INDUSTRY AND INNOVATION, 2016
VOL. 23, NO. 2, 157–176
http://dx.doi.org/10.1080/13662716.2016.1146125

Routledge
Taylor & Francis Group

R&D policy instruments – a critical review of what we do and don't know

Ben R. Martin[a,b]

[a]SPRU, University of Sussex, Brighton, UK; [b]CSaP and CBR, University of Cambridge, Cambridge, UK

ABSTRACT

In recent years, the term "policy instrument" has been used frequently with regard to R&D policy and innovation policy. This article examines the development of the term as part of a body of research known as "policy design". Over the last 50 years, there has been substantial progress in setting policy design on a more systematic basis, with the development of established concepts and analytical frameworks, including various taxonomies of policy instruments. However, with just a few exceptions, this body of research seems to have had little impact in the world of R&D policy. The paper reviews the literature on R&D policy instruments, identifies a number of challenges for R&D policy instruments in the light of four transitions and sets out a research agenda for the study of R&D policy instruments, before ending with a number of conclusions.

KEYWORDS

Policy instruments; R&D policy; policy design; policy mix

1. Introduction

Innovation policy consists of a set of policy instruments, many financial in nature. But how useful are existing policy instruments? What changes are needed to make innovation policies more effective? For reasons of space, the focus in this paper is on a subset of "innovation policies", namely R&D policy (defined below). The aim is to situate R&D policy within the broader context of public policy design, and then to critically review the literature on R&D policy instruments to ascertain what we do and don't know about such instruments with a view to establishing a fruitful agenda for future research. Again for space reasons, the topic is dealt with in fairly general terms, rather than going into specific details about the policy practices of individual countries or the evaluations by funding agencies and others such as OECD and the EU of particular RDI policy instruments.

The structure of the paper is as follows. Section 2 defines key terms, in particular "policy instruments", and sets out the issues to be confronted in any analysis of R&D policy instruments. The methodology employed in this study is summarised in Section 3. Section 4 outlines key concepts and developments in the field of policy design. The literature on R&D policy instruments is reviewed in Section 5. In Section 6, we consider four fundamental

CONTACT Ben R. Martin b.martin@sussex.ac.uk

transitions and the challenges they pose for R&D policy instruments. Section 7 then sets out a research agenda for future work on the topic, while Section 8 draws together the main conclusions.

2. Background

2.1. Scope and definitions

In what follows, I adopt the definitions set out in Doern and Stoney (2009a):

> Policy refers … to statements of purpose and intent regarding research, S&T [and] innovation … enunciated and discussed by the … government in various ways and in myriad arenas of debate. Such policies mobilize all of the key instruments of taxation, spending, regulation and persuasion. (ibid., 8)
> "Research policy refers to policies aimed at the funding, conduct and dissemination of basic and applied research in the natural, health and social sciences" (ibid., 8) – in other words, the focus is on policies *for* research (or for science).
> In contrast, science policy or S&T policy is somewhat broader.
> "S&T policy also promotes and governs the use of scientific and technical knowledge in public policy and regulation ('science *in* policy'), where governments need to draw on their internal S&T or the S&T capacities of others to carry out their responsibilities under laws, rules and international agreements, especially in public interest areas such as environment, health and safety policy, and regulation" (ibid., 9; emphasis added).
> Broader still is the concept of innovation policy.
> "Innovation policies refer to government policies aimed at fostering the use of the best S&T to produce new and competitive 'first-to-market' products and new production processes, and the innovative organizational approaches and management practices to support these activities" (ibid.).

To simplify things, I use the term "R&D policy" in what follows to include science policy, research policy, and science and technology policy (at least as far as this relates to policy *for* science and technology). "R&D policy" overlaps considerably with "innovation policy" but, as the above definitions make clear, the latter is much broader, in particular including commercialisation policy (see Doern and Stoney 2009a, 10–11) and various demand-side policies for innovation (see e.g. Edquist and Hommen 1999; Edler and Georghiou 2007; Edler 2009; Kaiser and Kripp 2010; Georghiou et al. 2014).

The term "policy instrument" has previously been used rather loosely in much science and innovation policy literature. As Flanagan, Uyarra, and Laranja (2011, 706) note, the term has a high degree of "interpretive flexibility, carrying quite different meanings from time to time, place to place and actor to actor". However, "policy instrument" is a well-established (and clearly defined) concept in the field of policy design (in turn, part of the wider field of public policy or policy studies). Policy instruments can be defined as "techniques of governance which, one way or another, involve the utilization of state resources, or their conscious limitation, in order to achieve policy goals" (Howlett and Rayner 2007, 2).

