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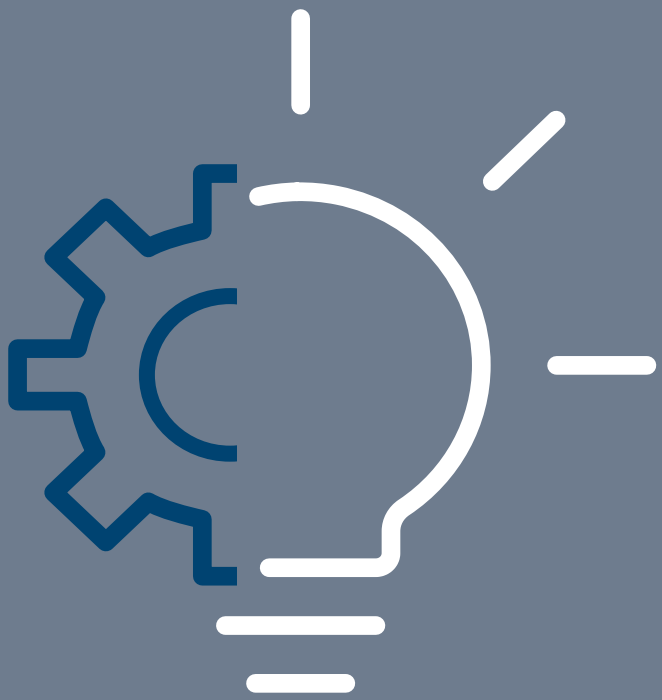

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Innovation Policy

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Innovation Policy and Causality

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INTRODUCTION

A classic result in innovation economics states that firms tend to underinvest in research and development (R&D) compared to a socially optimal level. This is due to the public good character of knowledge, which prohibits firms from fully appropriating the returns to innovation (Arrow 1962). To overcome this market failure, most countries have policies in place that are supposed to increase the incentives for knowledge production. First and foremost, governments sponsor education and basic research at universities, and subsidize the supply of skilled labor in that way. More directly, the patent system is meant to improve the opportunities to appropriate gains from innovation by granting temporal monopoly rights to inventors. On the input side, tax benefits can reduce the costs for firms to engage in R&D. Lastly, R&D grants represent perhaps the most direct form of subsidizing knowledge production, because governments cover a share of the costs of a proposed innovation project.

The total amount of taxpayer money paid out as R&D grants in Europe is not negligible. Direct government support for R&D amounted to, on average, 0.64 percent of GDP in the EU28 in 2017.[1] Naturally, the question arises whether this money is well spent. Or, asked differently, are R&D grants effective at incentivizing firms to invest more in knowledge production and at stimulating growth? There are good theoretical arguments to believe that this is the case. By contrast, it is also possible that firms simply substitute grants for what they would have anyway spent on research. If such a crowding out of private R&D occurs, grants will be nothing more than a cash transfer that will have no noteworthy effect on overall investment levels in the economy. To discriminate between these two hypotheses and check whether R&D grants achieve their goal, an econometric policy evaluation becomes necessary. Economists have developed a variety of tools for estimating the effect of grants on innovation and growth with the help of statistical analysis.

One of the challenges that need to be overcome in policy evaluation studies is that there is hardly any experimental evidence related to R&D grants. An experiment would involve randomly partitioning a population of firms into a treatment and a control group. The treatment group then receives financial support, while funding is denied to firms in the control group. Differences measured in performance between the two groups would in this case be directly attributable to the grant.

Governments are – understandably – quite reluctant to engage in this kind of experimentation. R&D grants can be large, often worth several tens of thousands of euros. Handing them out randomly, without extensive due diligence, could be met with significant resistance by taxpayers. Therefore, in the overwhelming majority of cases, evaluators have to work with ex-post observed data collected from subsidy pro-

Figure 1

Graphical Illustration of the Confounding Problem

Note: The evaluator's goal is to estimate the causal effect of R&D grants on firm growth and innovation (depicted by the solid arrow connecting the two variables). However, differences in firm characteristics between funded and non-funded firms can lead to a correlation that does not reflect any genuine causal relationship. Not all of these confounding firm characteristics might be observable to the evaluator.
Source: Authors' illustration.

[1] Source: Rathenau Institute https://www.rathenau.nl/en/science-figures/investments/international-perspective-rd-investments/government-support-rd-gdp

grams where grants have not been allocated randomly, but instead a certain number of firms have been hand-selected from a list of applicants. This, as the present article argues, renders the econometric policy evaluation task much more complicated. In particular, the lack of experimental evidence makes it hard to quantify the causal effect of R&D grants on firm performance, which has to be distinguished from a positive correlation that is merely the result of picking already high-performing firms for funding. In the following, we will explain this causal inference problem in more detail and discuss a number of recent papers that have successfully tackled it.

THE CONFOUNDING PROBLEM IN POLICY EVALUATION

Causal inference lies at the heart of econometric policy evaluation. In order to assess the cost-efficiency of their interventions, policy-makers need to know whether R&D grants are effective at influencing key target metrics such as firm growth and innovation. Formulated in counterfactual language, the relevant question is: "Would firms grow slower, or be less innovative, if they had not received a public R&D grant?". This is a causal question. The policy evaluator's job is then to quantify this counterfactual by estimating the magnitude of the stipulated causal effect (depicted by the solid arrow connecting *R&D grants* and *Firm growth & innovation* in Figure 1) with the help of econometric methods.

Ex-post policy evaluation is plagued with several technical difficulties though. One of the most pressing is the so-called confounding problem (Bareinboim and Pearl 2016). R&D grants are rarely given out randomly. Therefore, funded firms will differ from non-funded firms along several dimensions. In the case of R&D subsidy programs, the selection process usually entails two stages. First, a firm needs to decide whether it will apply for an R&D grant. This decision depends, among other things, on whether the firm has a suitable project idea, how costly it is to apply, the availability of other funding opportunities, and the general entrepreneurial orientation of the firm's management team (Covin and Lumpkin 2011). Second, the quality of the submitted project proposals has to be assessed, which is usually done with the help of independent technical experts. Only the best-evaluated proposals will then be chosen for funding. Selection criteria at this stage can range from general firm characteristics such as size, age, or a firm's industry, to more specific indicators based on detailed project descriptions contained in the application files.

If left unaccounted for, differences between funded and non-funded firms resulting from the selection process can significantly affect the outcome of evaluation studies. Think of an example where evaluators systematically favor firms in industries with high average R&D intensities. These high-tech firms are likely to be more innovative and grow faster than firms operating in less dynamic sectors. A naïve comparison of firm growth between funded and non-funded firms would then suggest higher growth rates in the former group, even if R&D grants had no causal effect whatsoever on innovative performance. This is the confounding problem. In order to tackle it, evaluators need to account for any confounding influence factors in their analysis. By assessing the effect of R&D grants separately for firms in high- and medium-tech industries, for example, sector-specific differences can be eliminated.

However, for such a strategy to work, all confounders need to be observable to the researcher. And this is rarely the case unfortunately. Firm characteristics such as size, age, and industry are relatively easy to obtain from standard firm-level databases. By contrast, many other variables relevant for the funding decision often remain unobserved (depicted by the dashed arrows in Figure 1). To overcome this problem, it is of crucial importance that program agencies collaborate with researchers and make their internal records (i.e., project descriptions, internal selection criteria, financial indicators, etc.) available for evaluation purposes. Even then, however, it is quite likely that unobservable confounders will remain. Firms with a higher entrepreneurial orientation and better management quality, for example, apply more frequently for R&D grants and are also more successful in the selection process. These variables, which are notoriously difficult to measure, will exert an effect on future performance and thus bias the results of the evaluation.

RECENT CAUSAL EVIDENCE FOR THE EFFECTIVENESS OF R&D GRANTS

Zúñiga-Vincente et al. (2014) provide a comprehensive overview of the state of the literature on R&D subsidies at the time of their writing. The systematic review includes 77 papers that empirically investigate the relationship between public financial support and company-sponsored R&D. Only very few of these studies, however, adequately take the confounding problem into account. It is therefore not surprising that in a majority of cases (60.17 percent), the researchers conclude a positive effect of grants on internal R&D expenditures. This positive correlation could simply be due to a selection of already highly innovative firms into funding and thus need not reflect a genuine causal relationship.

Since then, however, a couple of other papers have been published that provide more convincing causal evidence. Using an instrumental variable approach – an econometric technique that is able to deal with unobserved confounding – Einiö (2014) establishes a positive effect of public financial support on R&D expenditures, employment, and sales in a sample of Finnish firms. Likewise, using instrumental variable tools, Aguiar and Gagnepain (2017) find positive effects of European Framework Programme grants on the labor productiv-

ity of participating firms, while they can detect only a very limited effect on profit margins.

Two more recent papers investigate the effectiveness of R&D subsidies with the help of a so-called regression discontinuity design (RDD). This particular econometric evaluation technique relies on information about program-specific evaluation scores and compares only firms that obtained project evaluations very close to the program's minimum threshold for funding. As a result of this sample restriction, funded and non-funded firms can be assumed to be very similar with respect to the quality of their innovation projects, as well as other unobservable characteristics, which solves the confounding problem. Making use of the RDD in a sample of firms from northern Italy for the period from 2000 to 2007, Bronzini and Iachini (2014) find no effect of R&D grants on general investments (not specific to R&D). Only when they split the sample into small and large firms are they able to detect a positive effect for SMEs. By contrast, according to the evidence presented by Howell (2017), public SBIR grants in the United States had an unambiguously positive effect on a range of performance indicators, such as patents, revenue, and the likelihood of obtaining follow-up funding from private VCs.

Overall, the causal evidence presented by recent studies seems to be rather mixed. Effect estimates show a fair amount of heterogeneity across samples and outcome indicators. This calls for further research on the topic.

EVIDENCE FROM EUROPEAN JOINT PROGRAMMING

In Hünermund and Czarnitzki (2019), we present novel evidence from a European-wide subsidy program to contribute to the ongoing debate about the effectiveness of public R&D support. The program, with the name Eurostars, is an example of the newly emerging Joint Programming Initiatives, which aim to support cross-border research collaborations in Europe. It combines financial contributions from 33 countries (including five non-EU members). In our period of observation, between 2008 and 2013, the program allocated a total budget of EUR 472 million, of which 25 percent was co-funded by the European Commission.

Due to their international scope, Joint Programming Initiatives employ a rather complicated budget allocation rule – a so-called Virtual Common Pot (VCP) – that is designed to avoid cross-subsidization between countries. In Eurostars, project proposals are required to be submitted by at least two international partners and all proposals are evaluated centrally. However, each participating country funds only its respective participants. This means that in a project consortium of two firms from Belgium and Germany, the Belgian partner would receive financial contributions exclusively from the Belgian authorities, while the German firm would receive funding only from the German authorities. If one of the countries involved uses up its earmarked budget, the entire project cannot be funded anymore. Due to these additional national budget constraints, the VCP partly offsets a selection of project proposals based on quality. It would, for example, be possible for another Belgian firm with a lower-ranked project to receive funding, if it teamed up with a Dutch instead of a German firm, assuming that the binding budget constraint was the German one (which is not an unrealistic example, since the German contribution to Eurostars was relatively low compared to the number of grant applications that were submitted).

In our paper, we make use of this VCP budget allocation rule to tackle the confounding problem. Our identification strategy basically consists of comparing direct neighbors in the project evaluation ranking, of which some received a grant and others were denied funding because their respective national budgets were already depleted. This is an improvement over standard regression discontinuity designs, since a VCP induces variation in funding not just at one particular threshold, but in a wider region of the evaluation ranking, which makes the results more generalizable. Our analysis shows that Eurostars grants had on average no effect on employment growth, revenue growth, and patenting. This rather disappointing result masks a large effect heterogeneity, however. For projects with relatively high evaluation scores, we find a substantial positive impact on employment and revenue growth (the effect on patenting remains insignificant throughout). Firms with low-ranked projects, by contrast, do not benefit from grants, which contributes to the relatively low average impact we find.

This effect heterogeneity has implications for the optimal design of Joint Programming Initiatives. Due to the additional national budget constraints, a VCP tends to allocate funding to projects with lower evaluation scores (since selection into funding is not based entirely on project quality anymore). Because grants have lower beneficial effects for these types of projects, a VCP thus reduces the average impact of the program. According to our estimates, this reduction can be up to 50 percent compared to a situation where there was only one single program budget.

CONCLUSION

There is a great deal of empirical literature on the relationship between direct R&D grants and firm-level variables, such as investment and performancee. However, most studies fail to meet the necessary standards for causal evidence (David et al. 2000). Isolating the causal impact of grants is thereby of essential importance for assessing the cost efficiency of a policy. A positive correlation alone is not very informative, if it is merely the result of a selection process that favors higher-performing firms to begin with. Thus, without taking the problem of potentially unobserved confounding influence factors into account, econometric

evaluation studies are not able to tell whether public R&D grants are worth their money.

In recent years, a handful of papers have been published that apply more rigorous methods in order to overcome these shortcomings of the prior literature. The limited evidence that we have so far provides a mixed picture though. Overall, there seems to be a tendency towards finding positive effects. However, estimation results vary widely, not only across but even within studies. Whether R&D grants prove to be effective appears to depend a lot on particularities such as the specific performance indicator considered or the geographical and temporal context in which the data was obtained. Therefore, we are still far away from having robust, generalizable causal evidence on how well direct innovation policy measures actually work. More research will be needed. In particular, future studies should assess the circumstances under which grants are most likely to be effective. In addition, more focus should be placed on researching the optimal design of policies. Which features of an R&D subsidy program are essential for maximizing its impact? And what types of firms benefit most from receiving a grant? These kinds of questions are highly relevant for practical policy-making and academics should start to investigate them more thoroughly (Duflo 2017).

In order to facilitate this research program, however, increased cooperation from government agencies will be necessary. Recent calls for more evidence-based policy-making and evaluation plans that are already built-in at the start of a program are very welcome. Nevertheless, in order to tackle the causal inference problem, governments should also become more open to the use of experiments in R&D policy evaluations. Reservations against experimentation in this area are quite understandable. The sums of money involved are large and taxpayers might therefore not be too enthusiastic about a random allocation of grants. One way to overcome this resistance could be to use pilot studies, which would systematically test the effectiveness of design features on a smaller scale, before the program is eventually scaled up to the entire population. This is a well-established strategy, for example, in development economics (Duflo et al. 2008). Experimenting should be seen as a worthwhile investment in our knowledge of how to design more effective innovation policies. As is characteristic for investments, this might initially be associated with higher costs, which will hopefully be outweighed by larger social returns in the future though.

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Innovation Policy in Poland

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The pursuit of efficient innovation policy requires vision, institutional capabilities, and adequate government funding. It also assumes that there are businesses willing to innovate and – in this respect – to cooperate with government agencies. In a middle-income country, especially in one that has been engaged in a range of social and economic reforms, the conditions for successful innovation policy are particularly hard to meet, and Poland is a good example of this difficulty. However, Poland is also a story of clear progress in innovation policy formulation and implementation, one that has been vastly aided by EU structural policy.

THE EARLY TRANSITION DIFFICULTIES

As noted by Woodward et al. (2012), for more than a decade after 1989, science, technology, and innovation (STI) policy in Poland was low on the priority lists of policymakers, who were occupied first with key economic reforms and then with EU accession. Three specific aspects of STI policy illustrate this negligence well.

First, the institutional setting underpinning direct innovation support for firms took a long time to develop. The first specialized government actor, the Agency for Technique and Technology (ATT), was created in 1996, and it remained a minuscule organization (a staff of fewer than 40 people, and an annual budget of EUR 1–2 million, Donocik 2010) until 2002, when it was absorbed by the then formed Polish Agency for Enterprise Development (PARP). That agency was designed mainly to promote entrepreneurship and SMEs, but it also became the chief actor in innovation policy implementation in the first ten years following Poland's EU accession in 2004.

Second, before the EU accession, the scope of innovation support for firms was minimal. According to data from the Community Innovation Survey for 1998–2000, the first edition in which Poland participated, the share of medium and large manufacturing firms that received innovation support in Poland was 2.88 percent (the reason we look at medium and large firms is that they are better surveyed in CIS). The respective numbers for some other Central and Eastern European countries were: 8.45 percent in the Czech Republic, 12.77 percent in Hungary, and 9.61 percent in Slovenia.

The third aspect that illustrates the failure of STI policy after 1989 is the problem of public R&D institutes. The network of R&D institutes inherited from the Communist period mirrored the industrial structure of the Polish economy before 1989. Economic transformation in Poland came with the deepest structural changes in the region (Marczewski and Szczygielski 2007) and it involved the privatization or bankruptcy of large state-owned enterprises (SOEs), which had been the main partners of R&D institutes during Communism. Although the private sector expanded rapidly, it consisted mainly of SMEs that had neither the potential nor the interest to cooperate with R&D institutes in technology development (Woodward 2004). Policymakers failed to respond to the increasing mismatch between science and industry either by privatizing the R&D institutes together with "their" SOEs or reforming the R&D sector. The institutes continued to operate under the same legal framework as before (the 1985 act was revised several times but replaced only in 2010), and most of them relied mainly on modest block grants from the government (some even pursued activities not related to R&D, like renting their venues). While there were some cases of institutes that developed world-class R&D and maintained closed links to industry, these were an exception.

Importantly, these three specific areas are but some of the examples of how STI policy was marginalized in Poland in the 1990s and early 2000s. Other problems (some of which continue to this day) were: the severe underfunding of basic research, the unstable and discouraging tax policy, and the lack of coordination between government bodies relevant for the national innovation system.

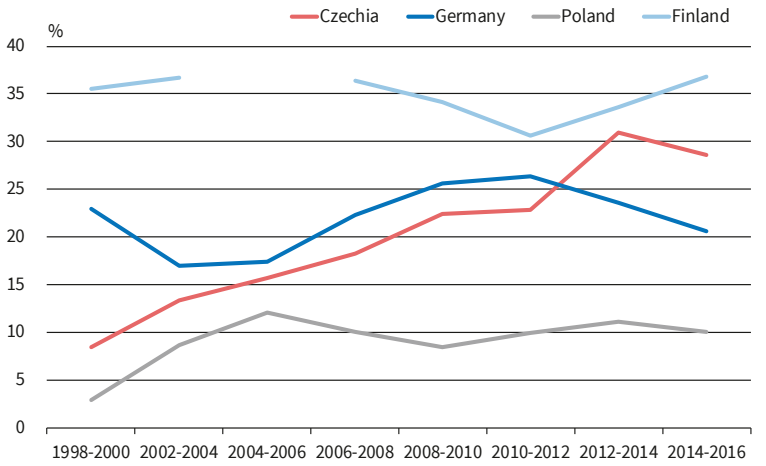
THE POST-ACCESSION SHOCK

It is fair to say that Poland's accession to the European Union on May 1, 2004 marked a breakthrough for national innovation policy, and especially for direct aid for firms. Innovation support for companies, which was probably not more than a few million euros per year before 2004, increased to more than EUR 500 million in 2008 thanks to the EU's structural policy, and it reached more than EUR 1.3 billion in 2010 (Kapil et al. 2013). The fraction of (medium and large) firms that received public support of innovation quadrupled between the 1998–2000 and 2004–06 periods (Figure 1). The money was disbursed mainly in the form of grants and matching grants by different national and regional "operational programs" (OPs). Of these the most important was the "Innovative Economy" OP, which accounted for about 86 percent of all innovation-related funding. The European Union financed 85 percent of the programs, while the rest was provided by the Polish government.

Faced with the challenge of spending the biggest innovation policy budget in the country's history, the policymakers played it safe. The priority was to maintain transparency and to avoid fraud while disbursing as much of the available funding as possible (Szczygielski et al. 2017). More than half of the money spent in 2004–10 funded the acquisition of machinery and equipment (also software and intellectual property rights to a small degree), while the rest was spent on

Figure 1

Medium and Large Firms that Received Public Support for Innovation



Source: Community Innovation Survey (2019). © ifo Institute

R&D activities and concept development (Kapil et al. 2013). The funding procedures, however, were not designed to maximize the innovation effects of public support. As mentioned earlier, the main implementing agency (PARP) did not have technology development in its core mission.

Szczygielski et al. (2017) offered a comparative analysis of direct innovation support for firms in Poland and in Turkey, another middle-income country, but one where systematic innovation aid for firms started back in the mid-1990s. The analysis of the grant selection and evaluation processes in 2004–10 showed Turkey clearly ahead of Poland, where the assessment was initially a one-stage, document-based procedure, and tools like expert panels and on-site visits were virtually never implemented. The econometric analysis of the efficiency of government support revealed that while the grants for R&D activities contributed to better innovation performance on the part of Polish manufacturing firms, this was not the case with the EU-funded grants for physical and human capital upgrading. Thus, while the funding was much more generous in Poland, the support was more efficient and better targeted in Turkey.

THE NEW DEVELOPMENTS AND CHALLENGES AHEAD

While the 2004–10 period was characterized by an asymmetry between the increased innovation policy budget and limited government capabilities, it allowed the Polish public administration to accumulate knowledge on innovation policy planning and implementation. In 2007, the National Centre for Research and Development (NCBR) was formed, and by 2015 it took over from PARP responsibility for the bulk of innovation-related structural-policy programs. Currently, NCBR is the principal body responsible for funding applied R&D in firms, although PARP also continues to offer some innovation aid for SMEs. Support is also offered by regional authorities, and, most recently, a new actor called the Polish Development Fund (PFR), which focuses on financing venture capital vehicles investing in early-stage development of technological innovations.

The grants from the main operational program under the current perspective ("Intelligent Development" OP) fund almost exclusively R&D activities (also some counseling services for SMEs). The program includes a horizontal scheme to which all firms can apply, a number of sectoral programs developed in cooperation with the representatives of the industry, and an investment-fund-like instrument. In addition to the EU-funded initiatives, NCBR runs programs funded from the national budget, including strategic programs (e.g., in biomedicine and materials research), a scheme co-funding the launch of firm R&D labs, and several others. The project selection and assessment schemes have become much more elaborate over the years, and one can observe some degree of experimenting with different procedures (one- or two-step processes, pre-selection, various kinds of panels, etc.).

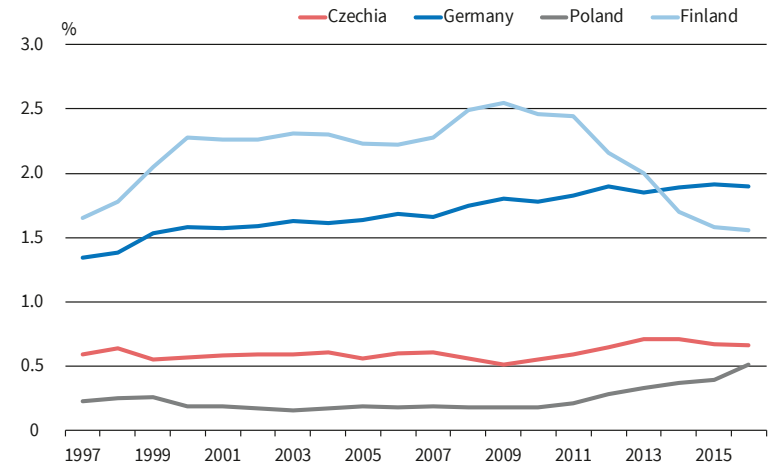
There have also been changes to the architecture of the R&D institute sector. After nearly 30 years of slow, mostly enforced, consolidation (between 2001 and 2017 the number of public institutes reduced from 232 to 113, cf. Woodward 2004, and Statistics Poland 2018), a radical change came in 2019, as 38 of the institutes were included in the newly created Łukasiewicz Research Network. The Network, named after the 19th-century innovator and oil-industry pioneer Ignacy Łukasiewicz, has the ambition of becoming the Polish counterpart to Germany's Fraunhofer Society or Finland's VTT. Time will tell the extent to which these aspirations can come true, but integrating the dispersed institutes into one organization is certainly an important step (although critics say the reform is incomplete, as member institutes continue to be separate, if not independent, legal bodies).

