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The Retreat of Public Research

and its Adverse Consequences on Innovation

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Abstract

Does it matter whether research is conducted by the private business rather than in universities or government research centres? While most of the attention of science and innovation policy in the last decades has explored the relevance of the interconnections between public and business players in enhancing knowledge-based societies, a major trend has been ignored: both the quota of public R&D and its share over the total R&D investment has shrunk in the majority of OECD countries. As a result, a larger fraction of knowledge is today generated in the business sector. We argue that this is a major problem since public research and private research differ along a number of characteristics, e.g. public access, potential for future technological innovations, criteria of resource allocation. This trend can have adverse implications for long-term innovation and economic welfare in our societies. Through the lens of the public goods theory and of the sector of funding and execution of R&D for the period 1981-2013 we try to explain why.

Keywords

R&D, knowledge economy, public sector, public goods, intellectual property rights, technology transfer

1. Introduction: the shift from public R&D to business R&D

In the last decades a major attack has been directed against the public sector. Everything labelled public – from hospitals to drinking fountains, from airports to motorways – has been described as inefficient, costly and ultimately useless. This is hardly a solely intellectual fashion; it is strictly associated to an attempt to move as many as possible of these public infrastructures and their associated economic value to the profit-seeking sector. There have been important economic consequences: public expenditure has been reduced while many public utilities – from trains to telephones – have been privatised. This trend can be observed in virtually all advanced countries (see Megginson and Netter, 2001).

The realm of knowledge has not been immune from this overall mood. While governments and the business community continuously recognize the importance of knowledge and innovation as crucial components of economic development and human welfare, there has been a long-term trend to belittle the contribution of public institutions and to glorify the virtuous of business investment (see the enthusiastic call for the downsizing of public R&D by Kealey, 1996; and the critical rejoinder by David, 1997). This general reversal of policy emphasis was based from the presumption of a superior efficiency of markets over governments associate to a new view of knowledge as a "proprietary quasi-private good" (Antonelli, 2005). This is reflected in the most visible and measurable component of knowledge creation, namely the resources devoted to Research and Development (R&D) and knowledge development, as documented in Section two.

Most of the attention of science and innovation policy in the last decades has been directed towards the relevance of the interconnections between universities, industry and the governments (as in the Triple Helix view) (Colombo et al., 2011; Etzkowitz and Leydesdorff, 2000; Lawton Smith and Bagchi-Sen, 2010; Filippetti and Savona, 2017), and the major institutional transformations that have followed in the production of knowledge, exemplified in the Mode 2 knowledge production (Gibbons et al., 1994). University-industry linkages have become imperative and ubiquitous in the political agenda as a means to boost technology transfer and to improving training in skills required by the industry (D'Este et al., 2013; Gander, 1986; Hsu et al., 2015). Much less concern has been devoted to the overall shrinking of public research and to its main effect on innovation, long-term economic growth and social welfare (Conceicao et al., 2004).

The so often anticipated knowledge economy is on its way, at least judging from the resources devoted to R&D and other scientific, technological and engineering activities, but the profit seeking sector is gaining positions at the expenses of the public sector. Is this a problem? Two optimist arguments support the view that this is not such a trouble. The first states that this is irrelevant provided that new knowledge is generated. The important thing is that we know more things and we invest enough resources for it while it is less relevant if new discoveries and inventions are made by public or business players. The second is that the private sector is more efficient than the public sector, and research carried out in the latter has greater impact on business innovation performance and on countries' competitiveness. If the business sector proves to be more efficient in the way it generates knowledge, there is no reason why this should be kept within the public sector. Therefore, our research question is: *does it matter whether research is conducted in universities or government research centres, rather than by the private business?*

We will argue that the so often applauded current privatisation of research activity and knowledge (see Kealey, 1996; Ridley, 2015) can have major consequences on innovation and, ultimately, on long-term economic development and social welfare.[1] One of the central reasons why the threat to knowledge augmenting is largely ignored or under-estimated is associated to an unclear understanding of the economic characteristics of knowledge. In this paper we first develop an analysis of the differences between knowledge generated in the public sector and knowledge generated in the private sector. On the ground of data on R&D expenditure in OECD countries we discuss a number of implications for innovation and science policy. We will argue that it does matter *where* knowledge is produced: knowledge produced in the public sector has very different economic characteristics compared to knowledge produced in the business sector. And these differences become crucial for future innovation and long-term economic development since knowledge produced today is the fundamental input for future knowledge generation. When this is taken into account, the change in the composition between public and private research has consequences for the current and future pace of technological innovation and long-term economic development.

This paper is related to a broad discussion which is taking place both in academia and in policy circles: is science, through its application to technological innovation, an essential engine of long-term economic development? (Deiaco et al., 2012; Havas, 2008). The emergence of a new institutional reconfiguration of universities, as increasingly nested into the economic production process along with the industry and the government has been described as a major break in the production of knowledge, as in the "Mode 2" (Etzkowitz and Leydesdorff, 2000) or as an emerging system in which public and private institutions tend to overlap, as in the "Triple Helix" view (Leydesdorff and Etzkowitz, 1996). According to these scholars, these major changes have basically blurred the functional differentiation between *science and markets*, and that between *public and private* (Leydesdorff and Etzkowitz, 1996). Political scientists and sociologists have fiercely discussed the way in which neoliberal forces have been shaping the production and diffusion of knowledge, coining the term 'science regime' to describe a simple fact – and yet much disregarded in the realm of economics – namely that the practice of scientists is shaped by the environment they work in (Pestre, 2003).

Mariana Mazzucato (2013) has re-fuelled the debate about the role that the state, through investment in basic science, has played for technological development in the industry, somehow restating the value of the linear model of innovation (Balconi et al., 2010; Godin, 2006). We are therefore addressing the much heated debate about the economic relevance of the public funding of science. In brief, this debate opposes those arguing that government-funded basic research is an idle path toward innovations and that the market can do it better, to others countering that publicly-funded research provides benefits which cannot be substituted by private research. In the end, the debate seems to boil down to differences in opinion about *how much science should be publicly or privately funded*. This is what we are concerned about in this paper.

In the next section we develop our analytical distinction about public-generated and private-generated knowledge. In the third section we analyse data on public and private R&D.

[1] For opinions which go against the stream see Mazzucato (2013) and M.I.T. (2015).[2] Basic research is defined as an experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view (see the so-called Frascati Manual, OECD, 2015).

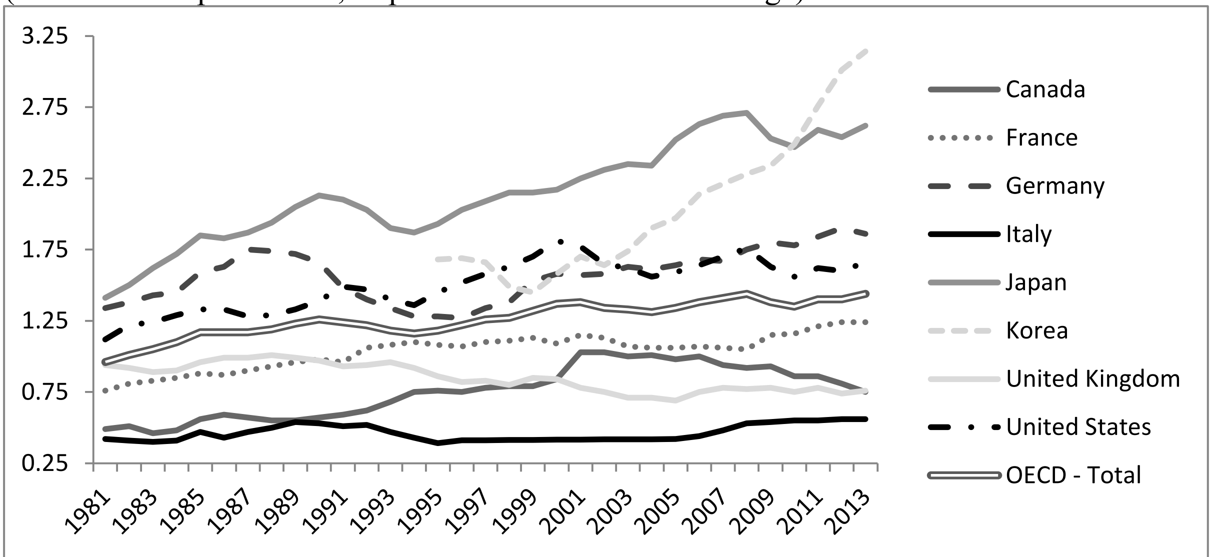
Section four puts forward some implications of our findings, while section five discusses our results in relation to the research in this field and section six concludes.

2. Main trends in R&D expenditure, total government expenditure, military spending and basic research

2.1 R&D expenditure

Figures 1 and 2 report data for, respectively, industry and government financed R&D. In most OECD countries a significant shift in the effort to finance public R&D has occurred: from 1981 to 2013 the share of public-financed R&D to GDP has been reduced from 0.82 per cent to 0.67 per cent. By contrast, the industry-financed R&D has increased from 0.96 per cent of GDP in 1981 to 1.44 per cent in 2013. There are significant differences across countries. Japan and Korea, Rep. exhibit a virtuous trend where both the business and the government have increased their own R&D expenditure; in Korea, Rep., particularly, the government expenditure increase has been spectacular. In the US, the UK, Canada, France and Germany, by contrast, we assist simultaneously to the growth of industry-financed R&D and to the decline of government-financed R&D. The temporary slowdown in Germany can be attributed to the unification of 1989, while for the UK a larger fraction of private-financed R&D comes from foreign sources and therefore it is not accounted for in these figures (see note on Table 1).