2.2. The problems

There seems to be relatively little literature focussing directly on R&D policy instruments (one exception is the series of reports by NESTA described later in Section 7.3). The term is mentioned in passing in some research evaluation studies (e.g. Papaconstantinou and Polt 1997; Edler et al. 2012). It is also discussed in policy reports, especially those relating to the EU (e.g. EPUB 2002; Johansson, Karlsson, and Backman 2007; Langfeldt et al. 2012). Apart from that, there is little literature dealing specifically with R&D policy instruments, or at least using that particular term, perhaps reflecting a lack of awareness of the established body of work on this in the area of policy design (and also giving rise to a lack of consistency in the terminology used).

A wide variety of R&D policy instruments have accumulated over time in an ad hoc manner (e.g. reflecting political or economic circumstances at the time), interacting with each other as well as with the intended actors in a complex and often unpredictable manner, and giving rise to legacy problems. As we shall see, there is little systematic empirical evidence regarding the effectiveness of different R&D policy instruments, their pros and cons, their interactions and their relationship to the wider environment.

3. Methodology

This study is based on a literature review. A search was carried out using online databases, including the Web of Science, Scopus and Google Scholar. Search terms relating to "research/ science/ technology/R&D AND policy instruments/tools" were used. Particular attention was paid to publications that seem to have had more impact (as reflected in a greater number of citations) and on recent contributions over the last ten years.

One limitation of the approach is that it mainly focused on more "academic" literature; official reports, "grey literature" and so on are mostly not included (of the various databases used, only Google Scholar covers some of these, although not in a very systematic manner). A second limitation of the approach is that it omitted studies which, although perhaps dealing with particular forms of policy instrument/tool, do not use that specific term. As a consequence, this should be regarded as an exploratory study, leaving it to subsequent research to examine the issues more comprehensively and to confirm (or reject) the conclusions arrived at here.

4. The research field of policy design

The last two decades have witnessed the emergence of the now well-established field of policy design concerned with a range of public policies (e.g. economic, social, health, education). Researchers within this have made considerable progress in developing analytical and conceptual frameworks. At the heart of what they study is the policy process or "policy cycle", seen as composed of several stages: "agenda-setting, policy formulation, decision-making, policy implementation, and policy evaluation" (Howlett 2011, 19). In each of these, governments can make use of various policy instruments (or "policy tools") to ensure state resources are used effectively in the pursuit of particular policy goals.

An early phase in this work was the development of "taxonomies" of different policy instruments (Howlett 2011, 45). Some of these were based on choices a government can

make, others on the categories of resources government can deploy, and yet others on the degree of control or freedom with regard to actors influenced by the policy instrument (Vedung 2010, 22–23). One can also differentiate between maximalist taxonomies (listing all possible types of policy instruments) and minimalist ones based on just a few main types of policy instrument (e.g. "carrots" VS "sticks"). One of the most widely used is the "NATO" model developed by Hood (1983, 1986), who argued that governments have four main types of resources they can draw upon in efforts to effect change, namely "nodality", authority, "treasure" (i.e. public funds) and organisation (Howlett 2011, 47). Hood's NATO taxonomy has been subject to various refinements, combining the original four resource categories with some other dimension, for example, whether the policy instruments are positive or negative, or substantive or procedural in nature (Howlett 2011, 52–53).

Besides distinguishing between different types of policy instrument, authors have also identified different criteria for the choice of a particular policy instrument. For example, Peters identified seven attributes that influence instrument choice: "directness, visibility, capital/labour intensity, automaticity or level of administration required, level of universality, reliance on persuasion vs. enforcement, and their 'forcing vs. enabling' nature" (reported in Howlett 2011, 55–56). In combination with the stages of the policy process and the taxonomy of policy instruments, these criteria can then be used to derive a comprehensive model of the instrument selection process in the task of policy design (Howlett 2011, 56).

Reflecting the changing context and agenda of policy studies, another development was a shift in the late 1990s from focusing on individual policy instruments to efforts aimed at arriving at some optimum combination of instruments or "policy mix" in order to achieve the intended policy goals (Bressers and O'Toole 2005; Howlett and Rayner 2007; Howlett 2011, 53). This, in turn, has given rise to certain design principles for policy mixes, for example, to employ a mix of instruments that interact positively with one another as well as taking account of the specific characteristics of the target sector, and to take full advantage of incentive-based instruments to encourage self-regulation by industry and others (Howlett and Rayner 2007, 4).

