The literature on the effects of research and development

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This paper was presented at The XXVIII ISPIM Innovation Conference – Composing the Innovation Symphony, Austria, Vienna on 18-21 June 2017. The publication is available to ISPIM members at www.ispim.org.

The literature on the effects of research and development

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Abstract: The economic return to public and private R&D is of enormous interest to academics and policy makers. First, private returns to R&D appear to be large and larger than the returns to alternative investments. Second, private R&D and R&D subsidies are positively correlated and there is no evidence for crowding out effects. Third, R&D cooperation increases private R&D. Fourth, there appear to exist complementarities between alternative sources of funding. Fifth, the mobility of R&D workers, particularly of university scientists is positively related to an increase in innovation. Sixth, there are many university spinoffs but these are no more successful than non-university spinoffs. Seventh, scientists with a migration background outperform domestic ones. Eights, universities constitute important collaboration partners. Ninth, clusters enhance collaboration, patents and productivity. A problem for economic policy is that little is known about the optimal design of policy measures since most studies analyze a single policy measure only.

Keywords: return to R&D; private return; social return, public R&D, university, innovation; mobility; knowledge transfer; human capital.

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> "There is nothing a government hates more than being well-informed; for it makes the process of arriving at decisions much more complicated and difficult" John Maynard Keynes

1 Introduction

The economic return to public and private R&D is of enormous interest to academics and policy makers alike, since public spending in growth-enhancing areas seems more important than ever given austerity and slow economic growth in many countries. The EU targeted an overall level of three percent relative to GDP in the Barcelona strategy, of which two thirds were supposed to be undertaken by the private sector, is achieved by more and more countries. However, it is also necessary that growth-related innovation projects are the target of the R&D investments.

It is important for a government to be well informed when it comes to prioritizing limited resources. What is the best way to subsidize private R&D? What is the effect of research based education? Good decision-making is based on evidence. The core problem is that evaluating the effects of public funding is not easy. This literature review summarizes the most recent high quality research on the effect of public R&D investment and R&D policies on firm performance to help in decision-making and focus future research policies.

The private sector plays an important role for the discovery and diffusion of new knowledge and technologies. R&D and innovation creates a competitive advantage. However, due to the risky and uncertain nature of R&D projects and the public good characteristics of knowledge, firms tend to underinvest in R&D activities (Arrow, 1962; Nelson, 1959), the private returns to R&D are below the social ones.

Governments hence seek to correct for this market failure in R&D and innovation by balancing public and private returns to R&D by subsidies and other policy measures. These measures may lead to free-riding behavior on part of the corporate sector. Government subsidies may, however, also increase private R&D if public and private R&D are complements rather than substitutes. Our review covers the most commonly applied policy measures to promote research and innovative activity: university research and education, technology transfer, R&D collaboration, tax subsidies, and direct R&D subsidies. We also review the latest literature on the private and social returns to private investment in R&D.

While a lot of ink has been spilled on describing the mapping between R&D policy and R&D outcomes, the empirical identification of causal effects is surprisingly weak. However, the existing evidence points towards generally positive relationships between the various policy measures and corporate R&D. To come to firm policy conclusions, one would need to have much more detailed and comprehensive data on all kinds of national and international policy measure as well as field experiments as they are commonly conducted in labor economics (List and Rasul, 2011).

Our review's focus is on the short run effects of R&D investments as, in fact, there is not much evidence on long-run effects either. The sparse literature on long run effects arrives at very large effects, in particular for technology adoption. Due to the complexity of general equilibrium effects that would also take into account changes in competitive advantage (Acemoglu et al., 2013), we focus on partial equilibrium models.

The focus is on research activities that influence growth and those activities that improve the general knowledge level and wellbeing/quality of life is not included.

2 Research design

The aim of this study is to evaluate the effectiveness of various policy instruments to stimulate investment in R&D and innovation. Capturing the policy instruments, we differentiate our analysis into seven research questions. According to the research questions, we divided our review into four main sections, a chapter on the effects of private R&D (Ch. 1), a chapter on public R&D funding (Ch. 2), a chapter on public research education and the labor market for R&D workers (Ch. 3) and a chapter on knowledge and technology transfer (Ch. 4).