Fig. 1
Industry-financed Gross expenditure on R&D (GERD) as a percentage of GDP, 1981-2013 (G-7 countries plus Korea, Rep. countries and OECD average)

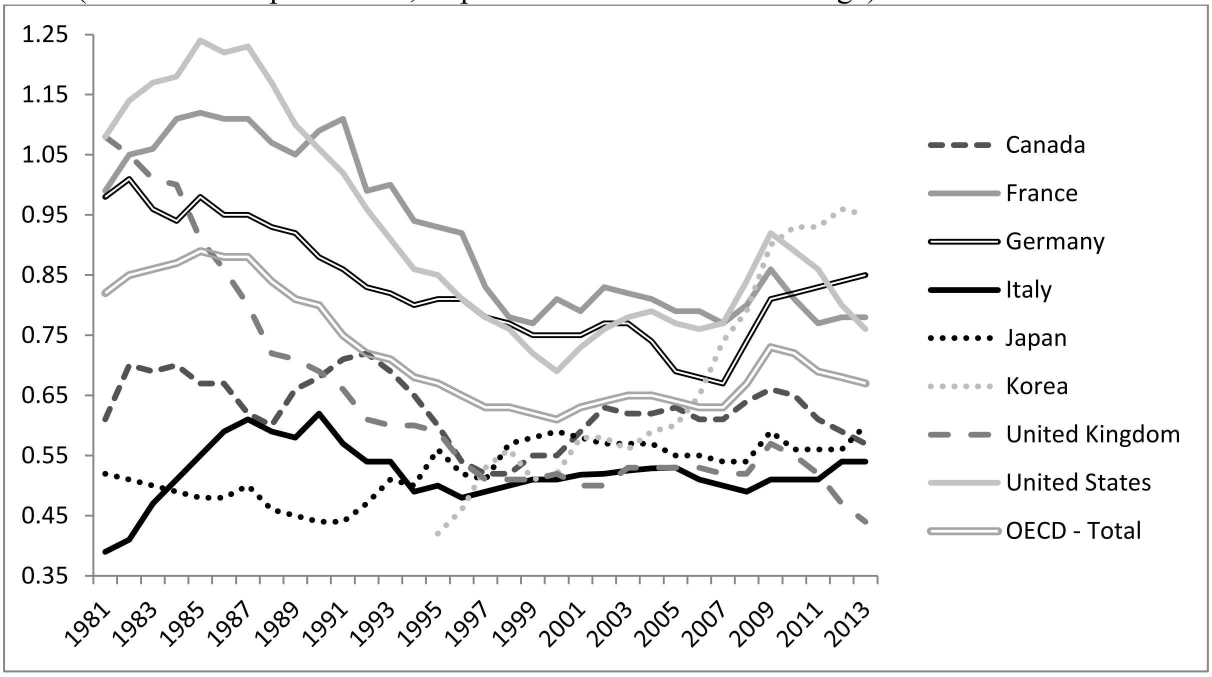


Source: Our elaboration on OECD Main Science and Technology Indicators (MSTI).

The consequence on the composition of R&D is remarkable (Table 1). On the one hand, the percentage of gross expenditure of R&D financed by the government has, in the OECD, shrunk from 44.2 per cent in 1981 to 28.3 per cent in 2013. The drop has been considerable in every country, particularly in the UK and in the US, while Korea, Rep. represents the only exception. On the other hand, the percentage of gross expenditure financed by industry has increased from 51.6 per cent of 1981 to 60.8 per cent of 2013. The increase is particularly strong in the US, Germany, and the UK. These trends show a clear structural change: the business sector is becoming more and more important in knowledge creation, while the

public sector is slowly retracting (on this trend see also Conceicao et al., 2004; Dinges et al., 2007; Van Pottelsberghe De La Potterie, 2008).
A major shift has also occurred within the composition of public R&D expenditure. By looking at the trends in OECD R&D expenditure as a share of GDP by the higher education and government sectors, 1981-2012, OECD (2014) shows a steady decline of *government* R&D expenditure, from 0.34 to 0.28; by contrast, in the same period *Higher education* R&D expenditure increases by 0.27 to 0.43.

Fig. 2
Government-financed Gross expenditure on R&D (GERD) as a percentage of GDP, 1981-2013 (G-7 countries plus Korea, Rep. countries and OECD average)



Source: as for Figure 1.

Table 1
Percentage of Gross expenditure on R&D (GERD) by source of funds (G-7 countries plus Korea, Rep. and OECD average)

	Percentage of GERD financed by industry			Percentage of GERD financed by government		
	1981	*2013*	*diff*	*1981*	*2013*	*diff*
Canada	40.8	46.5	13.9%	50.6	34.9	-31.1%
France	40.9	55.4	35.3%	53.4	35.0	-34.5%
Germany	56.9	65.2	14.7%	41.8	29.8	-28.7%
Italy	50.1	44.3	-11.6%	47.2	42.6	-9.9%
Japan	67.7	75.5	11.5%	24.9	17.3	-30.5%
Korea, Rep.*	76.3	75.7	-0.8%	19.0	22.8	19.9%
United Kingdom	42.1 *(70.1)***	46.6	10.7%	48.1	27.0	-43.9%
United States	49.4	60.9	23.2%	47.8	27.8	-41.9%
OECD - Total	51.6	60.8	17.7%	44.2	28.3	-36.0%

Source: as for Figure 1.
* Data for Korea, Rep. refer to 1995 instead of 1981; the sum of the shares does not add up to 100% since there are other minor sources that are not considered, namely “other national sources” and “abroad”.
** In the UK a significant higher proportion of R&D funding comes from overseas. When this is taken into account the share of private-funded R&D stands at 70% (Economic Insight, 2015, p. 7).

2.2 Public R&D, total government expenditure and basic research

The fall of government R&D can be examined within the broader trend of general government spending, as well as the specific trend of general government spending in defence. Data on general government spending show different patterns across countries (see Table 2). Countries in which spending was high in 1981, such as France and Germany, exhibit a moderate increase and a significant decline respectively. By contrast, government spending has risen in countries which scored low levels in 1995, particularly in Korea, Rep. and Japan. Military spending shows a considerable decline in all the considered countries, with the exception of Japan, although the share on GDP is still quite lower than other countries.

Table 2
General government spending as a percentage of GDP, rate of change 1981-2013;
Military expenditure as a percentage of GDP, rate of change 1988-2013.

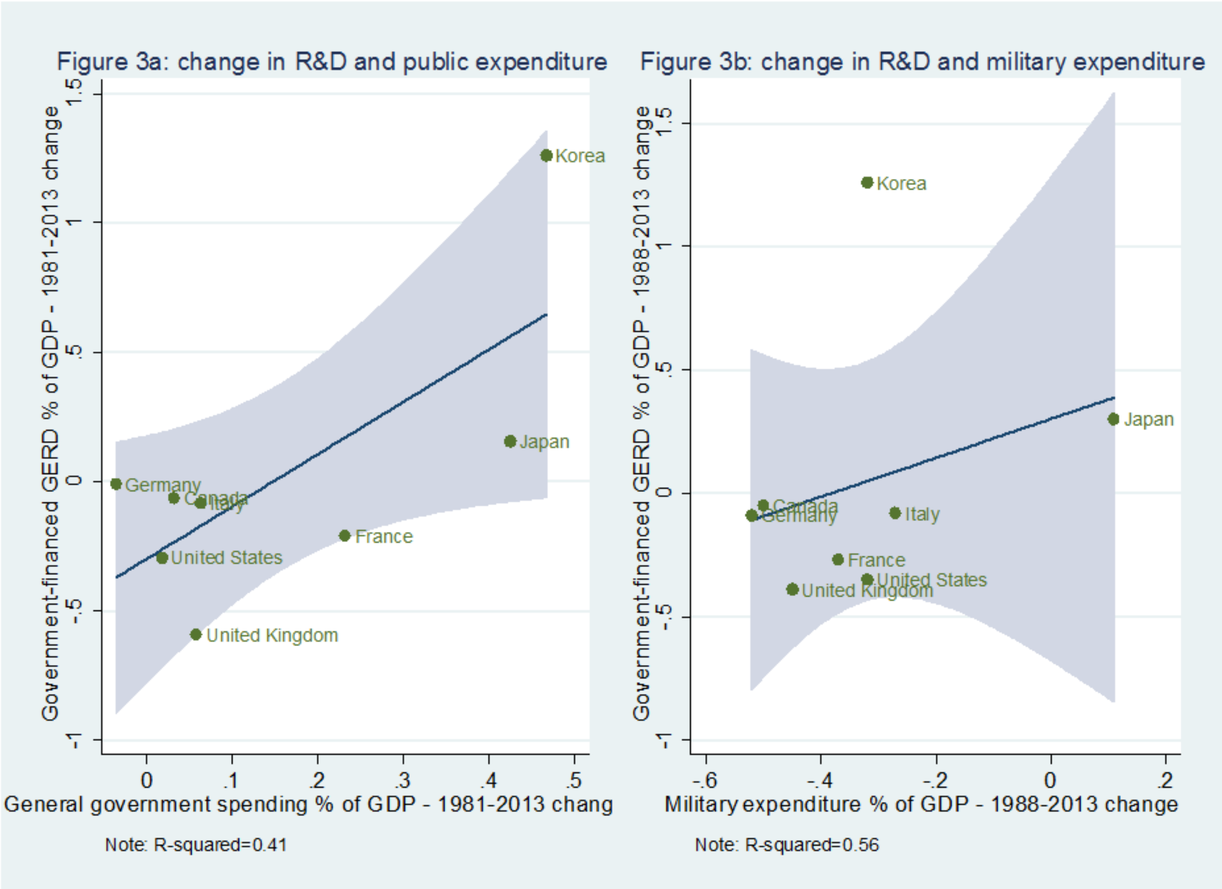
	General government spending % of GDP			Military expenditure % of GDP		
	1981	*2013*	*change*	*1988*	*2013*	*change*
Canada	39.1	40.3	3.3%	2.0	1.0	-50.0%
France	46.2	57.0	23.2%	3.5	2.2	-37.1%
Germany	46.4	44.7	-3.5%	2.5	1.2	-52.0%
Italy	48.0	51.0	6.4%	2.2	1.6	-27.3%
Japan	28.5	40.6	42.4%	0.9	1.0	11.1%
Korea, Rep.	14.2	20.9	46.7%	3.8	2.6	-31.6%
United Kingdom	39.7	42.0	5.8%	3.8	2.1	-44.7%
United States	38.0	38.7	1.8%	5.6	3.8	-32.1%

