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HOW MUCH SCIENCE?
THE 5 WS (AND 1 H) OF INVESTING IN BASIC RESEARCH

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HOW MUCH SCIENCE? THE 5 WS (AND 1 H) OF INVESTING IN BASIC RESEARCH[†]

Abstract

The aim of this paper is to identify possibilities for guiding policy in the area of basic research. We provide an extended review of basic research and offer new insights on its linkages to key economic variables and economic growth. After defining *what* basic research is, we identify and discuss a series of emerging policy issues by asking *why* we should invest in basic research, *who* should invest *how much* in basic research and *when*, over the course of a country's development? We finally address the question *where* investments in basic research should be targeted. Moreover, we explain why many pressing issues regarding basic research policy deserve to be explored further.

JEL Classification: H41 and O38
Keywords: basic research, economic growth and growth policy

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'I keep six honest serving-men:
(They taught me all I knew)
Their names are What and Why and When
And How and Where and Who.'
Rudyard Kipling (1902) – 'The Elephant's Child'

1 Introduction

Basic research is a key driving force of economic growth and development. Basic research expands the knowledge base and thus widens the scope for technological progress, which, in turn, leads to the development of new, improved products and production processes.[1]

Both investments in basic research and the economic and regulatory environment that shape the '*republic of science*' will not only have profound consequences for human welfare today, but also well into the future. It is therefore no surprise that governments all over the world should channel non-trivial shares of public funds into basic research and – not least in the aftermath of the great recession – seek to further stimulate innovation and growth by policy reforms in this area.[2]

The case for public engagement in basic research is very well substantiated in the economic literature. At the very least, policy actions can be motivated on the grounds that basic research and scientific knowledge exhibit key characteristics of a public good. Yet insights and ideas that can guide policy at a more detailed level are limited

[1] Much of the literature on basic research uses different terminologies such as 'science', 'basic research', 'academic / university research', or 'public research'. We subsume all of these terms under 'basic research'.

[2] South Korea and Singapore have stepped up their basic research investments considerably, more than doubling their expenditures as a percentage of GDP from 2000 to 2009 (*Source*: Own calculations, based on OECD (2012a); the data was downloaded in June 2013). The European Council aims at increasing total (public and private) R&D spending in the European Union to 3% of GDP by 2020 (General Secretariat of the European Council, 2010). With the aim of increasing its pool of scientists with state-of-the-art training, Brazil has initiated a program to support scientists going abroad (Brazilian Secretariat for Social Communication, 2011). After initiating big-push investments in basic research at the beginning of the 21st century, Ireland has installed a Research Prioritisation Steering Group to identify targets for future investments (Research Prioritisation Project Steering Group, Ireland, 2012). In 2013, Canada announced that it will direct its National Research Council towards more applied research and to transform it into a *'business-driven, industry-relevant research and technology organization'* (Goodyear, 2013). At a more general level, many developed economies aim at reindustrialization as a means of guaranteeing future economic growth and prosperity (Obama, 2013; European Commission, 2012). Emerging economies search for strategies to bring them nearer to the world technological frontier. As basic research provides the knowledge base and helps to spur private innovation, it can – or must – play an important role in such endeavors.

in number. This even applies to policy issues as fundamental as how much to invest in basic research.

Considering the active involvement of governments and the high value at stake, this lack of guidance is stunning. It may be attributable to the fact that while the benefits of basic research are manifold, they are often time-lagged and indirect. Hence they are difficult to conceptualize and may be even more difficult to grasp in empirical studies. In the words of Salter and Martin (2001, p. 529): '*Currently, we do not have the robust and reliable methodological tools needed to state with any certainty what the benefits of additional public support for science might be, other than suggesting that some support is necessary to ensure that there is a 'critical mass' of research activities.*'[3]

Policy decisions in the field of basic research have to be taken under great uncertainty. Technological progress can be fostered, but it can neither be fully described ex ante in detail nor even guaranteed. Yet a thorough understanding of basic research and how it can affect the overall economy suggests ways for guiding policy. In this paper, we thus seek to put some of the most pressing policy issues back on the agenda of research in the social sciences.

We begin by defining *what* basic research is and by summarizing its key characteristics (section 2). We then consolidate our knowledge of *why* it is critical that we invest large funds into basic research (section 3) and ask *who* should provide these funds. We show that there is a strong case not only for public funding, but for public provision as well (section 4).

Taking the large benefits associated with basic research and the strong need for public engagement for granted, we proceed by addressing the three most pressing policy issues:

- *How* much should countries invest in basic research (section 5)?
- *When*, over the course of economic development, should they invest in basic research (section 6)?
- *Where* should they target these investments, if at all (section 7)?

For each of these policy issues, we briefly summarize the current state of affairs and consolidate the available knowledge that may help to guide policy. Most importantly, we seek to take a step towards better-informed policies in the future. In particular, we

[3]Cf. also Stephan (2012).

present some new perspectives on the data and suggest ways of reframing the debate by addressing related and/or more detailed questions that may prove worth scrutinizing.

2 What is basic research?

The OECD (2002, p. 30) classifies research and development (R&D) activities into three main categories: basic research, applied research, and experimental development. It defines basic research as '*experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.*'[4] According to this definition, basic research in general does not provide (potentially commercial) solutions for specific practical problems, but rather provides the knowledge base needed to tackle these problems.

In this paper, we are mainly interested in basic research policies and their implications for innovation and economic growth. We thus follow most of the economic literature on basic research in subsuming experimental development under applied research.[5] Unlike basic research, applied research sets out to *'[...] provide [...] complete answers'* to important practical problems (Bush, 1945, p. 13), thus directly contributing to the improvement and development of specific production technologies or products.

In line with the definitions above, the following key characteristics are typically attributed to basic research:[6]

Embryonic	Basic research outcomes are embryonic in the sense that they are early-stage findings with little or no commercial use in view.
Cumulative	Basic research builds on and further develops the insights provided by prior (basic) research.
Time-lags	The generation of new knowledge within basic research and its reflection in new and refined products or processes involve major

[4]Note, however, that this is not the case with basic research in the so-called *Pasteur's Quadrant* (cf., for example, Nelson, 2004). *Pasteur's Quadrant* is a term introduced by Stokes (1997) to characterize basic research with immediate commercial use in view.

[5]This main classification goes back at least to Bush (1945). Cf. Cozzi and Galli (2009), Akcigit et al. (2013), and Gersbach et al. (2013) for recent examples of economic literature dividing research into basic research and applied research.

[6]Cf. Amon (2011) for a discussion of these characteristics.

time lags.

Uncertainty	Basic research outcomes are highly uncertain.
Hierarchy	Basic and applied research typically have a hierarchical order, with the former preparing the ground for the latter.
Two-way spillovers	Not only does applied research benefit from basic research, it stimulates basic research in return. Thus, there is cross-fertilization between basic and applied research.

3 Why should we invest in basic research?

It is generally believed that in aggregate, the effects of (public) basic research on economic innovation and growth are positive and significant.[7] The profound measurement problems inherent to the benefits of basic research notwithstanding, a large body of the literature supports this view: Empirical studies point to high social rates of return to investments in basic research[8] as well as to significant positive effects on productivity and GDP growth.[9]

These aggregate empirical studies have been mainly criticized on two grounds. First, the empirical strategies were questioned.[10] Second, these studies do not provide insights with regard to the different channels linking basic research to economic innovation and growth. These questions were addressed in more detailed empirical studies based on the citation of scientific publications in patents, for example, in surveys among R&D managers, and in detailed case studies tracing the inputs of preceding basic research in the process of major innovations. Generally, these studies also underline the importance

[7]For these benefits to materialize, the innovation system arguably relies on a well-run state (cf., for example, Economist, 2013b).