Table 1 Research questions and concepts

Section	Research questions	Concepts
Chapter 1: Effects of private R&D on firm performance and economic growth	(1) What is the effect of private R&D investment on firm performance or economic growth? (2) What is the societal return of private R&D investment?	R&D; effect; firm R&D; effect; societal
Chapter 2: Effect of public funding of R&D	(3) What is the effect of public funding of research on private R&D investment or firm performance? (4) How does the distribution of public funding/research matter for knowledge, private R&D investment or firm performance?	R&D; effect; subsidy R&D; public; fund; distribution
Chapter 3: Labor market for R&D personnel and education	(5) How important is investment in research based education? (6) How important is the mobility of R&D personnel for investment in R&D and knowledge diffusion?	research based; learning; firm R&D; personnel; mobility; diffusion
Chapter 4: Knowledge transfer	(7) What is the effect of knowledge transfer on firm performance or growth?	Knowledge; technology transfer; effect

We base our analysis on a broad systemic literature search. For each research question, we developed a search string using different key concepts. Our search was conducted using ECONLIT and gave 2276 articles from journals for the period 2010 to 2016 and 595 working papers for the period 2013-2016. The search output was screened in a three-step procedure.

The first screening step was based on title and journal, and the second step on abstract. In the final step, we applied a criteria-scoring approach. We read the articles and gave them points according to relevance (0-5 points), importance of findings (0-5 points), and methodological rigor (0-5 points).

The total number of articles entering the screening process is 2276. Table 2 shows how the 2276 articles were distributed by research questions. A similar table is provided for working papers (can be provided by the authors). The initial search produced a huge number of papers that was of little interest for the review. 592 went into the abstract screening process, and have been re-distributed to the related research questions. In this stage, we excluded a number of papers, i.e. papers on emerging, transitional, or developing economies; papers with too narrow an industry focus; comments and book reviews; and qualitative research that lacks an empirical foundation. Finally, 204 papers went into criteria screening process, which is based on methodological rigor, relevance for the report, and importance of findings for the report.

We defined a score threshold, which the papers should pass to enter the review. The threshold was not the same across research questions, because i.e. methodological rigor differs, and we took that into account be lowering the standard in research questions with low scores. The resulting sample of papers was 101.

Table 2 Search results for articles in journals.

Research question	#of hits	#screening on title	#screening on criteria
(1)	1115	460	48
(2)	396	48	36
(3)	229	17	54
(4)	139	31	27
(5)	57	21	24
(6)	37	15	14
(7)	303	84	46
TOTAL AMOUNT	2276	592	204

We did a similar screening on working papers from ECONLIT. However, we were much stricter on relevance, because the working papers have not been peer reviewed and they do not necessarily live up to the scientific standard of peer reviewed papers. In addition, we wanted to include grey literature in the search. We compiled a list of homepages that was manually searched for relevant literature. Most of this literature was like working papers not peer reviewed. Again, we were stricter on relevance. Most of this literature was like working papers not peer reviewed. Again, we were stricter on relevance. The full list of grey literatures is available upon request by the authors. We did not score the grey literature like journal articles and working papers in ECONLIT. The reason is that these reports are seldom well documented, which makes it hard to judge their quality.

Despite the broad systematic search, we did not cover certain areas particularly well. we cover macro effects but in a limited sense. Most of our papers are based on micro data and almost exclusively on partial equilibrium models. In principle, these effects are also the macro effects. At least two important aspects must be taken into account. First, the sample must be representative, which is often not the case. Most studies are based on innovative firms, which is a just a small (but important) subpopulation of the population. Second, partial models ignore general equilibrium effects. The latter include price effects but also that competition induced by innovation can have some very important negative consequences. There is some recent literature that includes these effects (Acemoglu et al. (2013). However, these models, which are highly complex, do not solve the hard to do identification of knowledge spillovers, and only include heterogeneity, which is found as very important in all micro studies, in a limited way, are not part of the review.

3 The literature review

3.1 Overview of the review

Our review falls into four core chapters, the effects of private R&D on firm performance and economic growth; public funding of R&D investment; public research education and the R&D labor market as well as the effect of knowledge transfers on firms. Figure 1 shows how these four elements relate to one another.