Source: International Monetary Fund for general government expenditure; World Development Indicator (World Bank) for military spending.
Note: for General government spending, data for Germany, Italy and Korea start from 1991, 1988 and 1995 respectively.

Figure 3.a reports the percentage rate of change (2013 to 1981) of government spending in major OECD countries on the horizontal axe, and the rate of change of government-funded R&D on the vertical axe. Similarly, Figure 3.b reports the percentage rate of change (2013 to 1988) of military spending on the horizontal axe and the rate of change of government-funded R&D on the vertical axe. In both the charts a positive correlation arises between changes in R&D intensity and the changes in total government expenditure and military expenditure respectively.

This suggests two things. Firstly, a significant fraction of government R&D is related to military programmes in the Unites States, the United Kingdom, France and other states. Note that government-financed expenditure also includes public procurement that is largely employed by governments to foster technological advances in the defence sector. This has been true in the case of the United States, particularly in the information technology sector, in which post-war R&D military programs provided a great impetus to the development of semiconductors, computer hardware and software (Mowery et al., 2010). Second, this confirms that the relative reduction of public research is associated to a general decline in the role of government in the economies of advanced countries (Tanzi and Schuknecht, 2000).

Fig. 3
3a - Government-financed Gross expenditure on R&D (GERD) and general government spending as a percentage of GDP, 1981-2013 rates of change;
3b - Government-financed Gross expenditure on R&D (GERD) military expenditure as a percentage of GDP, 1988-2013 rates of change



Source: as for Table 2.
Note: the grey areas report the confidence interval at 95%.

The decline of government-financed R&D can also be discussed in relation to *basic research.*[2] In fact, although companies also engage in basic research, as in the biotechnology and pharmaceutical industries, the bunch of basic research is performed either in the public sector or in the business sector through public procurement (Nelson, 1959; Rosenberg, 1990).

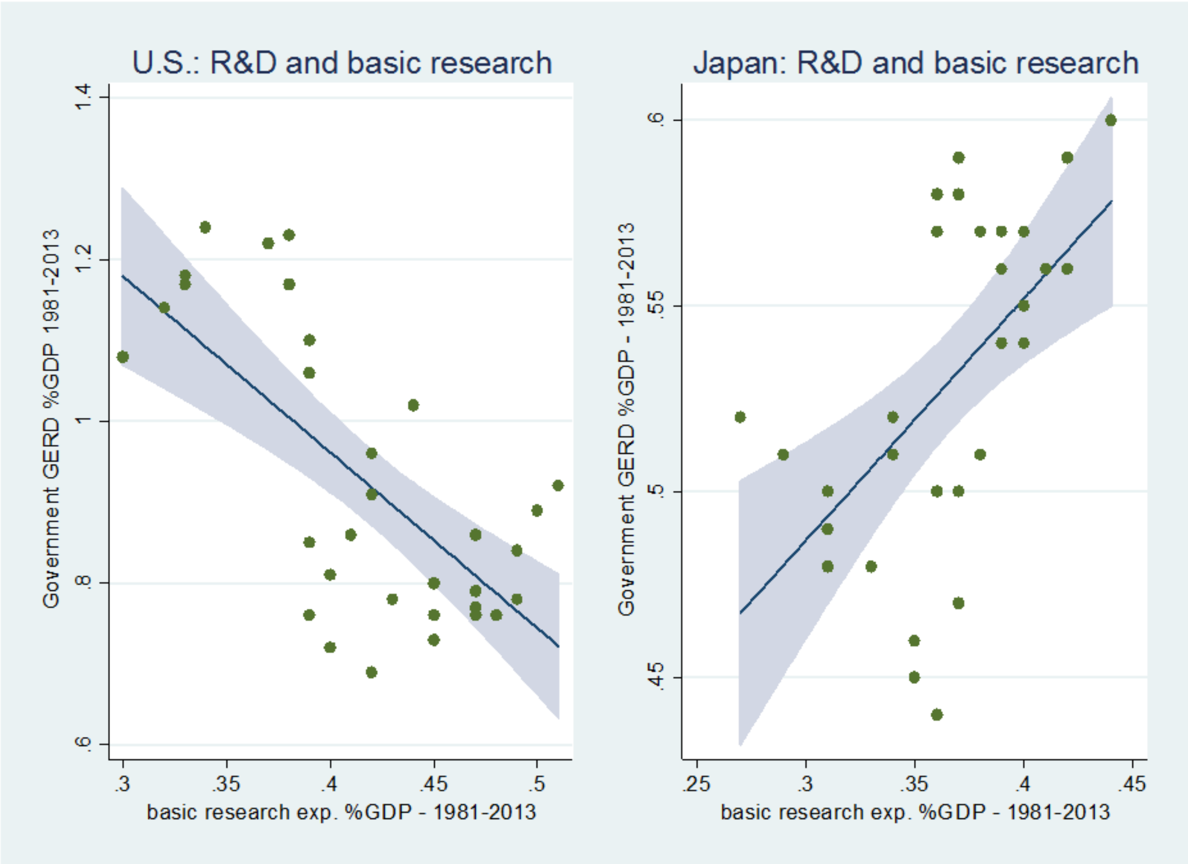
The two largest R&D spenders, Unites States and Japan, have experienced an increase in the basic research as a percentage of GDP in 1981-2013, from 0.30 to 0.48 in the Unites States and from 0.27 to 0.44 in Japan.

We report in Figure 4 the relationship between expenditure in basic research and government-R&D for the Unites States and Japan for the years 1981-2013. The charts suggest two opposite relationships: on the one hand, the Unites States show a negative and quite significant correlation; despite a fall in government-funded R&D (as show in Table 2)

[2] Basic research is defined as an experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view (see the so-called Frascati Manual, OECD, 2015).

they have managed to increase the share of basic research. By contrast, the positive correlation arising for Japan indicates that basic research is driven by government funding.

Fig. 4
Government-financed Gross expenditure on R&D (GERD) and basic research expenditure as a percentage of GDP, for selected countries, 1981-2013



Source: as for Figure 1.
Note: the grey areas report the confidence interval at 95%

Summing up, we have documented a major trend across the most advanced countries: a systematic retreat of public R&D compared to R&D financed by the industry. This decline is part of a broader retreat of the public sector in the economy, a generalised trend of privatization and the end of public companies in many high-tech sectors. What is the impact of these trends on innovation, long-term economic development and social welfare? The remaining of this article addresses these issues.

3. Beyond the knowledge-as-a-public-good view: an analytical framework of public-generated knowledge and private-generated knowledge

For many years knowledge has been considered to be a public good. Economics Nobel Prize winner Kenneth Arrow (1962) contributed to disseminate this view in one of the most cited articles in the economics of innovation, arguing that knowledge is costly to produce but could be disseminated as information at zero or very low costs. This view is rather persistent if it was re-stated by another authoritative Nobel Prize winner such as Joseph Stiglitz (1999). The view originated from the classic welfare economics perspective in which the public-good characteristics of knowledge lead to under-investment in the private sector, a market failure which could be solved either by assigning (intellectual) property rights to the inventor or with the intervention of the public sector (Arrow 1962. For a review, see Archibugi and Filippetti, 2015b).

While that theory addressed the problem of the optimal level of the *production* of knowledge, it did not consider the problem of the *diffusion* of knowledge. This is consistent with the assumption that knowledge could be considered a public good: if this is the case, once it is generated it would spread throughout the economic system and the society thanks to its characteristics of non-rivalry and non-excludability. However, a great body of research has demonstrated that knowledge has both public and private components (Callon, 1994; Nelson, 1989; Pavitt, 1987). We stress that *public-generated* knowledge and *private-generated* knowledge have different economic characteristics, particularly in terms of the degree of rivalry and excludability. This in turn shapes the diffusion process and the subsequent generation of knowledge and innovation. The way in which knowledge production is funded – public or business - does matter for subsequent application for innovation. In particular, the differences in: *i)* resources allocation; *ii*) excludability in consumption; and *iii*) excludability in production should be considered. These differences become crucial for social welfare purposes when one takes into account that knowledge generated in both the public and the business sector is going to represent a major input for further knowledge generation. Here lies the importance of shedding light on how the economic differences between public-generated knowledge and private-generated knowledge affect the process of diffusion of knowledge.
Table 3 summarizes some fundamental differences between public-generated and private-generated knowledge (for a similar attempt, see also Antonelli, 2005).