[8]Salter and Martin (2001) provide a summary table from estimated rates of return to publicly funded R&D, mostly in the agricultural sector. Most of these estimated rates of return were around 30% or even higher. In a more recent study, Toole (2012) considers the impact of publicly funded basic research on the pharmaceutical industry. His analyses suggest that public basic research significantly spurs innovation, with the rate of return to these public investments being as high as 43%. Cf. also Hall et al. (2009) for a survey of the literature measuring the returns to R&D in general.

[9]Cf. Mansfield (1980), Link (1981), Griliches (1986), Adams (1990), Martin (1998), Guellec and Van Pottelsberghe de la Potterie (2004), Luintel and Khan (2011), and Czarnitzki and Thorwarth (2012).

[10]Main criticisms involve potential errors in the measurement of R&D inputs and the resulting outputs, the reliance on simplified production functions, and the possibility of reversed causality (cf. Griliches, 1998; Salter and Martin, 2001; Cockburn and Henderson, 2001; Hall et al., 2009).

of basic research for growth and innovation. In addition, they suggest that the benefits of basic research for innovation are diverse, indirect, and often involve major time lags. Based on an in-depth review of the existing literature, Salter and Martin (2001) propose a clustering of these manifold benefits in six different groups. Schneller (2011) adopts their classification of benefits and extends their review to the more recent literature. These diverse benefits are key to well-informed basic research policies, and hence we now summarize each of these categories. The interested reader is referred to the work of Salter and Martin (2001) and Schneller (2011) for further details on the underlying literature.

Knowledge base

Basic research is generally understood to increase the knowledge base, comprising, for example, ideas, technologies, theories, and prototypes. The knowledge base can then be taken up in more applied research aimed at developing new and refined products or processes. This channel from basic research to innovation was the main subject of the early literature on basic research.[11] It was addressed and analyzed in many studies.[12]

Skilled graduates

Graduate students who have recently been trained in university research help firms in accessing the knowledge base generated by basic research.[13] It may thus be seen as a transmission channel for the benefits addressed above. However, graduate training in university research also develops skills in complex problem-solving that are relevant for private innovation beyond their importance for accessing the knowledge base. Moreover, skilled graduates are important drivers of innovative entrepreneurship.[14]

[11] Cf., for example, Nelson (1959) and Arrow (1962).

[12] Cf. Narin et al. (1997) for a leading example of a patent-citation study showing that patents frequently refer to scientific publications. Mansfield (1995), Cohen et al. (2002), and Monjon and Waelbroeck (2003), for example, address the importance of knowledge generated from basic research in surveys among industrial firms. Arundel and Geuna (2004) argue that these studies typically point to a low importance of basic research as a direct external source of information used in innovation. However, this does not exclude a more indirect and time-lagged link from basic research to innovation.

[13] Cf., for example, Cohen et al. (2002) and Arundel and Geuna (2004).

[14] Arvanitis and Stucki (2012) show for the case of Switzerland that innovative activities of a start-up critically depend on the founders' university education and their prior work experience in R&D.

Instrumentation and methodologies

As a byproduct of basic research, new instrumentation and techniques are often developed, which are needed to tackle the fundamental problems under scrutiny. Industrial surveys typically point to the high relevance of new problem-solving techniques for private innovation.[15]

Scientific networks

Advances in technological and scientific knowledge also increase the *burden of knowledge*.[16] It follows that *'increasingly, knowledge and intelligence are organised in social ways, rather than being accessed on an individual basis'* (Salter and Martin, 2001, p. 524). Hence having access to these scientific networks is of primary importance for private, science-based innovation. Public basic research can provide firms with access to these networks. Indeed, empirical studies suggest that the proximity to universities has a positive effect on innovation, and surveys point to the importance of networking with university staff to foster innovation.[17]

Problem-solving capacity

Basic research enhances the overall ability to tackle and solve complex problems. Obviously, this ability largely draws on the knowledge base of the economy, the trained graduates, existing instrumentation and methodologies, and scientific networks. Hence it is closely linked to the four benefit categories discussed above. Yet Salter and Martin (2001) include it as a separate category, mainly because of the importance attributed to it by industrial R&D managers.

New firms

Salter and Martin (2001) identify the creation of new firms as a last category of benefits from basic research, although they point out that evidence for this benefit is mixed. The more recent literature seems to justify the inclusion of these benefits in our list.

[15] Cf., for example, Arundel et al. (1995) and Cohen et al. (2002).

[16] The term *burden of knowledge* captures the fact that individuals have to approach the knowledge frontier, before they can engage in state-of-the-art research. Jones (2009, p. 284) summarizes the idea in a nice figurative way: *'... if one is to stand on the shoulders of giants, one must first climb up their backs, and the greater the body of knowledge, the harder this climb becomes.'*

[17] Cf. Jaffe et al. (1993) and Cohen et al. (2002), for example.

Schneller (2011) reviews some empirical studies that suggest that basic research does indeed have a positive local effect on the creation and growth of new firms.

4 Who should invest in basic research?

Considering the various benefits described in the previous section, it becomes apparent that basic research exhibits key characteristics of a public good. Some beneficial effects are more local, such as positive regional effects on innovative capacity and growth of firms,[18] and the provision of trained scientists and of access to scientific networks. Others are global, such as the knowledge base including new instrumentation and methodologies. Hence basic research is maybe best characterized as a local public good with cross-country spillovers. As we will show next, this, among other things, motivates strong engagement of the public sector in basic research.

Current state of affairs

The main part of basic research is both publicly funded and publicly provided. Gersbach et al. (2013) analyze data from the OECD Main Science and Technology Indicators to find that for a selection of 15 countries, the average share of basic research that was performed in the government and higher education sector was more than 75% in 2009. While there is little data available on the source of funds for basic research, Gersbach et al. (2014) point out that the OECD Main Science and Technology Indicators show that around 80% of the total research performed in either the government or the higher education sector is also funded by the government. Together, these findings suggest that a major share of basic research investments is publicly funded.

This evidence is broadly in line with the patterns observed from US data. The National Science Board (2012, Table 4-3) reports basic research expenditures by sector of performance and by source of funds for 2009. According to this table, around two thirds of total US basic research are performed either by the federal government or by universities and colleges. The same holds true with regard to the funding of basic

[18] Cf. Jaffe et al. (1993), Anselin et al. (1997), and Audretsch and Lehmann (2004), for example.

research, whereas only around 1/5 is funded by the business sector.[19,20]

Toward policy guidance

The case for the public funding of basic research is well established in the literature. The classical argument dates back to the seminal work of Nelson (1959) and Arrow (1962) and is based on a lack of appropriability of the returns from basic research. Put simply, as the benefits from basic research are diverse, uncertain, and lagging over time, they typically do not all accrue within a single firm. What is more, improved patentability of innovations from basic research alone cannot give rise to socially optimal outcomes. Any strengthening of upstream patent rights comes at the cost of an *anticommons effect*.[21] In this regard, Nelson (1959) argues that as the knowledge from basic research is a public good, it should be fully and freely disseminated.[22]

Some authors questioned the public-good nature of basic research, in particular its non-rivalry.[23] These authors argue that to be able to apply existing scientific knowledge in applied research, firms need to invest in complementary absorptive capacities via private basic research. Yet, due to the non-rivalry of knowledge from basic research, any such knowledge should still be fully and freely disseminated, at least among those firms that have the necessary absorptive capacities. Hence there is still a case for public funding. More generally, public funding of basic research can also be supported on the grounds of an *evolutionary approach* to the economics of basic research. This approach assumes a more integrative perspective on basic research and the innovation system. Basic research arguably generates diverse benefits, which partly accrue in the form of tacit knowledge incorporated in individual researchers or research networks.[24] According to Salter and Martin (2001), these benefits establish a new rationale for the public funding of basic research.[25]

[19] Note further that by far, the main part of basic research performed by either the federal government or by universities and colleges is also funded by these two sectors, which endorses the line of reasoning applied above to the OECD data for a broader range of countries.

