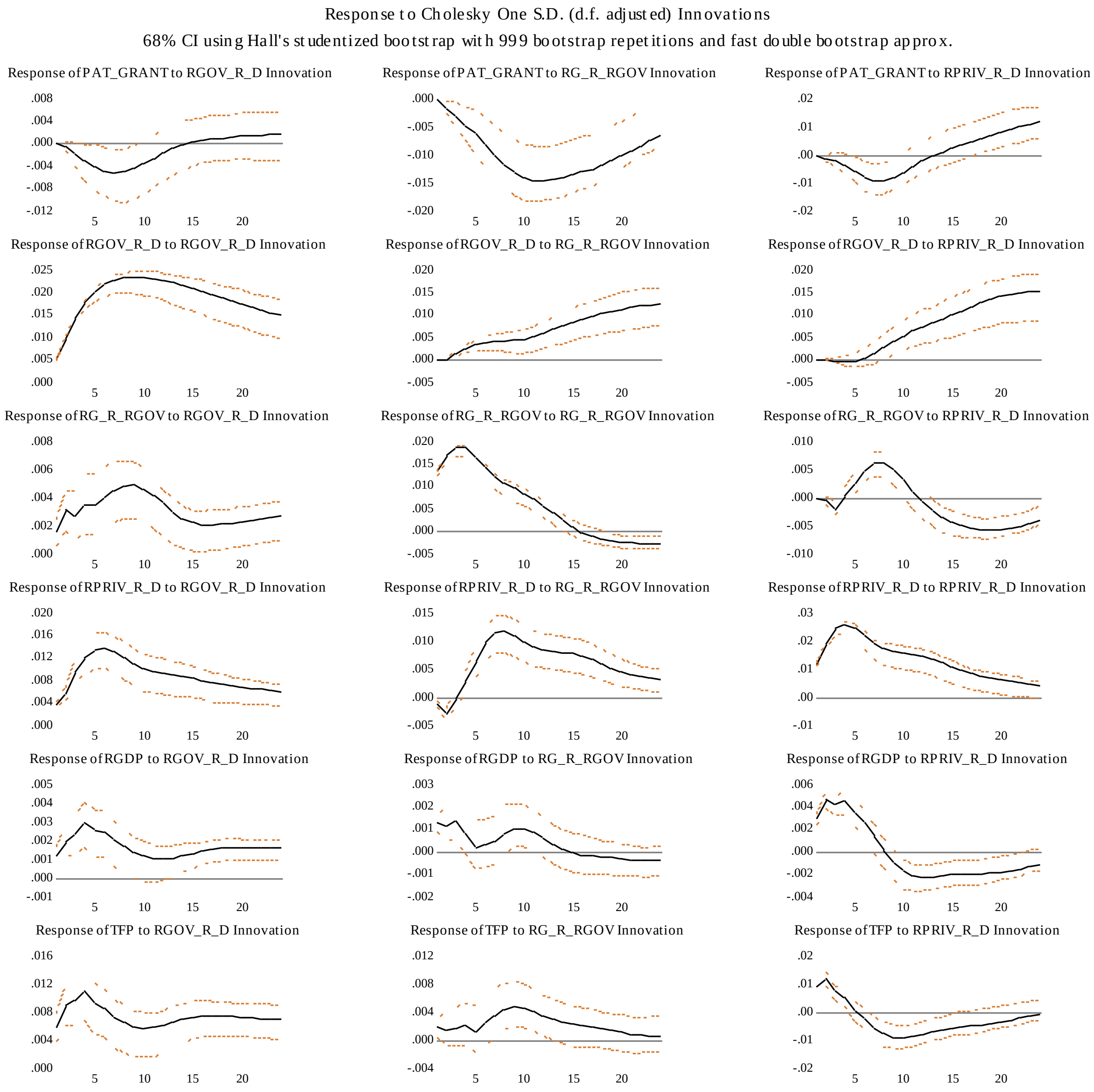

Figure 8 – The impulse response functions IRFs) obtained from the SVAR estimation on Model 2 for the period 1948Q1-2007Q4. Dotted lines are 68% confidence bands estimated through a Bootstrapping procedure (1,000 repetitions). *Source*: author’s elaboration.