3.1 Allocation mechanisms

There is a great difference between *public-generated* and *private-generated* allocation of resources for knowledge. Indeed, one of the criteria identified by Ostrom and Ostrom (1999) to divide private and public goods is precisely the allocation mechanism. According to their classification, a good is *private* if the allocation mechanisms are made primarily by *market mechanisms;* by contrast, a good is *public* if the allocation decisions are made primarily *by political process.* According to this definition, private-generated knowledge would clearly be regarded as a *private* good.

Mowery et al. (2010) illustrate the prominent role of political process in deciding the allocation of public R&D spending in both the U.S. and the U.K. In the biomedical industry, the U.S. Congress is mostly directing resources towards basic research to improve fundamental scientific understanding; but at the same time it is pursuing a few specific programs, namely those for cancer and artificial hearth, which policy makers deemed to be socially encouraged. While the governments have autonomy in the sectors of allocation of R&D, there are several different ways to organize the administration of these funding, for example centralized versus decentralized agencies. In addition, the quality check is often demanded to the scientific community itself by means of peer-review mechanisms. By contrast, in the case of business R&D, projects are selected according to profit expectations and they are ultimately selected by the market.

The allocation of resources for R&D is a key determinant of the possible outcome and future development of science. It is the allocation of resources that determines the direction of scientific discovery, although with some degree of uncertainty that is inherent to any discovery process. For instance, it is well known that 'serendipity' (Gilles, 2015) is a key characteristic of science, especially basic science. But it is hard to get a cure for cancer by doing research in cosmetics, while it is more likely to get some fundamental medical discoveries by doing basic research on genes and cells. New anti-cancer therapies stemmed from federally-funded basic research into the fundamental working of cells in the USA (Mowery et al., 2010; MIT, 2015). Nobel Laureate Arthur Kornberg put this very well: "The pursuit of curiosity about the basic facts of nature has proven to be the route by which the successful drugs and devices of modern medicine were most often discovered".

Table 3
Economic differences between *private-generated* and *public-generated* knowledge

Private-generated knowledge	**Public-generated knowledge**
Resources allocated through market mechanism. The main purpose is to contribute to profits though knowledge-based products, services and processes.	Resources allocated through political process. The main purpose is to contribute to the advancement of knowledge and social welfare.
Excludability in consumption pursued through active strategies such as industrial secrecy and the use of intellectual property rights.	Non-excludability in consumption implemented through technology transfer policies and full disclosure (e.g. open science and non-proprietary forms of intellectual property).
Excludability in production associated to firm-specific technical knowledge, tacit knowledge and industrial secrecy.	Non-excludability in production actively sought through reducing tacit knowledge and technology transfer strategies.

Source: Authors elaboration.

3.2 Excludability in consumption

If knowledge were a pure public good, the only concern would be about the *nature* of the knowledge produced under the assumption that the business sector would direct its investment towards the more palatable areas for the market rather than those of greatest societal and scientific interest. But it would not create problems related to its social distribution and diffusion. However, the modern economics of science and innovation has rejected the idea that knowledge is a pure public good arguing that it has both private and public attributes (Callon, 1994; Nelson, 1989; Pavitt, 1987, Antonelli, 2005) and that a different balance occurs for each component.

Accepting the Arrow-Stiglitz view implies that knowledge is strictly non-excludable, while most of the industrial technology is largely firm-specific and it is difficult to be used elsewhere (Pavitt, 1987). At best, it depends on whether the focus is on generic knowledge or firm-specific knowledge. In the latter cases, when knowledge is about technological improvements that are very specific to the firm, knowledge is closer to a private good since it is easier for the firm to *exclude* others from using it (Nelson, 1989).

Economic agents may be willing to invest resources to generate knowledge only if they expect that they profit from it. And this leads profit-seeking agents to use technical and institutional devices to exclude potential users from the utilization of the knowledge they have generated. The literature on technological appropriation (Arundel, 2001; Cohen et al., 2000; Levin et al., 1987) has shown that there are a variety of methods, ranging from intellectual property rights to industrial secrecy that firms use to protect their inventive and innovative activities and to prevent the dissemination to actual and prospective competitors. These methods are very much industry-specific and guarantee partial protection, all of which tries to make imitation and dissemination more costly and difficult.

Therefore, there is a basic difference between the knowledge promoted by the public and the business sectors. While the former is generated with the purpose to be widely disseminated and to be offered for use to most economic agents, the latter is financed taking into account that any result should be protected to make it as difficult as possible to imitate, replicate and disseminate it.[3] Disclosure strategies work in the opposite direction. While researchers in the private sector keep their results as secret as possible, in the public sector researchers rush to disclose them to establish a priority, since the latter represents a key mechanism in public science to establish extra-rewards (Dasgupta and David, 1994). Since public disclosure is a major desirable feature of research for the society, it is easy to see that in the case of public research the mechanism of priority and rewards align the incentive of the scientists to that of the society: the larger the social impact of the research, the higher the rewards for scientists.

The public sector also encourages diffusion when financing R&D in the private sector, as in the case of public procurement. Particularly, during the 1960s and 1970s governments were pursuing loose intellectual property rights policies in order to prevent companies involved in these projects to appropriate the new technology and knowledge generated; this would encourage diffusion also outside the companies directly involved in the project (see Foray et al., 2012).

3.3 Excludability in production

Other major differences arise when one considers the role of tacit knowledge. As well-known in every process of knowledge generation there is an explicit and a tacit component. While the former can be articulated and codified, the latter cannot (Cowan et al., 2000; Polanyi, 1966). This has great implication on the diffusion of knowledge. While explicit knowledge can be relatively easily transferred and re-used in different contexts, the process of tacit knowledge diffusion can take place only locally as it implies personal interactions. There are relevant differences between the public and the private sectors in this regard. First, tacit knowledge is mostly associated to technical development, innovations, and improvements in production processes that take place within the firms. This not only reduces the share of codified knowledge diffused by the private sector, but also the opportunity to use the codified knowledge itself, since the application of such knowledge requires other tacit knowledge and more personal interaction (Faulkner et al., 1995). Conversely, by its very nature, the knowledge domain of basic research is formal (e.g. in the forms of experiments or computer simulations) and explicit. Results of research carried out in the public sector tend to be rigorously codified, as for instance into protocols or scientific articles, in order to be diffused, published and checked by the peer community. Second, even the tacit component of knowledge generated in the public sector is more likely to be diffused compared to that in the

[3] It is well known for example that even if a publication of a patent should in principle allow others to replicate the invention, companies are in fact quite successful in making this unlikely.

business sector. In fact, in the public domain researchers are continuously encouraged to engage in interactions thought meetings, collaborative projects, internships and other forms of interactions. Therefore while it is true that both the public research and private research produce tacit knowledge, a major difference is that business companies do not diffuse it, while this is deliberately done in the public sector (Pavitt, 1993).

3.4 Similarities should not hide differences

From the user perspective, there is a basic difference between freely available knowledge and the knowledge that can be used without costs (as rightly noted by Callon, 1994) and this applies to both public and business funded knowledge. Even when the knowledge is generated by public institutions that have the best intentions to diffuse it, this does not mean that potential users will be able to put it into practical use without sustaining additional costs devoted to learning and absorbing it. All the experience of technology transfer schemes shows that it is not enough that there is the intention of the producer to transfer the knowledge (Bozeman, 2000). Successful stories require that prospective users invest their own time and resources to absorb it through capacity building. Even when it is publicly funded and freely available, it is not a free meal.

We also know that, in spite of all efforts made by companies to protect their knowledge with a mixture of industrial secrecy and intellectual property rights, it is very difficult to prevent competitors and the public at large to use the knowledge. The Coca-Cola receipt has been well kept confidential but this has not prevented competitors to bring to the market substitute products, and the same applies to results with a higher knowledge-base in industries such as pharmaceutical to ICTs.

However, there is a difference in the degree of excludability between private and public knowledge which has enormous implications in terms of welfare when one considers a fundamental characteristic of learning: knowledge is at the same time an output and the primary input for future knowledge and research. All prospective researchers and innovators build new knowledge on the shoulders of other previous researchers, drawing from the pool of knowledge that is socially available: the larger this pool the greater the opportunities to explore new venues to solve.[4] By contrast, if the pool of ideas that are publicity available is smaller, this will reduce the technological opportunity available. Further, this also serves as an important set of signals of where to search for finding effective solutions to technical problems, in that it also suggests indirectly what does not work (David, 1997).

The business sector has been itself the greater benefiter of the public pool of knowledge. Rosenberg and Nelson (1994) have shown that that public R&D is not a substitute to business R&D, but rather an enhancer of it. Both the ICT industry and the bio-tech industry, the more innovative and dynamic industries over the past two decades, have enormously benefited from basic research done in the public sector (Guellec and Potterie, 2003; Mazzucato, 2013). Even big companies in the pharmaceutical and biotech industries that are provided with large R&D labs rely heavily on the results of basic research carried out in universities and public research centres (D'Este et al., 2013; Lane and Probert, 2007). In these industries, the intensity of university-industry collaborations precisely witnesses the importance that this pool of knowledge in the public sector plays for private companies.

[4] This point has been raised by Dosi and Stiglitz (2013) who define knowledge as a *quasi*-public good; see also Klevorick et al. (1995). For a review on the benefits of public research see also Salter and Martin (2001).