[20] As opposed to basic research, the National Science Board (2012, Table 4-3) also shows that applied research and development together are mainly performed in the business sector (roughly 82%) and funded by it (roughly 70%).

[21] Several facets of such *anticommons effects* were discussed in the literature. Cf. Merges and Nelson (1990), Scotchmer (1991), Heller and Eisenberg (1998), Shapiro (2001), Lerner and Tirole (2004), Llanes and Trento (2012), and Hall et al. (2013).

[22] Cf. also Mowery et al. (2001) and Nelson (2004), for example.

[23] Cf. Cohen and Levinthal (1989), Rosenberg (1990), and Callon (1994), for example.

[24] Cf. the discussion in section 3 for further details.

[25] In the US, in particular, households donate significant funds for basic research. While such

As Aghion et al. (2008) point out, while the classical public-good argument supports the public funding of basic research, it does not clarify why basic research should be organized in public universities rather than by subsidizing private firms doing basic research. This aspect of public engagement in basic research has been given less attention in the literature. Yet several arguments in favor of public engagement have been put forward. Concerning the organizational form of research, Aghion et al. (2008) suggest that the fundamental trade-off is one of creative control versus focus. While private firms can dictate the lines of research to the scientists they employ, scientists working in academia have creative control over their work. They argue further that scientists value creative control, implying that private firms have to pay a wage premium when compared to academia. They develop a model based on this rationale, showing that early-stage research, which is far from being commercialized and hence has a relatively low expected value today, should be performed in academia.

Akcigit et al. (2013) present a different rationale for public basic research. In essence, they suggest that while subsidizing private basic research is, in principle, preferable to public provision, it may not be feasible due to asymmetric information and the resulting moral hazard problem. They propose public basic research as a feasible second-best solution.

Public provision of basic research may also be justified, in the spirit of Nelson (1959), on the grounds that it enables a better diffusion of the associated knowledge. Irrespective of their funding sources, private firms typically have little incentive to disseminate their insights from basic research. A classical argument in favor of patents takes up this concern, arguing that patents force firms to disclose their research.[26]

Arguments of a more qualitative nature for pursuing basic research in academia were proposed by Callon (1994) and Salter and Martin (2001). Callon (1994) argues that public engagement in basic research is needed to counteract the path-dependency and convergence inherent to private-sector innovation. Put differently, public basic research is needed as a source of new networks and technological opportunities that preserve variety and flexibility in the economy. Salter and Martin (2001) identify the supply of

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charitable funds may partly substitute for public investments, they potentially come at the cost of redirecting research towards fields of science that reflect the donators' preferences (Broad, 2014).

[26] Cf. Eisenberg (1989), for example. Note, however, that university researchers also sometimes refrain from disclosing commercially valuable research, due to lack of interest or lack of awareness, for example. Cf. the discussions in Thursby and Thursby (2002) and Howitt (2013), for example.

trained researchers to private firms as a major benefit from basic research.[27] They conclude that basic research and the education of graduate students need to be integrated closely.[28]

5 How much should we invest in basic research?

We have learned that basic research provides many benefits beyond building the knowledge base for applied research and that there is a strong need for public engagement in the field of basic research. Market forces alone will not guarantee a socially efficient level of investment in this public good. However, how much do countries invest in this good with such multi-faceted economic benefits? And how much should they invest?

Current state of affairs

On a global scale, USD 1.4 trillion is directed annually towards R&D at present (Economist, 2013a). Table 1 outlines R&D expenditures as a percentage of GDP, along with the share of these funds channeled into basic research for a selection of OECD countries plus Singapore, China, one African country (South Africa), and one Latin American country (Argentina), for which the OECD reports data.[29] This comparison reveals three main patterns: First, the share of aggregate income directed to R&D tends to increase over time.[30,31] Second, roughly one fifth of total R&D expenditures is spent on basic research. As the share of basic research in total R&D is slightly increasing on average, the share of GDP spent on basic research has increased over

[27] Cf. section 3.

[28] Cf. also Rosenberg and Nelson (1994), UNESCO (2010a), and Howitt (2013).

[29] As pointed out by Dougherty et al. (2007), the ratios of R&D to GDP provide a measure for the society's burden of investing in R&D. R&D-specific purchasing power parities are useful to compare R&D investments across different countries. There is little such data available. Throughout this paper, we thus refer to R&D expenditures over GDP as a measure of the R&D intensity of different countries.

[30] Note that for the selection of countries considered in Table 1, all countries except the Slovak Republic increased their R&D spending as a percentage of GDP from 2000 to 2009. A similar pattern can be observed when considering a longer time horizon and/or a broader selection of countries. Most of the 41 countries included in the OECD Main Science and Technology Indicators increased their share of GDP spent on R&D over the time-span for which there is data available. The only exceptions are Luxembourg, which basically kept its R&D investment intensity constant, the UK, and a selection of former member states of the Warsaw Pact, including Russia.

[31] This global trend is expected to endure. Cf. European Commission (2013).

time.[32] Third, industrialized countries tend to spend a higher share of their GDP on R&D than emerging countries and hence, R&D investments are highly concentrated.[33] This is also the case for basic research investments.[34]

Table 1: R&D expenditures of countries[a]

	Gross domestic expenditures on R&D as a percentage of GDP		Basic research expenditures as a percentage of total R&D expenditures		Applied research expenditures as a percentage of total R&D expenditures[b]	
	2000	2009	2000	2009	2000	2009
Argentina	0.44	0.60	27.75	29.80	72.25	70.20
Australia	1.47	2.26[c]	25.81	20.07[c]	74.19	79.93[c]
China	0.90	1.70	5.22	4.66	94.78	95.34
Czech Republic	1.17	1.47	23.34	27.10	76.66	72.90
France	2.15	2.27	23.60	26.08	76.40	73.92
Hungary	0.81	1.17	24.24	20.62	75.76	79.38
Ireland	1.10[d]	1.76	15.84[d]	22.90	84.16[d]	77.10
Israel	4.29	4.49	17.16	13.70	82.84	86.30
Japan	3.00	3.36	12.38	12.46	87.62	87.54
Korea	2.30	3.56	12.61	18.06	87.39	81.94
Portugal	0.73	1.64	22.85	18.93	77.15	81.07
Singapore	1.85	2.24	11.75	20.28	88.25	79.72
Slovak Republic	0.65	0.48	22.77	40.80	77.23	59.20
South Africa	0.73[e]	0.87	27.75[e]	23.26	72.25[e]	76.74
Switzerland	2.47	2.87[c]	27.96	26.78[c]	72.04	73.22[c]
United States	2.71	2.91	15.95	18.75	84.05	81.25
Average	1.67	2.10	19.81	21.52	80.19	78.48

[a] *Source*: Own calculations, based on OECD (2012a). The data was downloaded in June 2013. This table is a slightly updated version of the table presented in Gersbach et al. (2013).
[b] The OECD categorizes R&D into 'basic research', 'applied research', 'experimental development' and 'not elsewhere classified'. We summarize the last three items under 'applied research'.
[c] Data from 2008.
[d] Data from 2002.
[e] Data from 2001.