The establishment of the Łukasiewicz Network is one of the few accomplishments of the industrial strategy of the new cabinet that came to power in Poland in 2015 (Ministry of Development 2017). While several other initiatives were announced – most notably a rapid expansion of the Polish electric automobile industry – these projects have not been successful as of yet (cf. Woźniak 2019). However, the government created a new actor, the Polish Development Fund (PFR), a state-owned joint-stock company, that, in addition to

assuming shares in some firms and banks, offers innovation-related support for companies by activating VC investments. Also, starting 2019, a generous R&D tax credit and a an IP box scheme (a reduced tax rate for IP income) were introduced.

Figure 2

Intramural R&D Expenditure of Business Sector as a Share of GDP



Source: OECD (2019). © ifo Institute

FINAL REMARKS

Three decades after the collapse of Communism, Polish innovation policy is a mixed picture. Largely neglected after 1989, it received adequate funding thanks to the EU accession. Ever since, institutions have been built and programs developed that resemble the architecture of the innovation support system in Western Europe. The percentage of firms that receive public support increased substantially as compared to the pre-accession period (although then it stagnated, frustrating innovation policymakers). Business expenditure on R&D as a share of GDP, while far behind that of old EU member states, has increased markedly, too (Figure 2).

On the other hand, some major problems remain unaddressed. Innovation policy lacks co-ordination, both in terms of instruments offered by different agencies and, more broadly, in terms of strategies applied by different ministries. Universities remain underfunded, ranking low in international comparisons and finding it hard to produce world-class research or compete for talents. The fiscal rules for businesses are subject to almost continuous changes.

Perhaps the biggest dilemma is, however, how to shape innovation policy in a middle-income country that has been catching-up at an impressive pace (Piątkowski 2018), but where this catch-up process has so far not been based on the development of new technologies. This question deserves to be addressed by policymakers and academics alike.

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The Impact of Innovation Policy on Firm Innovation and Performance: A Review of Recent Research Developments

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The importance of R&D and innovation in explaining economic growth and productivity is well documented in the research literature. Government policies also increasingly recognise the benefits of supporting firms' R&D and innovation. In the UK, for instance, research and innovation have been placed at the heart of the Industrial Strategy. In Germany, the Hightech Strategy governs the focus of public research and innovation policies on identified areas of priority. For the European Union as a whole, the renewed European Agenda for Research and Innovation sets out that "innovation must be a central driver for EU policies and programmes for 2021-2027" (European Commission 2018, p. 6).

Recent research on a range of countries provides evidence of the effectiveness of public R&D and innovation policy in increasing private R&D investment and innovation. The most common direct types of policy interventions are subsidies or research grants, which are the subject of this review article, as well as tax credits.[1] More limited in number are studies of the impact of innovation policy support on firms' business performance, measured as, for instance, productivity or turnover growth. Results generally confirm the existence of a positive relationship between public R&D support, innovation and firm performance.

However, there remains heterogeneity of results across studies, in particular due to differences in the design and implementation of subsidy programmes across countries, regions, industries and time periods; the R&D stage in which policy is implemented (Clausen 2009; Hottenrott et al. 2017); issues related to the research methodologies and the units of the analyses (Klette et al. 2000), in particular selection and matching (Jaffe 2013); data limitations; and, regarding collaborative projects, the types of partners involved.[2]

INNOVATION POLICY: RATIONALE AND IMPACT MECHANISMS

R&D investment has well-recognised social and private benefits (Mohnen 1996; Ceh 2009). However, the classic public goods problem means that R&D is both non-rivalrous and not (completely) excludable. Firms are therefore unable to fully appropriate the returns from their investments. Consistent with the theory, empirical evidence confirms that the private rate of return typically is below the social rate of return (Griliches 1979, 1998). This mismatch of returns provides the key economic rationale for corrective public intervention to support private firms' R&D investments (Arrow 1962; Nelson 1959; Rigby and Ramlogan 2013). Moreover, policy support is often justified by more strategic objectives linked to the desire to build capacity in specific sectors, technologies or localities.

In either case, the public policy objective typically is to incentivize firms to increase, or start, R&D activity as an input into the innovation process. This is likely to increase firms' innovation capabilities and innovation output, as well as business performance and hence ceteris paribus economic growth in the longer term. Less focus has to date been placed on policies designed to support innovation output directly. This could benefit in particular small or micro-enterprises, which often do not have the capacity for an R&D department and thus are not able benefit from R&D – innovation input – subsidies, whilst still being very innovative.

The extant literature has identified four mechanisms through which public policy support may lead to increased private-sector R&D and innovation, and economic performance. First, financial support raises firms' liquidity and financial slack, thus reducing the financial riskiness of R&D and innovation projects (Zona 2012). However, slack resources may also encourage inertia or laxity in risk taking (Nohria and Gulati 1996), hence suggesting an inverted U-curve effect (Görg and Strobl 2007; Kilponen and Santavirta 2007). Second, the cost-sharing resulting from public subsidy reduces the investment required and de-risks this investment in terms of the technologies involved and commercial profitability (Keizer and Halman 2007; Roper et al. 2008; Cabrales et al. 2008). Third, public support can play a market-making role in addressing particular social or economic challenges (Mazzucato 2016), e.g. in terms of emergent technologies (Van Alphen et al. 2009) or wider social benefits (Zehavi and Breznitz 2017). Fourth, policy can enable firms to access otherwise unavailable knowledge, one possible tool being innovation vouchers (OECD 2010).[3]

[1] For a review of the literature on R&D policy instruments, see Martin (2016).
[2] This review is an extended version of Becker (January 2019).

[3] There is some evidence that award of a government subsidy may serve as a positive signal of a firm's quality and thus help the firm attract additional private funding. Through this channel, innovation policy will then indirectly help ease the adverse effect of capital market imperfections (Feldman and Kelley 2006; Meuleman and De Maeseneire 2012; Romero-Jordán et al. 2014).

THE EMPIRICAL EVIDENCE

The Effect of Innovation Policy on Firms' Innovation Input

Two recent reviews of the empirical evidence on the relationship between public policy and private R&D as an innovation input conclude that the majority of studies find a positive effect (Zuniga-Vicente et al. 2014; Becker 2015). The latter review also concludes that the large body of more recent literature suggests a shift away from the earlier results that public subsidies often crowd out private R&D to finding that subsidies typically stimulate private R&D. One reason for this shift is the availability of new econometric techniques that control for sample selection bias, i.e. for the fact that firms that already are R&D-intensive may be more likely to apply for a subsidy. Since it is likley that these firms would have undertaken at least part of the R&D even in the absence of the subsidy, the results of studies that did not take account of the selection effect may have been biased towards finding crowding-out effects.

There is substantial evidence that the policy additionality effect on R&D is particularly strong for small firms, which are more likely to experience financial constraints. Small firms have less collateral in terms of existing assets to be used for obtaining loans, for instance, and as a group are likely to include more young firms. There also is evidence of a positive inducement effect, again in particular for small firms (e.g. Hall et al. 2009; Hall and Lerner 2010; Czarnitzki and Lopes-Bento 2012). Large firms often substitute incremental public funding for internal funding, as they would have performed the R&D anyway even in the absence of government support.

The inverted U-curve effect between financial support and R&D requires careful fine-tuning of policy. It indicates that lower and in particular intermediate levels of support stimulate private R&D, but overtly high levels of support lead to crowding-out (Görg and Strobl 2007; Kilponen and Santavirta 2007). So for any given public R&D and innovation budget, it may be more effective to grant intermediate levels of support to a larger number of firms than to provide large amounts of support to fewer firms.

The recent review by Dimos and Pugh (2017) employs meta-regression analysis to investigate subsidy effects on both, firms' innovation input and innovation output. These results, too, reject crowding-out of private investment by public subsidies, however the study does not find evidence of additionality, stressing the importance of controlling for firm heterogeneity and omitted variable bias in the estimation of effects.

The Effect of Innovation Policy on Firms' Innovation Output

The effect of public support on innovation outputs rather than inputs has received somewhat less attention in the literature, but is typically also confirmed to be positive. Recent evidence for the US indicates how bundling of uncommitted resources can improve innovation outputs (Marlin and Geiger 2015). Lee (2015) finds weaker evidence for Korea, however, depending on firm size and internal firm capabilities. Other recent studies include Moretti and Wilson (2014), Beck et al. (2016) and Bronzini and Piselli (2016). Research finding positive effects on innovation output as measured by patenting or patent applications includes Czarnitzki and Lopes-Bento (2014), Doh and Kim (2014), Howell (2017) and Wang et al. (2017), while Czarnitzki and Lopes-Bento (2013) identify positive R&D employment effects.

One potentially important factor that remains under-researched to date is the role played by the specific funding source of the innovation policy support in the effectiveness of this support. Where it is analysed, typically one or two sources are compared, e.g. national versus EU support (Czarnitzki and Lopes-Bento 2014; Huergo and Moreno 2017), regional versus other support (Czarnitzki and Lopes-Bento 2013), or national support (Huergo et al. 2016). Szczygielski et al. (2017) compare the effects of domestic innovation support, which the authors define as receiving national and/or regional support, with EU support. This cross-sectional study is one of the relatively few studies that research the effect of innovation policy on innovation output in catching-up countries, or 'technology followers' (Catellacci and Archiburgi 2008); although with Turkey and Poland, it considers two such economies with comparatively high per-capita incomes and relatively well developed institutions. The results indicate that only domestic innovation policy support stimulates firms' process and product innovation in both countries. In a comparative panel data study on the UK and Spain, Becker et al. (2017) examine the effects of regional, national and EU funding sources. The results suggest that national innovation support is associated with a higher probability of, and a higher degree of novelty of, product or service innovation. Regionalised support is most influential in increasing the probability of undertaking innovation for process change and organisational innovation types. The comparison of the UK and Spain is particularly interesting given the very different levels of engagement of the public sector in the innovation system in the two countries, the greater regionalisation of innovation support in Spain (Mate-Sanchez-Val and Harris 2014), and other aspects of the business environment in the two countries such as regulation (Capelleras et al. 2008). The importance of innovation funding at the regional level as such is particularly emphasized in Zehavi and Breznitz' (2017) recent

research on 'distribution sensitive innovation policies', with one suggested measure being R&D funds targeted at relatively under-developed regions.

The Effect of Innovation Policy on the Innovation Activities of Firms Participating in Research Collaboration

A growing literature suggests positive firm level R&D or innovation effects of research collaborations between firms and a variety of institutions, and between firms and universities in particular. Consistent with these results, public subsidies targeted at such research collaborations has also been shown to stimulate participating firms' R&D investment and innovation. Benefits from research collaboration include risk and cost sharing, internalisation of spillovers, signalling of the quality of firms' innovative activities, and acceleration or upgrading of the innovations. Set against these advantages are possible adverse outcomes such as potential free-riding of partners on each other's R&D investments and opportunistic behavior, leakage of information, curtailing of competition in other stages of the firms' interaction, the costs of finding suitable partners, and the coordination and management of research networks (see, inter alia, Kamien et al. 1992; Laursen and Salter 2006; Grimpe and Keiser 2010; Lokshin et al. 2011; Love et al. 2011; Petruzzelli 2011; Hottenrott and Lopes-Bento 2016; Bellucci et al. 2019; for surveys see Hagedoorn et al. 2000; Caloghirou et al. 2003; Becker 2015). Results by Ponds et al. (2007) were among the first to indicate that proximity can matter more when cooperating partners have different institutional backgrounds than when partners have similar institutional backgrounds, and hence that geographic proximity may help overcome institutional differences between co-operators. Very recent evidence on the impact of collaborative subsidies on innovation input includes Bellucci et al. (2019), who compare the effectiveness of two regional research and innovation policies, one designed to support individual firms' research projects, and the other designed to support collaborative projects between firms and universities. The authors show that both policy programmes succeeded in stimulating additional private R&D investment, although the latter policy's effects were weaker. Scandura (2016) also finds positive effects on innovation input as well as innovation output measures from grants awarded to university-industry collaborations.

The Firm Performance Effect of Innovation Policy Targeted at Individual Firms

The ultimate, longer-term, objective of most R&D and innovation policy support to date has been to improve business performance. Overall, the evidence remains mixed. A number of recent studies conclude that research and innovation grants improve firms' financial performance (Zhao and Ziedonis 2012; Howell 2017), or increase their investments (Von Ehrlich and Seidel. 2015), employment growth (Criscuolo et al. 2019), value added (Duch et al. 2009) or productivity (Cin et al. 2017). Other studies, however, do not find significant positive effects from research and innovation grants on productivity, employment growth, export performance, venture funding or firm survival (Martin 2012; Karhunen and Huovari 2015; De Blasio et al. 2015; Wang et al. 2017; Criscuolo et al. 2019). With regards to the firm performance impacts of the European Union Framework Programmes, Bayona-Sáez and Garcia-Marco (2010), for instance, identify positive effects, while Hünermund and Czarnitzki (2019) conclude that effects can depend on the specific rule used to allocate the budget to recipients: Under a rule referred to as Virtual Common Pot, which avoids cross-subsidization between participating countries, there were no average job creation or sales growth effects, although positive effects could be observed for projects of high quality. However, the study indicates that substantial positive effects on employment and on sales would have been achieved under the standard situation of a Real Common Pot rule, whereby a single budget is allocated according to uniform project evaluation criteria.

The Firm Performance Effect of Innovation Policy Targeted at Research Collaborations

The smaller literature on the performance impacts of public R&D subsidies awarded to research and innovation collaborations also remains mixed, although on balance it suggests that there is a positive relationship between public policy support of close-to-market R&D cooperation and economic performance (Aguiar and Gagnepain 2017). Research on the EU Framework Programmes, for example, suggests that there is a positive effect on the growth of intangible fixed assets of Spanish firms that participate in thus supported research collaborations, and an indirect positive effect on these firms' productivity (Barajas et al. 2012). Similarly, Aguiar and Gagnepain (2017) conclude that there are strong long-term effects on the labour productivity of firms collaborating on projects funded under the 5th EU Framework Programme. Scandura (2016) finds positive effects on firms' share of R&D employment two years after the end of their university-firm collaborations funded by the Engineering and Physical Science Research Council in the UK. Analysing all projects funded by all Research Councils' in the UK, Vanino et al. (2019) identify positive short-term and medium-term effects on the employment and turnover of participating firms.

The relative firm performance effects of innovation funding of individual firm projects compared with collaborative R&D projects may depend on the country-specific absorptive capacity, as suggested in Guisado-González et al. (2017). The study concludes that due to the low absorptive capacity of Spanish manufacturing firms, receiving public subsidies through participat-

ing in R&D cooperation agreements has a lower impact on the firms' productivity than the sum of the individual effects of R&D cooperation and R&D subsidies. Heterogeneity in the results from different studies may also be related to, for instance, the differences in the frameworks of the supporting programmes, the types of the collaboration partners and the focus of the cooperation projects, e.g. whether this is industry-oriented or knowledge oriented (Hewitt-Dundas et al. 2017; Du et al. 2014). In a similar way, as for the R&D additionality effect (Engel et al. 2016), the funding history also plays a role in the firm performance effect in that, as might be expected, firms participating in a series of funded collaborative projects experience stronger performance improvements than firms participating in only a single project (Vanino et al. 2019).

RESEARCH OUTLOOK AND CONCLUSION

While some heterogeneities in research results remain, recent evidence confirms that public R&D and innovation policy support can play a significant role in increasing firms' R&D investment and innovation. However, issues such as firms' R&D dynamics and composition, the source of the public R&D funding, and other firm constraints have not received very much attention so far.

There is substantial evidence that firm size matters in the effectiveness of policy support. The R&D and innovation additionality effects have been shown to be particularly prevalent for small firms, which are more likely to experience external financial constraints. For small firms there also is evidence of a positive inducement effect. Moreover, many small or micro-enterprises do not have the capacity for an R&D department, while still being very innovative. So in order to maximize the effectiveness of policy support, it is important to target those types of firms and industries, for which additionality is largest, and to support both innovation input and output.

Somewhat more heterogeneity exists in the results of the smaller literature on the impact of innovation policy support on firm performance. However, overall, findings confirm the existence of a positive relationship between public R&D support, innovation and firms performance. Again firm size matters, as do productivity levels and sectors (e.g. Vanino et al. 2019). Greater access to, and use of, administrative data could contribute to moving the knowledge frontier forward here (e.g. OECD 2013; Card et al. 2011, for NSF; Costanzo, for ISTAT; UK Data Forum 2018).

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Research versus Development: When are R&D Subsidies most Effective?[1]

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Subsidies for research and development (R&D) are one of the largest and fastest-growing forms of industrial aid in developed countries (OECD 2015). R&D subsidies are often designed as project-based grants offered and administered by public funding bodies. The economic rationale behind the implementation of such policies is that private sector R&D creates positive externalities to society (Jones and Williams 1998). While the investing firm carries all the risk, the returns from R&D are not only uncertain, but are also hard to fully appropriate. Means of intellectual property protection such as copyrights, patents or trademarks are important, but provide only incomplete protection and are not always applicable. This results in levels of private sector R&D spending that are likely below the social optimum. In addition to appropriation concerns, outcome uncertainty results in financing constraints particularly for smaller firms and firms pursuing a risky R&D agenda (Czarnitzki and Hottenrott 2011a, b; Hottenrott and Peters 2012; Hottenrott and Lopes-Bento 2014).

From a public policy point of view, the major objectives of R&D subsidies are to compensate firms for the social returns to their R&D investments and to ease financial market frictions that increase the private costs of financing R&D (David et al. 2000). Grant-based public funding schemes therefore aim at incentivizing R&D projects by covering parts of the project cost thereby reducing the need for other external financing or even facilitating it through the grants' signaling effect to lenders and investors (Hottenrott et al. 2018).

R&D GRANTS AS AN INNOVATION POLICY TOOL

Direct subsidies differ from fiscal incentives for R&D in two main ways. First, grants are awarded ex-ante, thereby allowing firms to receive funding for a planned, but not yet pursued project while tax credits reward R&D activities ex-post. Second, grants allow the funder to target specific technology areas (e.g. renewable energy technologies) that promise high social returns or focus on specific geographical regions. Since direct grant programs are costly to implement as they require expert review of project proposals as well as the administration of the financial payments, the cost-efficiency of providing R&D grants is still under debate (Takalo et al. 2013).

Estimating causal effects of R&D grants on the firms' own-financed R&D efforts is often difficult due to limited data availability (i.e. on the funding amounts and R&D expenditures) and due to the selectivity that is inherent to these programs: firms with more ambitious R&D plans are more likely to apply for grants and more successful in the funding competition. Even if the grantee has higher R&D spending in the future, it is not clear whether this is due to the grant and whether the firm would have spent more, even in the absence of public support. Dimos and Pugh (2016) critically review the evaluation literature and conclude that while full crowding out, i.e. full displacement of own-financed R&D by public grants, can be ruled out, there is little evidence on the ability of grants to trigger additional R&D, on average. One explanation for this observation may be found in the heterogeneity of treatment effects. For instance, grants may make a bigger difference to the R&D budget in smaller or younger firms. Likewise, grants my be more effective if they encourage collaborative R&D which increases the returns on investment (Hottenrott and Lopes-Bento 2014).

In addition, it seems crucial to distinguish between the types of projects that are supported because R&D subsidies affect two related, but distinct activities: research ('R') and development ('D'). Research activities are quite different from development activities as research typically produces tacit knowledge and intangible results (Usher 1964). Moreover, basic research typically involves early-stage activities with a wider set of possible applications and hence higher knowledge spillovers and a potential for greater social returns (Akcigit et al. 2016). Research is furthermore characterized by a greater outcome uncertainty and a larger distance to the market when compared to product or process development. As the development trajectory is often more focused and builds on earlier (successful) research investments, it is less prone to unintended knowledge spillovers when compared to research. In addition, because development projects are closer to the actual implementation of an invention or of the introduction of a new product to the market, firms will typically protect their "close-to-the-market" inventions through formal IP strategies (Cassiman and Veugelers 2002). Therefore, appropriability tends to be stronger for development investments when compared to research investments. These basic features of research activities also result in financial constraints for research which are more binding than for development projects (Czarnitzki et al. 2011). The often cited market failure arguments are therefore more applicable to the R-component of R&D, resulting in an underprovision associated with research that is more severe than that for development.

[1] This article is based on the paper "Direct and Cross-Scheme Effects in a Research and Development Subsidy Program" by Hanna Hottenrott, Cindy Lopes-Bento and Reinhilde Veugelers published in Research Policy 46 (6), 2017, 1118–1132.

TARGETED GRANT-BASED SUBSIDY PROGRAMS

If research and development have different characteristics affecting the gap between private and social returns and invoke different degrees of financial constraints, an optimal subsidy policy should be tailored to address these different characteristics. If the arguments raised above apply, grants supporting research project should have a stronger incentivizing effect than grants focusing on later stages of product or process development. On the other hand, firms may find it easier to raise funding for development projects for instance through bank loans, resulting in more available funds and hence higher own-financed development investments. If funding for research is indeed constrained, firms may find it too hard to raise sufficient own funding to complement the government-funded part in the project. In that case, we would expect input additionality to be higher for development than for research grants, as the latter may lack financing for the privately funded part of the project.

At the same time, research and development are interdependent activities. Product and process development often depends on the outcome of research activities. Firms may need to do (basic) research in order to understand how to solve problems of a more applied nature and be more effective in development activities. Subsidy schemes focusing on research or development are therefore also likely to affect the returns to the respective other activity.

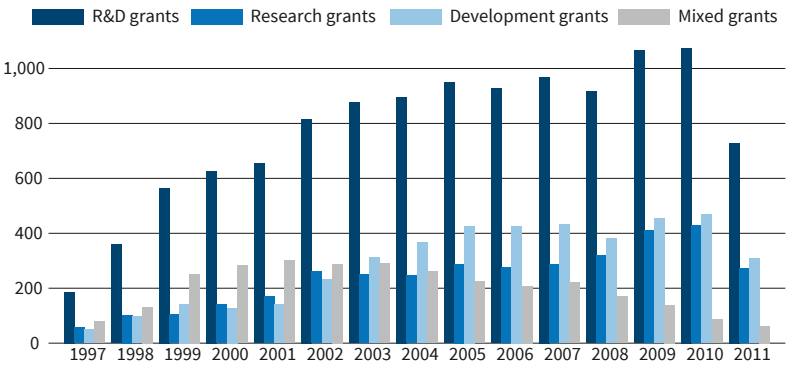
Based on detailed data on R&D grants from a Belgian funding agency (Vlaio, Vlaanderen Agentshap Innoveren & Ondernemen, formerly IWT) of the population of publicly co-financed projects over the period 2000 to 2011 (ICAROS database) and on information on firms' research and development activities (OECD R&D survey), we can investigate the effects of targeted research and development grants on both research and development spending. The policy program explicitly provides different schemes for research projects, development projects and for mixed R&D projects. This allows measuring the effects from the different types of grants, but also to test for any cross-scheme effects from research grants on development spending and vice versa.

Unlike in the case of public "top-down R&D programs" such as thematic calls for project proposals issued by the government or public procurement, for these R&D subsidies, the project idea and the planning is initiated by the applying company and not by the government itself. The program is therefore characterized by a bottom-up approach, which leaves the project choice and timing to the applicant.