The pool of publicly available knowledge affects also the *direction* of research. To the extent that the private sector succeeds in excluding some parts of the knowledge pool, researchers and prospective innovators will be induced to look for venues in which it is easier (and less costly) to have access to knowledge to build on it. This is a typical case in the bio-tech, and particularly in gene-based research. In this area, research has to make extensive use of database creation, but genes have been heavily and effectively patented. As a result, drug companies have been pushed away from promising line of research towards those that are less problematic in terms of intellectual property (Heller and Eisenberg, 1998).

We have therefore learnt that: i) it is not enough that some knowledge is financed by the public sector to make it a pure public good, and ii) in spite of many attempts made by the business sector to limit the leak-out of knowledge they generated, companies do not manage to make it a pure private good. However, it cannot be ignored the presence of radical differences between the two components. Increasing the business component at the expenses of the public one has a simple and straightforward effect: the generation of knowledge is becoming more and more a competitive process where the main objectives is to exclude rather than include users and this is precisely the opposite of what dominated the republic of science for centuries.

4. Sectors of financing and of performance of R&D

The financing of knowledge generation is not the only predictor of its public and private outcomes. It is possible to be more specific by taking into account also the nature of the organizations where this knowledge is developed. As already identified in the Frascati Manual (OECD, 2015), the public and the business sectors perform indoor a substantial amount of activities, but not all of what they fund. Since funding does not overlap entirely with execution, R&D expenditure is classified by the sectors of financing and of performance.

Figure 5 subdivides R&D expenditure in four main categories.[5] In the first box we find the R&D financed by public sources and also performed in public institutions: it comprises what governments provide to universities and public labs ranging from NASA to NHS. Within the public sector, a further break-down between the R&D carried out in governmental research centres and universities can be made. In most countries, universities are public institutions, in a few countries they have special status (in the UK they are civil corporations), in several countries, including the USA and Japan, they can be both public and private. Besides the juridical details, universities are mostly committed to the non-commercial knowledge and therefore we classify their R&D expenditure as public. The fourth box reports what companies do with their own money. The predominant rationale to invest in R&D is to support products, processes and services sold in the market. Companies do it with internal resources as part of competitive behaviour and try to make the knowledge generated as excludable as possible. A large portion of this knowledge, however, generates fall-outs and welfare gains; business R&D creates a lot of externalities.

[5] In fact, the OECD provides a more detailed statistical classification. The sector of financing, besides government and the business enterprises also includes R&D financed from abroad and from other national sources (comprising the non-profit sector). The sector of performance is further disaggregated in the business, higher education, government and private non-profit sectors. In order to obtain a two-by-two matrix which reflects the public-private sectors, government R&D and higher education R&D have been aggregated in figure 5 and in table 4.

Boxes 2 and 3 of Figure 5 report financial linkages among public and business players; in these cases, there is not intellectual collaboration but also financial commitments. On the one hand, the public sector often finances business R&D (Box 3) when it requires specific results or products which embody the knowledge. Cases of public procurement include government grants to business corporations for military, space, medical or ICTs objectives. In other occasions, governments support the innovative activities of their companies for the positive externalities generated by business R&D. More often, governments support business performed R&D since this helps to foster their economic competitiveness, especially against foreign competitors. Conversely, universities and other public research centres are more and more willing to carry out R&D for the business sector (Box 2).

Fig. 5
R&D by sector of financing and sector of performance

		Sector of performance	
		public	business
Source of funding	public	1) Generation of pure goods; Public priorities; Policies of dissemination and technology transfer; Public allocation mechanism.	3) Private-public procurement; Efficiency; Mixed allocation mechanisms.
	business	2) Triple-helix mechanism; Mixed allocation mechanisms.	4) Knowledge with public and private characteristics; Private priorities; Market allocation mechanisms; Active excludability through industrial secrecy and IPRs.

Source: Authors elaboration on the basis of OECD (2015).

Table 4 reports the subdivision of R&D resources according to the criteria indicated in Figure 5 for eight OECD countries for 1981 and 2013. This allows following how the composition of R&D expenditure has changed across different national innovation systems. The data show a generalized trend in which research financed and performed in the public sector has declined, while research financed and performed in the business sector has raised.

This trend is also confirmed by looking at Figure 6 in which we have performed a share-shift decomposition analysis of R&D intensity for the considered countries. R&D intensity has been decomposed into four main component each corresponding to one of the box identified above in Figure 5: public to public (box 1); business to business (box 4); public to business (box 3); business to public (box 2). We have then calculated the relative contribution of each of this component to the *change* in R&D intensity for each year and then we have calculated the 3-year moving averages which are reported in the charts.[6] By looking at the whole period, a systematic retreat of public-funded research arises (the two grey lines). In particular, the contribution of the public-to-public component is negative from 1983 to 1999; after that it shows a more volatile trend due to the two major recessions, the dot-com bubble in the early 2000s and the great recession of 2008. A similar trend is also revealed by looking at the public-to-business component, where the remarkable disengagement of the public sector in terms of public procurement is reflected in the negative values of all the 1980s and 1990s; after that an up and down trend reflecting the business cycle arises also in this case. By contrast, by looking at business-funded R&D one can observe that the business-to-business component is the essential contributor to R&D intensity change over the whole period, with the exception of the years of recessions (early 1990s, early 2000s, and 2008-2010) where the private sector tends to be relatively more cyclical compared to the public component. Finally, the negligible contribution of the private-to-business component is visible throughout the entire period.

A simple cluster analysis performed on the relative contribution of the four components described above reveals the presence of two different groups of countries. The first, including France, Germany, the Unites States and Japan (which account for most of the R&D expenditure among OECD countries), exhibits a remarkable contribution of the business-to-business component, and a significant drop in the contribution of the public-to-private component, with basically no contribution of the public-to-public component. The second cluster, including Canada, the United Kingdom, Korea, Rep., and Italy, shows instead an increase in the contribution of the business-to-business component but at the same time a moderate contribution of the public-to-public component.

Box 1 – Publicly funded and performed R&D. These resources are directly steered by public priorities and should correspond to the generation of pure public goods since the government target is to disseminate as much as possible the outcome of R&D programmes to the public at large and should therefore aim to remove barriers to acquire the new expertise. The landing on the moon in the 1960s and the war on cancer in 1970s, just to cite two major US science policy priorities, were mostly carried out with publicly funded and performed R&D and large part of the outcomes were made publicly available.

Table 4 shows a drop of the share of publicly funded and performed R&D in the period 1981-2013. The decrease has occurred in Canada, France, Germany, Japan, and the US. By, contrast, it has remained stable in Italy and the UK. A simple average among these countries (excluding Korea, Rep.) indicates that the share of the public-public R&D expenditure drops from 37.5% to 33.1%.

The reduction of the share of publicly funded and performed R&D raises concern: the benefits of knowledge in the next decades will be lower and there is the risk that what the populace perceive as major priorities, especially in fields such as health and environment will get lower resources than they should be. Even in terms of sustaining business opportunities, entire industries, including ICTs and Bio-tech, started from a few basic discoveries and inventions done in the public sector and that have been developed and commercialized, sometimes after decades, within companies (see Mazuccato, 2013). The scientific openings generated by public R&D have often stimulated companies to carry out commercial follow-ups finalized to introduce technological innovations, thus also contributing to the expansion

[6] We have used 3-year moving averages to smooth fluctuations in R&D expenditure.

of total R&D expenditure (Rosenberg and Nelson, 1994). In fact, the stability over time of public R&D expenditure has proved to be fundamental for attracting R&D from the business sector. Freeman and Van Reenen and (2009) argue that the boom and downscaling of National Institute of Health in the United States has caused significant problems also in the labour market. More recently, the public funding in the green technology sector has proved to be necessary for the generation of business investment by means for the strong demand of new technologies generated by public policies (Mowery et al., 2010).

Can publicly funded and performed R&D be subtracted to the public domain and therefore lose some of the properties of pure public good? This depends very much from the objectives and strategies carried out by the government; research associated to military and security objectives has traditionally been kept out from the public domain. But also civilian R&D can be subtracted to the public domain: since the Bayh-Dole act was approved in the 1980, the US government has allowed individual scientists and Universities to privatize inventions made with public funding through IPRs. The number of patents taken by Universities has steadily increased, making the use of publicly funded knowledge more often excludable than before (Lissoni et al., 2008).

After the Bayh-Dole was introduced in the USA, several other countries have imitated it (Grimaldi et al., 2011). The supporters of the Bayh-Dole act argue that this privatisation of publicly funded knowledge has increased the dissemination: by providing an additional incentive besides the academic glory, it is more likely that the results achieved are not kept sleeping, and that academic inventors actively seek opportunities to deliver the outcomes to the market and to society at large (Geuna and Rossi, 2011). The Bayh-Dole legislation is an attempt to transform inventions into innovations, to motivate academe to be more active in technology transfer and empirical analyses have confirmed its effectiveness.

Publicly funded and performed R&D is the closest to be a pure public good. The economic benefits of knowledge will not be collected if it is reduced. To promote the maximum diffusion, actions for capacity building in prospective users should be combined to policies that transfer IPRs to inventors.