[32]For the selection of 35 countries for which the OECD Main Science and Technology Indicators report data on basic research expenditures as a percentage of GDP, only Chile, Germany, Israel, The Netherlands, New Zealand, Slovenia, South Africa, Sweden, and Switzerland (slightly) decreased their share of GDP spent on basic research over the maximal time-span for which there is data available. For most of these countries, this maximal time-span of data on basic research is relatively short. If we limit our attention to countries for which there is data available from the 1980s up to today, the tendency becomes more pronounced: All of these 12 countries, including the US and Japan, increased their share of GDP spent on basic research substantially over the period considered, with the relative increase ranging from 27% in the case of Russia to as much as 536% in the case of Portugal, albeit starting from a low level.

[33]In 2008, 25% of global R&D investments were undertaken by the US and another 10% by Japan. *Source*: Own calculations, based on World Bank (2013). The data was downloaded in June 2013.

[34]Cf. also section 6.

Toward policy guidance

Many economic studies have estimated the private and social rates of return on basic research.[35] But although these empirical measures generally indicate high returns on basic research, they cannot provide a basis for concrete policy actions, as Salter and Martin (2001) point out. A complementary approach is to break down this issue and to identify factors for optimal basic research investment. We follow this approach and consider two specific determinants: (1) a country's openness, and (2) linkages between basic research and the manufacturing base.

Openness

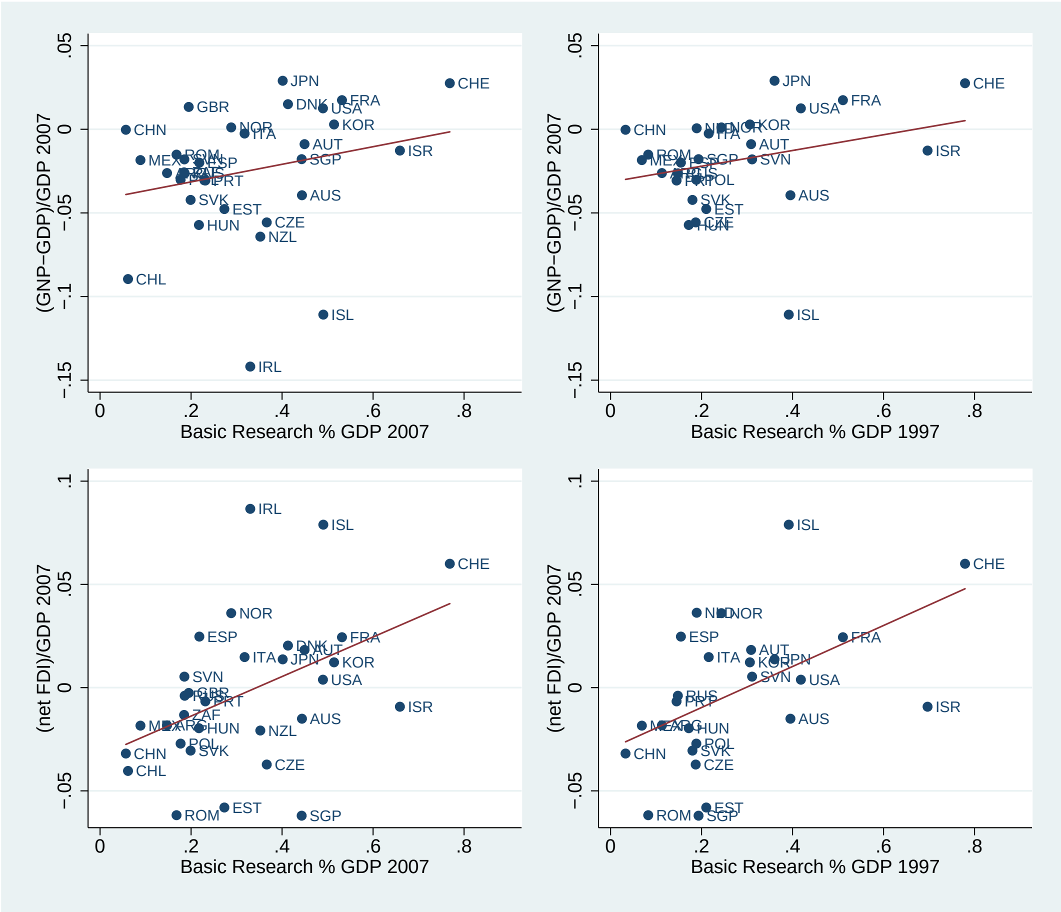
In an international context, building up the knowledge base through basic research has various effects. New knowledge generated domestically by basic research can spill over to other countries, either directly or indirectly via exports or foreign direct investments. If domestic firms earn monopoly profits in foreign markets, innovating countries can benefit from these spillovers. Conversely, countries can try to free ride on basic research investments from the rest of the world, potentially at the cost of losing domestic monopoly profits if innovative foreign firms enter the market. The spillovers to and from a country depend on this country's degree of openness. Hence openness is a critical factor for basic research investment.

We address the connection between openness and basic research investment from two different angles, FDI/trade and researcher mobility. We start with the former. Figure 1 plots two indicators of how successful domestic firms are when investing abroad against current and lagged basic research intensities: the first indicator being the difference between GNP and GDP over GDP and the second net FDI over GDP. While the former reflects accumulated past investments, the latter reflects current investment. Based on the reasoning discussed above, we could expect these measures to be positively correlated with (lagged) basic research intensities. This is exactly what we observe.[36] Obviously, such simple correlations do not allow to identify causal relationships. Yet

[35] Cf. the discussion in section 3.

[36] The correlation coefficients are 0.24 (GNP(t)-GDP(t), BR(t)), 0.29 (GNP(t)-GDP(t), BR(t-10)), 0.46 (FDI(t), BR(t)), and 0.51 (FDI(t), BR(t-10)). 2007 was considered because data on foreign direct investments are available from 2005 onwards only. These data may have been influenced by the great recession that started in late 2007. Results are essentially the same when we consider 3-year centered moving averages in 2006. Note, however, that basic research investments over GDP exhibit a relatively low time variance.

Figure 1: Basic research and net income from abroad



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages.

they highlight an important channel through which a country's openness matters for (optimal) basic research investments.

Gersbach et al. (2013) address these issues from a theoretical point of view. They show that in a fast-paced environment with large gains from innovation, it may be optimal for open economies to (partly) free ride on basic research investments of the rest of the world. Gersbach and Schneider (ming) explicitly take into account the interdependencies of national investment decisions in basic research in a two-country set-up. They show that in a decentralized equilibrium, some countries – in particular small open economies – may overinvest in basic research in comparison with basic research policies coordinated among countries. Yet, total global investment in basic research tends to be below the social optimum. Hence Gersbach and Schneider (ming) provide a rationale for both the relatively high investment in basic research by technologically advanced small open economies such as Switzerland and South Korea and for international coordination within the EU or CERN, for instance.[37]

The mobility of researchers is a further important factor for basic research policies.[38] It has an impact on the supply of skilled graduates and problem-solvers, one of the major benefits deriving from public basic research identified by Salter and Martin (2001).