Figure 1 shows the distribution of ongoing grants within the different schemes over time. During the earlier years of the observed period mainly mixed-scheme projects had been co-funded, while in later years the funding agency shifted to primarily targeted programs for research or development. Note that in the funding program the subsidy rate, i.e. the share in project cost borne by the funding agency, differs by grant type and firm characteristics. The base rate can increase depending on firm characteristics (smaller firms may receive a higher share in total project funding) and depending on whether the project is being conducted in collaboration with other firms or a university. Figure 2 shows Kernel density plots of the subsidy rates by

Figure 1

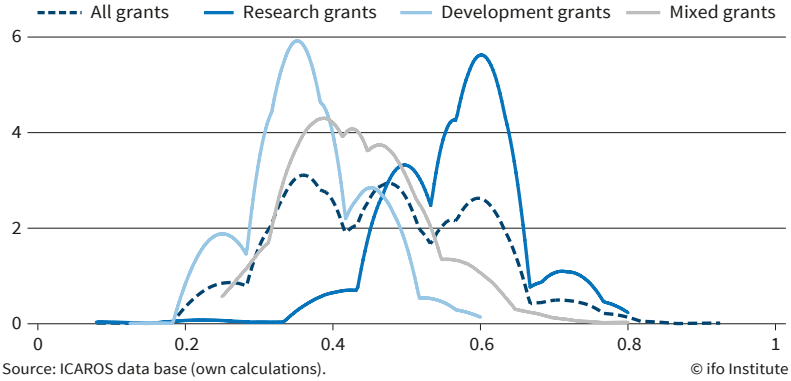
Grants by Type



Source: ICAROS data base (own calculations). © ifo Institute

Figure 2

Subsidy Rates
Kernel density estimates by grant type



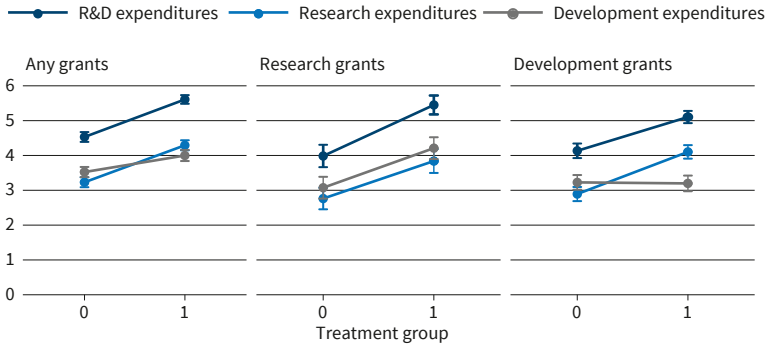
Source: ICAROS data base (own calculations). © ifo Institute

project type. As can be seen, the subsidy rate tends to be higher for research projects (mean = 57 percent) than for development projects (mean = 37 percent). Mixed projects' subsidy rates are between the two (mean = 44 percent).

R and D expenditures are obtained from the Belgian part of the OECD/Eurostat R&D survey. Guidelines for the surveyed firms described in detail how to attribute spending to research and development activities based on the Frascati Manual. The survey also contains information on other firm characteristics that can be used for constructing control variables such as the number of R&D employees, group and ownership structure, subsidies from other sources and R&D collaborations. We complemented the survey data covering the years 2000-2011 with patent statistics issued by the European Patent Office (EPO) and balance sheet information from the Bel-First data base.

Figure 3

Estimated Treatment Effects
After matching, differences between groups (in logged expenditures in T€)



Source: Hottenrott et al. (2017).

The sample comprises firms that receive at least one grant during the period under review as well as firms that never received a grant. We calculate net expenditures as firms' annual total spending on R and D less the annualized subsidy amount received in a year (if any). The minimum funding amount over the entire project duration is EUR 100,000 and the grant amount is capped at EUR 3 million per project. The average payment received is EUR 259,000 (median = EUR 111,000). Amounts are highest for mixed grants and lowest for research grants. The average project length is two years with a slightly lower mean for research projects and a higher one for mixed projects.

In Hottenrott et al. (2017), we estimated the direct average treatment effects and the cross-scheme average treatment effects using a nearest-neighbor propensity score matching procedure. The matching accounts for selection effects that explain the difference in R&D between subsidized and unsubsidized firms in addition to the treatment effect. By making firms in the subsidized group and in the unsubsidized group comparable in terms of a large set of observable characteristics, the ex-post difference between both groups can be attributed to the treatment. The estimation sample covers 12,138 firm-year observations from 1,994 different firms and about 15 percent of these firm-year observations have benefited from some type of subsidy within the three thematic schemes.

The probability to receive a subsidy from any of the three schemes is higher when a firm has had past research, past development, or past mixed grants. Mixed-grant receipt is more likely when the firm had a research grant in the past. The probability of receiving a development grant after having had a research grant is larger than the probability of receiving a research grant after having had development grant previously. The patent stock per employee as well as R&D collaboration have a positive and significant impact on all grant receipts. Older firms are less likely to receive grants, irrespective of the type of scheme. Finally, larger firms are more likely to obtain mixed grants and are also more likely to hold multiple grants from different schemes in the same year.

After the matching, the respective treatment groups and the control group are balanced in terms of all control variables and the propensity scores. Figure 3 illustrates the differences in logged outcome variables (net R&D expenditures, net Research expenditures, and net Development expenditures) for firms participating in the subsidy scheme and the control group. The results show that R&D grants of any type result in a higher R and D expenditures in the recipient firms (treatment group = 1) compared to the control sample (treatment group = 0). Research grants show positive within scheme effects as well as positive cross-scheme effects. That is firms with research grants invest more in both research and development than similar control firms. For development grants, however, there is no positive within scheme effect of development grants on development expenditures. Considering cross-scheme effects, we find that development grants trigger addition research expenditures. The treatment effects of research grants and development grants are in fact quite similar when we look at net research expenditures. These results are robust to alternative estimation strategies.

Further analyses in Hottenrott et al. (2017) show that mixed grants lead to more research, but not to more development expenditures and that the overall achieved R&D additionality increased as the funding agency moved from mixed schemes towards targeted schemes over time.

POLICY IMPLICATIONS

Studies on R&D subsidies as an innovation policy tool provided ambiguous conclusions regarding their usefulness for triggering additional R&D in the private sector (Dimos and Pugh 2016). However, previous research did not provide any insights regarding possible differences in the responsiveness of research versus development activities to this policy instrument. With higher outgoing spillovers, higher risk and constrained access to external financing, gaps between social and private returns are larger for research than for development projects. Research subsidies may therefore yield higher additionality effects than development subsidies. At the same time, research and development are complementary activities, with investment in one activity increasing the productivity of the other. Targeted schemes are therefore likely to generate cross-scheme effects, with research grants having knock-on effects on development expenditures and vice versa. The analysis of a policy design that explicitly distinguishes between research projects, development projects and mixed R&D projects shows that when decomposing the type of grant and the type of investment, research grants indeed yield higher average direct effects than development grants. In the assessment of these targeted grants, however, we have to consider that there are significant cross-scheme effects from research grants on development expenditures and from development grants on research expenditures. These results, pointing to higher direct additionality from research grants compared to development grants, are consistent with theory suggesting higher market failures associated with (basic) research (Akcigit et al. 2016). They are moreover consistent with the view that research and development are complementary activities each increasing the productivity of the other (Cassiman et al. 2002). The lower within scheme effectiveness of development grants compared to research grants could be explained by companies shifting their budget from a less financially constrained activity (development) to a more financially constrained activity (research). Typically, information asymmetries between firms and the funding agency prevent full control of the funding agency over the use of funds in the recipient firms.

The detailed results in Hottenrott et al. (2017) further show that mixed grants, which support both research and development activities, turn out to trigger additional research, but not additional development activities.

One important policy implication that arises from this analysis is that re-directing the amounts spent on development subsidies towards research projects may lead to a better budget utilization of public resources for R&D supporting programs. Despite the positive cross-effects from development grants on research spending, the average return to funding research projects is higher than the returns to supporting the development stage. This suggests a higher priority for subsidy programs targeting projects that involve (basic) research activities. Furthermore, funding agencies can expect that their research subsidies will not only invoke additional research with potentially higher social returns, but also additional development activities. In other words, the results show that the impact of the R&D policy increased under the targeted schemes compared to the mixed grant scheme design.

However, for publicly co-funded research projects the outcome uncertainty is higher than for development projects, making it a potentially less attractive policy tool when evaluating output additionality rather than input additionality. Moreover, it would be highly desirable to investigate the full cost-benefit trade-off of targeted R and D subsidy programs in a setting that allows to monitor the internal processes in the funding agency in addition to firms' investments.

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Enrico Vanino, Stephen Roper and Bettina Becker

Knowledge to Money: Assessing the Business Performance Effects of Publicly Funded R&D Grants[1]

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INTRODUCTION

Through its publicly funded Research Councils (UKRCs), the UK invests around GBP 3 billion per year in supporting R&D and innovation. This investment is set to increase sharply in future years as the Industrial Strategy Challenge Fund – announced in the government's 2016 Autumn Statement – is steadily expanded to an additional GBP 2 billion per year by 2020. Of particular importance in terms of business engagement in the UK Research Councils are Innovate UK, which provides grants to firms and other organizations to support innovation, and the Engineering and Physical Science Research Council (EPSRC), which funds university research, often in collaboration with industry.

To date, assessments of the impact of UK Research Council grants have been largely partial and case based. Where quantitative assessments of impact have been attempted, they have often relied on the limited information available in innovation surveys or focused on specific elements of the public science system. However, several previous reviews provide evidence from a range of countries on the positive role of research grants, subsidies, and tax credits in helping firms to innovate successfully (Zuniga-Vicente et al. 2014; Becker 2015; Dimos and Pugh 2016). A more limited strand of the literature looks at the impact of R&D subsidies and programs on the overall performance of firms, taking into consideration turnover or productivity growth (Belderbos et al. 2004; Cin et al. 2017). Although somewhat mixed, this literature has generally supported the existence of a positive relationship between public R&D support, innovation, and firms' growth (Aguiar and Gagnepain 2017).

Here, for the first time we link data on all UK Research Council grants with longitudinal data on the performance of all UK firms to assess the impacts on business growth of participating in UK Research Council funded projects but also to explore how growth impacts vary depending on firm characteristics, project participants, and the particular Research Council providing finance. Our results show that participating in Research Council projects had a positive impact on firms' growth although, as expected, this effect varies depending on the nature of the participating firm, the characteristics of project participants, and the funder.

PUBLIC FUNDING FOR R&D AND INNOVATION IN THE UK – THE UK RESEARCH COUNCILS

Our analysis covers the years 2006 to 2016, a period during which there were significant changes in the UK innovation and industrial policy landscape (Hildreth and Bailey 2013). In England, Regional Development Agencies (RDAs) originally established by the Labour government (1998–2002) were abolished in 2010–12, leading to a centralization of innovation policy in what is now Innovate UK. Innovate UK projects aim to support innovation in firms; competitive grant funding is provided directly to private companies often for collaborative projects.

Changes in innovation support policy in the UK have been accompanied by relative stability in the provision of public funding for university R&D and collaborative basic research. The UK's seven Research Councils[2] vary in size, with the most significant in terms of business engagement being the Engineering and Physical Sciences Research Council (EPSRC). Originally established in 1994, by the end of our study period EPSRC had an annual budget of around GBP 900 million, which is used to fund research (c. GBP 700 million) and training and fellowship grants (c. GBP 200 million) (EPSRC 2015). Individual EPSRC research projects are university-led, often involving business collaborators, and are selected for funding on a competitive basis. EPSRC funding is provided only to university partners, with business partners either making financial or in-kind contributions (e.g., equipment use or staff time) to a project. Evidence of the impact of EPSRC support on participating firms is relatively limited, although Scandura (2016) provides evidence of input additionality in terms of both R&D expenditure and employment two years after the end of EPSRC projects.

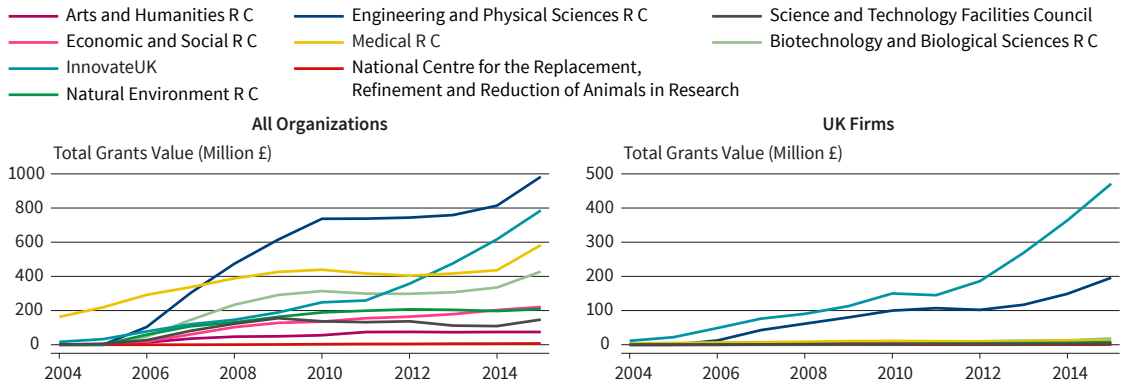
A breakdown of the total number and value of projects supported by the UK Research Councils over the period 2004–2016 by funding source is provided in Figure 1. Over 13 years, the UK Research Councils funded more than 70,000 research projects, allocating almost GBP 32 billion. The largest funders were the Engineering and Physical Sciences Research Council (EPSRC), supporting 22 percent of total projects and allocating almost 30 percent of the overall funds available, followed by the Medical Research Council – funding only

[1] A longer version of this article can be found at: Vanino, E. et al. (2019), "Knowledge to money: Assessing the business performance effects of publicly-funded R&D grants", Research Policy 48(7): 1714-1737.
This work has been supported by the Enterprise Research Centre (ERC), ESRC grant ES/K006614/1. The statistical data used here is from the Office of National Statistics (ONS) and is Crown copyright and reproduced with the permission of the controller of HMSO and Queens Printer for Scotland. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. The analysis upon which this paper is based uses research datasets which may not exactly reproduce National Statistics aggregates.

[2] That is the Arts and Humanities Research Council (AHRC), the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Engineering and Physical Sciences Research Council (EPSRC), the Medical Research Council (MRC), the Natural Environment Research Council (NERC).

Figure 1

Total Grants Value per Research Council (RC)



Note: Statistics based on Gateway to research (GtR) data for the period 2004-2016.
Source: GtR Data (2004–2015).

10 percent of the total number of projects but accounting for more than 22 percent of the total value – and Innovate UK, responsible for the support of almost 20 percent of all projects and allocating more than 15 percent of all resources.

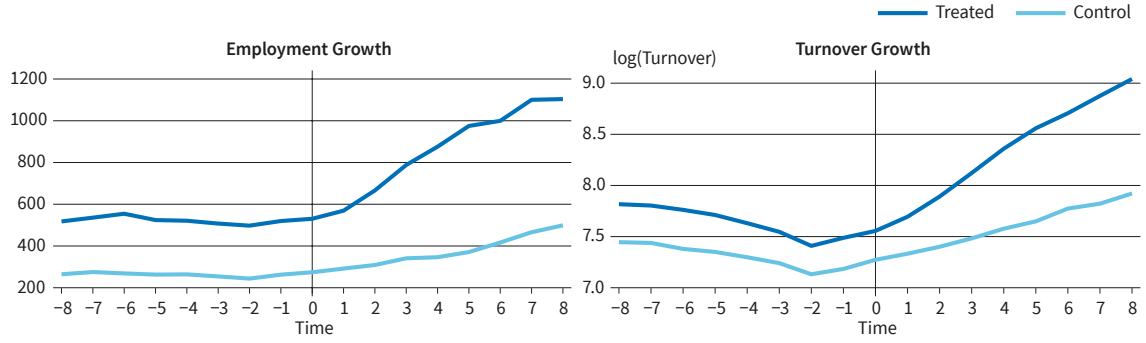
IDENTIFYING THE BUSINESS PERFORMANCE EFFECTS OF THE RESEARCH COUNCILS

A significant hurdle in the identification of the causal relationship between R&D grants are non-random allocation decisions and the self-selection of firms into this kind of program. To overcome these issues, we apply a propensity score matching (PSM) technique at the firm level to create a suitable control group of non-treated firms that is as similar as possible to the group of treated firms based on the likelihood of receiving the treatment (Caliendo and Kopeinig 2008). We estimate the probability that any firm participates in a publicly funded research project, the so-called propensity score, based on a large set of relevant observable characteristics, which have been found to influence the likelihood of participation in the previous literature. These include firm-level variables such as employment, employment squared, turnover, firm age, employment, and productivity growth in the 2-year period before the projects have been awarded, firms' market share, group membership, foreign ownership, and single-plant firm dummies to control for firms' characteristics, and the total number of patents to control for firms' previous innovation activities. In addition, we include a number of variables to reflect the characteristics of the local business ecosystem.

We then compare the performance of participating firms before and after their participation in publicly funded projects compared to the difference in performance of a control group of similar but non-participating firms over the same period. This approach is known as difference-in-difference. Note that firms in our sample may have received Research Council grants in any year between 2006 and 2016, and although they may have participated in more than one project, we focus on the impact of the first project in order to better identify the causal effect of receiving public support while

Figure 2

Employment and Turnover Trends for Treated and Untreated Firms Before and After the Beginning of the UK Research Council Funded Projects (t=0)



Note: Statistics based on Gateway to Research (GtR) and the Business Structure Database (BSD) for the period 2004-2016. Average value of employment and turnover for treated observations reported up to 8 years before and after the treatment year t=0.
Source: GtR Data (2004–2015).

getting rid of other externalities and learning processes occurring during the implementation of a project (Scandura, 2016).

After estimating the propensity score, our final sample contains almost 6,000 UK firms participating in their first R&D project funded by UKRCs and an equal number of similar untreated firms included in the control group. Figure 2 plots the time trends for the two main outcome variables for the pre-project and treatment periods for all firms in our dataset. In the pre-project period, i.e., before the beginning of the UK Research Council funded projects at time *t=0*, the outcome variables employment and turnover exhibit very similar trends to the group of untreated firms.

Table 1

Impact of Participation in Publicly Funded Research on UK firms' Performance – Average Treatment Effects (ATTs) Using Two Alternative Estimation Approaches

	General		General - Kernel	
	Short-term	Medium-term	Short-term	Medium-term
Employment	0.0483***	0.207***	0.0642***	0.171***
	(0.0101)	(0.0196)	(0.0071)	(0.0121)
Turnover	0.0763***	0.231***	0.0892***	0.252***
	(0.0182)	(0.0371)	(0.0173)	(0.0299)
No. Treated	5662	3668	5662	3668

Notes: Estimation based on Gateway to Research (GtR) and the Business Structure Database (BSD) for the period 2004-2016. ATT effect estimated using a propensity score nearest-neighbour matching procedure. Abadie and Imbens (2011) standard errors (s.e.) reported in parentheses for the Nearest-Neighbour matching, while bootstrapped standard errors for the Kernel matching. *** p<0.001, ** p<0.01, * p<0.05. The number of firms included in the treated group is reported. Short-term (ST) refers to growth between t-1 and t+2, medium-term (MT) between t-1 and t+5. Source: Authors' calculations (2019).

EMPIRICAL RESULTS

Columns 1 and 2 in Table 1 show that participating in projects funded by Research Councils has a positive impact on firms' employment and turnover growth in our general sample, both in the short and medium term. Employment grows on average 4.8 percent faster in treated firms in the 3 years following the award, and almost 21 percent in the medium term. Turnover growth is also positively affected by participation, increasing in the short term by almost 7.6 percent and 23 percent in the medium term. These findings are in line with the previous literature, explaining the larger effect in the medium term due to the time needed to develop new R&D activities after the start of a research project and to commercially exploit the results of new innovations (Barajas et al. 2012; NESTA 2012; Dimos and Pugh 2016).

Overall, we also find that participation in RC-funded projects has a similar effect on the employment growth of firms in both manufacturing and services industries, increasing it by around 24 percent after 6 years. However, the impact on turnover growth is greater for manufacturing companies, increasing by almost 31 percent in the medium term, compared to only 19.5 percent in service firms. Differentiating between high-tech/low-tech manufacturing firms and between Knowledge Intensive Services (KIS) and non-KIS companies, we find that the effects on employment are relatively similar for high-tech compared with low-tech manufacturing firms, while the substantial effects on medium-term turnover growth, almost 30 percent, are experienced only by high-tech firms. This latter result is similar to what might be anticipated on the basis of the previous literature (Love et al. 2011; Bellucci et al. 2016). Participating firms in KIS sectors benefit substantially more in terms of both short-term and medium-term employment compared with those in non-KIS sectors, 25 percent versus 11 percent in the medium term, for example, while here turnover growth effects are more balanced between the two groups of firms. Overall, these results suggest that participation in publicly funded research projects has a positive effect even on the performance of firms in sectors with low average R&D intensity, however only in the medium term.

We also considered the effect of different project characteristics on the performance of participating firms. In particular, we consider the number of projects in which firms participated, the number and characteristics of participants, and the value of project grants.

- We find a stronger positive impact for participants in multiple projects (rather than one project), increasing their size by almost 30 percent and their turnover by 36 percent six years after the beginning of their first Research Council-funded project.
- The number of partners in Research Council-funded projects has little effect on subsequent employment growth. Larger projects with more partners do have some beneficial influence only on turnover growth.
- About 25 percent of the treated firms in our sample participated in Research Council-funded projects that involved one or more foreign partners. With regard to turnover growth over a medium-term horizon, external knowledge introduced by foreign partners and leaders seems to be conducive to better performance for participating domestic firms.

RESEARCH COUNCILS COMPARED

Our data also allows us to analyze the effectiveness of research projects funded by different UK Research Councils in accelerating the growth of participating firms. We focus our attention mainly on the grants awarded by the two main bodies responsible for the

Table 2

Impact of Participation in Publicly Funded Research on UK Firms' Performance – Average Treatment Effects (ATTs) for EPSRC and Innovate UK

	EPSRC		Innovate UK	
	Short-term	Medium-term	Short-term	Medium-term
Employment	0.0618**	0.242***	0.0437***	0.165***
	(0.0239)	(0.0428)	(0.0102)	(0.0204)
Turnover	0.163***	0.266***	0.0353*	0.175***
	(0.0441)	(0.0741)	(0.0198)	(0.0388)
No. Treated	931	723	4160	2471

Notes: Estimation based on Gateway to Research (GtR) and the Business Structure Database (BSD) for the period 2004-2016. ATT effect estimated using a propensity score nearest-neighbour matching procedure. Abadie and Imbens (2011) standard errors (s.e.) reported in parentheses for the Nearest-Neighbour matching, while bootstrapped standard errors for the Kernel matching. *** p<0.001, ** p<0.01, * p<0.05. The number of firms included in the treated group is reported. Short-term (ST) refers to growth between t-1 and t+2, medium-term (MT) between t-1 and t+5. Source: Authors' calculations (2019).

largest part of grants involving private firms: Innovate UK and the Engineering and Physical Science Research Council (EPSRC). The performance impact on firms participating in R&D projects supported by these two bodies could differ systematically from each other given the different focus and target of their policy intervention. Innovate UK provides support to private firms with a focus on reducing R&D risks, enabling and supporting business innovation and the commercialization of R&D outputs. By contrast, the EPSRC focuses mainly on the support of universities' basic and applied research, i.e., well before the commercialization phase of innovation, and extends only to private firms that collaborate with funded universities in University-Industry partnerships.

Firms involved in projects funded by EPSRC seem to benefit strongly in terms of both employment and turnover growth, increasing their scale by 24 percent in respect to comparable non-treated firms six years after the start of the project, while experiencing turnover growth by 26 percent after six years. Firms supported by Innovate UK experience smaller short-term and medium-term performance gains, both in terms of employment and turnover.

We further explored the heterogeneity of the EPSRC and Innovate UK by comparing projects involving and not involving a university partner. Contrary to expectations, we find larger impacts on both employment and turnover growth in the short and medium term for firms participating in Innovate UK projects that do not involve a university partner. One possibility is that these non-university Innovate UK projects are closer to market than those involving universities, and that this leads to stronger commercial impacts on participating firms in the short and medium term. It is difficult from our data, however, to identify the precise nature of the R&D being conducted as part of any specific project, so this interpretation remains somewhat speculative.