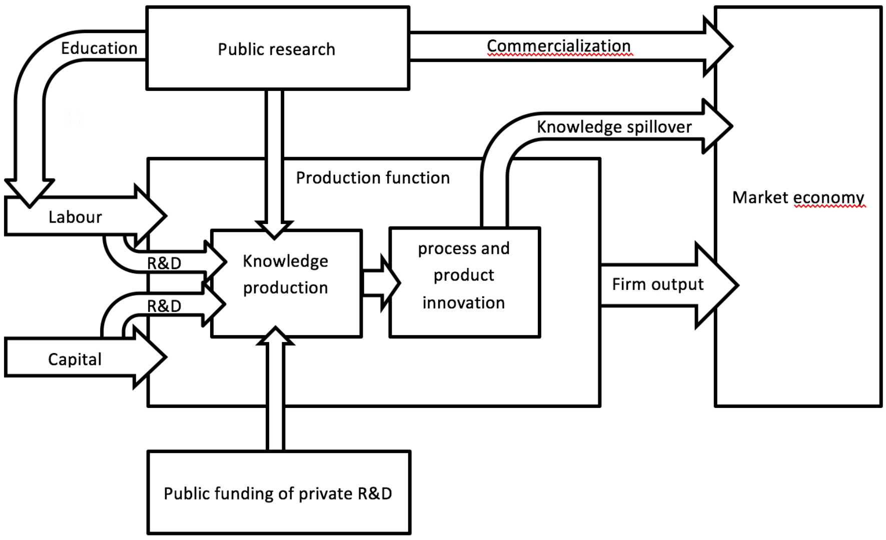

Figure 1 A simple model of R&D investment

The cornerstone of the figure is the knowledge production function of private firms and the R&D spillovers to rest of the economy. Chapter three of our review deals with the private incentives to invest in R&D and the knowledge spillovers to other firms.

The remaining three chapters deal with the environment out of the private sector R&D box and primarily study the role of the public sector. In chapter four we review the effect of direct public funding for private R&D investment. We specifically cover direct subsidies and tax incentives. In chapter five we analyze the role of public research as a knowledge supplier and producer of skilled labor. Our sixth chapter is concerned with knowledge transfer between the public and private sector like commercialization of research, collaboration between public research and private research.

We have covered the most important channels from R&D investment to market economy in the review. However, there remain a few other channels that we do not cover. First, we have not touched upon innovation that is not related to R&D, like organizational and marketing innovation. Research-based education, in particular in social science and humanities, is important for these types of innovation. Second, we did not deal with rent spillovers which occur when firms purchase products with embodied R&D and where the product price may not fully cover the value of the product. This channel seems to be important in the long run, when technologies are adopted.

3.2 Findings

Table 3 summarizes the main findings. In most cases, we are unable to give a precise summary of the size of the effect on the economy. The reason is that the studies in these areas are incomparable despite being numerous there is too much heterogeneity. Therefore, the best we can do is to indicate the general sign of the average effect and how much evidence is found for the effect.

Table 3 Results on the economy.

	Average effect	Evidence
Private R&D investment	20%-30% IRR	Strong
Private R&D knowledge spillovers	Not negative	Robust
R&D subsidies	Positive	Robust
R&D taxes	Positive	Robust
Education	Positive	Robust
Public research	Positive	Robust
Labor mobility	Positive	Robust
Technology transfer	Some positive	Modest

Note: IRR is the internal rate of return

3.2.1 Private and social return to private investment in R&D

> "As all economics data files have weaknesses – measurement error, unmeasured variables, sample survey quirks – and all model specifications are questionable, contaminated by data mining, any 'finding' ought to be replicated on several data sets and under 'plausible' model specifications before one accepts it as valid" (Freeman, 1989, p. xi)

The literature shows that private rate of return to R&D is positive, significant and higher than the rate of return to other types of capital. Most of the studies find that the annual rate of return is between 20% - 30%. But, the effect ranges from 3% to 66% in the review, and different data, different definitions etc. are driving some of the differences in results. There is some evidence that investment in R&D has a diminishing rate of return as investment in R&D increases. The evidence is most clear for the manufacturing sector, as most studies pertain to that sector. However, increasingly more studies are analyzing the service sector and the results are comparable in magnitude with the manufacturing sector with respect to the rate of return. Across industries, the high-tech sectors have better technological opportunities and invest more in R&D. There is some evidence that the rate of return is higher in these sectors, which is due to more uncertainty (radical innovation) and higher depreciations.