Moreover, mobility affects the domestic knowledge base to the extent that this knowledge base takes the form of tacit knowledge of individual researchers. One might ask whether public basic research is needed to prevent – or at least mitigate – a 'brain drain', presumably involving the most talented researchers. Conversely, can countries that invest heavily in basic research attract skilled researchers from abroad, thereby strengthening their domestic talent-pool? Empirical evidence underlines the importance of such effects for basic research policies.[39]

Manufacturing base

Basic research mainly impacts the economy indirectly through the applied research undertaken by private firms. There are two-way spillovers between basic and applied research. Moreover, manufacturing accounts for the main proportion of business R&D expenditure (McKinsey Global Institute, 2012). Hence the strength of the domestic manufacturing base is a further key factor for optimal public investments in basic research. This is particularly important in the aftermath of the great recession that started in late 2007, as policy-makers in many Western countries are aiming at the reindustrialization of their economies to enhance future economic growth and prosperity.[40]

[37]Such coordination can also be justified by the large lump-sum investments required to perform basic research in some areas.

[38]Cf. UNESCO (2010a), for example.

[39]Today, around 45% of PhD students in the US and 60% of PostDocs are temporary residents (Stephan, 2012). Cf. also Hunter et al. (2009), for example. What is more, there are large cross-country differences, calling for a better understanding of causes and consequences. Franzoni et al. (2012) surveyed the corresponding authors of articles published in 2009 to find that in a sample of 16 countries, Switzerland's research community exhibited the highest mobility. It had the highest share of immigrants among its researchers (56.7%) and the second-highest share of emigrants (33.1%). In contrast, Japan had a very low share of immigrants (5%) and emigrants (3.1%). The US had many immigrants (38.4%) but few emigrants (5%), unlike India with 0.8% immigrants and 39.8% emigrants.

[40]Cf., for example, Obama (2013) and European Commission (2012).

Pisano and Shih (2012) suggest that the manufacturing base is an important element of a country's innovation system. They argue that firms should locally integrate R&D and production, notably in immature industries and in industries with low *modularity*, i.e. in industries where product characteristics and production processes are intimately linked. The McKinsey Global Institute (2012) presents survey-based evidence in support of these conjectures. Their work suggests that the benefits generated by local integration of R&D and production are larger for more complex and R&D-intensive industries. Following the innovation process further and considering the local effects of basic research, this suggests potentially significant benefits from liaising basic research with a strong manufacturing base, in particular in high-tech industries. Several empirical studies support this finding by pointing to significant positive effects on productivity in various (manufacturing) industries, the potential of these effects being particularly strong for high-tech industries.[41]

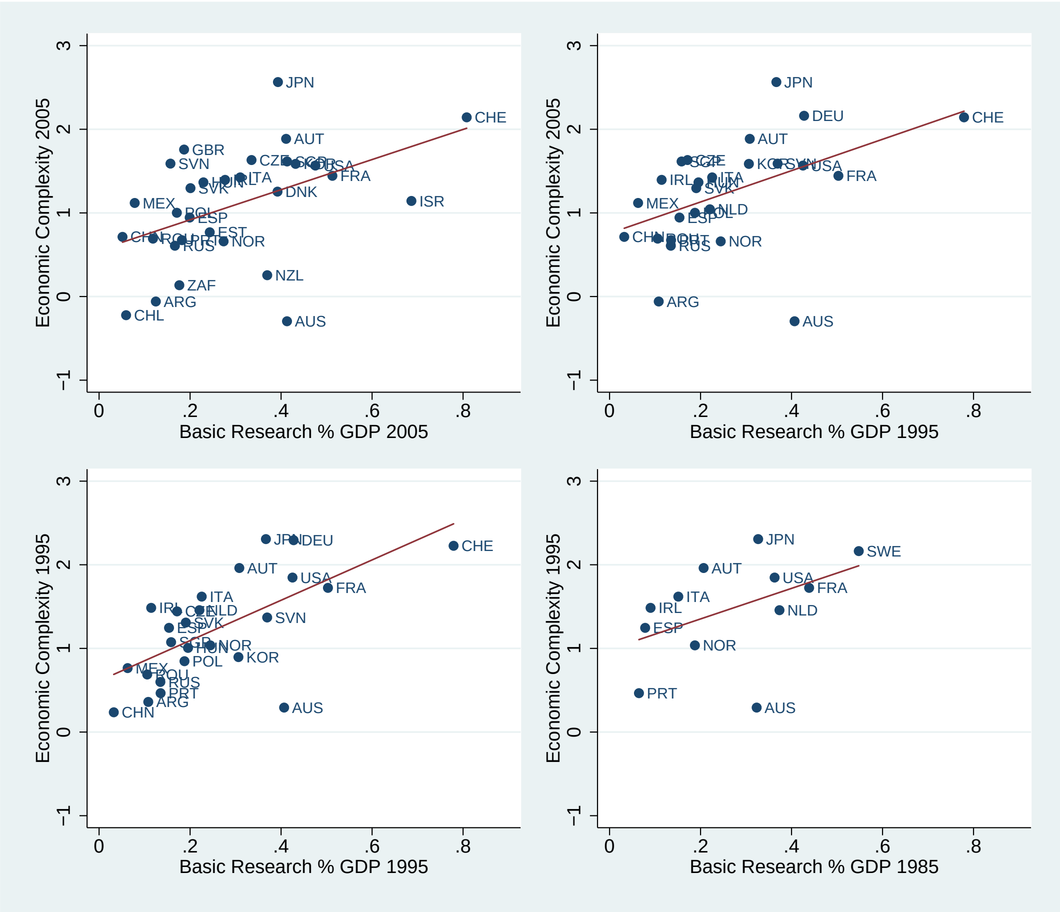
Such empirical studies are based on simplified production functions, and the underlying empirical strategies have been criticized on various grounds. Figure 2 takes a different approach. It plots countries' basic research intensities against the measure of countries' economic complexity, as proposed by Hidalgo and Hausmann (2009) and Hausmann et al. (2011).[42] Considering both contemporaneous and 10-year-lagging investments, this illustration reveals that there is a strong positive correlation between basic research investments and the degree of economic complexity.[43] Obviously, these simple correlations do not allow causal statements. Moreover, the measure of economic complexity may, in principle, either reflect the strength of an economy's manufacturing base or its potential to offshore production and refine domestically. The data, however, are a promising starting point for a more detailed examination of this mutual interdependency.

[41] Cf. footnote 9.

[42] This measure is based on a binary trade matrix, indicating for every country those products for which it has a revealed comparative advantage, where revealed comparative advantages refer to the measure originally developed by Balassa (1965). Broadly speaking, a country has a high value of economic complexity if it is a strong exporter of complex products, i.e. products exported by few and highly developed economies. This measure has several interesting properties. Among others, it is strongly positively correlated with GDP per capita and it has some predictive power for future economic growth (Hidalgo and Hausmann, 2009; Hausmann et al., 2011).