CONCLUSIONS

Over the past decade, UK Research Councils have invested more than GBP 3 billion per year in supporting R&D and innovation projects. In this study for the first time, we provide a comprehensive assessment of UK public support for R&D and innovation, assessing the impact of participation in publicly funded research grants on the performance of UK firms. Our analysis suggests four main conclusions, which prove robust across a range of different estimation methods and techniques. First, firms involved in UKRC-funded projects grew around 6 percent faster in the short term and 22 percent in the medium term than similar firms that did not participate in UK Research Council projects. Second, this effect is stronger in the most R&D intense regions and industries, in particular for smaller and less productive firms. Third, benefits from publicly funded R&D projects are significant in particular when collaborating with domestic and industrially related partners, regardless of the number or size of projects. Fourth, business growth is mainly driven by EPSRC and Innovate UK support, with a particularly relevant role played by Innovate UK in fostering SMEs' growth after the closure of the Regional Development Agencies in 2012.

Overall, our analysis shows that public support by Research Councils has a strong positive impact on participating firms' growth in the short and medium term. Our results reinforce those of other studies which have suggested – albeit on the basis of a more partial and largely case-based assessment – the benefits of public support for private R&D and innovation. Our analysis also suggests new insights related to how the characteristics of grant recipients, and the nature of research collaboration, affect the impact of public support. For the UK, where recent policy announcements point to significant increases in public support for private R&D and innovation in future years, our central results are reassuring: increasing levels of public support for R&D and innovation will have significant effects on future growth.

Our sub-sample results, however, raise some questions about whether the current focus of R&D and innovation policy in the UK is consistent with maximizing additionality. Policy in the UK currently focuses on supporting excellence in R&D and innovation, with resources allocated primarily through thematic competitions for funding. This results in a concentration of support in high-productivity businesses. Indeed, during our study period, 65 percent of public support for

business R&D and innovation in the UK was allocated to firms in the top quartile of the productivity distribution. Our results suggest that support provided to these already highly productive firms has limited additionality and growth effects. Additionality would be greater where support can be allocated to smaller firms with lower pre-award productivity. The size of grants – relative to the size of the firm – also seems important in shaping additionality and could be used along with prior productivity to guide the allocation of support. Over recent years, UK innovation policy has also adopted a strong sectoral focus. Our results provide support for this focused approach, suggesting that additionality is greatest in more R&D intensive industries.

Our study is subject to a number of limitations. First, at this point we consider only the direct impacts of public grant support for R&D and innovation on firms. Spillovers or multiplier effects may significantly enlarge these effects, while displacement or competition effects may reduce them (Roper et al. 2017). Both should be considered in future studies. Second, propensity score matching does not fully eliminate concerns that unobservable factors may explain grant allocation and post-grant performances. For instance, many of the firms participating in UK Research Council-funded projects (although not all small firms) will also be receiving R&D tax credits. As no data is available on which firms receive R&D tax credits, we are unable to explicitly condition our matching on whether or not a firm receives an R&D tax credit, or on the value of any tax relief. As any additional R&D investment carried out by a firm as a result of participating in a UKRC-funded project may increase the R&D tax relief received, it is conceivable that our results may also capture the effect of this second public innovation support instrument. Third, data linking and the timing of some grant awards in recent years mean that we are able to consider growth effects for only around two-thirds of firms that participated in publicly funded science and innovation projects. Fourth, despite all the robustness tests provided to assess the overall quality of our methodological approach, our identification strategy could still be affected by unobservable endogeneity bias. Further research is needed to investigate new approaches to improve the identification strategy; in this regard information on all grants applications, including the unsuccessful ones, would greatly improve the robustness of the policy evaluation. Finally, our study focuses only on UK public support for R&D and innovation. International evidence from similar ongoing studies may provide alternative perspectives reflecting different grant allocation mechanisms and selection priorities.

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Patent Shifting and Anti-Tax Avoidance Legislation

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INTRODUCTION

Multinational profit shifting has been high on policymakers' agendas for years and numerous anti-avoidance laws have been implemented and tightened, with the aim of hampering income flows to low-tax countries. While anti-shifting rules were traditionally designed and enacted unilaterally, recent years have seen comprehensive multilateral efforts to coordinate and tighten anti-shifting measures in the OECD's Base Erosion and Profit Shifting (BEPS) project and the European Union's Anti-Tax Avoidance Directive (ATAD). Two main areas of concern are the strategic location of patents and other intellectual property (IP) at low-tax affiliates and income shifting through the mis-pricing of intra-firm trade connected to IP.

In this article, we review the academic literature on multinational profit shifting, with a particular focus on the role of patents (and other IP) in these strategies. Three questions are addressed: 1) Is patent-related income shifting a quantitatively relevant phenomenon?; 2) Should it be contained?; 3) How can it be contained?

PATENT OWNERSHIP AND PROFIT SHIFTING

Patents are internationally highly mobile assets and earn a significant fraction of total profits in many modern multinational enterprises (MNEs). Locating them in low-tax countries hence allows for significant reductions in firms' tax costs. Given that intellectual property is, moreover, firm-specific in nature, arm's length prices are difficult to obtain, which creates additional opportunities for MNEs to shift income to low-tax countries by mispricing intra-firm royalties and license fees.

Anecdotes suggest that MNEs do engage in these strategies. Microsoft, Apple, Starbucks, Google, and others operate patent holding units in low-tax countries that assume a significant fraction of firms' total incomes. In the academic literature, researchers assess patent-related income shifting in comprehensive firm databases to determine whether such strategies are confined to individual cases or are a more common phenomenon.

Authors unambiguously find that multinational firms disproportionally locate patent ownership in low-tax countries. In an early study, Karkinsky and Riedel (2012) analyze panel data on multinational firms in Europe and show that the number of patent applications filed by multinational affiliates strongly responds to changes in corporate tax incentives. The estimated semi-elasticity ranges between -3.5 and -3.8. Griffith et al. (2014) assess the same question but estimate random coefficient models that allow computing realistic own and cross-country tax elasticities. Their estimated own-tax semi-elasticity of patent location choices ranges between -0.5 and -3.9. Similar results are reported by Dudar and Voget (2016) and others. The empirical literature, moreover, shows that multinational firms sort high-value patents to low-tax countries, implying that tax responses of IP income exceed the estimated tax effects on patent numbers (e.g., Griffith et al. 2014; Baumann et al. 2018).

As outlined above, IP ownership, on top of that, creates opportunities for strategic mispricing of intra-firm trade. Several studies provide evidence in line with that notion. Liu et al. (2018) show that tax-motivated intra-firm trade mispricing is centered in R&D-intensive firms. Cristea and Nguyen (2016) find that the tax sensitivity of intra-firm trade prices is particularly large for differentiated goods, where product complexity and quality differentiation hamper the application of arm's length pricing. Hebous and Johannesen (2015) provide evidence consistent with tax-induced mispricing of IP-related service trade. Hopland et al. (2018) find that short-run adjustments in international profit shifting strategies are confined to distortions of user fees for intangible assets.

PATENT BOX REGIMES AND COMPANY BEHAVIOR

Governments, in consequence, have incentives to keep tax rates on patent and other IP income low in order to attract and retain the related mobile multinational tax base. Consistent with this notion, recent decades have seen a steep increase in the number of countries offering patent or intellectual property boxes that grant special low tax rates on patent and other IP income. Ireland was the first to introduce such a regime in 1973, but it was only when the Netherlands enacted their patent box legislation in 2007 that patent boxes began to attract widespread attention among policymakers in Europe and around the world (see e.g., Fabris 2019). Today, intellectual property boxes are in place in several (mostly European) countries, including Belgium, Cyprus, France, Hungary, Ireland, Luxembourg, the Netherlands, Malta, Portugal, Spain, Switzerland, and the United Kingdom.

Existing IP boxes differ widely in their design and generosity; important design elements are the effective tax reduction granted, the IP covered, and the existence of a development condition.[1] Alstadsaeter et al. (2018) estimate the effect of patent box regimes on multinational firm behavior drawing on a sample of large corporate R&D investors. Their findings suggest

[1] While the majority of patent box regimes did not specify a development condition at the time of their introduction, countries revised their patent box regimes to comply with the nexus requirement of the OECD/G20 BEPS Action 5 on countering harmful tax practices in recent years (see next page).

that patent boxes have a strong impact on patent location decisions, especially when it comes to the location of patents with a high earnings potential. The estimated tax semi-elasticity varies between -0.6 and -1.9 in the base models. Patent location is, moreover, reported to be more sensitive to the tax advantages offered by patent boxes if patent box regimes have a large scope in terms of the IP covered. Importantly, the results also suggest that patent boxes attract patent registrations rather than real R&D in the absence of nexus requirements. With nexus requirements, significant R&D effects emerge.

The sketched findings are broadly in line with other results in the literature. Chen et al. (2017), Bösenberg and Egger (2017), Gaessler et al. (2019), and Köthenbürger et al. (2018) confirm the positive impact of patent boxes on countries' propensity to attract patent ownership and mobile profits. It is less clear from existing work, however, whether patent boxes are effective in expanding real R&D investments, with some studies reporting positive and others reporting zero or even negative effects. Design elements of the patent box regimes – like the existence of a development condition – might, in part, explain these differences (see e.g., Mohnen et al. 2017; Chen et al. 2017; Bösenberg and Egger 2017; Bornemann et al. 2018; Gaessler et al. 2019).[2]

PATENT BOX REGIMES: WELFARE CONSEQUENCES

Even if countries attract mobile profits and R&D to their borders by introducing and expanding patent box regimes, it is a priori unclear whether this raises national welfare: welfare benefits from newly attracted profits and R&D investments (e.g., related to additional tax revenues or knowledge spillovers to the local economy) may be overcompensated by lower tax revenues collected from infra-marginal R&D investments. Chatagny et al. (2017) and Griffith et al. (2014) indeed suggest that the IP boxes in Switzerland and the UK may come with negative revenue effects.

What is more, patent box regimes may harm neighboring countries if the latter experience IP and R&D outflows. Neighbors, in consequence, may have incentives to retaliate the policy move and introduce patent box regimes themselves. IP mobility in this scenario undermines the ability of countries to tax the related income and tax rates in equilibrium are inefficiently low (see e.g., Zodrow and Mieszkowski 1986 and Wilson 1986).

Note, however, that it is a priori unclear whether patent box regimes really do harm neighboring jurisdictions. If MNEs have the flexibility to shift profits to low-tax economies, they may retain R&D activities in high-tax environments in turn (and even expand aggregate R&D, see Schwab and Todtenhaupt 2018); high-tax countries then reap welfare benefits (e.g., from higher employment and knowledge creation) that may compensate them for the welfare losses from outward profit shifting. In line with these considerations, Baumann et al. (2018) find that patents owned in tax haven countries, in a large number of cases, protect technologies that are invented in high-tax jurisdictions. Analogously, Egger et al. (2014) find that the tax sensitivity of multinational real investments significantly declines, in absolute terms, when MNEs have profit shifting opportunities.

ANTI-AVOIDANCE MEASURES: EFFECTIVE LIMITS ON PATENT SHIFTING?

The welfare consequences of (IP-related) profit shifting are thus ambiguous; if countries want to contain such shifting, they can draw on anti-tax avoidance instruments belonging to three broad categories: 1) source countries may levy taxes on IP-related payment flows from their borders; 2) headquarter countries may levy taxes on foreign IP-income if tax rates in destination countries are low; and 3) countries may implement measures that limit the mispricing of intra-firm royalties and license fees. In the following, we will discuss these instruments in turn.

Source Country Taxes on Royalty and License Payments

Countries can mitigate IP-related profit outflows by levying source country taxes. Germany and Austria, for example, enacted so-called royalty and license restrictions, which deny multinational firms to deduct intra-firm royalty and license payments destined for low-tax countries from the corporate tax base. The respective payments are hence effectively taxed at the source country, i.e., at the German and Austrian, corporate tax rate.

Such deduction limits are conceptually similar to withholding taxes on royalty and license payments, which also have been proposed to combat IP-related profit shifting (e.g., Finke et al. 2014; Juranek et al. 2018). The Netherlands, for example, just recently enacted a conditional withholding tax on royalty payments to low-tax countries. There are two key differences between the instruments: First, with deduction limits, royalties are taxed at the source country's corporate tax rate, whereas withholding tax rates may divert from this rate. Taxing "shifting income" at the source country rate is conceptually sound, but it might, on efficiency grounds, be beneficial to differentiate the tax burden on royalties/licenses from other corporate income. On top of that, the two regimes may also differ in terms of firms' exposure to double taxation.[3]

[2] Bradley et al. (2015) find no effect of patent box regimes on the propensity to attract foreign patents but a positive effect on the number of patents filed and invented in the country.

[3] While "classic" withholding taxes apply to all payments from countries' borders, using withholding taxes as instruments to combat multinational profit shifting may imply to limit their application to payments directed towards low-tax countries. To avoid MNEs bypassing the measures by channeling royalty flows through conduits requires that indirect payments to low-tax countries are also covered.

Note, moreover, that royalties and license payments differ from true "(IP-related) shifting income" in several ways: For example, tax-induced price distortions for (IP-intensive) goods traded within MNEs remain unaccounted and royalty payments related to real business activity are unduely captured.[4] Furthermore note that the US recently implemented a source country minimum tax scheme ("BEAT") with an even broader definition of "shifting income": For certain MNEs, royalty, license, and interest payments from the US as well as a number of other intra-firm payments are included in the corporate tax base; this "modified taxable income" is then assessed at a given tax rate and the taxpayer is liable for the maximum of this tax burden and the tax levy from standard corporate tax rules.

Comprehensive empirical evaluations of the effects of source country taxes that target IP-related multinational profit shifting are still missing to date. One notable exception is Hemmerich (2019) who investigates the economic consequences of the introduction of a royalty deduction limit in Austria in 2014 that denies deduction for tax purposes if royalties are taxed at a rate below 10 percent in the receiving country. Based on data on cross-country royalty flows, he finds that royalty payments to affected destination countries dropped by a massive 50 percent in the wake of the introduction. He interprets the response as evidence for a reduction in IP-related income shifting and the effectiveness of the law. Future research should complement this analysis by determining how real investments in Austria and other countries responded (in order to assess whether part of the observed drop in outward royalty flows might reflect that affected MNEs relocated real investments to other countries).[5]

Controlled Foreign Company Rules and Destination Country Minimum Taxes

An alternative instrument to combat IP-related profit shifting to low-tax countries is controlled foreign company (CFC) legislation that make passive multinational income earned in low-tax countries taxable in the MNE's parent country. Numerous countries have implemented CFC legislations in their national tax laws over recent decades; with BEPS and ATAD, countries moreover agreed to internationally coordinate their CFC legislations. A number of empirical studies quantify the impact of CFC laws on profit shifting activity, commonly reporting significant reductions in shifting behavior (see e.g., Clifford 2019). Interestingly, this also holds true if IP-related income shifting is considered (see Baumann et al. 2018 and Heckemeyer et al. 2018). Moreover, while the applicability of CFC rules against other EU members was significantly reduced by the European Court of Justice's Cadbury-Schweppes ruling in 2006, Clifford (2019) shows that the legislation was still effective in limiting income shifting to low-tax countries afterwards.

The OECD, moreover, proposed to alter and expand destination country taxation: according to the proposal (OECD 2019) parent countries should levy – internationally coordinated – minimum taxes on income earned at foreign affiliates. If effective tax rates fall short of a pre-determined minimum level, the parent country levies a tax equal to the difference between the two rates. The proposal has complex economic and welfare implications, which cannot be discussed in detail in this article. Importantly, however, the proposal adds complexity to an already complex set of anti-profit shifting rules. It is hence of key importance that anti-shifting measures are integrated to limit the risk of double taxation and avoid high corporate compliance and administrative costs.

Transfer Pricing Legislations

As outlined above, multinational firms may also shift income to low-tax countries by strategically mispricing intra-firm royalties. Transfer price documentation regulations, which require MNEs to document their transfer prices and show that they adhere to arm's length rules, are expected to reduce such shifting activities. A number of papers present evidence in line with that notion (e.g., Beer and Loeprick 2015; Riedel et al. 2016). Importantly, however, recent work also suggests that transfer pricing rules exert no dampening effect on shifting activities related to IP-trade (Beer and Loeprick 2015; Baumann et al. 2018). The lack of third-party prices for patents and other IP appears to leave room for mispricing practices even in the presence of documentation requirements.

Coordinated Measures: BEPS and ATAD

Anti-tax avoidance measures have, moreover, not only been implemented unilaterally, but countries have also agreed to tighten and coordinate instruments in the OECD's BEPS process and the EU's ATAD. Numerous measures have been implemented, (some of) which also target IP-related income shifting to low-tax countries. It is still to be seen how effective these measures are in limiting (IP-related) profit flows to lower-tax entities. Preliminary evidence points to the effectiveness of some measures, like country-by-country reporting (Hugger 2019).[6] BEPS Action 5, moreover, defines nexus requirements for patent box regimes. The evidence presented above suggests that this will reduce interna-

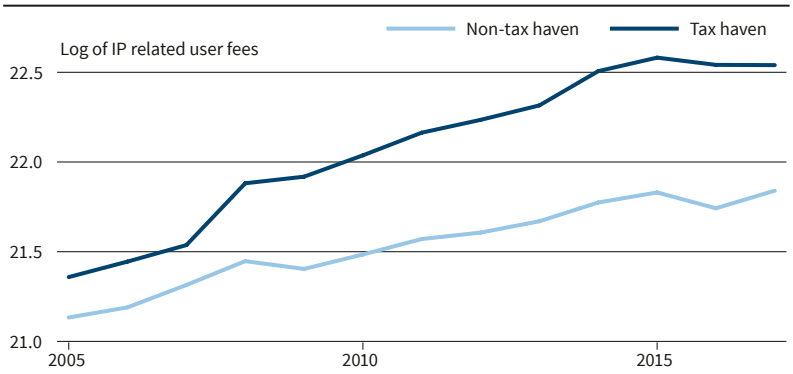
[4] The application of withholding taxes should hence be limited to payments directed towards low-tax affiliates to avoid unnecessary burdens on real business activities. Any tax threshold defining the set of "low tax countries" is arbitrary, however. If set low, profit shifting may not be substantially reduced but just diverted to lower-tax countries above the threshold.

[5] The welfare implications of the policy reform are very different in scenarios where MNEs retain their real activity in Austria but restrict profit shifting to low-tax countries and scenarios where MNEs relocate real activity to other countries without deduction limits and shift income from there to low-tax entities.

[6] Under country-by-country reporting, MNEs have to provide basic information on taxable income and real activity allocation across affiliates to tax authorities.

Figure 1

IP Related User Fees



Source: World Development Indicators (2019). © ifo Institute

tional patent shifting to IP box countries (but might trigger shifts of real R&D activity in turn). More rigorous evaluations of the profit shifting effects of ATAD and BEPS have to be left to future research as many of the measures of ATAD and BEPS have just recently become effective (since 2016) or will become effective only in the upcoming years.[7] Country-level data on IP-related user fee inflows does not suggest that tax haven countries have experienced a dip in IP-related user fee receipts after BEPS and ATAD yet (see Figure 1).[8] This may, however, change in the years to come when the measures become effective in more countries.

CONCLUSION

In this article, we reviewed existing empirical evidence on patent-related income shifting to low-tax countries, which largely suggests that such shifting practices are a quantitatively relevant phenomenon. We, moreover, discussed anti-avoidance measures to combat such activities. While empirical work suggests that transfer pricing laws are of limited effectiveness in containing IP-related profit shifting, there is evidence that deduction limits and CFC regimes "bite" and lower IP-related shifting activities. We also highlight, however, that the welfare consequences of anti-avoidance laws are ambiguous. Even if profit shifting is contained, the location of corporate real activity might become more tax-sensitive and tax competition might, therefore, even intensify (see e.g., Mongrain 2019).

[7] ATAD was adopted in 2016 only and countries were granted a two-and-a-half year period to transform the directive into national law. A number of BEPS countermeasures have been in place since 2016; this for example relates to the nexus requirements for patent box regimes. Here generous phasing out periods until 2021 were granted, however, during which former regimes remain active but new entrants are only allowed to opt for the new regime (e.g., Hemmerich 2019).

[8] The graph shows the natural logarithm of the average royalty payments in 92 non-haven countries and 18 tax havens (in a balanced sample). The haven countries are Antigua and Barbuda, the Bahamas, Belize, Switzerland, Dominica, Grenada, Hong Kong, Ireland, St. Kitts and Nevis, St. Lucia, Luxembourg, Macao, Malta, Mauritius, Panama, Singapore, Seychelles, St. Vincent, and the Grenadines.

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Promoting Clean Energy Innovation

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Meeting today's most ambitious climate policy goals, such as the European Union's plans to reduce emissions by 40 percent below 1990 levels by 2030 or California's goal to rely solely on zero-emission energy sources by 2045, requires replacing vast amounts of fossil fuel energy sources with alternative, carbon-free energy sources. While innovation over the past decades helped reduce the cost of wind and solar energy, many technical challenges remain, such as low-cost battery storage, both for intermittent energy sources and to bring down the cost of electric vehicles.

Well-designed climate and energy policies facilitate these technological advances. Regulatory pressures spur firms to develop new and better ways to improve environmental performance. Understanding how policy promotes clean energy innovation involves the study of what economists have termed "market failures," meaning that market forces alone will not lead to optimal allocation of resources. Two market failures are particularly relevant to energy and environmental technology:

- **The Economics of Pollution:** Because pollution is not priced by the market, firms and consumers have little incentive to reduce emissions without policy intervention. The market for technologies that reduce emissions will otherwise be limited, further slowing commercialization and reducing incentives to develop such technologies. Policies addressing these environmental externalities increase the potential market size for clean energy innovation, and are often referred to as *demand-pull* policies in the literature.
- **The Economics of Knowledge:** At the same time, the "public good" nature of knowledge creates spillovers that benefit the public as a whole, but not the innovator. Because they do not reap the rewards of these spillovers, potential innovators do less research than would otherwise be desirable, even if environmental policies to address externalities are in place. Science policy to support research performed in both the private and the public sectors helps bridge this gap. Examples include direct government funding of research projects and indirect support such as tax credits for private-sector research and development. Policies addressing knowledge market failures are often referred to as *technology-push* policies.

These two market failures could, in principle, be addressed separately. Since knowledge market failures apply generally across technologies, economy-wide policies affecting all types of innovation could address knowledge market failures, leaving it to environmental policy to "get the prices right" to encourage green innovation. A carbon tax exemplifies the economist's goal of "getting prices right" by putting a price on emissions related to climate change. However, recent evidence suggests that such broad policy strokes are not enough to promote clean energy innovation.

In addition to broad-based policies such as carbon taxes or cap-and-trade, which target all greenhouse gas emissions, governments use a variety of targeted policies to promote clean energy and reduce emissions. Examples include fuel economy standards for vehicles, renewable energy mandates, and tax incentives for purchasing rooftop solar photovoltaic equipment. Whether targeted or broad-based, policies to promote clean energy can be classified as *technology-neutral* or *technology-specific*. Technology-neutral policies provide broad mandates, but leave it to consumers and firms to decide how to comply. Examples include a carbon tax, which targets all emissions equally, as well as more focused policies such as renewable energy mandates. Such mandates require that utilities generate a set proportion of electricity from renewable energy, but do not dictate what types of renewable sources be used. Technology-specific policies stipulate the use of individual technologies. For example, tax credits for electric vehicles or rooftop solar energy are available only to consumers who purchase these products. Feed-in tariffs for solar energy in Germany were more than seven times higher than the feed-in tariffs for wind energy, thus encouraging investment in solar energy (OECD-EPAU 2013). Below, I review the evidence on how both broad-based and targeted policies shape the pace and direction of clean energy innovation, and I discuss the implications of this literature for climate and energy policy.[1]

INNOVATION FROM BROAD-BASED POLICIES

I first present evidence on innovation resulting from market forces such as higher energy prices or from broad-based policies. Most technological solutions to reduce climate emissions address the energy sector through one of two mechanisms: providing cleaner energy resources or improving energy efficiency. Understanding how the private sector will innovate on these technological areas *without* targeted support is important for understanding when targeted support will be most effective. Three key lessons emerge.