Box 2 – Business funded and publicly performed R&D. It is good news when companies finance research in universities and public research centres. Often, companies require and obtain that the outcome of the R&D is kept confidential. Even if the results are non-rivalrous, firms can obtain that the public contractor makes them excludable, at least in the short and medium term. The data indicate that big money is not involved. On average, the share of this type of research grows from 1.5% to a modest 2%. Canada and Germany show larger increases, passing respectively from 1.4% to 3.7% and 0.4 and 4.2%. A moderate growth arises also in France, while the UK confirms a relative importance of the business as a source of funding for the public research sector. The US shows very low values, 0.4% in 1981 and 0.7% in 2013 suggesting that the Silicon Valley model is a rather limited phenomenon.

Within this component, it is possible to identify a vicious and a virtuous circle. The vicious circle occurs when public institutions are forced to replace the traditional sources of public funding with business sources. This has often been denounced because it leads public institutions to abandon basic research programmes to carry out testing, measurements, provision of standards and other very practical activities to support themselves. If universities and public centres are too much obsessed with fund-raising, they can lose their original social function and be transformed in academic capitalist firms (Slaughter and Leslie, 1997), impoverishing the advancement of knowledge. The virtuous circle, on the contrary, occurs when the business sector is attracted to the public institutions because the latter has a unique set of competences and has generated major scientific discoveries and advances that could be used for business opportunities. However, both the critics (Slaughter and Leslie, 1997) and the enthusiasts (Etzkowitz and Leydesdorff, 2000) of the university-business integration seems to largely overestimate the phenomenon. In spite of the variations across universities and scientific fields (Rossi and Rosli, 2015), on the aggregate business penetration in universities is quantitatively rather limited.

Box 3 – Publicly funded and business performed R&D. When the government provides funding to business R&D, both criteria of rivalry and excludability are blurred. In terms of rivalry, companies compete in order to secure the public grants and the outcome is used in a competitive environment. We are in a typical case where there is competition for the market even when there is no rivalry in consumption. Excludability is very much specific to the way programmes are designed: in some cases, the government requires that the outcome is kept confidential (as in the case of military procurement) and therefore the performing enterprise can exclude potential rivals from the benefits. In other cases, the government requires that the knowledge is properly disseminated. In both cases the performing organization has some advantages over competitors since it has a deeper understanding and often also lead time over what it originally generated.

A generalized reduction of the public sector financing the business enterprises has occurred. On average (again excluding Korea, Rep.), the share drops from 11.7% in 1981 to 4.5% in 2013. This dynamic, considered along the drop in the public-public box, reflects a generalized reduction in the public funding for R&D across virtually every country. The drop has been substantial in the US, where the share shrunk from 21.3% to 8.8%; in Germany, from 11.9% to 3.1%; and in France, from 15.5% to 5.6%. Part of this reflects the general reduction of defence expenditure at the end of the cold war.

Why should the public sector opt to finance R&D carried out in the business sector rather than internally? A first justification is that the business sector is better equipped to provide the expected outcome. This is a justification often provided when, for example, defence-related contracts are assigned to corporations. The second reason is that governments are not particularly interested in specific outcomes but wish to use R&D as an industrial policy tool with the aim to make companies more competitive, especially in front of foreign competitors. The third is that there is the hope that, if funded by the public sector, business companies will expand their own investment and therefore the societal investment in knowledge will be higher than what is provided by the government. Finally, thanks to public support companies should be more willing to undertake projects that otherwise would have not undertaken due to a high rate of risk and uncertainty, or long-term expected outcomes. To this respect public policy would generate additional R&D carried out in the business sector.

The three issues need to be proven. First, if there is a problem of efficiency and efficacy in the publicly performed R&D, this should be addressed by revising the incentives and the organization of the public sector rather than by moving out of it. Second, to concentrate on the total amount of R&D rather than on its direction is a major mistake. Common sense suggests that too much scientific investigation is carried out in cosmetics while too little in vaccines. Within the medical area, it is often denounced the distortion of scientific research towards areas that are more profitable rather than useful. Third, investigations about the effects of public funding to business R&D have provided uncertain results and in some cases it seems that an increase in public funding has even generated a reduction of firms' own investment (for some recent review see Marino et al., 2016; Dimos and Pugh, 2016).

Table 4
Business and public (higher education + government) share of R&D by sector of performance and source of funds, 1981 and 2013 (selected countries)

	CANADA					
	1981			2013		
sector of performance		public	business		public	business
	public	51.0%	5.5%	public	45.1%	2.3%
source of funds	business	1.4%	42.1%	business	3.7%	49.0%

	FRANCE					
	1981			2013		
sector of performance		public	business		public	business
	public	41.0%	15.5%	public	33.7%	5.6%
source of funds	business	0.7%	42.8%	business	1.8%	59.0%

	GERMANY					
	1981			2013		
sector of performance		public	business		public	business
	public	30.3%	11.9%	public	27.6%	3.1%
source of funds	business	0.4%	57.4%	business	4.2%	65.2%

	ITALY					
	1981			2013		
sector of performance		public	business		public	business
	public	43.4%	5.1%	public	44.8%	4.4%
source of funds	business	1.1%	50.4%	business	1.3%	49.5%

	JAPAN					
	1981			2013		
sector of performance		public	business		public	business
	public	36.4%	1.2%	public	21.7%	0.9%
source of funds	business	0.4%	62.0%	business	0.5%	76.9%

	KOREA, REP.					
	1995			2013		
sector of performance		public	business		public	business
	public	19.4%	2.7%	public	19.3%	4.8%
source of funds	business	4.8%	73.1%	business	1.5%	74.4%

	UNITED STATES					
	1981			2013		
sector of performance		public	business		public	business
	public	28.0%	21.3%	public	26.7%	8.8%
source of funds	business	0.4%	50.3%	business	0.7%	63.8%

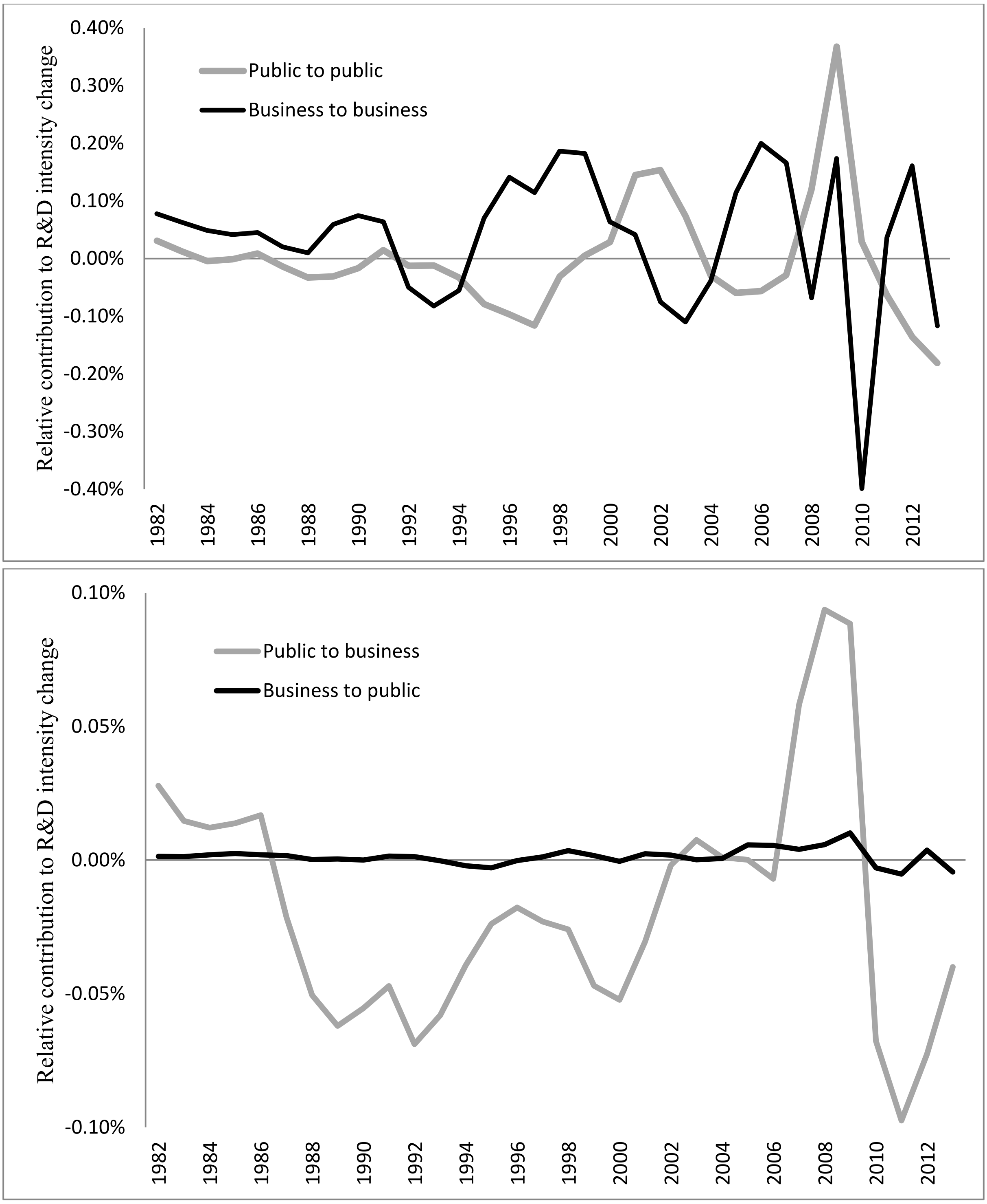
	UNITED KINGDOM					
	1981			2013		
sector of performance		public	business		public	business
	public	32.5%	21.2%	public	32.5%	6.7%
source of funds	business	3.0%	43.3%	business	2.8%	58.0%

Source: As for Figure 1.