[43] The correlation coefficients are 0.47 (2005) and 0.65 (1995) if current basic research investments are considered, and 0.47 (2005) and 0.46 (1995) for 10-year-lagging basic research investments.

Figure 2: Basic research and economic complexity



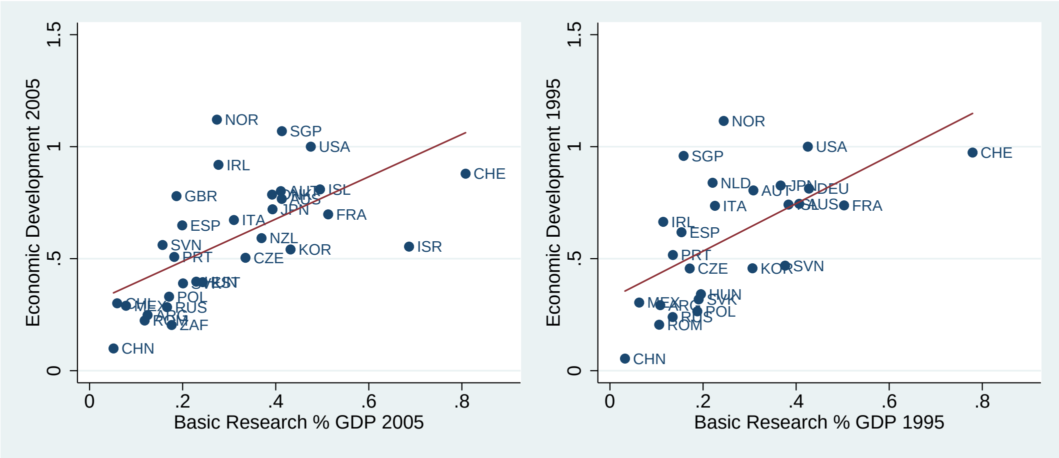
Source: Own illustration, based on data taken from http://atlas.media.mit.edu/rankings and from OECD (2012a). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages. 'Economic complexity' is the index value as downloaded from http://atlas.media.mit.edu/rankings.

6 When, over the course of economic development, should we invest in basic research?

Scientific and technological progress is a cumulative process in which every advance is rooted in the knowledge base developed by prior research.[44] Hence it seems natural that a stock of scientific and technological expertise is needed to conduct – and benefit from – state-of-the-art basic research. We can conjecture that industrialized countries should invest more in basic research when compared to developing countries. But if

[44]Cf. Scotchmer (1991), Scotchmer (2004), and Nelson (2004), for example.

Figure 3: Basic research and economic development – overview



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values on both axes refer to 5-year centered moving averages. 'Economic development' is defined as $\frac{\text{GDP per capita in PPP}}{\text{US GDP per capita in PPP}}$.

developing countries are to ever approach the world-technological frontier, we have to ask if and when and how they should initiate domestic investments in basic research, an issue we address now.

Current state of affairs

In line with the reasoning above, basic research is mainly performed by industrialized economies that are at – or near – the global technological frontier.[45] Moreover, as Figure 3 illustrates, on balance, the closer countries are to the global technological frontier, the more they tend to invest in basic research.[46]

This cross-country comparison is also in accordance with many country-level strategies over the course of economic development: Starting in the early 2000s, South Korea, for example, has – in parallel with its overall economic development – considerably increased its basic research investments.[47] The EU-target of increasing the share of R&D in GDP to 3% by 2020 builds upon demanding country-level targets for devel-

[45] Cf. section 5.

[46] The ratio of GDP per capita in PPP over US GDP per capita in PPP is used as a proxy for the status of economic development. (cf., for example, Acemoglu et al., 2006; Gersbach et al., 2013). To smooth short-term fluctuations, centered 5-year moving averages are considered. The correlation coefficients are 0.62 (2005) and 0.61 (1995).

[47] Cf. Figure 4.

oping member-states, in particular.[48] And China considers the build-up of innovative capacities to be a cornerstone of its pursuit of a sustainable growth path that shall lead to a well-off society. Its 'national medium- and long-term program for science and technology development' aims at increasing the share of R&D spending in GDP to 2.5% by 2020 and explicitly envisions a strengthening of domestic basic research (GOV.cn, 2006), albeit starting from a low level.

Toward policy guidance

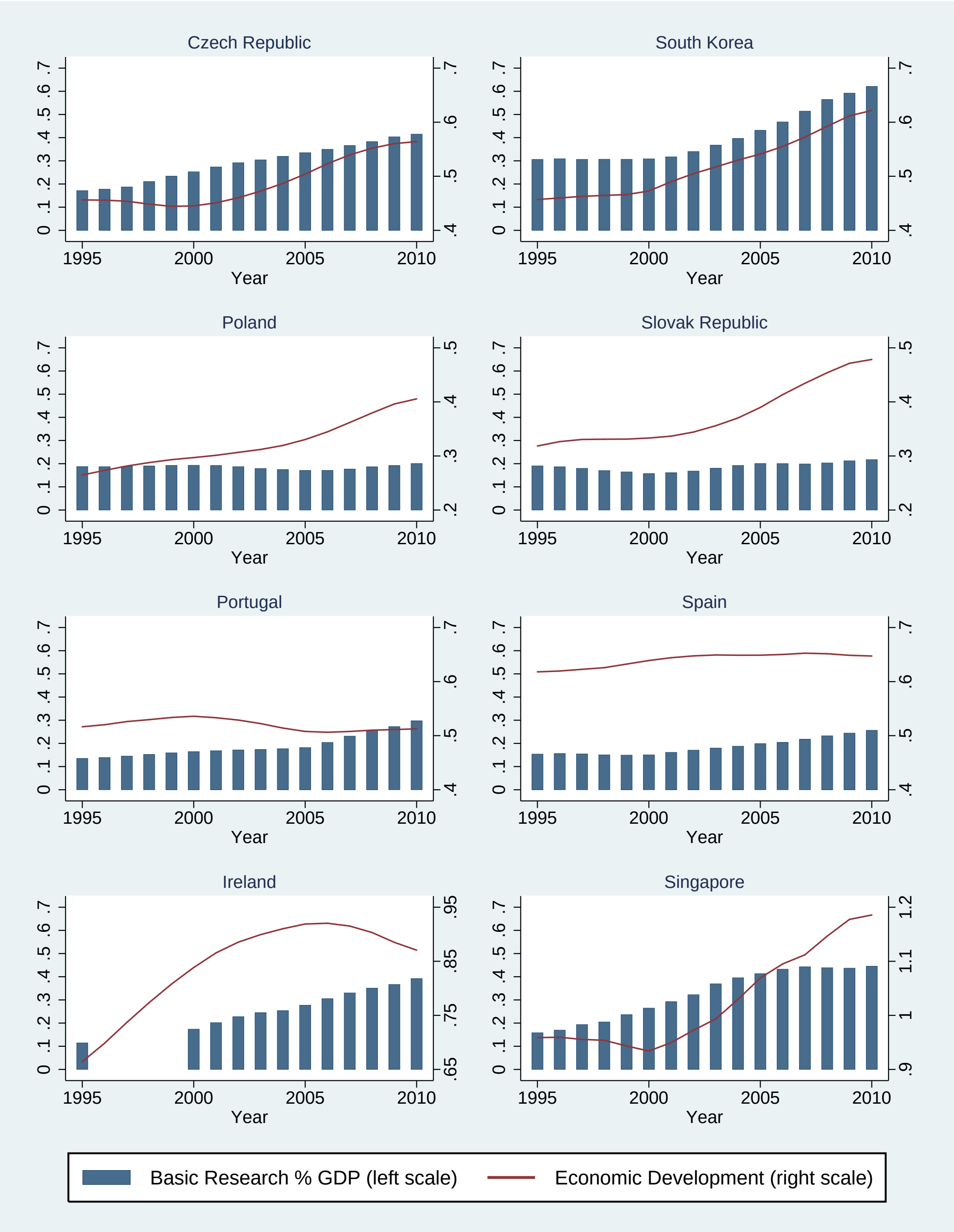
Optimal basic research investments over the course of economic development have experienced relatively little attention in the economic literature so far. The simple rationale for the observed positive relationship between a country's status of economic development and its basic research investment is developed in Gersbach et al. (2010). In a small open economy model with creative destruction, the closer a country is to the world technological frontier, the more it should invest in basic research. The main intuition is that the closer an economy is to the world technological frontier, the more effective basic research becomes in deterring technologically-advanced foreign firms from entry, and, conversely, the more effective it is in supporting domestic firms operating on the world market.[49]