First, higher energy prices encourage innovation on alternative energy sources and on some energy efficiency technologies. Over the long term, a 10 percent increase in energy prices leads to a 3.5 percent rise in the number of US patents in 11 different alternative energy and energy efficiency technologies (Popp 2002). Most of the response occurs quickly after a change in energy prices, with an average lag between an energy

[1] Popp (2019) provides a more extensive review of this literature.

price change and patenting activity of 3.71 years. Verdolini and Galeotti (2011) find similar results using a multi-country sample from 1975 to 2000. Similarly, when facing higher fuel prices, firms in the automotive industry produce more innovations on clean technologies, such as electric and hybrid cars, and less in fossil fuel technologies that improve internal combustion engines (Aghion et al. 2016). A 10 percent higher fuel price is associated with about 10 percent more low-emission energy patents and 7 percent fewer fossil fuel patents.

Second, prices alone do not encourage sufficient energy efficiency innovation. There are incentives to develop and deploy energy efficient technologies even without climate policy in place, as improving energy efficiency not only reduces emissions, but also lowers costs. However, because reduced emissions are an external benefit, environmental market failures mean that individuals will not consider the social benefits of using technologies that reduce emissions, leading them to underinvest in energy efficient technologies. Thus, energy efficiency standards also help spur innovation. Using the relationship between fuel efficiency and vehicle characteristics to infer rates of technological progress, Knittel (2011) finds that fuel economy regulations have a positive effect on observed technological progress for cars, but not for trucks. The effect of energy prices on energy efficiency innovation is also limited by their saliency. While studies on the auto industry and on renewable energy find that higher energy prices spur innovation, energy prices are less effective for promoting innovation on home energy efficiency. Prices are particularly ineffective for inducing innovation on less visible technologies such as insulation that are installed by builders and are not easily modified. Instead, building code changes induce innovation for home energy efficiency (Noailly, 2012).

A third key lesson is that even the choice of broad-based policies focusing on overall emissions (e.g. a carbon tax) or on technology-neutral goals (e.g. renewable energy mandates) implicitly favors some technologies over others. Technology-neutral policies promote technologies closest to being competitive in the market without policy support. Johnstone et al.'s (2010) study of renewable energy innovation is an example. Because wind energy was the closest to being competitive with traditional energy sources at the time of this study, innovation in countries with mandates to provide alternative energy focused on wind. In contrast, direct investment incentives such as feed-in tariffs supported innovation in solar and waste-to-energy technologies. These technologies were less competitive with traditional energy technologies and required the guaranteed revenue from a feed-in tariff to compete.

These results suggest particular challenges to policymakers who wish to encourage long-term innovation for technologies that have yet to approach market competitiveness. Using technology-neutral policies that let markets "pick winners" leads to lower compliance costs in the short term, as firms choose the lowest-cost short-term strategy. However, the policy choice to let the market decide also implicitly "picks a winner." Because firms will focus on those technologies closest to the market, broad-based market policies and technology-neutral targeted policies provide less incentive to develop technologies with longer-term research needs, such as offshore wind energy. Because no one technology will be fully able to meet all energy demands, complementary policies to promote the development of low-emission technologies further from the market are also needed. These policies will often target specific technologies.

WHEN SHOULD POLICY TARGET SPECIFIC TECHNOLOGIES?

Recent theoretical work suggests that other market failures may require governments to support specific technologies – particularly those furthest from the market. Such market failures include learning-by-doing, path dependency, and capital market failures (Acemoglu et al. 2016, Fischer et al. 2017, Lehmann and Söderholm 2018). Both learning-by-doing and path dependency justify technology-specific deployment policies such as feed-in tariffs or tax credits – most notably when the resulting cost reductions benefit not only early adopters, but also those who wait to adopt until costs fall (e.g. Lehmann and Söderholm 2018). However, the existing literature on learning-by-doing generally suggests that the benefits of learning-by-doing are not sufficient to justify current levels of deployment subsidies (e.g., Nemet 2012; Fischer et al. 2017; Tang 2018). Empirical evidence on path dependency is slim. Path dependency creates a market failure if switching costs make it difficult for firms previously investing in one type of technology to switch to profitable opportunities in another. While some recent studies find evidence of path dependency in energy innovation (e.g., Aghion et al. 2016; Stucki and Woerter 2017), none of these studies tests whether the observed path dependency results from high switching costs or are simply a reaction to better research opportunities. More research on the relationship between switching costs and path dependency is needed.

In contrast, the evidence on capital market failures for energy is limited but suggestive of such market failures. In an evaluation of the US Department of Energy Small Business Innovation Research (SBIR) program, Howell (2017) provides evidence that early financing helps overcome capital market failures in clean energy. SBIR grants improve the performance of new clean energy firms, but are ineffective for older technologies such as coal, natural gas, and biofuels. Similarly, Popp (2017) provides evidence that bringing new energy technologies to market takes longer in clean energy than in other fields (e.g., Branstattter and Ogura 2005; Finardi 2011), suggesting that the length of time necessary for commercialization of energy R&D creates a bar-

rier to raising private sector financial support. Finally, both Mowrey et al. (2010) and Weyant (2011) argue that government research helps new energy technologies overcome roadblocks to commercialization. Significant energy innovations typically have disproportionately large capital expenses, leaving a role for collaboration with the public sector to provide support for both initial project development and demonstration projects. Such demonstration projects can promote further learning (Mowrey et al. 2010). Palage et al. (2019a) find supporting evidence, showing that advanced biofuel patenting increases after investments in demonstration projects in EU countries. While more research is needed, the evidence to date suggests a need for policies that help bridge the gap between laboratory research and commercial success.

THE EFFECTIVENESS OF GOVERNMENT R&D

The market failures above are addressed using policies that focus on deployment, which induce innovation by creating new markets for renewable energy. These policies do not address market failures affecting the supply of innovation. High social returns to R&D justify government research investment. However, this is true for all technologies, not just clean energy. Thus, an important question becomes whether spillovers from green innovation are larger, so that government R&D should play a larger role for cleaner technologies. Several recent papers use patent citations to study spillovers from energy innovations. Citations received by a patent indicate that the knowledge represented in the patent was utilized in a subsequent invention, providing evidence of potential knowledge spillovers. These studies generally provide support for a larger role for government-funded clean energy R&D, particularly for technologies that are still emerging. Both Dechezleprêtre et al. (2017) and Popp and Newell (2012) find that clean energy R&D generates large spillovers, comparable to spillovers in other emerging fields such as IT or nanotechnology. Noailly and Shestalova (2017) find similar results, but only for younger clean energy technologies. For emerging technologies such as energy storage, spillovers occur across technology domains, making it less likely that private sector inventors can capture the full benefits of these innovations.

The most important and most widely used policy addressing the supply side of clean energy innovation is government R&D funding. To study the effectiveness of public energy research, Popp (2016) links data on scientific publications to public energy R&D funding. The paper provides four key results. First, USD 1 million in additional government R&D funding leads to 1–2 additional publications, but with lags as long as ten years between initial funding and publication. Second, adjustment costs associated with large increases in research funding are of little concern at current levels of public energy R&D support. These results suggest that there is room to expand public R&D budgets for renewable energy, but that the impact of any such expansion may not be realized for several years. Third, factors found to influence private R&D activity in other papers, such as energy prices and policy, have little impact on publications, suggesting that current R&D funding efforts do appear to support different types of research than generated by the private sector. Finally, since the ultimate goal of government energy R&D funding is not an article, but rather a new technology, Popp uses citations from patents to scientific literature to link these articles to new energy patents. While public funding does lead to new articles, lags in both the creation of a new publication and the transfer of this knowledge to applied work mean that public R&D spending may take over a decade to go from a new article to a new patent.

The state of technology development also matters for government R&D effectiveness. Government R&D should focus on technologies furthest from the market. Costantini et al. (2015) compare patenting in conventional first-generation biofuels to patenting in more advanced second-generation biofuels. While technology-push policies do not induce innovation for more mature technologies (e.g. first-generation biofuels), they are important for fostering foster development in emerging, more advanced technologies. Thus, government support for clean energy R&D should focus on emerging technological areas such as energy storage, rather than more established technologies such as onshore wind energy.

Governments support research not only by providing financial support to private firms and universities, but also through performing research in government laboratories and research institutes (e.g., the US National Renewable Energy Laboratory). Such institutions have proven to be particularly valuable for promoting innovation in clean energy. Clean energy patents assigned to governments are more likely to be cited than clean energy patents from other institutions, signaling higher quality and highlighting the value of research performed at government institutions (Popp 2017). Moreover, government articles on clean energy technology are more likely to be cited by patents than similar articles from any other institution, including universities. This suggests that clean energy research performed at government institutions plays an important role linking basic and applied research. Collaborations across institutions also promote technology transfer. For clean energy technologies, both scientific articles and patents with authors from multiple types of institutions (e.g., universities and corporations) are cited more frequently, suggesting that collaborations across institutions enhance research quality (Popp 2017). These examples highlight the role of government R&D projects and laboratories in aiding the commercialization of new technologies, often referred to as "technology transfer."

Finally, it is important to remember that R&D subsidies address the supply of clean energy technology,

but do not create demand for new technology. In a study of solar PV patent data from 13 European countries from 1978 to 2008, Palage et al. (2019b) find that public R&D support for solar PV innovation induces more private sector patenting when accompanied by a feed-in tariff. Their result emphasizes that public R&D can complement demand-pull polices to enhance innovation, but it is not a substitute for policies that create demand for clean technology.

INNOVATION IN A GLOBAL ECONOMY

Climate change is a global problem. Innovators partake in global markets and are influenced by regulation not only at home, but in other countries where they do business. Two recent studies compare the effect of domestic and foreign environmental policy for renewable energy. Dechezleprêtre and Glachant (2014) compare wind energy patents across OECD countries, using data from 1991 to 2008. Their observations are country pairs, as they look at both the source (i.e., where patents are filed from) and destination (i.e., where patents are granted) of invention. While both domestic and foreign demand-pull renewable policies positively affect renewable technology innovation, the marginal effect of policies implemented at home is 12 times higher. However, since the foreign market is much larger than the domestic market across the sampled countries, the overall impact of foreign policies is on average twice as large as the overall impact of domestic policies on innovation. Both trade barriers and weak intellectual property rights dampen the influence of foreign policies on wind energy patenting in any given country. In a study of 15 OECD countries using patent data from 1978 to 2005, Peters et al. (2012) also find both domestic and foreign demand-pull policies (such as renewable portfolio standards or feed-in tariffs) are important for the development of solar PV technology. However, technology-push policies such as R&D subsidies increase only domestic innovation.

Fabrizio et al. (2017) compare the effect of policy on domestic and foreign innovation for energy storage. Unlike the aforementioned papers, their sample includes patents from countries that do not directly regulate energy storage, as they combine data on energy storage policies in 11 OECD countries from 1990 to 2011 with data on energy storage patents from 61 countries during the same time frame. Demand-pull polices both promote domestic innovation and increase technology transfer coming into the country, measured as domestic patent applications filed for technologies that originally filed for patent protection elsewhere. Thus, increased innovation from environmental policy may come from abroad. In contrast, technology-push policies promote domestic innovation, but do not increase technology transfer.

Given the international nature of innovation, Stucki and Woerter (2017) ask whether technological followers might benefit from a "wait-and-see" strategy whereby they wait for knowledge spillovers to close the gap between themselves and technology leaders. By waiting, countries could avoid locking in early higher-cost green technology inventions. Focusing on the technology gap between technology leaders and other nations, they find that while knowledge spillovers from abroad enhance innovation in follower countries, they do not enable late movers to catch up to technology leaders. A wait-and-see strategy does not appear beneficial.

Finally, the global distribution of R&D expenditures is changing. By 2015, OECD nations' share of global R&D fell to 65 percent. China alone performed 21 percent of global R&D. Only the US, with 26 percent, performed more (National Science Board 2018). As such, it is important to understand the drivers and impact of environmental R&D from emerging economies. In recent years, researchers have begun to assess environmental innovation in emerging economies, particularly in China.

Lam *et al.* (2017) use patent citation data to study the quality of wind innovation in China. During the 2000s, China dramatically increased the deployment of wind energy, so that by 2012 it had the most installed wind capacity of any country. Similarly, the number of Chinese wind energy patents awarded to domestic firms increased dramatically during this time period. However, few of these patents were of sufficient quality to be awarded protection abroad, and Chinese wind energy patents are cited less frequently than patents from other countries. Thus, while China's wind energy innovation grew rapidly in the 2000s, its impact has yet to spread to other nations.

Given the dramatic increase in Chinese wind energy deployment, several studies use learning curves to look for evidence of technological progress. Tang and Popp (2016) consider the role of knowledge spillovers, using data on the projected costs of wind projects financed through the Clean Development Mechanism (CDM). Wind project developers benefit from their past experiences with both wind farm installation and wind power generation. More importantly, previous collaborative experience between a project developer and foreign turbine manufacturer leads to both the greatest reduction in project costs and the greatest improvement in productivity. Joint learning occurs between partners during interactions on wind farm installations, and the CDM helped achieve this goal by encouraging collaboration between project developers and foreign turbine manufacturers.

Hayashi et al. (2018) update the work of Tang and Popp using actual, rather than predicted, performance of CDM wind turbines. They find less evidence of learning when using actual performance data. Comparing the productivity of wind turbines in China and the US, Huenteler et al. (2018) offer several reasons for poor performance of wind energy in China, including delays in grid connection, curtailment of energy due to grid management, and suboptimal turbine selection and

wind farm siting. These last features are locked in for the life of a wind farm, suggesting that it will take time to improve the overall performance of Chinese wind production.

CONCLUSIONS

Recent history provides many successful examples of environmental innovation. Better pollution control technologies, such as catalytic converters for automobiles, led to dramatic reductions in air pollution in the developed world. The costs of clean energy sources such as wind and solar power are now low enough to be competitive with fossil fuel sources, reducing emissions from the electric power sector. While private sector companies created many of these technologies, public support for their research was essential. This support comes in the form of both regulations to create demand for clean technology and public funding of the science underlying new green technologies.

Moving forward, the changing nature of technology suggests greater challenges lie ahead. Continued growth of intermittent renewable energy sources cannot continue without long-term energy storage solutions and smart grid technologies to integrate renewable generation into the grid (IRENA 2017). Breakthrough innovations are imperative if policymakers aim to reduce carbon emissions to near zero in the long term. For example, as the share of electricity generated by intermittent renewable power grows, managing the electric grid becomes more complicated. Advances in energy storage would greatly improve grid management. Energy storage breakthroughs leading to better batteries would also make electric vehicles more attractive to consumers by both reducing costs and increasing vehicle range. Because advances in energy storage could have spillover effects to multiple sectors, public sector R&D is likely to play a more important role in coming years. Similarly, innovation for public infrastructure, such as charging stations for electric vehicles, will also be needed. An important next step for both researchers and policymakers is to better understand the potential role of private vs. public sector innovation in a changing technological environment.

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Bernd Genser and Robert Holzmann

Taxing German Old-age Pensions Fairly and Efficiently

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INTRODUCTION

In the German pension system, the statutory pension pillar is dominating whereas occupational and personal pension schemes still play a minor role. German pension taxation was changed fundamentally by the Retirement Income Act of 2005. Based on a decision of the Federal Constitutional Court, which declared the rules for taxing pensions to be unconstitutional, the taxation of different forms of old-age pensions will become aligned over a period of 35 years and deferred pension taxation will become the pension tax standard by 2040. Despite compliance with the recommendation of the EU Commission,[1] questions arose in EU member states if deferred pension taxation is too generous because the income tax rate at which pension contributions are deductible is generally much higher than the tax rate on pension benefits after retirement, or because returns in pension funds are tax-exempt, or because pension wealth accumulation is taxed differently from other forms of wealth accumulation, e.g., through private saving, investment in owner-occupied housing, or saving of business owners.

In this paper we address these problems and recommend a fundamental change to German pension taxation by replacing deferred income taxation of pensions by a front-loaded pension tax regime, which avoids the problems sketched above and offers further attractive features.

The remainder of the paper is organized as follows. Section two starts with a short review on pension taxation in Germany. In section three, we check the economic relevance of critical remarks on deferred pension taxation and identify the existence of a double fairness dilemma. Sections four and five present the reform proposal and discuss the pros and cons of a switch to front-loaded pension income taxation. Section six summarizes and concludes.

Income Taxation of Old-Age Pensions in Germany

Up to 2004, pension benefits paid out under the German statutory pension scheme were income-taxed as life-time annuities. The income tax code determines splitting factors that separate the tax-free wealth repayment component and the interest component of pension benefits. Factors vary with the retirement age of the pensioner and remain fixed for the rest of their life span.

The Retirement Income Act 2004 codified deferred pension taxation, to be implemented gradually between 2005 and 2040. Pensioners who retired before 2005 are given a tax-free allowance of 50 percent of their pension benefits. The allowance for those retiring between 2005 and 2039 is reduced in steps of 2 percent until 2020 and then 1 percent per year, and finally becomes zero in 2040. As a compensating measure, the deductibility of contributions to the statutory pension insurance scheme is increased from 20 percent in 2005 in steps of 4 percent up to 100 percent in 2025.

Old-age pension benefits of civil servants (or comparable pensions of workers) who do not pay contributions during their working life remain fully taxable under deferred income taxation. But the tax base of these retirement benefits is reduced by a specific pension allowance, which is also phased out over the transition period 2005–2040.

Occupational pension benefits are taxed differently depending on the pension scheme applied. Pension benefits that are paid by the employer directly or via a benefit fund are taxable as deferred labor income but allow for the deduction of the specific pension allowance. Occupational pension benefits paid out by pension funds, pension insurance funds, or by insurance companies are taxed differently depending on the tax treatment of individual contributions to the pension scheme.

Private pension benefits are also taxed differently depending on the tax treatment of contributions. The income tax code codifies deferred income taxation of the full amount of pension benefits, splitting rules to separate a repayment and an interest component, or reduced taxation of the interest component depending on the duration of pension contract and the age of the retiree. Moreover, the application of an old-age relief allowance, which is also phased out in steps by 2040, reduces the tax base of taxable pension benefits.

The German regime of pension taxation is complex, nontransparent, and generates substantial compliance and administration costs. This situation will last for the whole transition period up to 2040 because only new retirees will be subject to deferred income taxation then, whereas pensioners who retired earlier still keep their cohort-specific allowances for the rest of their life. Nevertheless, the shift to deferred pension taxation will reduce the complexity of the German tax system in the long run. The following section, however, points out two caveats related to progressivity and international migration.

PROBLEMS OF BACK-LOADED PENSION TAXATION

With respect to the critical remarks on deferred pension taxation addressed in the introduction, non-taxation of returns of pension funds must not be qualified

[1] The Commission supports the elimination of obstacles to pension saving (European Commission 2001) although the arguments in favor of deferred taxation, viz. “deductible contributions to pension funds diminish a person’s ability to pay taxes” deferred taxation “encourages citizens to save for their old age”, are economically weak (EU Commission 2019).

as a tax break because returns are taxed when pension wealth is withdrawn. Moreover, the "discrimination" of non-pension saving vanishes if expenditure taxation is extended. But progressivity erosion remains a critical point and fairness infringements emerge as a new problem in a global economy setting.

Progressivity Erosion

Progressive taxation of fluctuating annual income violates horizontal equity in a lifetime perspective. Although this is well known, tax codes do not provide general measures to correct such horizontal equity violations, even though strategic tax-base smoothing has become a tax planning strategy for highly taxed individuals. Deferred pension taxation subject to a progressive income tax schedule generates a built-in tax-base smoothing effect because deductible contributions shift earned income to retirement years. Resulting erosion of tax progressivity favors all pensioners and might therefore even be regarded as welcome. But there are also social costs of deferred pension taxation, namely the permanent loss of national income tax revenue as well as the violation of vertical equity in a lifetime perspective.

The crucial problem of identifying revenue losses and redistributive effects is the choice of a benchmark. Caminada and Goodsworth (2008) and Johnson (2018) chose comprehensive income taxation, namely T-T-E, and report substantial tax revenue losses of 1.5 percent of GDP for the Netherlands in 2003 and 1.7 percent of GDP for the UK in 2016–17. On the other hand, the European Commission (2014), the OECD (2015), and most recently Barrios et al. (2016, 2018) chose deferred pension taxation, namely E-E-T, and consequently tax revenue losses are quite small.

Given the lack of studies that would help to answer questions on the generosity of tax-base smoothing, we quantify these effects in a simple life-cycle model for a cohort of single wage earners under the German statutory pension and taxation system of 2018. To concentrate on the tax-base smoothing effect, we regard a cohort of heterogeneous workers in a zero-inflation and zero-growth economy. Each worker earns constant labor income for 45 years and receives pension benefits for 20 years after their retirement in 2018. In this setting, E-E-T and T-T-E taxation are equivalent under a proportional income tax due to the zero-normal-interest assumption, but progressivity matters if taxable period income changes. Table 1 compares comprehensive income taxation, T-T-E, as the benchmark, with deferred income taxation, E-E-T. Column 1 shows that base smoothing under E-E-T causes a substantial reduction of the lifetime average tax burden over the whole income range. Tax reliefs for workers with annual wages between EUR 40,000 and EUR 80,000 exceed eight percentage points, the tax burden of the average wage earner (EUR 38,000) is reduced by more than one third. Tax relief for higher income levels shrinks due to the pension benefit cap, but is still almost six percentage points lower for a EUR 100,000 earner. The last column shows that front-loaded expenditure taxation without taxing excess returns, T-E-E, generates a tax relief in comparison to T-T-E, because German statutory pensions include injections from the federal budget which remain untaxed. Compared to E-E-T, under a T-E-E regime the tax increase by abolishing tax-base smoothing is partly compensated by exempting these returns.

The Double Fairness Dilemma

International migration of workers and pensioners has only recently been recognized as a problem of pension taxation (see Genser/Holzmann 2016, 2018, 2018a, 2019). According to article 18 of the OECD model tax convention (OECD 2017), pension benefits disbursed across borders "in consideration of past employment" are taxable only in the residence country of the recipient. The consequence of deferred pension taxation therefore is that fully deductible pension contributions leave a source state with zero income tax revenue on the corresponding earned income of a migrant because income tax revenue on pension benefits accrues to the residence state.

The OECD is aware of national claims of source countries to receive a fair share of income tax revenue on trans-border pension payments and lists a set of provisions in the commentary to article 18, e.g., exclusive, or non-exclusive, or limited, or conditional source taxation of pension benefits, which might be codified in bilateral tax treaties if both treaty states agree (cf.

Table 1

Lifetime Income Tax Burdens under Different Tax Regimes for Statutory Pensions in Germany (Average Tax Rates in Percent)

Annual income in EUR	Tax regime for statutory pensions		
	E-E-T	T-T-E	T-E-E
10,000	0	3.00	1.24
20,000	6.38	13.76	10.96
30,000	11.31	19.17	15.98
40,000	14.82	23.09	19.34
50,000	17.51	26.78	22.19
60,000	20.17	29.52	25.35
70,000	22.88	30.99	27.93
80,000	24.89	32.18	30.12
90,000	26.68	33.20	31.36
100,000	28.13	34.03	32.37

Source: own calculation based on a no-growth, no-inflation cohort model of single wage earners who earn statutory pension claims for 45 years and receive pension benefits for 20 years; contribution rates 9.3% employer and 9.3% employee; mandatory social contributions for health, unemployment, and care are considered deductible in all tax regimes.

OECD 2017a, C(18)-3ff.). But the OECD is reluctant in recommending such treaty amendments due to foreseeable administrative problems necessary to avoid double taxation.