In summary, over the last 50 years, there has been substantial progress in setting policy design on a systematic basis, with the development of established concepts and analytical frameworks. However, there has been only limited cross-over with the world of R&D and innovation policy. It is somewhat ironic that R&D policy should have been less subject to rigorous scientific scrutiny than public policy more generally!

Among the few who have attempted to link policy design with R&D or innovation policy are Landry and Varone (2005), Doern and Stoney (2009b), Rubio and Tshipamba (2010) and Flanagan, Uyarra, and Laranja (2011), the last being the most systematic attempt (and one which I deal with separately in Section 7). The first of these, Landry and Varone (2005), consists of a chapter on "the choice of policy instruments" in an edited book on policy design (Eliadis, Hill, and Howlett 2005), but it is illustrated by reference to innovation policy. The authors identify limitations in the current state of knowledge regarding choice of policy instrument, in particular, the fact that at best the existing literature yields hypotheses in an ad hoc and non-operational manner, and that empirical studies are rare and the comparability of results is limited (Landry and Varone 2005, 108).

Doern and Stoney (2009b) are also part of the prominent Canadian school of public policy studies. In the introductory chapter (2009a) to their book (2009b), they focus explicitly on research and innovation policy, identifying the driving forces behind recent trends,

for example, the increasing government and societal need for objective and useful social, economic and policy-relevant research (Doern and Stoney 2009a, 20), the growing support for network and partnership-based research and knowledge-sharing (Doern and Stoney 2009a), and escalating demands for the commercialisation of university research (Doern and Stoney 2009a, 21). They set out an analytical framework for examining research and innovation policies structured around four main components (Doern and Stoney 2009a, Table 1.1, 16): (1) high-level policy and conceptual discourse; (2) core policy values and ideas; (3) policy instruments; and (4) institutional and governance change. Doern and Stoney provide one of the very few analyses of different policy instruments and instrument mixes specifically geared to research and innovation policy, mainly illustrated by reference to examples drawn from Canada.

Lastly, Rubio and Tshipamba (2010) analyse the structure, elements and formulation of science, technology and innovation policy, drawing on examples from countries across several continents. However, although this article contains a specific section on "Science policy instruments" (Rubio and Tshipamba, 70–75), these authors adopt a looser definition of "policy instruments" than in the policy design literature. As such, it adds rather less to our discussion here.

5. Review of literature on R&D policy instruments

5.1. Theoretical framework

Is there any theory on R&D policy instruments? Not much! With regard to economic theory, there is a substantial literature on the economics of science and R&D, and on the rationale for public intervention. For example, Laranja, Uyarra, and Flanagan (2008) examine "what rationales for public intervention can be derived from different economic theories", and more specifically "what policy instruments or policy-mixes can be associated with the various rationales". However, there is far less on the economics of specific science or R&D *policies*, and little if anything on the economic theory of R&D *policy instruments*.

Some efforts have been made to embed science policy in principal-agent theory, science policy being a particularly fruitful area for exploring this theory since this is one case where the identity of the "principal" and the "agents" is relatively clear. One of the pioneers here was Guston (1996), who showed how principal-agent theory offers a potentially useful analytical framework for science policy analysis. The principal-agent approach to science policy was further developed by Van der Meulen (1998) and applied to one particular set of policy instruments, namely those devoted to the introduction of (technology) foresight, showing how foresight represented a step in the further development of the contractual relationship between government and science. This study shows that principal-agent theory can certainly be used to address in general terms how the principal and agents respectively view different policy instruments and respond to them. Yet aside from this, not a lot has been written from a theoretical perspective about specific R&D policy instruments.

5.2. Empirical evidence

The literature search reveals numerous assessments of R&D policy instruments (particularly more recent ones) but most focus on just a single type of policy instrument, which means that the existing literature is inevitably rather fragmentary.

For example, Himanen et al. (2009) have analysed and compared the effect of policy instruments based on university research assessment and performance-related funding. They found there is no simple relationship between competitive funding schemes and research performance, while more traditional state steering models emphasising university autonomy appear to be more beneficial to research performance. Jacob and Meek (2013) focused on policy instruments aimed at promoting scientific mobility and engaging in international research networks. They argued that scientific mobility, while indispensable for building capacity and integrating into international research networks and thus helping countries with modest scientific resources to leverage themselves into a more advantageous position, could be a mixed blessing because scientists (as with any scarce resource) tend to cluster towards the centre.