However, the general pattern masks important differences in the way countries with similar stages of economic development select their basic research policies. Figure 4 plots basic research expenditures and the status of economic development for a selection of eight countries from 1995 to 2010. These countries exhibit very different patterns with regard to basic research investments over the process of economic devel-

[48]Cf. European Commission (2011). However, these country-level targets refer to total R&D and not to basic research. Yet considering that the EU targets at a share of publicly funded R&D in total R&D of 1/3, and considering that it acknowledges the importance of basic research (European Union, 2004), we may conjecture that the targeted sharp increases in R&D spendings involve major investments in basic research.

[49]Howitt (2000) and Acemoglu et al. (2006) analyze convergence to the world technological frontier in macroeconomic models. These models, however, do not address the importance of basic research for convergence. Howitt (2000) presents a model where countries grow through investments in physical capital and productivity-enhancing R&D. Countries converge to a constant productivity level relative to the world technological frontier, depending on the exogenous savings rate, research subsidies, and research effectiveness. Howitt (2000), however, does not focus on optimal policies. Acemoglu et al. (2006) present a model where countries switch from investment (imitation) to innovation as they approach the world technological frontier. Without a switch in growth strategies, the countries are stuck in a non-convergence trap. In the model of Acemoglu et al. (2006), there are cross-country technological spillovers, and innovation is driven by entrepreneurial selection.

Figure 4: Basic research and economic development – country patterns



Source: Own illustration, based on data taken from OECD (2012a) and from World Bank (2013). The data was downloaded in June 2013. Values refer to 5-year centered moving averages. 'Economic Development' is defined as $\frac{\text{GDP per capita in PPP}}{\text{US GDP per capita in PPP}}$.

opment. The Czech Republic and South Korea were significantly catching up with the world technological frontier. In parallel, they heavily increased their investments in basic research. By contrast, Poland and the Slovak Republic kept a more or less constant, and relatively low, level of basic research over the course of their development, starting, however, from a slightly lower level of economic development than the Czech Republic and South Korea. At the same time, Portugal and Spain invested little in basic research, only increasing these investments slightly towards the end of the period considered. They stagnated at levels of economic development roughly comparable to the Czech Republic and South Korea in 2010. Finally, Ireland and Singapore reached relatively high levels of economic development with comparatively little investment in basic research and then initiated strategic *big-push* investments in basic research to establish globally competitive and innovative knowledge economies.[50] While Singapore managed to sharply increase its standard of living since 2000 compared to the US, the development of Ireland is hump-shaped, and its GDP per capita, relative to US GDP per capita, was only slightly higher in 2010 than in 2000.[51,52]

These findings indicate that policy-makers face some critical decisions with regard to basic research policies over the course of economic development. The most pressing

[50] Cf. Irish Council for Science, Technology and Innovation (1999) and RIE Secretariat (2011).

[51] Note, however, that Ireland was hit particularly severely by the great recession that started in late 2007. Still, Singapore seems to have been more successful with its *big-push* policies than Ireland. This conjecture is also supported by examining a more direct measure of the respective productive capacities, as proposed by Hidalgo and Hausmann (2009) and Hausmann et al. (2011). In the period from 1997 to 1999, the three years prior to and including the launch of its *big-push* policies, Ireland was, on average, ranked 12.3 in the proposed country ranking of economic complexity. This average rank dropped to 16.7 for the period 2006 to 2008. By contrast, from 1989 to 1991, the three years prior to and including the launch of its *big-push* policies, Singapore had an average rank of 19.7, and managed to reach an average rank of 10.7 for the period 2006 to 2008 (country rankings were downloaded from http://atlas.media.mit.edu/rankings/country in June 2013).

[52] The basic research data considered in Figure 4 include both public and private basic research. For a better view of the importance of government policies for these developments, it would be interesting to consider public basic research only. For the selection of countries considered, there is little data on the share of basic research investments funded by the government. However, with the exception of South Korea, in which more than 50% of basic research are performed by private firms, the reasoning outlined in section 4 also applies to the selection of countries considered here. It suggests that public investments account for the main part of total basic research investments. As an alternative, we can consider government-financed gross domestic expenditures on R&D (GERD) as a percentage of GDP, as reported by OECD (2012a). For the selection of countries considered, these public investments in all categories of research and development follow a pattern over time that is similar to the ones shown in Figure 4 for basic research. The main difference is that the public investments in R&D tend to be higher than total basic research investments in the economy. This indicates that the governments significantly fund applied research and/or experimental development in addition to the funding of basic research.

issue is to determine at which stage of the development investment in basic research should be accelerated, be it gradually or via sudden-action policies. Future economic research may shed more light on the underlying linkages and thus support policy-making in this area. The described examples set the stage for such an investigation.