A number of papers utilize multi-country dataset to investigate the difference in the rate of return between countries. The type of study is interesting from a policy perspective, because this provides evidence of the importance of innovation systems. The evidence shows that EU countries have lower investment in R&D than in the US, but the EU also has a lower return to R&D. This points at a superior US innovation system compared with EU. The results for Denmark are in line with the literature and we find that the rate of return is in the range 20% to 30%.

In the literature on the social rate of return to R&D, the estimate is found to be (much) larger, 2-3 times, than the private rate of return to R&D, indicating that the knowledge spillover effect to other firms potentially is large. The most common transmission channels of knowledge are technological and geographical proximity and both channels seem to be important, and one does not appear more important than the other. The spillover effect is positive intra-industry, inter-industry and international. In a small open economy, the international channel plays a larger role than the other channels relative to large countries. Business stealing and product market rivalry have found to have negative spillover effects. Although not of the same magnitude as knowledge spillover.

A key problem with the literature on spillovers is that knowledge transfers are not observed; instead, the literature approximates the channel with other measures of closeness between entities. The estimates are therefore likely to be biased, because not only knowledge might flow between entities, and given the enormous variation in (mainly positive) results must be said to give very weak evidence. Data that directly addresses knowledge flows are scarce and not representative for economy.

3.2.2 Public funding of R&D investment

> „The prevalence of innovation market failure and underinvestment in technology implies the need to establish a long-term institutional framework for the support of basic research, generic-enabling research, and commercialization.“ (Martin and Scott, 2000, p. 445)

Generally, the studies after 2000 on the empirical evaluation of direct public R&D support clearly lead to the conclusion that there is substantial empirical evidence that public R&D subsidies succeed in stimulating private R&D investment, and some empirical evidence that direct R&D support can enhance innovation outcomes such as patens, innovative sales, and R&D employment as well as productivity.

The current understanding in empirical research on the effects of tax credits leads to the conclusion that tax credits can stimulate private R&D investments. Tax credits increase the amount of corporate R&D efforts, and lowers its marginal costs.

Both policy instruments are able to stimulate R&D in the private sector. Empirical studies suggest, that tax incentive schemes are effective in the short-run, and constitute effective means to increase R&D efforts in SMEs, and low-tech sectors, and countries with an incremental incentive schemes. Notably, the tax incentive schemes need to be designed in accordance to the general tax scheme. Direct public R&D subsidies require a minimum amount of grant size, and time in order to create additionalities. Empirical evidence shows that direct subsidies are especially effective to stimulate innovation in areas with higher degree of innovation novelty. From a policy perspective, building on Guellec and Van Pottelsberghe (2003) we would like to draw some general policy recommendations. First, any type of policy instrument is more likely to show the desired effects, if the policy is integrated in a long-term policy framework and somehow stable over time. The positive effects might be related to the decrease in uncertainty for firms, and hence enabling better strategic planning and coordination. Second, there should be consistency between the policy instruments with each other which requires coordination and management between the agencies involved. Third, positive effects from public funding for R&D in the private sector require a certain amount of governmental support, hence the subsidy should either not be too low nor too high. Fourth, the policies instruments and schemes (e.g. awarding criteria, level of grants) should be designed in alignment with the national innovation system, and the national or regional industry structure.

3.2.3 Public research, education and labor mobility

The literature on the link between public and corporate research is vast and shows that public research institutions have a significant economic impact on industrial research. To study these relations, scholars have mostly used patent citations and survey data. These data show that public research crowds in rather than crowds out private R&D. Scholars have recently begun to use register data coupled with patent and patent citations data as well as survey which allows them to track the entire working history of individuals. The corresponding studies show that there is a statistically and economically significantly positive link between the public and the private sector for innovations. Most studies do, however, focus on a few high technology sectors while little is known about public research effects on low tech industries. Existing research has so far ignored reverse relationships from industry to university.