	Cumulative Elasticities (TFP)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 2 (1948-2019)								
G_IN	**1.06**	**0.75**	**0.53**	**0.49**	**0.50**	**0.53**	1.06 (1)	0.60
G_R	**0.22**	0.01	0.13	0.20	0.30	0.40	0.40 (25)	0.21
R&D	**0.65**	**0.32**	0.07	-0.02	-0.05	-0.05	0.65 (1)	0.11
Model 2 (1948-2007)								
G_IN	**1.11**	**0.66**	**0.43**	**0.38**	**0.38**	**0.39**	1.11 (1)	0.51
G_R	0.14	0.10	**0.20**	0.27	0.34	0.39	0.39 (25)	0.24
R&D	**0.77**	0.32	**0.00**	-0.14	-0.19	-0.20	0.77 (1)	0.04

Table 5 – The cumulative elasticities of total factor productivity with respect to government R&D, generic public expenditure and private R&D (25 quarters), obtained from Model 2 (1948Q1-2019Q4) and Model 2 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak elasticities and average elasticities are shown. *Source*: author's elaboration.

	Cumulative Multipliers (R&D Crowding-in)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 2 (1948-2019)								
G_IN	**0.75**	**0.67**	**0.59**	**0.54**	**0.52**	**0.52**	0.75 (1)	0.58
G_R	**-0.01**	**0.00**	**0.02**	**0.03**	**0.03**	**0.04**	0.04 (21)	0.02
Model 2 (1948-2007)								
G_IN	**0.78**	**0.71**	**0.62**	**0.55**	**0.52**	**0.50**	0.78 (1)	0.60
G_R	**-0.01**	**0.00**	**0.03**	**0.04**	**0.05**	**0.07**	0.07 (25)	0.03

Table 6 – The cumulative crowding-in multipliers of private R&D with respect to government R&D and generic public expenditure (25 quarters), obtained from Model 2 (1948Q1-2019Q4) and Model 2 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak crowding-in multipliers and average crowding-in multipliers are shown. *Source*: author's elaboration.

	Cumulative Multipliers (GDP)							
	1Q	5Q	10Q	15Q	20Q	25Q	Peak	Av 25Q
Model 2 (1948-2019)								
G_IN	**19.35**	**17.82**	**13.79**	**12.43**	**12.91**	**13.93**	19.81 (2)	14.63
G_R	**0.57**	0.21	-0.02	-0.20	-0.40	-0.61	0.57 (1)	-0.11
Model 2 (1948-2007)								
G_IN	**20.04**	**14.78**	9.88	**7.90**	**7.81**	**8.09**	20.04 (1)	10.64
G_R	**0.50**	0.29	**0.31**	0.33	0.31	0.28	0.50 (1)	0.32

Table 7 – The cumulative multipliers of government R&D and generic public expenditure (25 quarters), obtained from Model 2 (1948Q1-2019Q4) and Model 2 on the shorter 1948Q1-2007Q4 horizon. In the last two columns peak multipliers and average multipliers are shown. *Source*: author's elaboration.

The results obtained in the empirical exercise can be analysed and interpreted to get an assessment on what is the impact, at the macroeconomic level, of public innovation expenditures. The fields of analysis are three. First, the impact of different types of public expenditure and one type of private expenditure on labour productivity. According to our estimates, labour productivity shows a neatly greater response to changes in the public types of expenditure rather than the private. In fact, we can see from Table 2 that on average public expenditure in R&D and residual generic public spending exhibit a higher positive impact than private R&D. When we compare them, the respective magnitudes are very similar. Therefore, at least in this respect, there seem to be no particular difference between types of public expenditure. What emerges from the analysis is also the fact that, in addition to the sizable difference between public and private spending, the latter type of outlay also exhibits over the sample negative contributions to labour productivity. This impacts on the average effects that are consistently brought down to values close to zero. Such kind of evidence adds to the results obtained by Goel et al. (2008), Deleidi and Mazzucato (2021), Ziesemer (2021a) for what concerns the positive impacts of public R&D on GDP and TFP, pointing the attention this time to labour productivity whose pattern is, has seen, among the most important indicators stressed in the literature of Secular Stagnation to single out the worrisome trends undertaken by the US economy in the last decades.