7 Where should we target investments in basic research?

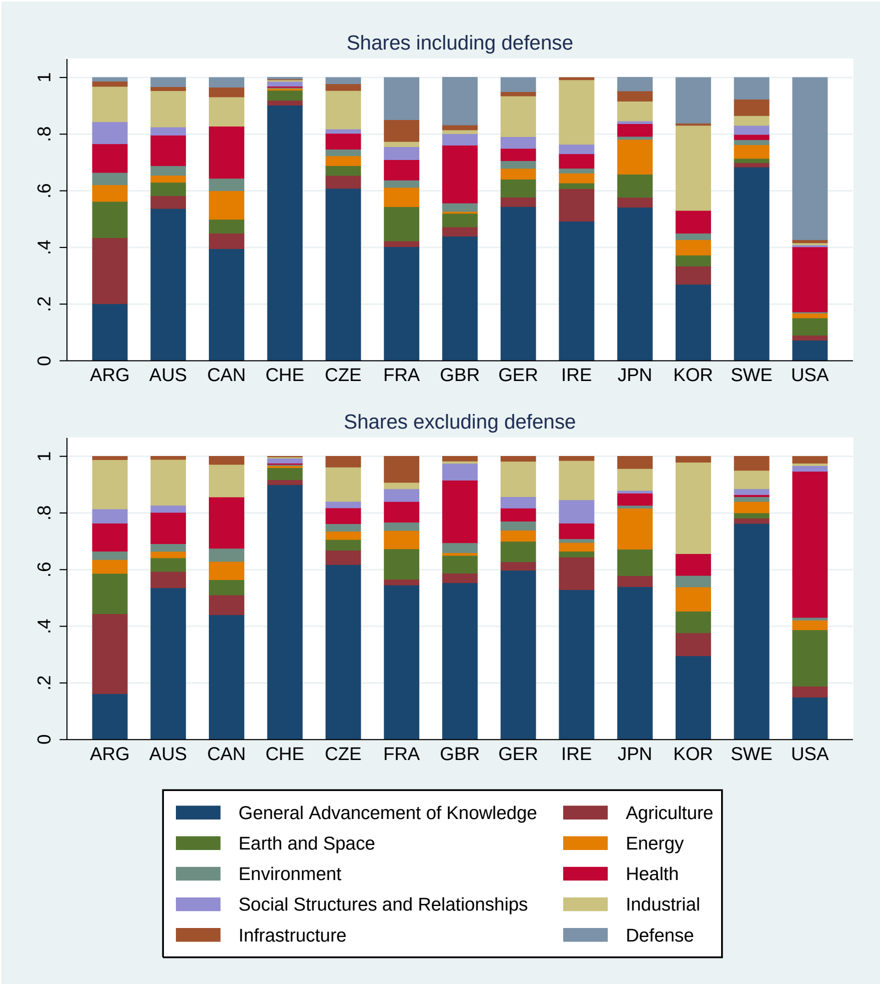
In the famous words of Wernher von Braun, basic research is what you are doing if you don't know what you are doing. If so, can there nonetheless be room for targeting investments in basic research to specific socio-economic needs, economic sectors, or fields of science, for instance? And why should such targeting take place? To help lagging industries to reach the world technological frontier? To support domestic industries that are particularly active in applied research? Or to establish scientific centers of excellence? We address these issues next.

Current state of affairs

Figure 5 considers a selection of 13 countries and compares shares of public resources for research allocated to socio-economic objectives. The chart suggests that countries differ widely in their concentration of public funds on research, with Switzerland and the US representing the polar cases. While Switzerland devotes almost 90% of these funds to the 'General Advancement of Knowledge', the US spend almost 60% on defense-oriented research (upper graph). Within civil R&D, the US concentrate more than 70% of total funds on healthcare-oriented research and on the exploration of the earth and space (lower graph).[53]

[53] The strong concentration of research funds in the US also applies to fields of science, with an increasing-over-time focus on life sciences. Cf. National Science Board (2010) and National Science Board (2012).

Figure 5: Government budget obligations or outlays for R&D by socio-economic objective, 2008



Source: Own illustration, based on OECD (2012b). The data was downloaded in June 2013 and was grouped as follows:

- *General Advancement of Knowledge* := 'General advancement of knowledge : R&D financed from General University Funds (GUF)' + 'General advancement of knowledge : R&D financed from other sources than GUF';
- *Agriculture* := 'Agriculture';
- *Earth and Space* := 'Exploration and exploitation of the earth' + 'Exploration and exploitation of space';
- *Energy* := 'Energy';
- *Environment* := 'Environment';
- *Health* := 'Health';
- *Social Structures and Relationships* := 'Education' + 'Culture, recreation religion and mass media' + 'Political and social systems, structures and processes';
- *Industrial* := 'Industrial production and technology';
- *Infrastructure* := 'Transport, telecommunication and other infrastructures';
- *Defense* := 'Defence'.

The data for Argentina, Australia, Canada, Switzerland, Japan, and the United States refers to the corresponding federal or central government only. Canada and South Korea do not report information on what we define as 'Social Structures and Relationships'. In the case of South Korea, these data are included in our 'General Advancement of Knowledge' aggregate.

Understanding these differences and their implications for the national innovation system is all the more important as several countries are currently implementing more US-like policies with a stronger targeting of public investments in basic research.[54]

Toward policy guidance

Any targeting of public basic research investments will eventually impact on their effectiveness in stimulating economic growth and prosperity.[55] Yet, while the policy-shift in Ireland, for example, follows a well-defined strategy, identifying priority areas on the basis of the competitiveness of Irish companies, the complementarity with private (applied) research, the existing scientific expertise, and relevance, the particularly strong targeting conducted by the US seems attributable to historically-grown institutional and societal factors.[56]

We can say little about the effectiveness of such targeting. Cohen et al. (2002) present survey-based evidence that confirms the basic intuition that first, fields of science significantly differ in their overall direct relevance for the private sector; and second, that the importance of any given field of science varies significantly across industries. These findings provide means for targeting basic research investments to the needs of specific industries, if desired. Yet the 'republic of science' might be most effective in providing efficient coordination of research efforts, and any kind of directive by central authorities

[54]The European Commission, for example, seeks to achieve reindustrialization by concentrating investments on 'advanced manufacturing technologies for clean production', 'key enable technologies', 'bio-based product markets', 'sustainable industrial policy, construction and raw materials', 'clean vehicles and vessels' and 'smart grids' (European Commission, 2012). Such strategies would necessarily involve a significant amount of targeted basic research. As part of its 'national medium- and long-term program for science and technology development (2006-2020)', China has defined 11 priority areas for technological development (cf. http://www.gov.cn/english/2006-02/09/content_184426.htm, retrieved on 15 August 2014). Ireland has implemented a Research Prioritisation Steering Group, which has identified 14 priority areas for Ireland's science, technology, and innovation strategy (Research Prioritisation Project Steering Group, Ireland, 2012).

[55]In the case of the US, for example, the targeting is reflected in university patenting and publications, at least: In 1998, 41% of US university patents belonged to one of three areas of biomedical research (Geuna and Nesta, 2006). Similarly, US publications are concentrated in biomedical and clinical research (UNESCO, 2010b).

[56]Nelson (2004) suggests that this targeting may have been inspired by the experience made during World War II. During that time, publicly funded research made important contributions to the development of new weapons and to the improvement of healthcare. He also points to the fact that today, most funds are provided by mission-oriented agencies. Stephan (2012) presents a political economy explanation for the strong US focus on healthcare-related research: Investments in health sciences are easy to justify in general. Interest groups heavily lobby to support research for specific diseases. Moreover, decision-makers are fairly old on average, and are thus potentially guided by personal interests.

may impede this coordination process (Polanyi, 1962), all the more as it is impossible to identify fruitful avenues for research ex-ante (Geuna and Nesta, 2006). With serendipity being an important factor for scientific progress (Nelson, 2004), it may well be optimal to divert public spending on basic research to counteract specialization tendencies inherent to private markets (Callon, 1994). We conjecture that the more basic research is leaned towards *Pasteur's Quadrant*, i.e. the more it has a specific practical use in view, the more it may be targeted. Yet such targeting should not undermine the support for truly fundamental, undirected basic research, partly relying on serendipity, as these may result in major scientific breakthroughs which, in turn, may widen the scope for targeting more applied research in the future.

8 Conclusion

Basic research is a key driver of modern economic growth. It is also an area that leaves policy-makers ample room for decisions that can foster the long-term well-being of their citizens. It is evident that policy decisions in the area of basic research have to be taken under major uncertainty. Technological progress can be fostered but neither fully described ex ante nor guaranteed. Yet we demonstrate that conceptual reasoning can be combined with empirical evidence to assess the main causes and consequences of basic research investments. This allows to identify the most pressing issues in basic research policy and enable policy-makers to base their decisions on the best possible information and best possible reasoning.

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