Another possibility for source states to reduce the migration-induced revenue loss would be taxing pensions during the contribution and the pension wealth accumulation phase. But pension taxes, which are not levied on pension benefits, e.g., by limited deductibility of contributions or income taxation of pension wealth returns, are not addressed in the model tax convention and do not give rise to tax credits and therefore result in international double taxation.

The double fairness dilemma of deferred cross-border pensions taxation reveals the incompability of two worldwidely recognized equity targets, viz., double taxation avoidance for individual migrants and fair tax revenue sharing among states, under the current treaty network. And there is little hope that a satisfactory tradeoff between these conflicting targets can be found by renegotiating the complex network of bilateral double taxation treaties.

FRONT-LOADED PENSION TAXATION

The starting point for a new framework for pension taxation is the existence of two unsolved problems in the prevailing architecture of pension tax systems.

First, there is the simultaneous orientation of tax equity along two mutually exclusive equity standards: comprehensive income taxation and expenditure taxation.[2] These standards imply different time patterns of capital income taxation over the cycle of accumulation and use of capital. The Schanz/Haig/Simons principle requires taxation while capital wealth accrues, namely T-T-E, whereas the Fisher/Kaldor principle defers taxation until capital wealth is withdrawn and used for consumption, namely E-E-T. The Fisher/Kaldor approach exempts the normal rate of return on saving and establishes intertemporal neutrality of consumer spending decisions, but erodes progressivity by shifting earned individual income to after retirement years and reducing the lifetime income tax burden. The Schanz/Haig/Simons approach taxes nominal returns on saving, including normal returns, and thereby distorts intertemporal consumption but avoids tax-base shifting to post-retirement periods and progressivity erosion.

Second, tax assignment and double taxation avoidance methods in tax treaties are codified only for cross-border pension benefit flows. These treaty rules ignore the fact that pensions might have already been pre-taxed when pension wealth was accumulated.

To overcome these two deficiencies, we formulate two requirements for fair and efficient pension taxation:

- pensions should be taxed according to the Fisher/Kaldor principle[3], and
- fair pension taxation has to account for the pension tax burden over the whole pension cycle.

To satisfy the first requirement, the proposal makes use of a fundamental equivalence property of the Fisher/Kaldor approach. Intertemporal neutrality cannot only be ensured by a E-E-T regime, but also by a front-loaded income tax regime (T-t-E), which can be shown to be economically equivalent under a set of simplifying assumptions.[4] Under a T-t-E regime, income spent on pension savings is taxed when contributions are made and exempted when pension benefits are paid out. Returns on pension wealth are only liable to income tax if they exceed normal returns which are tax-exempt. This partial income tax exemption of returns is indicated by t. t<T immediately reveals that tax liability under Fisher/Kaldor taxation, namely E-E-T and T-t-E, is smaller than under comprehensive income taxation, T-T-E.

The second requirement makes use of the time pattern of T-t-E taxation which pre-taxes pensions when pension wealth is accumulated but exempts pension benefits.

Pre-taxing pensions following the Fisher/Kaldor principle should be attractive to treaty partners because this principle generates a fair distribution of income tax revenues and avoids international double taxation of pensioners even under the existing assignment rules in bilateral treaties.

- Pre-taxation of pension implies that the recouping pressure of deferred income taxation in source states is absent upon migration because pension wealth has been appropriately taxed upon accrual. No income tax is due for pension benefits paid out to migrants and non-migrants in source as well as in residence states. Pre-taxation of pension income accounts for the personal circumstances of the income earner and their ability to pay under unlimited tax liability as a resident of the source state.
- Since pension premiums are not deductible, no administrative check is necessary to verify the status of the pension system.

[2] The inconsistencies in cross-border taxation of pensions are grounded in theoretical ambiguities of taxation of pensions and their implementation in the national context. For the state of the theory of pension taxation and the implementation of pension taxation in key industrialized countries, consult Holzmann and Piggott (2018). Mirrlees (2011) proposes broader perspectives on the taxation of labor and capital and calls for an integrated approach for the design of pensions and their taxation.

[3] Genser/Holzmann (2018, 2018a) show that deferred income taxation of pension schemes is quite common in OECD countries but the diversity of tax regimes is huge within and across countries. See also OECD 2015, 2017.

[4] Standard assumptions are that the tax schedule remains unchanged over the pension cycle, the tax schedule is perfectly adjusted to inflation, and the tax regime treats positive and negative incomes symmetrically. Another crucial issue is the implicit assumption of progressive tax systems of what is considered tolerable and not regarded as violating tax equity under fluctuating period incomes over the lifecycle, which affects the lifetime tax burden of individuals with exactly the same present value of lifetime income. Perfect lifetime tax equity would require applying the progressive tax schedule to a notional average gross period income over the lifecycle. The same implicit assumption is necessary for lifetime pensions, although the tax burden differences are salient: in contrast to T-t-E taxation, deferred income taxation E-E-T implies that low pension benefits after retirement may go untaxed if they fall below the general income tax allowance. Perfect equivalence is attained under the implicit assumption that taxable lifetime earnings, including taxable pension benefits, are taxed by calculating the notional gross period income over the pension cycle.

- Pensioners do not have to file income tax returns in the new residence state after migration because pension benefits are tax-exempt.
- If both treaty states tax pensions T-t-E, then assignments according to articles 18 and 19 become irrelevant.

If, however, one treaty state decides to keep deferred pension taxation and to tax pension benefits, then avoidance of international double taxation requires the residence state to account for pre-taxation of pensions in the source state. The simplest solution would be to codify a pension article in the OECD model tax convention that assigns the right to tax pension benefits exclusively to the source state.

PROS AND CONS OF FRONT-LOADED PENSION TAXATION

Section four focused on the features of a well-established front-loaded pension tax system and left aside the transition process from deferred to front-loaded pension taxation.

The switch to front-loaded pension taxation is straightforward for pension contributions that are paid after the tax reform. They are no longer deductible and the individual income tax bases include pension contributions of employers and employees. As accumulated pension wealth must cover only net pension benefits after the reform, pension funds should split contributions into a net pension wealth component and an income tax component that is used to pay income tax demands by the tax authority.

Pension wealth accumulated under deferred income taxation before the tax reform can analogously be split into a net pension wealth and an income tax component that can be used to cover the reform-induced implicit tax liability rather than charging the future recipient of pension benefits directly.

Shifting the responsibility for appropriate pension taxation to the pension fund will require administrative provisions there, in particular the obligation to establish and to manage transparent individual accounts for each pension saver. Individual pension accounts should already be the rule within every classified pension fund in order to keep track of a pension saver's history and to inform fund clients swiftly and precisely about their financial status as a pensioner. Extending this obligation by providing tax-proof values of individual pension wealth for all pension schemes would help to manage the portability of pensions. Basing individual pension claims on publicly approved and readily available pension wealth data opens a promising path to guarantee pension claims for workers who intend or are forced to change their pension regime within a state or across national borders. Non-transparency and legal uncertainty of pension claims in case of individual mobility are substantial impediments to free mobility and economic efficiency.

An additional requirement of front-loaded pension taxation is the appropriate calculation of excess returns on pension wealth. Based on the operational availability of individual pension wealth data the pension fund is able to calculate individual excess returns as the difference between total returns and the rate of normal return. This normal rate of return must be fixed by the tax authority for every year. The tax code must define whether individual excess returns are taxed subject to a progressive schedule or to a flat rate under a dual income tax, and whether "negative excess returns" can be carried forward.

If front-loaded income taxation is introduced without adjusting the tax schedule, individual tax burdens will rise because the tax-base smoothing effect is no longer effective (cf. Table 1). Thus, the pension tax reform also requires political decisions on tax equity and socially desirable income tax schedules to meet the targets of poverty avoidance and consumption smoothing over the pension cycle.

For the income tax authority, pre-taxation of pensions implies that the personal circumstances of the income earner before retirement determine the income tax burden. The obligation to withhold income tax must be assigned efficiently to employers and pension funds, ensuring that both have access to all tax-relevant information.

Apart from circumventing the double fairness dilemma without tedious renegotiations of tax treaties, front-loaded pension taxation offers some additional attractive features which should be considered in political disputes on the future of pension taxation.

- Administration and compliance costs of pre-taxing pensions should be lower than under deferred pension taxation because monitoring of deductible pension saving becomes redundant.
- Pre-taxed pension benefits imply that pensioners who do not earn other market income need not file tax returns, which also saves tax compliance and administration costs.
- Monitoring and compliance obligations in source and residence states, which are necessary under E-E-T taxation, become unnecessary.
- Pre-taxation also backs free mobility in the single market since portable pension claims can be linked to national pension wealth data and double taxation is excluded if the pension saver emigrates as a worker (see Genser/Holzmann 2019).
- Finally, pre-taxation of pensions stimulates the labor market by offering pensioners a tax-free income supplement on top of their pension benefits as long as these additional earnings do not exceed the personal income tax allowance.

These additional advantages must be balanced against problems that are created by the pension tax reform. We did already mention the higher tax burden imposed during the working years unless the income tax schedule is adjusted appropriately, in line with tax equity and tax yield objectives. This adjustment must take into account

that a substantial part of the front-loaded individual tax demand can be paid out of gross pension contributions collected by the pension funds. Reducing individual pension wealth accumulation by a tax factor (1-T) causes no income effect as long as wealth accumulation remains sufficient to pay out pension benefits that are equivalent to after-tax pension benefits under E-E-T.

Individual pre-retirement purchasing power losses can also be prevented if front-loaded income tax liabilities are not paid immediately but can be deferred in the same fiscal way as back-loaded expenditure taxation defers taxation of pension saving. Deferred payment of tax debt is neutral with respect to the intertemporal government budget constraint as long as the present value of deferred tax payments is equal to the present value of the assessed tax liability. In Genser/Holzmann (2018), we propose two options for decoupling pension tax assessment and pension tax payment. Under both options, front-loaded pension tax liabilities are accumulated during the working life. Under the deferred pension tax payment option, payment of the pension tax liability is annuitized upon retirement and withheld by the pension fund when pension benefits are paid out. Under the distributed pension tax payment option, pro-rata tax payments are linked to cash flows over the whole pension cycle, viz. to contribution payments, returns on pension wealth, and pension benefit withdrawals. The latter option requires a recalculation of the relevant pro-rata rate to ensure full repayment of the tax liability over the retirement period. Tax payments are made by the pension fund and directly transferred to the tax authority when contributions flow in, returns accrue, and pensions benefits are paid out. The advantage of expanding payment of tax liabilities over the whole pension cycle is, of course, the low tax rate on pension cash flows, which might alleviate opposition against the front-loaded pension tax reform. Moreover, deferred payment of pension taxes reduces the political pressure on the government to expand budget expenditures that will certainly emerge if income tax revenue increases after the pension tax reform.

CONCLUDING REMARKS

The system of deferred pension taxation is a widely recommended and implemented form of pension taxation across the OECD countries. While deferred pension taxation exhibits attractive features with respect to economic efficiency and administrative simplicity, critical remarks point at national tax revenue losses. Two strands of arguments addressed in this paper question the recommendation of the EU in favor of deferred pension taxation: erosion of income tax progressivity and a lack of fairness and efficiency in a global setting.

The tax-base smoothing effect of deferred pension taxation results in substantial reductions of individual tax burdens and national income tax revenue, and undermines tax equity objectives that the progressive income tax schedule aspires to achieve. The double fairness dilemma of deferred pension taxation gains importance with the increasing international mobility of individuals during their working life and after retirement, and the current practice of taxing cross-border pensions following the OECD model convention. The existing network of bilateral double taxation treaties produces income tax losses in source states that are unable to recoup revenue losses caused by deductible contributions to pension schemes. If source states try to reduce these revenue losses by taxing pensions during pension wealth accumulation, migrants face double taxation because the OECD model tax convention allows for tax credits only on source taxes paid on pension benefits.

This paper proposes front-loaded expenditure taxation of pensions as a tax regime that maintains the attractive properties of expenditure taxation but avoids progressivity erosion and the double fairness dilemma. Considering a move toward front-loaded pension taxation and discussing the pros and cons of its implementation should be worthwhile for Germany, which is highly affected by migration. Moreover, a discussion on such a pension tax reform might be an incentive for the EU to rethink its current position and to scrutinize front-loaded pension taxation and pension portability as a viable reform package to ensure the basic liberties of the European single market and to cope with the economic challenges of globalization.

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Initial Placement Restrictions: Opportunity or Challenge for Refugee Integration?

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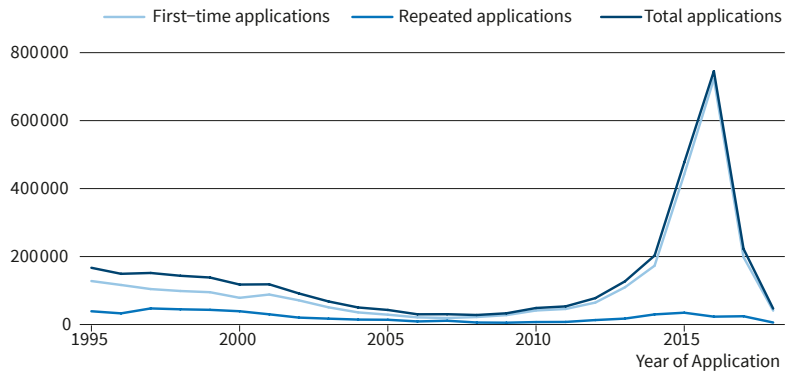
The sudden influx of migrants to Europe in recent years, followed by economic deterioration and political upheaval in the Middle East and North Africa (MENA) countries, poses challenges to national governments and creates the need for innovative and targeted policy measures that foster integration. This is crucial considering that many refugees have been granted protection and will stay in their host country for an extended period of time, if not permanently.

Germany has been particularly affected, with the number of asylum applications increasing sharply since 2014 (Figure 1). Compared to the other EU member states, Germany received the highest number of refugees in absolute terms[1] and ranks third after Sweden and Austria in relative measures (OECD 2017, p. 17ff.).

[1] 1.2 million persons in 2015 and 2016.

Figure 1

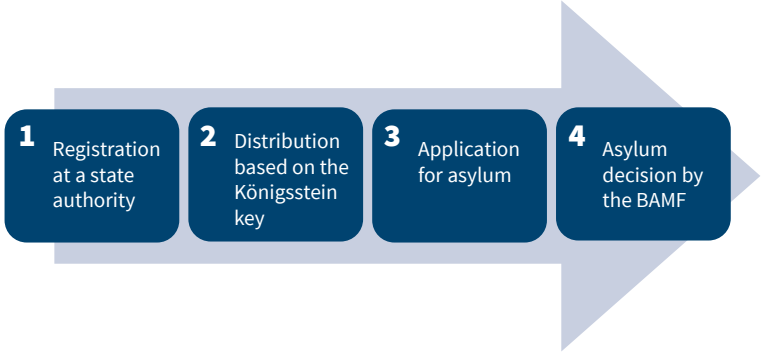
Number of Asylum Applications in Germany



Source: BAMF (2019), author's illustration. © ifo Institute

Figure 2

Stages of the Asylum Procedure



Source: BAMF (2016), author's illustration. © ifo Institute

With the August 2016 Integration Act, the German federal government introduced several integration measures for refugees with protected status, including the residence rule (*Wohnsitzauflage*). The residence rule limits refugees' ability to choose their place of residence for an initial period of three years after being granted asylum. As such, the policy aims at distributing financial burdens more evenly across municipalities and facilitating the planning of integration activities and language courses (SVR, 2016, p. 4ff.).

The economic literature establishes a strong link between immigrants' language skills and prospective labor market outcomes.[2] Consequently, completing a language course may be considered an essential first step toward successful integration. Against this background, this report analyzes the effects of the residence rule on participation in integration courses and refugees' language proficiency levels in Germany.

INSTITUTIONAL BACKGROUND

The Asylum Procedure in Germany

Figure 2 illustrates that the asylum procedure in Germany has a four-stage structure (BAMF, 2016). (1) Upon arrival in Germany, an individual seeking political asylum must report to a state authority, e.g., a border authority or a security authority. (2) They will then be registered in the EASY system[3] and subsequently distributed to an initial reception facility based on an allocation scheme that considers both a state's annual tax revenue and population size, the *Königsstein key*. As such, the Königsstein key strives to ensure an equal allocation of refugees across states without taking individual preferences into account. (3) The refugee may then formally apply for political asylum. (4) Following examination of the application and a personal interview, the Federal Office for Migration and Refugees (BAMF) makes its final decision.

[2] See for example Chiswick (1991); Chiswick and Miller (1995); Dustmann and van Soest (2001); Dustmann and Fabbri (2003); Bleakley and Chin (2004).

[3] EASY (Erstverteilung von Asylbegehrenden, English: Initial Distribution of Asylum Seekers).

The Residence Rule

While asylum seekers face strict travel restrictions (*Residenzpflicht*) throughout the asylum process, previously, refugees with protected status could choose their place of residence freely within Germany. However, for asylum decisions since August 2016, the residence rule enforces severe restrictions on where individuals can reside, under certain conditions. There are a few exemptions from the residence rule; for example, if the migrant or a close relative (spouse, domestic partner, or child) attends school/university or has taken up employment with a certain number of working hours.[4] Those who are subject to the residence rule but do not comply lose their social benefits.

If none of the exemption criteria applies, a refugee with protected status must stay in the state in which they formally applied for asylum, i.e., the state initially determined by the Königsstein key, for three years after the asylum decision. Hence, the residence rule restricts mobility between states. Especially in economically less developed states, this regulation may be very restrictive.

Besides state-level restrictions, the Integration Act enables states to impose additional regulations. As a result, as of January 2017, five states have adopted even stricter placement policies that limit refugees' place of residence to the district level: Baden-Wurttemberg, Bavaria, North Rhine-Westphalia, Saarland, and Saxony-Anhalt (OECD 2017, p. 49). In all other German states, refugees with protected status remain free to move within their assigned state.

Integration Courses in Germany

An immigrant who lacks adequate command of German in speaking and/or writing may apply for an integration course. This is why refugees with protected status are generally eligible.[5] An integration course consists of two parts: an orientation course on life in Germany lasting 100 hours and a language course lasting 600 hours, which conveys the vocabulary necessary for everyday situations. Upon completion of the course curriculum, participants take a final language test and a quiz on the orientation part.

Because the Integration Act seeks to facilitate access to integration measures at a local level, the report focuses on two primary integration outcomes: language proficiency levels and the probability of completing an integration course in the year of the asylum decision. For this purpose, the empirical analysis relies on certified language proficiency levels from the language test[6] rather than on self-assessed language skills, because they are less prone to measurement error.

HOW WAS THIS RESEARCH CONDUCTED?

Refugees with protected status who meet the exclusion restriction (and, hence, must not comply with initial placement restrictions) and refugees who are subject to the residence rule may be distinct in observable and unobservable characteristics that in turn may determine respective outcome variables. Thus, a simple comparison of the two groups may not convey the true causal estimate.

For this reason, the empirical analysis restricts the sample to those who do not satisfy the exclusion restriction. With introduction of the Integration Act, however, states implemented the residence rule to varying degrees: either requiring refugees with protected status to stay in the state where they formally submitted their asylum request (control group) or limiting residence to a particular district (treatment group) for a period of three years. An interesting detail of the asylum process in Germany is that refugees may not freely choose their first residence; instead they are assigned to states on the basis of the Königsstein key (see section *The Asylum Procedure in Germany*). Further, treatment and comparison states do not differ in their geographic, economic, or political characteristics. Thus, the analysis uses both the temporal variation in the regulation's implementation and the variation in the legal provisions across states in a *difference-in-differences* setting. This quasi-experimental design then controls for permanent differences between treatment and control groups as well as for existing time trends. Assuming that the treatment and control groups behaved similarly prior to the reform, the difference-in-differences estimate yields the causal effect of initial placement restrictions on participation in integration courses and certified language proficiency levels among refugees with protected status in Germany.

The data source for this report is the Socio-Economic Panel (SOEP), a representative survey of about 15,000 households in Germany (Göbel et al. 2019). In 2016, the SOEP included the IAB-BAMF-SOEP Survey of Refugees, which surveys refugees who have arrived in Germany since 2013, to allow for quantitative and empirical social research on this timely topic. It is important to note that the SOEP includes all information relevant for the analyses: the timing of the asylum decision and the type of residence permit, the place of residence at the district level, as well as information on the participation in, and results of, language courses for all household members. As stated previously, the empirical analyses consider only refugees with protected status who are subject to the residence rule.

[4] For further information, see the Federal Ministry of Justice and Consumer Protection, 2016, Residence Act (*Aufenthaltsgesetz*) Section 12a, Art. 1.

[5] Eligibility is less clear for asylum seekers. In the past, only refugees who successfully passed the asylum procedure had the right to attend an integration course. This has partly changed with the Integration Act, which fosters participation for asylum seekers with a high probability of staying. Since the empirical analysis focuses on refugees with protected status, this does not affect the results.

[6] Language skills are measured on a scale from 0 to 3 (0 – No certified level, 1 – Level A1, 2 – Level A2, 3 – Level B1). cf. https://www.coe.int/en/web/common-european-framework-reference-languages/home, accessed 22 July 2019.

STRICT PLACEMENT RESTRICTIONS HAVE A POSITIVE EFFECT ON THE PROBABILITY TO COMPLETE AN INTEGRATION COURSE AND ON REFUGEES' LANGUAGE SKILLS

Do initial placement restrictions determine refugees' language proficiency levels? If so, what are potential mechanisms driving the results? The difference-in-differences results demonstrate that refugees who live in a state with strict limitations on residence decisions have a much higher probability of completing an integration course in the year of the asylum decision than those who remain free to choose their residency within a given state. Living in a state that limits the initial place of residence to the district rather than to the state level increases the probability of completing an integration course in the year of the asylum decision by 7.0 percentage points. This is a very large effect (+ 81.4 percent), given that, on average, only 8.6 percent of the sample graduates from an integration course in the year of the asylum decision. The effects are robust to varying subsamples, e.g., for male refugees or a sample without the three city-states,[7] where placement restrictions may be less severe. Further, Table 1 shows that there is an equally strong effect on refugees' language proficiency levels: living in a high-intensity treatment state increases language proficiency levels by 0.132 units measured on a scale from zero to three.

SUPPLY-SIDE DIFFERENCES EXPLAIN PART OF THE EFFECT

As a further step, the report considers two potential mechanisms that may explain (part of) the preceding results: existing ties to the local network and the spatial mismatch hypothesis. The effect of a local network on refugees' language abilities is theoretically unclear. On the one hand, living in an ethnic enclave may increase the opportunity costs of learning the host country's language; on the other hand, refugees may be better informed about potential course offerings. Interestingly, a simple comparison of treatment and control individuals shows that both groups do not differ in the number of ties to people from their country of origin. Additionally, including this self-reported measure in the regression does not change the quantitative results.

Strict placement policies may facilitate the planning of integration measures at a local level, since districts have better information on the demand for language and integration courses. In states where refugees remain relatively free to choose their home district, however, supply may not be as easily adjusted. Likewise, it may take more time for refugees with protected status to find a suitable course offering. To assess the theory of spatial mismatch, the report includes BAMF information from the statistical report on integration courses. This external database lists the annual number of courses begun, ended, and the number of course graduates at the district level. Table 2 then illustrates the results once these proxies for local access to integration courses are taken into account, both individually (columns 2–4) and as a whole (column 5).[8] Accounting for supply-side differences in the accessibility of language courses decreases estimate sizes by 20 to 30 percent. This holds true for the probability of completing an integration course and for respective language proficiency levels. The effect is more pronounced for the latter; besides smaller estimates, estimation results are much less robust and are weakly statistically significant. These findings suggest that spatial mismatch of integration courses in non-treated states is by far a more important driver than potential networking effects.

CONCLUDING REMARKS

The controversial debate about how to integrate immigrants best into European society, fueled by the recent influx of foreigners, prompted several European countries to adapt their legislation. This includes Germany, which introduced the Integration Act in the summer of 2016. In this context, this report uses differences in the residence rule's implementation across states to investigate if initial restrictions in refugees' residency choice have an effect on participation in integration measures and overall language skills.