When we turn the attention to the possibility of crowding-in effects generated by government expenditures in innovation, other relevant outcomes arise. In light of Ziesemer (2021c) literature review, it is then interesting to see whether the general results of incomplete crowding-in of public R&D with respect to private R&D hold also in our scenario. As we can see, the evidence appears to buttress the case for substantial crowding-in of public R&D with respect to private R&D. In both samples private research and development spending strongly reacts to public R&D, and they do it with the stronger response at the impact, thereby pinning down an immediate crowding-in of private research. At odds with the previous case, here we clearly see a different impact of different types of public expenditure on private R&D. Indeed, together with the remarkable effect of public R&D we also see a much lower, albeit positive, effect of generic public expenditure. This is not surprising as the specificity of research and development expenditures calls into play a type of complementarity between the public and private sectors which can hardly exist when we consider the generic residual expenditure of the government. Therefore, in light of Bloom et al. (2019) cookbook for innovation policies, it appears that a direct decision from the government side to carry out public research and development activities can be considered a very powerful tool to enhance overall domestic research and development.

At last, we comment on the multipliers associated with the two types of public expenditure. Differently from the analysis of labour productivity elasticity, here we can see a stark difference for what concerns the impact of differentiated public spending on output. Indeed, the part of public spending related to research and development shows a multiplier which is remarkably higher than that related to residual generic public expenditure. Indeed, while both multipliers are positive, those in the two samples related to innovation activities are very high, and in the full-sample case it reaches a double digit magnitude. In the pre-Great Recession sample there is a significant drop in the value of the multiplier after the initial impact, and this drives down the average size of the multiplier. Nonetheless, also in this case the magnitude remains considerably high, and consistently higher than the generic public expenditure multiplier. This confirms the sizeable magnitude of multipliers associated with innovation and research with respect to generic residual expenditure (Deleidi and Mazzucato 2021), and the fact that multipliers can widely differ according to the particular class of expenditure they refer to (Deleidi et al. 2021a, 2021b, 2021c). In our case, we do not go into greater detail for what concerns the types of multipliers related to public consumption, investment, and so forth.

5. Conclusions

The patterns of technical progress and its progressively waning impact on potential growth, as well as on labour productivity growth, are at the centre of the analysis for what concerns the issue of long-lasting stagnation. Solow (1987) in the past as well as Gordon (2018a, 2018b), together with other authors, warned about the possibility for innovation and growth not to necessarily proceed hand in hand. These gloomy prospects recently found further back up from the studies on research productivity, which has been falling in the last decades, thereby adding concerns about the foreseeable trends of productivity and GDP growth (Bloom et al. 2020; Cauwels and Sornette 2022). This latter phenomenon occurs in an environment in which we also witness a progressive retreat of the public sector from the R&D activity (Goel et al. 2008; Archibugi and Filippetti 2018).

Our SVAR analysis of the US shows that public innovation spending exerts a positive effect on productivity, and together with generic public expenditure it has a greater effect than private expenditure in innovation. Moreover, it also strongly stimulates private R&D and generates positive and high fiscal multipliers. Therefore, according to the evidence we find, we maintain that a prolonged and sustained fall of public expenditure in innovation in relation to private expenditure of the same type helps in explaining stagnation. By linking our findings to the mentioned list of Bloom et al. (2020, p. 1138), we can thus conclude that the (so far unmet) “necessity to increase more and more research inputs” and “the decline of basic, publicly funded research” are indeed not only among the factors that impaired research productivity growth, but also among those that stifled US long-run labour productivity and GDP growth in recent decades.

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