Another familiar policy instrument is the funding of science and technology institutes. Barge-Gil and Modrego-Rico (2008) addressed the issue of whether technology institutes are a satisfactory tool for encouraging innovativeness in firms. Based on a study of Spanish technology institutes, they concluded that these institutes "are helping to reduce market failures in the area of technology and to foster relationships among innovation-system actors" (Barge-Gil and Modrego-Rico 2008, 808); in other words, they are having a positive impact both from a neoclassical viewpoint and from an evolutionary perspective. Moreover, while they found clear differences between different regions, these reflected the characteristics of the respective regional innovation systems (Barge-Gil and Modrego-Rico 2008, 821).

As the evolutionary perspective and the notion of innovation systems have grown in influence, so many assessments have focused on policy instruments relating to R&D collaboration. For example, Sá and Litwin (2011) analysed the range of policy instruments used by the Canadian Federal Government to stimulate university-industry research linkages. They found a significant diversification in the policy mix during the previous 10–15 years, providing incentives to various forms of university–industry interaction. However, the growing emphasis on policy tools to stimulate the commercialisation of university research was not without drawbacks, especially where the mode of technology transfer associated with biotechnology had been foisted on other sectors such as ICT, where innovation practices are quite different. Moreover, the "emphasis on producing short-term commercial outcomes steers university research towards near-term applications, and may not necessarily lead to deep relationships between universities and firms or to building capacity in the firms" (Sá and Litwin 2011, 432). One particular policy instrument to encourage and facilitate university–industry R&D collaboration is the establishment of science parks. Squicciarini (2008), in a comparison of Finnish firms located within science parks and those outside, showed that the former exhibit relatively better performance in terms of innovative output, at least as reflected in patenting. However, as Brown (2016, this issue) rightly warns, those responsible for designing policy instruments relating to universities and spillovers from their activities need to beware the danger of exaggerating the potential for research commercialisation, not least because of "the substantive disconnect between universities and the local entrepreneurial ecosystem".

Matt, Robin, and Wolff (2012), in contrast, focused on policy instruments aiming to stimulate inter-firm R&D collaboration as a means to encourage access to new resources and to innovate. They compared R&D collaborations funded by the European Union with those that were non-sponsored and arose spontaneously. They found the former tended to be more exploratory and focused on peripheral competences, while the latter were more flexible.

Moreover, since "there is no major difference between the different types of EU-sponsored collaborations, … [this suggests the need] for a simplification of these policy instruments" (Matt, Robin, and Wolff 2012, 885). (A review of the impact and effectiveness of policy instruments aimed at supporting collaboration for R&D and innovation can be found in the NESTA report by Cunningham and Gök 2012).

With the rise in importance attached to innovation systems (discussed further in Section 6.1 below) has also come increased emphasis on policies to encourage the development of networks and clusters, in particular to strengthen sectoral and regional innovation systems. For example, Cooke (2004a) showed how in life sciences the decline in R&D effort by large corporations has been "accompanied by the rise of specialist research firms … along with university and other research labs in proximity to which knowledge-intensive firms increasingly cluster" (Cooke 2004a, 1113). He argued that this growing emphasis on clusters in the knowledge economy pointed to the need for much stronger *regional* science policy, outlining a number of "new regional science policy instruments … that move beyond mere innovation support" (ibid.). (For a review of the effects of cluster-based policy instruments, see Uyarra and Ramlogan (2012), while network-based policies are reviewed in another NESTA report by Cunningham and Ramlogan (2012).)

One of the more traditional R&D policy tools consists of R&D subsidies to firms, a policy instrument much studied by economists. There has been fierce debate as to whether public R&D funding tends to "crowd out" private funding or whether it encourages the investment of additional private funds. The literature is far too great to summarise here so instead the reader is referred to the authoritative review by David, Hall, and Toole (2000), which concluded that the findings from the literature are ambiguous as to whether public funding is a substitute for, or a complement to, private R&D funding (see also the review in Klette, Møen, and Griliches 2000). However, since then, several studies have appeared concluding that there is no evidence of a "crowding out" effect and some evidence that, without public funds, firms would have invested significantly less of their own funds in R&D (e.g. Aerts and Schmidt 2008; González and Pazó 2008; Hussinger 2008; Clausen 2009; Czarnitzki and Bento 2012). Engel, Rothgang, and Eckl (2016, this issue) assess the effects of a particular German scheme to provide project funding to firms, showing that repeated participation in such projects leads to increased R&D expenditure by those firms, especially if those projects involve collaboration with other firms. (Cunningham, Laredo, and Gök 2013a) review the impact of policy instruments based on the direct support of R&D and innovation in firms.)