Note: The total amount of R&D expenditure has been calculated summing three main three sources of funding, namely government, higher education and the business sector. For Korea, Rep. data refer to 1995 instead of 1981.

Fig. 6

Relative contribution to overall R&D intensity change, *weighted* averaged across G-7 countries plus Korea, Rep. countries, three-year moving averages for the period 1981-2013.



Source: As for Figure 1.

Note: countries included are G-7 Canada, France, Germany, Italy, Japan, United Kingdom and United States plus Korea, Rep.

Box 4 – Business funded and performed R&D. Through their investment, the business sector has generated over the centuries an enormous amount of knowledge that has benefitted society, often contributing also to basic research (Nelson, 1959; Rosenberg, 1990). Transistors and semiconductors, drugs and medical devices have been generated by profit-seeking organizations and have considerably increased well-being and development.

Business funded and performed R&D rose from 49.8% in 1981 to 60.2% in 2013. The increase in the share of business-business is particularly significant in Canada, France, Japan, the US and the UK. The countries in which this share is larger are the two Asian economies, Japan and Korea, Rep., witnessing the importance that historically private enterprises have played in sustaining their innovation-drive growth. Canada and Italy have a share that accounts for less than 50%.

We expect that firms protect the knowledge they generate and make an effort to create some fences to appropriate the returns of their investment and to prevent competitors to use it without payment. First, companies manage to keep exclusive command of their knowledge, through a combination of industrial secrecy and IPRs, for limited periods of time only. Industrial secrets are penetrated in due course through reverse engineering, mobility of scientists and engineers, simultaneous discoveries and many other ways. Patents do not impede the possibility to invent around, and anyhow they have a limited time-span. The fact that most of the patents are not even renewed shows how quickly the frontier of knowledge moves (De Rassenfosse et al., 2013). Of course, the disclosure of information is not enough to allow competitors to put into practice the knowledge available: they will need to invest their own time and resources to do that successfully. But the fences available to firms to protect their own intellectual property are much weaker than those of any other form of property.

Second, in order to sustain their knowledge base, firms need to acquire information from a variety of sources, public and commercial. Failure to do that may lead to put into production obsolete, misleading or sub-optimal knowledge. In order to acquire information, firms also need to share knowledge with others. The evidence on strategic technological agreements shows that companies share and even develop core competences with competitors (Narula and Martinez-Noya, 2015). Moreover, even the individual scientists and engineers within companies are often part of circles of experts where information is exchanged on a voluntary basis and following the standard of communication typical of the academic community (von Hippel, 1987). The open innovation model, which has become so popular over the last decade, has clearly indicated that the sources to innovate are varied and that it is not in the interest of an enterprise to keep its knowledge development segregated from the wider realm of knowledge (Chesbrough et al., 2008).

These facts have important policy implications. The public sector could considerably concur to increase the knowledge generation of the business sector by producing good and accessible knowledge which could be used by businesses in a competitive environment. The necessity of the business sector to share and exchange knowledge with other knowledge-intensive sectors and even with competitors, need to be further enhanced through public policies. It would, for example, suggests that rather than to provide public funding to individual firms (distorting competition), the public sector would better devote its resources to promote open centres, such as science parks, where all knowledge intensive players, business and private, could exchange the knowledge at their disposal.

5. Results discussion and implications for policy

Using the public goods framework and the OECD classification of sector of funding and execution has allowed highlighting some trends that have often been ignored in recent science and innovation policy analysis. This has some implications also some of the recent theorizing about innovation.

Interactions are good, but the institutional nature of players should be preserved. The emphasis that the economics of science and technology has put for the last twenty years on the interactions (using a many terms such as: networks, clusters, public/private partnerships, milieu and others), should not hide the fact that public and business players have different incentive mechanisms and priorities which should be preserved. The changing composition of R&D expenditure provoked by the retreat of the public sphere on the one hand and the growth of business investment on the other hand, has already generated and will continue to generate long term consequences in the republic of knowledge. It should therefore be reaffirmed the idea that the main purpose of the public sector is to promote and disseminate good knowledge addressing socially relevant issues. Interactions cannot by themselves be a *substitute* for public funding. Once this basic principle is affirmed, interactions with the business world are welcomed, especially if they are designed to enhance the societal priorities dictated by the government. In fact, personal collaboration has been recognized as a major channel of knowledge transfer between universities and companies (Economic Insight, 2015).

R&D data show a clear pattern: the bulk of the research is both funded and performed either in the public or in the private sector, while the cross-funding between them is scarce and declined. Inasmuch as who puts the money decides the priorities, this result is consistent with our normative view that the priorities of the public and business sectors should be kept separated. We are not claiming that university and industry should not collaborate. Quite the contrary, the fact that the business sector is massively investing in R&D creates the ideal conditions for the industry itself to absorb and benefit by collaborating with the public research. It is in fact well known that business R&D get great advantages from the basic research conducted in universities (Cohen et al., 2002; Pavitt, 1993).

Therefore, reducing the public funding to basic research will ultimately also reduce business opportunities for the industry itself. In fact, in countries in which the involvement of the private sector is more prominent, such as the Unites States, Japan and Korea Rep., the share of basic research performed in the public sector is equal to 68.5, 56.2 and 42.4 per cent respectively in 2012 (OECD, 2014), reflecting a progressive disengagement of the public sector even rom basic research. This has to be taken into account considering that applied research or market-let research is important to fuel countries' competitiveness. While this can be true in the short run, a generalized reduction of basic research will eventually impoverish the sources of competitiveness of the industry. The current trend about the shrinking of public R&D can hence have major negative impact also on countries' dynamic efficiency. The dominance of China in the renewable energy technology sector is a case in point. In a few years, China has become the world leader in this sector boosted by massive investment in research funded by the public sector. Today, out of fifteen public research centres across the world, nine are Chinese, with the Chinese Academy of Sciences featuring as the world's number one public centre (KIK Innoenergy, 2015). Further, public funding to the private sector has often generated concerns for antitrust policies. Close relationship between the public and private sectors can in fact create a number of problems both in terms of antitrust policies, but also in terms of possible moral hazard and other forms of opportunistic behaviours.

What kind of policies do we need to promote research? Over the past years a policy mix approach has been increasingly employed (Rogge and Reichardt, 2016). Crespi and Quatraro (2013, 2015) provided specific arguments on the importance of policy mix variety for promoting new technologies generation for addressing a sustainable growth path in an eco-innovation context (e.g. Costantini et al., 2017). This approach is grounded on the recognition that an integrated framework is needed to address the interaction of different policy instruments, as well as the strong complementarities that exist between technological and market forces. This implies taking into account the possible virtuous interactions between financing basic public research and the creation of new demand from the business sector as new technological opportunities are uncovered. Different policy instruments can play a role, especially those, such as science parks and other forms of dissemination of the results, such as open spaces and living labs, which allow all potentially interested companies to use commercially the knowledge generated by the public sector. To this regard, concerns about a crowding-out on private research from public funded research are less relevant here, since funding pure research is more likely to lead to crowding-in effect; by contrast, the more governments fund public research close to the market, the higher the risk of a crowding-out effect on business R&D. This should be also considered in the light of the two most common public policies for supporting R&D in the business sector, namely R&D subsidies and R&D tax credits. As for the former, more recent empirical research tends to reject full crowding-out effects, hence being in favour of "crowding-in" effects (e.g. Marino et al., 2016). More recently, tax credits have been increasingly employed since they are cheaper to manage and minimize the discretionary decisions involved in project selection. To our purpose, which is attracting companies towards more breakthrough research project, subsidies are better than tax credits. Firstly, tax credits tend to favour short term projects that are not necessarily the projects that would most deserve public support (Atkinson, 2007; Cerulli and Potì, 2012; David et al., 2000). Secondly, because the automatic nature of the process does not allow governments to choose neither the sector nor the type of industry. In fact, according to our framework, in the case of tax credits the allocation mechanism would be closer to the private mechanism described above (see Figure 5), while in the case of public subsidies it would be closer to a public allocation mechanism.

Back to the linear model? – The considerations made above may lead to revaluate the linear model of innovation, which was so influential in the 1950s and 1960s. According to this model, there were logical links between the initial stages of knowledge development, mostly carried out by Universities and other public centres in the form of basic research, and the final stages of commercialization, carried out by profit-seeking companies (for a critique, see Kline and Rosenberg, 1986). This model is too schematic to guide science policy and, inasmuch as business innovation is concerned, has been replaced with models that privilege interactions at different stages of the knowledge-chain and across the various players. When addressing the SPRU 25th anniversary Conference, Nathan Rosenberg (1991) proudly declared that "the linear model is death", and for sure the audience he was lecturing (and Rosenberg himself) contributed to go beyond a rigid notion of how innovation develops. Nearly a quarter of a century has passed since this seminal conference. Over this period, much evidence has been produced on the relevance of loops, interactions, connections and feed-backs from the different stages of knowledge development (Caraça et al., 2009).

But the overemphasis on the importance of loops and the corresponding belittlement of the linear model (Balconi et al., 2010) also had the consequence of neglecting the trend we have singled out above. Short-termism has contaminated also the republic of knowledge that, by definition, provides its best outcome when is long-sighted.