The report indicates that tight placement restrictions at the district (rather than the state) level indeed increase the probability of completing an integration course and achieving higher language proficiency levels in the short

[7] Berlin, Bremen, and Hamburg.

[8] To relate these measures to the size of the relevant population per district, I compare the means of these proxies deflated by the share of foreigners versus natives in a district across groups.

Table 1

Effect on Completing an Integration Course and Language Proficiency Levels

	Completing an integration course	Language proficiency levels
	[1]	[2]
mean	0.086	0.143
	0.070***	0.132***
	(0.018)	(0.035)
Obs.	1450	1450
R2	0.046	0.077

Source: SOEP, v34. Notes: Standard errors are clustered at the state level and given in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. Outcome variable, completing an integration course, is equal to 1 for respondents who completed an integration course in the year of their asylum decision, 0 otherwise. Outcome variable, language proficiency levels, is measured on a scale from 0 to 3 (0 – No certified level, 1 – Level A1, 2 – Level A2, 3 – Level B1). All specifications control for being married, having children, wanting to stay in Germany, age, age squared, months since arrival in Germany, months since asylum decision, years of schooling (pre-migration), and country of origin fixed effects. Reference categories are as follows: male, Syrian nationality.

Table 2

Estimation Effects Accounting for Spatial Mismatch

	Baseline	Number of courses begun pD	Number of courses ended pD	Number of graduates pD	[2], [3], and [4]
Panel A: Completing an integration course	[1]	[2]	[3]	[4]	[5]
mean	0.087	0.087	0.087	0.087	0.087
	0.070***	0.051**	0.052***	0.052***	0.052**
	(0.018)	(0.017)	(0.017)	(0.016)	(0.019)
Obs.	1450	1375	1375	1386	1375
R2	0.046	0.048	0.049	0.046	0.05
Panel B: Language proficiency levels	[1]	[2]	[3]	[4]	[5]
mean	0.143	0.143	0.143	0.143	0.143
	0.132***	0.081	0.083	0.086*	0.089*
	(0.035)	(0.053)	(0.053)	(0.047)	(0.048)
Obs.	1450	1375	1375	1386	1375
R2	0.077	0.088	0.089	0.08	0.092

Source: SOEP, v34. Notes: Standard errors are clustered at the state level and given in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. Outcome variable, completing an integration course, is equal to 1 for respondents who completed an integration course in the year of their asylum decision, 0 otherwise (Panel A). Outcome variable, language proficiency levels, is measured on a scale from 0 to 3 (0 – No certified level, 1 – Level A1, 2 – Level A2, 3 – Level B1) (Panel B). All specifications control for being married, having children, wanting to stay in Germany, age, age squared, months since arrival in Germany, months since asylum decision, years of schooling (pre-migration), and country of origin fixed effects. Reference categories are as follows: male, Syrian nationality. Column 1 replicates baseline results (Table 1). Column 2 includes the annual number of courses begun per district (pD), column 3 incorporates the number of courses that terminated. Column 4 includes the number of course graduates, column 5 includes all three additional variables.

run. The effect is partly driven by a mechanical cause: because refugees in high-intensity treatment states find more favorable conditions in their district, i.e., more available integration courses, they tend to perform better than refugees who may choose where to live within their state. Further, since the report considers treatment effects in the year of the asylum decision only, it is of great importance to look at medium- and long-run effects before drawing final policy conclusions.

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Innovation – Global Trends and Regulation

In view of an increasingly interconnected world, countries have been competing for innovative ideas, a skilled workforce, and the development of ever newer technologies. To keep up, economies need policies that enable and promote innovation. Such policies focus in particular on establishing an ecosystem where new ideas can flourish and enter the market and where sources of funding are available to enable R&D activities, and ultimately innovation.

In recent years, the EU has spent less on research and development (R&D) than other major economies such as Japan and the US; therefore the concept of an *Innovation Union* has been developed, aiming at "creating better jobs, building a greener society, and improving our quality of life, but also to maintaining EU competitiveness in the global market" (European Parliament 2019). In this context, indicators have been introduced to measure and monitor innovation across different European countries. Furthermore, the research initiative *Horizon 2020* was launched as the EU's flagship initiative to allocate funding to R&D and other scientific and social projects, with a total budget of around EUR 75 billion. Some EU countries have also taken note of the issue and developed their own measures to foster innovation. Germany, for example, initiated its *High-Tech Strategy – Innovation for Germany* to promote research, technology, and innovation (BMWi 2019). The strategy constitutes programs to promote innovation and bring research to the market, in particular for small and medium-sized enterprises (SMEs). Even though firms often rely on internal financial sources to fund innovation, it seems as if other means of funding, e.g., government and private sector funding, have become increasingly important (Spielkamp and Rammer 2009).

Generally, government or public funding can be either direct (through the allocation of funds to specific R&D projects) or indirect (through subsidies or tax incentives). Within direct project funding, the government keeps a good overview on where the funds go. Since direct public funding allows the government to select very specific projects, sectors, etc., it actually gives the authorities a certain degree of influence over the direction in which research is carried out. However, project-based funding is often associated with a long and complex application process, which comes with high workloads and potential bureaucratic hurdles.

Indirect public funding, on the other hand, grants support automatically and thus saves companies and public authorities a lengthy application procedure. In addition, SMEs with possibly less experience in grant application can receive the same financial support as bigger, more experienced enterprises. On the downside, the government may lose control over what and whom exactly it finances.

Private sector investments, such as bank loans or venture capital investments, constitute another source of funding for R&D. Although potentially high-risk businesses may not always receive funding from the private sector, more resources may eventually be allocated if the application turns out to be successful. At the same time, companies that receive private sector financing

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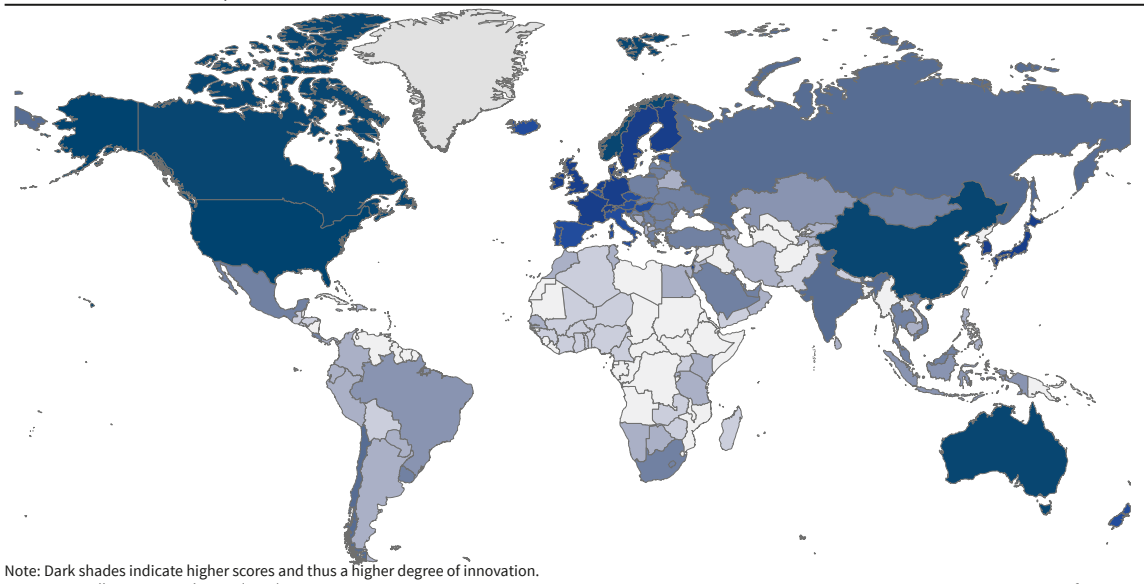
Figure 1

Global Innovation Index, 2018



Note: Dark shades indicate higher scores and thus a higher degree of innovation.
Source: Cornell, INSEAD, and WIPO (2018).

must maintain high financial discipline. In addition, they may have to exchange shares in return, thereby accepting a loss in control over the company (Spielkamp and Rammer 2009).

The present article begins by describing some important innovation measures in terms of effort and output across various OECD countries and China. Next, two global trends – venture capital financing and artificial intelligence as a key technology – will be discussed in more detail, with each section providing a broad overview as well as discussing regulatory opportunities and challenges. The section will also argue that innovation does not just require policies to promote innovate thinking and working, but also clear rules on possible consequences that can arise as innovation progresses. Finally, a summary concludes the article.

COUNTRY COMPARISON

In order to assess the extent to which countries are innovative, we turn to the Global Innovation Index (GII). The GII is a single summarizing statistic for innovation on the country level, ranging from 0 to 100. It represents a weighted average of indicators for both the effort to be innovative and the outcome that is achieved. In general, the GII strongly correlates with GDP per capita (Figure 1): industrialized countries score better than African, most Asian, and South American countries. China, however, scores better than some Western European countries such as Italy and Austria.

We turn to several useful indicators to consider differences in approach and success of fostering and financing innovative enterprises. Table 1 shows indicators for the public and private effort put into innovation for a selected group of OECD countries and China.

Although lacking a thorough separation between R&D and innovation, R&D is considered to represent the underlying inventions that foster innovation (Rogers 1998). Gross expenditures into whole R&D as a percentage of GDP (GERD, which can be subdivided into business enterprise, higher education, and non-profit) are several percent of GDP for the countries in scope. South Korea devotes the largest share to R&D (4.5 percent), more than three times as much as Italy (1.35 percent). Compared to this total expenditure, venture capital (VC) investments in seed-phase and start-up companies contribute approximately only 1 percent to total R&D investments. Sweden's figure of 0.14 percent of GDP sharply contrasts with that of Germany, which has only 0.005 percent. To consider the government role in business innovation, we turn to both indirect (through tax advantages) and direct government funding of the business enterprise part of R&D (BERD) expenditures as a percentage of GDP. In 2016, tax advantages for R&D expenditures amounted to 0.25 percent of GDP in Italy, whereas they were non-existent in Germany and Switzerland. For most countries, direct government funding is smaller than indirect government funding.

To assess the effort in R&D in terms of workforce, we consider the number of researchers per 1,000 people employed. Around 1 percent of the total workforce of the countries in scope is considered a researcher, ranging from 2.2 (China) to 15.5 (Denmark) per 1,000 employees.

To consider the extent to which knowledge is spread by training the future workforce, we resort to the public and private expenditures towards tertiary education. Together this amounts to a share of between 0.9 percent (Italy) and 2.8 percent (Canada) of GDP. However, there are large differences between who

Table 1
Measures of Innovation Effort in Selected Countries

	Gross Exp on R&D expenditures (% of GDP, 2018)	VC Investments in seed phase (% of GDP, 2016)	Number of researchers employed (per 1000 employed, 2017)	Indirect (tax advantages) government funding of BERD (% of GDP, 2016)	Direct government funding of BERD (% of GDP, 2016)	Public financing of tertiary education (% of GDP, 2016)	Private financing of tertiary education (% of GDP, 2016)	Ease of doing business: starting a company (Score, 2018)
Austria	3.16	0.009		0.15	0.12 (2015)	1.615	0.09	83.21
Canada	1.59	0.087		0.13	0.05	1.21	1.28	98.23
China	2.13		2.2	0.06	0.06			93.52
Denmark	3.06	0.025	15.5	0.02	0.05 (2015)	1.56	0.09	92.52
EU-28	1.96		8.3					
Finland	2.76	0.039	14.5		0.06	1.71	0.06	92.43
France	2.19	0.018	10.3	0.28 (2015)	0.13 (2015)	1.14	0.31	93.27
Germany	3.022	0.015	9.3	0	0.07	1.03	0.17	83.58
Italy	1.35	0.005	5.4	0.25	0.03	0.61	0.32	89.50
Japan	3.20	0.019	10	0.11	0.02	0.5	0.96	86.1
Netherlands	1.99	0.014	9.4	0.17	0.02	1.17	0.5	94.31
South Korea	4.55		14.4	0.14	0.14	0.775	1.48	95.83
Spain		0.018	6.8	0.03	0.06	0.85	0.39	86.91
Sweden	3.33	0.021	15.0			1.442	0.18	94.69
Switzerland		0.029		0 (2015)	0.03 (2015)	1.28		88.41
UK	1.66	0.019	9.0	0.15 (2015)	0.08	0.47	1.22	94.58
US	2.79	0.140			0.13	0.92	1.73	91.23

Source: Authors' compilation of various sources (2019).

Table 2

Measures of Public and Private Outcome Concerning Innovation

	Share of innovative enterprises (%, 2016)	Innovation intensity[3] (% of firms turnover, 2016)	Triadic patent family (number, 2018)	Growth of patent applications (R&D intensive technologies (2006-2016))	Foundation rates[2] (% of firms, 2016)
Austria	62	2.2	424.7		6.6
Canada			535.9	-21	
China			3890.3	671	
Denmark	52	3.3	298.4		12
EU-28	51		13660.3	2	
Finland	65	2.5	309.1	-21	6.9
France	58		2450	5	9.7
Germany	64	3.1	4520.3	-3	6.7
Italy	54	1.4	845.6	-11	7.7
Japan			17390.9	29	
Netherlands	60	1.6	1364.3	-2	9.6
South Korea			2598.6	67	
Spain	37	1.2	253.1		10.0
Sweden	54	3.8	678.9	26	7.0
Switzerland			1211.4	7	7.0
UK	59		1694.2	-6	15.0
US			14220.8	-1	

Notes: [2] Foundation rate: Number of company foundations in relation to the number of companies. [3] Innovation intensity: Innovation expenditure of enterprises in relation to total turnover.
Source: Authors' compilation of various sources (2019).

bears the cost. For example, Austria, Denmark, and Finland rely almost completely on public funding, whereas in South Korea, the UK, and the US the majority of education spending is privately borne.

Not only the financial but also the regulatory environment is important in fostering innovation. The World Bank's *Ease of Doing Business* database aims to give a score to several experience-based indicators per country, based on surveys conducted among experts. One of those is *Starting a Business*, which is particularly interesting in the context of innovations. Among the countries considered, Germany performed worst with a score of 83 out of 100. Compared to other OECD countries, the German procedure is more complicated and costly and requires a relatively high level of minimum capital (World Bank Group 2019). Canada scored highest with 98 out of 100 points, as it has no minimum capital requirement, the cost is only 0.3 percent of income per capita, and it takes on average only 1.5 days to start a business.

Table 2 shows several indicators considering the outcomes of innovation in the respective countries. One might argue that the amounts invested in innovation displayed in Table 1 already reflect the level of innovation: if investors or executives decide to finance R&D projects, they want to generate a return and would not invest if their investment did not lead to profitable innovation; instead they would invest it elsewhere.

Similarly, R&D expenditures can be seen as investments returning the technologies necessary for innovation. However, without other innovation-related measures it is impossible to determine with any certainty how fruitful the returns will be (Smith 2006). One could consider changes in products (materials, technical attributes, design, or performance) to observe the extent of the impact of innovation. Although it is hard to objectively quantify this on the product level, one could consider the firm level. This can be investigated through surveys, although this would not be a measure of the total size of innovative outcome. The Communication Innovation Survey of the European Commission (2019b) reports the share of companies that innovated their products in the period 2014–2016. The figure varies between 37 percent for Spain and 65 percent for Finland. For a more absolute indicator of how innovative companies are, we turn to expenditures on innovation. Although it is difficult to derive expenditures on innovation from the annual accounts of enterprises, EFI (2019) computes the share of innovative expenditures in the total turnover of private companies for a few countries on the basis of survey data (European Commission 2019b). Considerable differences have been found between Northern and Southern European countries: Italian and Spanish firms spend only 1.4 percent and 1.2 percent on innovation, whereas the figures are 3.3 percent and 3.8 percent in Denmark and Sweden, respectively.

To consider the fruits of research, we turn to the number of patent applications of the triadic patent family. The triadic patent family is a set of patents filed at either the US, European, or Japanese patent office. The count per country is a fractional count based on the country of residence of the applicants. The largest concentration of patent applicants is in Japan and the US, followed by the European Union, which has substantially more inhabitants. Despite the rapid growth of China's patent applications, the total number of patent applications is still dwarfed by the three large eco-

nomic blocks: Europe, the US, and Japan. Within Europe, there are also considerable differences: Spain has fewer patent applications than many significantly smaller countries. To consider recent developments in patent applications, we turn to the growth of patents in R&D-intensive technologies. In many countries, the number of patent applications declined or grew slowly between 2006 and 2016. The big exception is China, where the number of patent applications has grown almost sevenfold.

To examine the extent to which new companies, which usually enter the markets with innovative products, are founded, we turn to the number of firms founded in 2016 as a percentage of the total number of firms. Around 10 percent of firms were newly founded in 2016, ranging from only 6.6 percent in Austria to 15 percent in the UK.

GLOBAL TRENDS: START-UPS AND VENTURE CAPITAL

Microsoft, Amazon, Apple, Google, Facebook – The five companies with the largest market capitalization globally[2] have several things in common. In addition to all of them operating in high-technology industries and likely being very familiar names to the average reader, all of them were founded out of a US garage or a dorm room and subsequently provided with funding to scale their business. While Apple and Microsoft revolutionized the computer software and hardware market from the 1970s onwards, Amazon, Google, and Facebook brought about disruptive innovations on the internet after its commercialization in the 1990s, revolutionizing online markets, online searches, and online networking, respectively. The "creative destruction" of industries has been a concept since the 1940s as coined by Schumpeter (1942) and, arguably, the companies mentioned above are examples of it. However, what may differentiate them from previous cases is their use of the digitalization of our economy. The advent and increasing affordability of both computers and the internet led to companies disrupting industries at higher rates. In the latest trends, the development of the sharing economy based on *"the peer-to-peer based activity of obtaining, giving, or sharing the access to goods and services, coordinated through community-based online services"* (Hamari et al. 2016) gave rise to a new generation of companies such as AirBnB and Uber. Using online platforms, these companies innovated the hotel and transportation industry, respectively, having been small start-up companies back in 2010.

All previously mentioned examples of innovative companies were considered start-up companies at the beginning of their company history. Start-up companies are ventures initiated by entrepreneurial individuals or a group of entrepreneurs, with a business model that can typically be repeated and scaled up to a high-growth business without the need for large fixed costs and physical capital investments, thus mostly defined by their ability to grow (Robehmed 2013). Mostly, however, start-ups are associated with innovative new business ideas, and thus have been shown to be connected to innovation rates especially in developed countries (Anokhin and Wincent 2012). This association is stronger than for large existing corporations; while they do innovate, they do so at slower rates and less disruptively, as they have smaller incentives to erode their own competitive advantage in an established market (Granstrand and Alänge 1995). In addition to innovation, or perhaps as a consequence of it, higher start-up rates have also been shown to increase economic growth (Acs et al. 2009), the productivity of an economy (Bygrave et al. 2003), and the productivity of its workers (Audretsch and Keilbach 2004).

Policymakers have started to take note of this, and thus public innovation policy is increasingly connected to the encouragement of the formation of new start-up ventures by fostering a policy environment where these typically highly innovative companies are able to thrive.

An Overview of The Start-up Ecosystem

These environments where young companies can thrive are typically referred to as "start-up ecosystems" and are "formed by a set of interdependent actors and factors coordinated in such a way that they enable productive entrepreneurship within a particular territory" (Stam and Spigel 2016). Stemming from the idea that entrepreneurship may be the result of a social process rather than the sole achievement of any one individual entrepreneur, these ecosystems can support the ability and intention to start a business, help to provide entrepreneurs with sources of funding, and ultimately may encourage a successful exit from a firm. As seen previously in Table 1, multiple components of start-up ecosystems and the quality of their development are often considered indicators of public and private efforts for innovation. Components of such systems may include accessible markets, a favorable regulatory framework for starting businesses, a strong tertiary education system, a support system in the form of mentors, professional services, and incubators, a highly skilled workforce attracted by the location and services, as well as cultural support (World Economic Forum 2013).

While Silicon Valley remains the best-known start-up ecosystem, having produced a multitude of successful technology companies and continuing to do so, new such systems are beginning to develop in other areas of the world. Outside of the United States, Startup Genome (2019) identified ecosystems in London, Beijing, Tel Aviv, Shanghai, Paris, and Berlin as being among the top ten ecosystems globally. However, what we find most often is that public debate on start-up companies is focused on the potential lack of funding and, thus, on the investors. They provide funding and finance to young companies and thus typically allow for

[2] As of July 26, 2019.

further research and development as well as a scaling of the business, which allows companies to realize their growth potential. Due to the often early stages of development and lack of a credit record of young companies, entrepreneurs rarely have access to traditional bank funding (World Economic Forum 2013). Their main sources of funding are thus their or their families' personal savings, contributions from wealthy experienced individuals, often referred to as angel investors, or crowdfunding. Most prominently and with roles across all funding rounds, venture capitalists may typically take an equity position in the emerging venture in exchange for entrepreneurial support in the higher-risk growth phase.

While information asymmetries for these investors are a significant source of uncertainty, venture capitalists typically mitigate these through screening and monitoring of portfolio firms using instruments such as board memberships, employment of industry specialists, and a staged funding process. To justify the high risk of start-up projects, venture capitalists furthermore tend to invest in high-technology businesses with significant growth potential, especially in information and communication technology (ICT) and biotechnology (Harroch 2018); as a result, they arguably have a special importance for innovation policy and thus often attract the attention of public policymakers.

The Venture Capital Industry

Unlimited liability of shareholders and limited information systems initially discouraged equity investments in favor of less risky bank lending. However, changes in the US regulatory framework gradually led to an increase in investments in small businesses. From then onwards, the US venture capital industry progressively grew until reaching its peak during the dotcom bubble in 2000, with its particular focus on high-growth technology firms. Since then it has returned to growth as presented in Figure 2, with investment amounts once again reaching pre-dotcom levels in 2018.

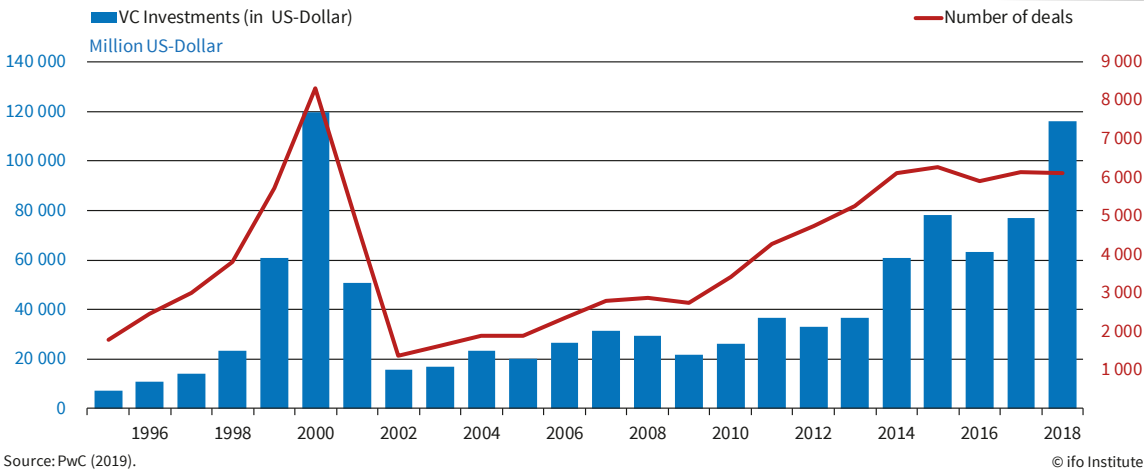
The US remains the largest venture capital market today (see Figure 3), with 86 percent of total venture capital investments in the OECD stemming from the US in 2016. Global venture capital investments have followed a similar growth trend over the past decade and have thus seen growth in investments since 2010, with a peak in 2018 (KPMG 2019). However, it has also been pointed out that the gap between US and European venture capital in particular is widening quite consistently across sectors (OECD 2018a), with European venture capital funds found to have lower returns than those based in the US (European Private Equity and Venture Capital Association 2014).