The training of qualified research workers constitutes an important mechanism through which university research affects industry. Studies have shown that these movements constitute an important mechanism through which academic knowledge disseminates. Another mechanism of knowledge transfer is the startup activity of graduates and post-graduates. The evidence on their importance to date is scant, in contrast to the research literature on direct university spinoffs. Existing research does, however, show that the number of startups founded by (post-) graduates is rising and that these startups do at least as well as other startups.

A key problem with the literature on the effects of universities on industry is that causal effects are inherently hard to identify as the sorting and matching of workers is non-random, knowledge flows between university and industry may be bi-directional and international mobility is characterized by self-selection. Quasi experiments of the type conducted by Alslev Christensen et al. (2016) would constitute an important step towards a more proper assessment of university-industry interactions.

Our review also shows that there is a positive relationship between the mobility of labor and corporate innovation as well as knowledge diffusion. In addition, mobility does not even appear to be a double-edged sword as existing studies show that both patenting and knowledge absorption of the firm that loses a worker can increase due the leave of R&D workers. This implies that policies restricting labor mobility have a negative effect on innovative activity and knowledge diffusion. The use of register data, and identification of individual inventors in this data as well as the design of an appropriate empirical identification strategy would constitute important next steps in our understanding of the mapping between labor mobility and innovation.

A second key purpose of universities apart from educating labor is the generation of knowledge, of course often indirectly transmitted through qualified academics. There exists a vast body of evidence showing that proximity to universities increases industrial innovation, which universities constitute an important source of information for industrial innovation and that universities not only increase innovation but also enables firms to tap into new technology fields. These studies are often empirically not particularly well identified and solid evidence for Denmark is lacking. The existing evidence does, however, indicate that universities do not only constitute important contributors to industrial innovation through education but through knowledge generation as well. University-based research has a very long tail and may affect industry with a delay of up to 20 years. It hence seems advisable to maintain basic “blue sky” funding to universities to lay the fundament for future industrial innovations by encouraging basic science.

3.2.4 Knowledge transfer and firm performance

Literature has pointed out that knowledge and technology are important characteristics of innovation and constitute important drivers for economic growth. Our review also focuses on how technological knowledge created at universities can stimulate private sector R&D and contribute to industrial innovation. This is due to the fact that there are complementarities between university research and private R&D (Nelson, 1986). In addition to public support mechanisms such as subsidies and tax incentives which are designed to increase input additionalities such as R&D investments in the private sector, additional policy measures support the commercialization and diffusion of technological knowledge from universities and other research institutes. To review the effects of knowledge and technology transfer from academia to the private sector, we account for policy instruments such as, research partnerships, research services including academic consulting, technology transfer offices, academic entrepreneurship (i.e. academic spin-offs), intellectual property rights, and further entrepreneurship and technology policies. Taking all together, these public support policies address the market failure in R&D and innovation, and aim to contribute to increase innovation in the private sector.

Generally, universities and industry have become increasingly connected due to policy pressure to contribute to national competiveness. This interconnectedness is indicated by more patents from universities, higher revenues created from licensing, increasing engagement by university scholars in academic entrepreneurship, higher industry funding, more established technology transfer offices (TTOs) and science parks. Research shows that firms using both internationally and domestic technology transfer mechanisms can reap the largest impact on productivity, whereas firms relying only on domestic technology transfer can harvest no additional effect.