Knowledge in the global arena – We have, so far, discussed the issue with reference to individual nations. But, of course, global interactions are the norm in the realm of knowledge (Archibugi and Filippetti, 2015a). Academe always had the propensity to share knowledge across borders and formal and informal contacts among scholars working in the same issues have been the norm (Heitor, 2015; Hennemann and Liefner, 2015). Over the last decades similar trends have occurred also within the business community (Cantwell and Molero, 2003; Iammarino and McCann, 2013, 2015). R&D intensive companies have increased their propensity to locate their facilities in more than one country, creating intra-firm but international networks. International strategic technology agreements have dramatically increased since the 1980s showing that companies are more willing than generally expected to share their know-how with competitors (Narula and Martinez-Noya, 2015).
In a world of blurred frontiers and where the national dimension of individual companies is more and more identifiable, governments should seriously re-think also their industrial policy based on innovation incentives. The more convincing strategy seems to enhance the capabilities within their territories, upgrading R&D infrastructures and training of qualified personnel. In their investment decisions, companies seem to be more attracted by these local capabilities than by cash incentives.

Governments would carry out their function much better through public international cooperation programmes rather than by supporting companies, especially if they are directed to pre-competitive R&D that could deliver global social benefits. An excellent example is the World Health Organization programme to eradicate small-pox (Fenner et al., 1988). The programme cost was rather moderate (about 300 million US dollars), it helped to eradicate a disease in developing as well as developed countries and contributed to create medical infrastructures in countries that desperately needed them. Such a programme took place between 1967 and 1980 and it is sad to note that in the last 35 years comparable programmes, such as those to fight AIDS, tuberculosis, malaria and polio had so much to rely on private donors (see Archibugi and Bizzarri, 2004; Koenig-Archibugi, 2011; Brown et al., 2014).

6. Discussion and conclusions

This article has discussed a series of facts that are not sufficiently addressed in science and technology policy: the public component of research has been reduced, while the business component is flourishing. On the ground of an analytical distinction which identifies the economic characteristics of knowledge produced in the public and in the private sectors, we have explained why this trend might generate long-term adverse consequences. First of all, because there is no guarantee that market-led opportunities correspond to societal needs and priorities. Second, because an excessive privatisation of knowledge reduces the possibilities of diffusing knowledge. Third, because long-term technological opportunities, especially when they are radical, are often associated to major scientific break-troughs generated by basic research carried out in public institutions. This has happened with electricity and chemicals, ICTs and pharmaceuticals, the global positioning system and the internet, and there is no reasons why this should not be happening again, provided governments are willing to properly support public research.

Our analysis covers a long span of time in which major changes have occurred in the way in which research is carried out and in the role of knowledge in contemporary societies. Knowledge has become the main engine of economic competitiveness of both states and companies, and, as a result, R&D represents the main source of comparative advantage. Looking at the data for 1981 and 2013 we are comparing two different worlds. The Triple Helix studies suggested that the realm of knowledge has gone through major changes and that universities, industries, and governments had greater interactions among them (Leydesdorff and Etzkowitz, 1996). To what extent is this reflected in R&D data? In principle, this should be evident by looking at our hybrid boxes (see figure 5, box 2 and 3) where the business sector and the public sector (both universities and governments) are financing the research expenditure of each other. However, the share of R&D expenditure financed by the private sector and performance by the public sector is still negligible. Further, the share of R&D expenditure financed by the public sector and performed in the industry has shrunk considerably. If the interactions envisaged by the aforementioned studies are actually increasing, they are taking place in collaborations which do not imply cross-financing between the public and the business sectors.

A great shift in the realm of the production of knowledge was already anticipated and advocated, among others, by Gibbons et al. (1994). They claimed that a new mode of knowledge generation is increasingly produced close to the context of application. The business sector has a key role here in consequence of the intensification of international competition. In this sense, the trend about the relative decline of public research that we have outlined here was already predicted. In a rather explicit language, Gibbons and colleagues argued that "this transformation is one of the more far-reaching […] because it involves drawing the universities into the heart of the commercial process" (Gibbons et al., 1994, p. 86). According to this view, the increased pressure of social accountability of publicly-financed scientific research has encouraged to move from curiosity-driven research on fundamental principles towards research closer to the context of application. This has changed the setting of research priorities that are, according to the authors, more adherent to social needs in terms of having greater wealth potential and greater impact on countries' competitiveness. This conclusion seems to be at odd with our claim about the risk that the shift towards the privatization of knowledge bears precisely on setting priorities that are less desirable from a social welfare standpoint.

Two comments are in order here. The first is that shifting the research priorities from fundamental knowledge towards more applied context does not necessarily generate higher wealth creation and long-term economic development. Concerns about the slowdown of innovation and technological progress have been raised recently by Robert Gordon and others (2016). In his influential book, Tyler Cowen (2002) argues that in the early 20th century there were many 'low hanging fruits' for the world economy to collect such as antibiotics, electricity-powered factories, radio, TV, planes and automobiles. But these have all been exploited. As we run out of low hanging fruit, the argument goes, we are likely to run out of rapid technological progress and growth will slow down. Crucially, most of these hanging fruits have been the results of major break-through in basic research. In fact, fundamental research carried out in public organizations is still delivering substantial technological innovation to the business sector. A research on the European Laboratory for Particle Physics

(CERN) shows a great impact of CERN over technological innovation in the business sectors across the most disparate industries, from medicine to electronics, including technologies for cancer therapy, photovoltaic cells, and x-ray (Le Goff, 2011).

The second comment is that social accountability can be defined in different ways. Gibbons et al. (1994) seem to interpret this in terms of activity that generate higher economic payoff, for example by rising competitiveness and economic growth. Others would leave the choice to the market, trusting that 'he market place does not worship false idols, it makes empirically correct judgments' (Kealey, 1996, pp. 344–45). We instead see social accountability more in terms of the process of priority setting. In our view fundamental public research has a better bearing on social desirability when the priorities are set through a political process, which, ultimately, has to be accountable to the society within the democratic process.

According to the collaborative science argument, we are witnessing a paramount paradigm shift in the way science is carried out (Nielsen, 2012). The major driver is the World Wide Web that is making possible to connect not only scientists, but also amateur citizens, that can contribute to substantial advancements in science thanks to an unprecedented mass of data and a distributed and amplified form of collective intelligence. A crucial factor to unleash the potential of this new pattern of collaborative science is the possibility to make an increasing mass of information (e.g. big data, measurements, results of experiments, etc.) freely available and accessible across the whole world. Here the possibility to spread knowledge and information at a cost close to zero is the *condition sine qua non* for further encouraging the democratization of science, while the presence of proprietary forms of IPRs can act as a deterrent (David, 2004).The risk of a privatization of knowledge and information, or a "Second Enclosure Movement" has been also discussed with relation to *knowledge-as-a-common* view, actually by another Nobel Prize winner, namely Elinor Ostrom together with other scholars (Boyle, 2003; Hess and Ostrom, 2006). These studies focus on the *accessibility* characteristic of knowledge as a common, in particular claiming the presence of new risks associated to new technologies that can enable the capture of what were once free and open public goods. We have outlined a similar risk in relation to private-generated knowledge that puts in place a number of strategies to artificially increase the excludability of knowledge. We share the same policy concern: public policy should refrain to use intellectual property in these cases, while it should instead encourage open science through the creation of public open platform to share basic information, such as for example data and basic knowledge.

This discussion is also related to the much heated current debate on the financing of basic research. A techno-libertarian view, recently exemplified by Matt Ridley (2015), argues that innovation is not the result of basic science; quite the contrary, advancements in technological applications close to the market drive research in basic science: 'Deep scientific insights are the fruits that fall from the tree of technological change'. If this was the case, there would be no scope for government intervention to support innovation; at best, 'they can only make sure that they don't hinder it' (Ridley, 2015) since the industry could do it better itself. Scientists have been concerned in recent years not only about the downsizing of funding for public research, but also that governments 'have been overemphasizing "translational research" (e.g. research intended to result in a product or the improvement of a product) at the expense of basic research' (Orac, 2015). We have here argued that it makes a great difference if basic science is carried out in the public sector or by business companies and that this has profound impact on the long-term rate of innovation, economic growth and social welfare.

We are not blind in front of the several problems faced by publicly funded and performed R&D. There is a traditional propensity of academia to close itself into the Ivory Tower and to ignore economic and social life. These issues should be addressed and there is room, through a revision of the incentives and the organization of scientific research, to improve the current situation. But the retreat of the public from the realm of knowledge is not the solution; on the contrary it is aggravating the problem because it forces universities and research centres to please the market, something they are not very good at, while making more difficult what they should be able to do at best, namely to generate good and useful knowledge accessible to all society.

We are also aware that promoting public research for industrial competitiveness is easier to sell from policy makers, especially in periods of dire financial straits, also as a consequence of the recent economic crisis.[7] The support for public R&D by means of taxpayers' money is a delicate matter, since it includes a sacrifice today for future and uncertain benefits, mostly accruing to citizens indirectly. This issue is explicit in the recent emphasis on the *impact for the society* that researchers applying for a research grant of the European Commission should be able to strictly demonstrate. However, it is also true that bad times can represent good windows of opportunities to pursue substantial political shifts (Drazen and Grilli, 1993).

In a world in which Google is carrying out research on artificial intelligence and biotechnologies, large NGOs like the Bill and Melinda Foundation funds research on vaccines, science and technology policy should be able to revisit its prescriptions. We hope to have contributed to shed some light on a major trend that has occurred over the past three decades that has already created social and economic disadvantages.

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[7] In fact both public and private R&D have been reduced as a result of the crisis (Filippetti and Archibugi 2011).

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