The Importance of Venture Capital Financing for Innovation

The difference in size and success of the venture capital industry could be tracked potentially both to the lower maturity of the European market as well as a difference in regulatory frameworks. However, the fact remains that the presence and availability of venture capital funding increases start-up company growth (Davila et al. 2003) and performance (Rosenbusch et al. 2013) and, in turn, increases innovation rates, productivity, and economic growth as desired by public policy (Kolmakov Vladimirovich et al. 2015; Sun et al. 2019; Lerner 2010; Brander et al. 2015). Indeed, VC funding has been shown to have a larger positive effect on patenting and innovation than corporate investments into research and development (Kortum and Lerner 2000). As well as providing funding, venture capitalists thus serve a number of other functions in the start-up ecosystem, among them teaching and embedding companies into the start-up ecosystem (Ferrary and Granovetter 2009). The fact that European venture capital lags significantly behind the US market, with Silicon Valley remaining the most successful and never replicated start-up ecosystem, poses an ongoing challenge to European policymakers. Thus, governments have begun to put significant effort into encouraging the development of

Figure 2

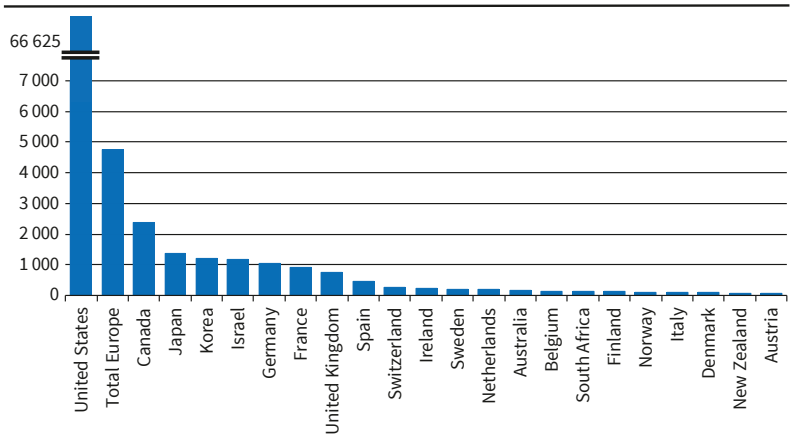
US Venture Capital Investments
1995–2018



Source: PwC (2019).

Figure 3

Venture Capital Investments by Country (in Million US Dollar)
2016



Note: 2014 data is shown for Israel (latest available).
Source: OECD (2018a).

the venture capital industry outside of the United States.

The Role of Government

Most public policy focused on encouraging the development of a national venture capital market centers around creating a tax environment favorable to investors, as well as creating government-funded venture capital programs (Da Rin et al. 2006; Bradley et al. 2019).

Tax policy may include capital gains taxation reductions (Da Rin et al. 2006; OECD 2018b) or tax credits for investment or company research and development (Bradley et al. 2019), which have been shown to encourage early-stage and high-tech investments in particular, thus supporting innovation rates. The reduction of capital gains taxation is notably directed mainly at increasing returns to investment into start-up companies and will thus influence decision-making and risk appetite (European Commission 2015). In general, such tax incentives most often take the form of tax credits in the amount invested, as well as tax exemptions on the investment returns.

Such policies pose an incentive to venture capitalists to increase investments despite the risky nature of the venture capital market. According to the European Commission (2015), which analyzed tax incentive schemes in the EU-28 and eight additional OECD countries, 19 out of the 36 countries operated tax incentives targeted at venture capital investors, with France and the UK implementing the highest number of tax incentive schemes. Furthermore, compared to the member states from the 2004 and 2007 accessions, a larger share of EU-15 members operate such schemes. Table 1 provides an overview of tax advantages as a percentage of GDP in a country-by-country comparison, showing the intensity of indirect government funding.

Directly government-funded venture capital programs are becoming increasingly prominent, especially in Europe, supported by the hypothesis that channeling more funds into venture capital markets will aid their development, encourage more private participation in the long run, and thus close the funding gap for small companies especially in their growth phase (Fuerlinger et al. 2015). Examples in Europe include the venture capital division of the European Investment Fund (Signore and Torfs 2017), the pan-European venture capital funds-of-funds program VentureEU, the Enterprise Capital Funds by the British Business Bank (British Business Bank plc 2018), Bpifrance (Bradley et al. 2019), the KfW Bank Group, or, for international examples, the Canadian Venture Capital Action Plan and the Venture Capital Catalyst Initiative.

While empirical evidence on the effectiveness of these measures is still contradictory, citing a crowding out of private investment by public sources (Da Rin et al. 2006; Lerner 2010), the impact of government-funded venture capital investments have a similar positive impact on the economy to private investments (Signore and Torfs 2017). Furthermore, they seem to have a positive impact on enterprise performance if combined with substantial funds from private venture capitalists (Brander et al. 2015; Grilli and Murtinu 2014). Finally, they have been shown effective as certification devices to private investors, thus increasing the likelihood that funded companies will also receive private venture capital (Guerini and Quas 2016). Within the European Union, government agencies committed around 18 percent of total venture funding in 2018[3], which amounts to the lowest proportion in the past ten years (InvestEurope 2019).

In less direct strategies, simplifying the act of both founding a company as well as exiting the company investment has been shown to be an effective method to develop the industry, by reducing the complexity of the company formation process on the one hand and increasing the availability of stock markets targeted at entrepreneurial companies on the other (Da Rin et al. 2006). Furthermore, the attraction and retention of innovative talent has been emphasized as essential (Bradley et al. 2019). While the evidence on immigrants contributing the majority of companies to Silicon Valley (Meeker 2018) is anecdotal, logically it may be sensible for potential innovators to emigrate to a better start-up ecosystem if their funding needs are not met

[3] Note that a commitment of venture funds does not guarantee a perfect translation into invested funds and is thus not equivalent to the metrics used in previous figures.

in their home country. Hence, devising policies that attract and retain talent can foster more frequent start-up creation and thus attract more venture capital investors that see viable investment opportunities.

GLOBAL TRENDS: ARTIFICIAL INTELLIGENCE AND INNOVATION POLICY

When considering global trends in innovation policy, one must consider current innovative technologies. Artificial intelligence (AI) is a key technology that has shaped technological progress in recent years and will continue to do so in the future. In the following, we will look at AI in more detail, drawing on the opportunities and challenges it brings and taking a closer look at the role of government. Although the future of the technology and its impact on society are somewhat unclear, it is certainly the responsibility of government to implement policies for developing and using it. It should be in the utmost interest of both government and business to exploit the benefits of AI while protecting its users and the people who developed it.

Artificial Intelligence at a Glance

In the following, we will take a closer look at artificial intelligence (AI). We will refer mainly to the paper "Economic Policy for Artificial Intelligence" by Agrawal, Gans, and Goldfarb (2018), who discuss the expansion of AI and the associated regulatory needs due to the emerging challenges.

According to Agrawal et al. (2018), recent progress in AI stems from advances in computational statistics, particularly in *machine learning*. Machine learning describes the process of computers learning patterns from existing data, potentially enabling superior prediction (without causal inference). However, AI can take a more sophisticated form called *artificial general intelligence (AGI)*, which refers to machines that are capable of performing basic cognitive tasks (such as understanding, problem-solving, and reasoning) with the ultimate goal of achieving a human-like consciousness. AGI is in its infancy and no meaningful statements can be made about its impact on innovation and the need for regulation. When it comes to artificial intelligence, we will therefore focus entirely on machine learning in the following. A short discussion of the origin and abilities of machine learning, and specifically deep learning, can be found in Box 1.

Artificial intelligence is likely to affect many sectors, so Agrawal et al. (2018) regard it as a general-purpose technology (GPT). Being a relatively new technology, the full impact of AI on society cannot yet be properly measured in many cases. According to the authors, the pessimistic view of AI focuses on rapid change and the belief that machines will take over jobs. Others (e.g., Stevenson 2018) view AI more optimistically and expect a rise in productivity ultimately leading to a rise in income and more spare time for employees as they no longer have to spend so much time on unpleasant tasks in their jobs.

BOX 1

The Rise of Deep Learning

Recently, the field of machine learning has started growing tremendously. This is mostly sparked by successes in image recognition by artificial neural networks (ANNs). An ANN is a self-learning network organized in multiple layers of many parallel nodes, each containing a non-linear function f(x,w) with inputs x from the previous layer (where the first layer contains the raw independent variables) and learnable parameters w. Based on a function after the last layer, which compares the prediction of the network to the actual dependent variable of interest, all those parameters are updated iteratively (called training or learning). Once the ANN is trained with sufficient data, we can supply a set of independent variables and obtain a prediction. These procedures are considered "deep" learning, because the best-performing networks are dozens of layers (of various kinds) deep. The field of deep learning engages in developing tools to ensure efficient learning and overcoming numerical issues in order to increase the accuracy of prediction and efficiency (e.g. Bottou et al. 2018).

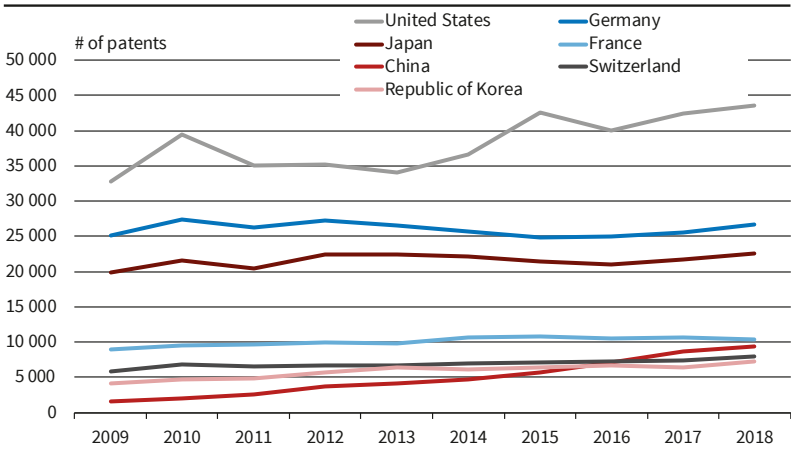
Since 2012, so-called convolutional neural networks (CNNs) have achieved impressive increases in accuracy when labeling pictures in the ImageNet database (a database containing millions of pictures, which are given a single label by hand, such as cat, dog, plane, frog, or car). Convolutional layers transform the data (with a mapping that also has learnable parameters) to extract meaningful structures, which heuristically work well for image recognition. Interestingly, these "convolutional" neural networks recognize those objects in a similar (but by no means identical) way to the animal brain: they recognize low-level features such as horizontal and vertical edges separately in different parts of the network, in a similar way to that found in cats by tilting a bar in their receptive field and measuring neural response (Hubel and Wiesel 1962). More applications of deep neural networks can be found in the fields of computer vision and natural language processing, which both deal with understanding sequences of data.

General Patents and Patents in AI

To assess to what extent AI research is being adopted around the world, we first look at the number of patents per country. Figure 3 illustrates that most patents originate from the US, followed by Germany and Japan. As mentioned before, countries like China, South Korea, and Switzerland also seem to have taken up the development in recent years and have seen an increasing number of patent applications. Next, we turn to the institutions and firms that apply for the most patents worldwide in the field of artificial intelligence, which all have applied for thousands of patents relating to AI. Figure 4 lists the top 30 firms, consisting of 26 compa-

Figure 4

Number of Patents by Country, 2009–2018
Countries with most patent applications in 2018



Source: European Patent Office (2019). © ifo Institute

nies and four public research institutions. Out of the top 20 companies, 12 have their headquarters in Japan, while many others are from the US. The main patent category among 19 of the top 20 applicants is *Computer Vision. Only IBM has most of its applications in the category Natural Language Processing* (WIPO 2019).

Not only large high-tech firms are developing AI applications, but also smaller firms. A 2018 survey among US executives showed that 62 percent of the respondents' firms apply *Natural Language Processing* (e.g., operating chatbots or to query datasets), 57 percent use *Computer Vision* (e.g., facial recognition and vision for autonomous vehicles), and 50 percent use some form of *Deep Learning* (Deloitte 2018). 70 percent report a rate of return of over 10 percent. AI-derived business value already encompasses trillions of USD per year and is expected to grow rapidly (Gartner 2018).

Artificial Intelligence and the Role of Government

The expansion of artificial intelligence will impact society in different ways. Policies that provide research support are likely to accelerate technological progress. Agrawal et al. (2018) define three policy categories around artificial intelligence that intensively require the attention of policymakers: liability, privacy, and trade. Not adequately addressing these issues could potentially hamper the development and diffusion of AI.

Artificial intelligence, like other technologies, relies heavily on data. Thus, privacy protection plays an important role: too little protection may prevent consumers from participating in the technology and thus from making their data available. Furthermore, a low level of privacy protection can induce a race to the bottom in privacy policy among countries in order to get ahead of each other in AI development. Too much data protection, on the other hand, may keep firms from innovating, as the potential costs from risks associated with privacy protection would be too high. The challenge for policymakers is therefore to find the right balance between the level of privacy regulation that is needed to ensure individual protection, while at the same time encouraging innovation.

In addition to privacy concerns, Agrawal et al. (2018) state that trade policies can impact the expansion of AI. Trade policies refer to behind-the-border policies often included in trade agreements. According to the authors, when international standards for data protection are included in trade agreements, such trade policies can mitigate the race to the bottom induced by lax privacy regulation.

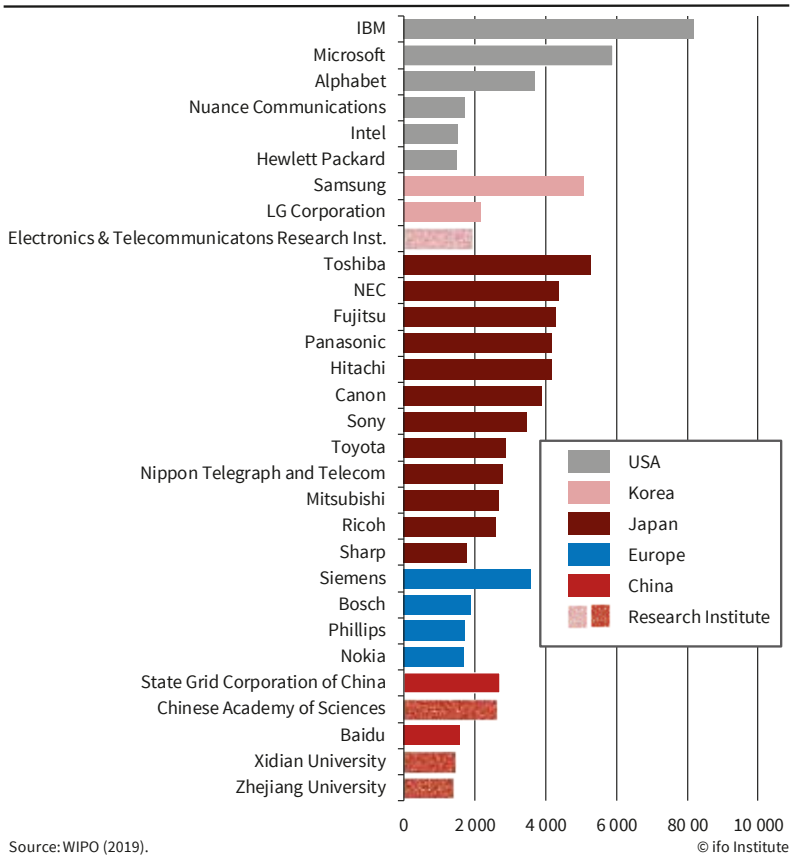
The authors address another concern relating to liability that can arise when people get injured and are consequently compensated by others. Unclear liability rules may increase the risk of unlawful actions with uncertain outcomes and potentially high payments. Therefore, firms may be reluctant to invest in AI for as long as the liability rules around AI are uncertain. In addition, algorithms used in AI might be biased, possibly leading to discrimination. Agrawal et al. (2018) refer to the example of a job advertisement for STEM occupations, which was more often advertised to men. The underlying bias was not that men are the better engineers but that women are underrepresented in STEM professions and therefore less often addressed by such advertisements. It is the task of policymakers to create clear liability rules and help dismantle potential preconceptions.

Other policies do not target advances in AI directly, but rather the consequences that may follow from its diffusion. AI is considered as a productivity enhancing technology; it will have an effect on jobs (and therefore income), inequality, and competition. Trajtenberg (2018) argues that with the expansion of AI, new skills will be needed. These are skills that machines cannot (yet) perform, like critical or creative thinking. Humans will probably need a combination of both technical and social skills in order to use the machines and tell them what to do (e.g., EC 2019a). Education policies can play a crucial role as humans may need to adapt their skill set to the new technology. According to Agrawal et al. (2018) education policy should therefore focus on "the skills taught and the structure of the delivery" (p. 15). However, it remains an open question what such an education policy may look like in detail.

Furthermore, leading AI companies are the ones collecting the most consumer data via their applications or on the internet. Since there is a growing market

Figure 5

Patent Applications in Artificial Intelligence by Enterprise and Country
2016



Source: WIPO (2019).

for personal (consumer) data, a company could be put in a monopolistic position if it owns most or a majority of such data. Therefore, policies should increasingly take into account the enforcement of antitrust law in the future (Agrawal et al. 2018).

Finally, there is a lively public and academic debate on the increase or decrease of inequality as AI progresses towards artificial general intelligence. To address possible impacts on the overall economy, Gries and Naudé (2018) argue for the necessity of maintaining labor income as AI increases the capital intensity of production. In order to prevent stagnation of the world economy and to address concerns regarding inequality and large-scale unemployment, policy proposals focus on adjustments to the social safety net, in particular through the taxation of capital, the introduction of a universal basic income (Bruckner et al. 2017), or even taxing robots (Oberson 2017).

SUMMARY

The success of innovative enterprises depends on many factors: financing, a suitable start-up environment, and a trained workforce, among others. For innovative firms to flourish, government regulation and policy is needed. Although government policy is omnipresent in the form of direct project funding and tax advantages, large differences between countries remain in terms of innovative outcome. Many countries aim to make financing more attractive, some financing start-ups themselves and creating Silicon Valley-style start-up ecosystems. In order to finance young companies, venture capital financing in particular is proving to be important, as many large high-tech companies were financed through VC. Despite the efforts of other governments around the world, the world's VC industry is strongly concentrated in the US.

After academic breakthroughs in past decades, artificial intelligence has recently become a heavily patented, multi-billion dollar technology. Concerns regarding the privacy of individuals' data, the inclusion of rules in trade agreements, and liability for the implications of the technology all require adequate legislation. A failure to implement suitable laws imposes a risk both on the adaptation of useful technologies and on society as a whole.

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New at DICE Database

RECENT ENTRIES TO THE DICE DATABAS

In the fourth quarter of 2019, the DICE Database received a number of new entries, consisting partly of new topics and partly of updates. The list below features some of these new entries:

- Innovation Effort Indicators in Selected Countries
- Innovation Outcome Indicators in Selected Countries
- Government Deficit/Surplus
- FDI Flows

Forthcoming Conferences

10th ifo Conference on Macroeconomics and Survey Data

21–22 February 2020, Munich, Germany

The conference is intended to discuss ongoing research on survey and micro data and its role and usage in macroeconomics.

Papers (theoretical, empirical and/or policy-oriented) are actively solicited on issues such as (non-exhaustive list):

- usage of micro-data to address macroeconomic questions
- role of expectations for behavior (of firms or individuals)
- measuring and modeling of uncertainty and its effect on behavior and/or the business cycle
- transmission of cyclical fluctuations
- distributional effects of macroeconomic shocks
- heterogeneity and evaluation of policies
- labor markets and the business cycle
- methodology of business surveys and forecasting performance of survey/micr data in business-cycle research

Preference is given to papers over abstracts. There is no registration fee for presenters. There is a fee for non-presenters of 250 Euros. This sum covers all-day refreshments, lunch, and the conference dinner.

Scientific organizer: Klaus Wohlrabe

14th ifo Dresden Workshop on Macroeconomics & Business Cycle Research

27–28 March 2020, Dresden, Germany

We cordially invite all interested parties to submit their current research work on the following topics:

- Business cycles and financial integration
- Economic uncertainty
- International financial markets
- Sovereign default risk
- Capital flows, capital controls, and exchange rates
- Unconventional monetary policy

Each accepted contribution will be reviewed by another workshop participant. A total of 45 minutes is available for each paper for presentation, presentation and general discussion. The annual workshop is jointly organized by the Dresden branch of the ifo Institute and the Dresden University of Technology. Further details can be found in the Call for Papers.

Scientific organizers: Stefan Eichler, Niels Gillmann, Robert Lehmann

10th ifo Dresden Workshop on Labor Economics and Social Policy

07–08 May 2020, Dresden, Germany

The ifo Institute, Dresden Branch, and the Technische Universität Dresden, announce the 10th ifo Dresden Workshop on Labor Economics and Social Policy. The workshop aims at facilitating the networking of young scientists and at promoting the exchange of their latest research. This year, preference is given to papers estimating causal effects of family policies, measures reducing gender differences in education and the labor market, and means of integrating migrants into the labor market. The workshop will be held in English. We specifically encourage PhD students and post-doctoral researchers to submit their latest research. Each paper will be allocated 45 minutes, to be divided between the presentation, a discussion by an assigned workshop participant and a general discussion.Please submit your (preliminary) paper by February 1st, 2020:

Scientific organizers: Alexander Kemnitz, Mona Förtsch, Katharina Heisig, Stefanie Knoll

Econometric Evaluation of School Reforms

15–16 May 2020, Munich, Germany

Trends in the global economy, technological change, and inequality pose fundamental challenges for the future of our societies. With its crucial role for future prosperity and cohesion, the educational achievement of the population promises an important lever for policy to empower people to face the societal challenges.

To better understand which educational policies can help improve the efficiency and equity of educa-

tion systems, this conference aims to bring together researchers who study how different school reforms affected student outcomes. We invite submissions that use convincing evaluation methods to estimate reform effects on short-run achievement or long-run life-course outcomes of affected students. Reform aspects under study may include different aspects of the length, structure, financing, curriculum, instruction, and examination of schooling. We are particularly interested in papers using differences-in-differences type analyses that exploit differences in the timing of reform implementation across regions within a country and in papers focusing on reforms of what is actually going on inside schools in terms of the content of school activities. The keynote lecture will be delivered by Joshua Angrist (MIT).

The conference is part of the project "Efficiency and Equity in Education: Quasi-Experimental Evidence from School Reforms across German States (EffEE)" generously funded by the Leibniz Association under its competitive procedure.

Scientific organizers: Ludger Woessmann, Larissa Zierow, Jutta Allmendinger, Marcel Helbig

New Books on Institutions

Meeting Globalization's Challenges: Policies to Make Trade Work for All
Luís Catão and Maurice Obstfeld
Princeton University Press, 2019

Artificial You: AI and the Future of Your Mind
Susan Schneider
Princeton University Press, 2019

Innovation + Equality - How to Create a Future That Is More Star Trek Than Terminator
Joshua Gans and Andrew Leigh
MIT Press, 2019

THE DATABASE FOR INSTITUTIONAL COMPARISONS OF ECONOMIES

The Database for Institutional Comparisons of Economies – DICE – was created to stimulate the political and academic discussion of institutional and economic policy reforms. DICE is a unique database offering comparative information on national institutions, regulations and economic policy. Although DICE is not a statistical database, it also contains data on the outputs (economic effects) of institutions and regulations where relevant.

DICE covers a broad range of institutional themes: Banking and Financial Markets, Business, Education and Innovation, Energy, Resources, Natural Environment, Infrastructure, Labor Market, Migration, Public Sector, Social Policy, Macroeconomics, and Country Characteristics.

The information is presented in tables (text or data), graphics, and reports. In most cases, all EU countries are covered as well as some other major OECD countries. Users can choose between current comparisons and time series that show developments over time.

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