Importantly, our review finds that a broad accepted empirical evidence on transfer mechanisms is lacking. Hence, we focus on individual studies addressing the specific policy measures indicated above. First, a very commonly practiced policy measure to increase industrial as well as academic innovation constitute university-industry partnerships. We find, that these research partnerships have a positive effect on innovation. However, there exists a lot of heterogeneity. In particular, large firms can benefit when opening-up towards science partners for radical and incremental innovations. Small firms have more difficulties to collaborate with science partners (i.e. with respect to incremental innovations). There is some evidence, that industry-science collaboration can better increase product innovation, but less process innovation. Further, industry collaboration with research intensive universities has positive effects on productivity. Noteworthy, the effects of research partnerships should retain a lot of attention by policy makers, as it constitutes a very important and frequently used policy measure and receive a lot of public funding. Second, research services in form of academic consulting constitute for R&D executives in industry a very important means of technology and knowledge transfer. Empirical evidence on academic consulting is however missing, with one exception which indicates no significant effect. Third, there are mainly studies on technology transfer offices highlighting appropriate configurations of TTOs, but there is only very little robust evidence on the outcomes of TTOs. Fourth, an increasingly popular policy instrument is academic entrepreneurship in terms of academic spin-offs, science parks as well as academic clusters and incubators. Findings show that economic impact of academic spin-offs exceeds governmental funding, which means that the public money is well invested. Generally, review the literature on the outcomes of academic entrepreneurship measures, we found a lot of heterogeneity in the studies. Nonetheless, one can state, that there are more academic spin-offs than "ordinary" start-ups, but not they do not necessarily perform "better". Our reviews find that results on the effects of incubators are mixed, science parks obviously increase collaboration, and in particular industry-science collaboration. With respect to the outcome effects of clusters, there exist only few empirical studies. These studies report an increased likelihood to become innovators due to collaboration. In particular, collaboration with public research institutes is promoted within clusters. In addition, clusters lead to an increased availability of suitable R&D labor. Importantly, results on clusters show that distance matters. There are positive effects of being located in a cluster, and these effects are strongest for Biotech firms. Overall, we find that establishing a network of wide-range collaboration within and beyond the cluster is of importance for the effectiveness of clusters. Fifth, there is not much empirical literature on the outcome effects of Intellectual property rights. Our review points out that licensing has large effects on GDP, industry output, and employment. Last, there exists almost no robust empirical evidence on the effectiveness of appropriate policy mixes. Studies without the claim of causality highlight the synergies between university and industrial R&D leading to higher sustainability of firms. Generally, literate emphasizes that university R&D can play an important role as an 'entrepreneurial mediator' in a region with high entrepreneurial activity.

Like in the previous paragraphs, the availability of data, and appropriate empirical evaluation strategies would enhance our understanding about the effects of knowledge and technology transfer.

3.2.5 Other results

The composition of public research activities, i.e. basic versus applied, competitive versus non-competitive, and research fields, was part of our study. We did not find much literature on these subjects, and we are unable to come up with results. Public research activities are such a large share of the public research budget, and this drives a need for evaluation. Many of the public research activities are expected to have long-term impacts and it might be very important for the long run innovative competitiveness of the economy. In particular, universities are educating labor, which the literature has shown is important for innovation and growth, but exactly how important research activities on universities are for this effect, we do not know much about.

4 Conclusion

Even though the literature reviewed in this survey is generally based on quite weak empirical identification, there are some broad findings existing work has so far produced. First, the private returns to R&D appear to be large and larger than the returns to alternative investments. Second, private R&D and R&D subsidies – be it in the form of tax deductions or direct subsidies – are positively correlated and there is no evidence for crowding out effects. Third, the mobility R&DF cooperation increases private R&D. Fourth, there appear to exist complementarities between alternative sources of funding. Fifth, the mobility of R&D workers and in particular movement of university scientists to industry is positively related to an increase in corporate innovation. Sixth, there are comparatively many university spinoffs but these are no more successful than non-university spinoffs. Seventh, scientists with a migration background outperform domestic ones. Eights, universities constitute important collaboration partners. Ninth, clusters enhance collaboration, patents and productivity.

A problem common to much of the literature reviewed in this survey is that it measures simple correlations. Few studies use quasi-experiments or sensible instrumental variables estimation. It hence appears difficult to arrive at sharp policy conclusions. By the same token and given the vast amounts of money spend by governments on R&D all over the world it seems advisable to allocate some of these funds to policy experiments as it common practice in labor economics. Better data simply leads to better – better identified and more comprehensive policy advise.

Another problem for economic policy is that little is known about the optimal design of policy measures since most studies analyze a single policy measure only. This prevents an analysis of how different policy measure should be combined and how large each component should be. Similarly, little is known about the long-run effects of government intervention.

With respect to labor mobility, the presumption that mobility of university scientists to industry enhances corporate innovation ignores that such moves entail a loss to academe that has not yet been quantified.

A final problem is the aggregation of the primarily micro-founded results. The analyzes covered in this review are all partial and do not consider second order effects like changes in the competitive environment due to innovation. It seems, however, to be a bit premature to tackle the aggregation problem as long as the microfoundations are so weak.

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