Another R&D policy instrument to have received much attention from economists is that of tax credits. The influential review by Hall and Van Reenen (2000) concluded that "a dollar in tax credit for R&D stimulates a dollar of additional R&D" (Hall and Van Reenen 2000, 449). Subsequently, Bloom, Griffith, and Van Reenen (2002) confirmed that:

> tax incentives are effective in increasing R&D intensity. … We estimate that a 10% fall in the cost of R&D stimulates just over a 1% rise in the level of R&D in the short-run, and just under a 10% rise in R&D in the long-run. (Bloom, Griffith, and Van Reenen 2002, 1)

A recent study of federal and provincial R&D tax credit programmes in Canada demonstrated that recipients of these credits achieved much better scores on most innovation performance indicators (Czarnitzki, Hanel, and Rosa 2011). Similarly, at the level of US state governments, Wu (2005) found that state R&D tax credit schemes were effective in stimulating industrial R&D expenditure. However, in economically disadvantaged regions the level of R&D tax credit may have to be substantially higher (Harris, Li, and Trainor

2009). (For a recent review of the impact and effectiveness of fiscal incentives for R&D, see the NESTA report by Köhler, Laredo, and Rammer (2012).)

A more recent R&D policy instrument is technology foresight, and the effectiveness of this is less well studied. However, Warnke and Heimeriks (2008) have identified four different modes of policy support that technology foresight may deliver, namely fostering innovation capability, orienting innovation towards societal needs, aiding in the agenda-setting process and providing anticipatory intelligence as the basis for decision-making. (Harper (2013) provides a review of the impact of foresight policy initiatives.)

Another comparatively recent R&D policy instrument is public engagement, especially for areas of science or technology where the public might be particularly sensitive and hence it is essential to obtain their views. Laurent (2011), for example, examines three forms of public engagement used in connection with nanotechnology in France, including their effectiveness in gaining the trust of the public and in generating inputs for public decision-making.

Within the European Union, a specific R&D policy instrument is the open method of coordination introduced after 2000 to encourage Member States to move towards the Lisbon Strategy targets. This has been subject to an assessment by Borrás, Chaminade and Edquist (2009), which concluded that "considerable achievements can be noted even though it has only been in place for 5 years", although several aspects need to be strengthened in order to exploit the full potential of this new policy instrument (Borrás, Chaminade and Edquist 2009, 3).

From this review, it is apparent that, while some policy instruments have been extensively studied, other more traditional ones instead seem to be taken for granted (e.g. individual research project grants, the dual-support system for university research) or at least are not subject to rigorous study. (Note there is a possible methodological problem here – if the term "policy instrument" was not used in a study, then it has not been "captured" in this review.) In addition, most studies of R&D policy instruments have focussed on a single instrument. There are a few comparisons of pairs of related policy instruments (e.g. Guellec and Van Pottelsbergue De La Potterie 2001; Pastor and Sandonís 2002; Petrakis and Poyago-Theotoky 2002; Czarnitzki, Ebersberger, and Fier 2007; Takalo, Tanayama, and Toivanen 2010; Guerzoni and Raiteri 2012). However, there is much less by way of systematic comparison and assessment of the full range of existing R&D policy instruments, the exceptions being Arnold and Boekholt (2002), Boekholt et al. (2001) and Takalo (2009). In addition, there are assessments focussing on a specific field or sector (e.g. Rip and Nederhof 1986; Bressers 1988; Parry 1995, 2003; Carew 2005; Shapira and Wang 2007; Fier and Heneric 2009; Mansikkasalo and Söderholm 2012) or a specific country or region (Larsen 2000; Kuhlmann 2003; Sanz-Menéndez and Cruz-Castro 2005; Högselius 2008; Persson 2008; Sandhu and Anghel 2010), but with these it is less clear how far one can generalise from that particular case.

There seems to be little literature on policy choice and policy mix with regard to R&D policy. One exception is Borrás (2009), who discussed how:

> The introduction of new and more sophisticated policy instruments (deepening) has been accompanied by an expansion of the realm of action for innovation policy (widening) … [raising] questions about the conditions under which innovation policy contributes to an effective governance of the innovation system. (Borrás 2009, 1)

Subsequently, Borrás and Edquist (2013) examined criteria used in the selection and design of innovation policy instruments, and how these are combined into "policy mixes" that address the specific problems of a particular innovation system. The issue of policy mixes for innovation has also been considered by Flanagan, Uyarra, and Laranja (2011), to which we return in Section 7. (For a recent review of policy mix and instrument interaction, see Cunningham et al. (2013b), although this focuses more broadly on innovation policy rather than R&D policy.)

6. Challenges for R&D policy instruments

Four main developments over recent decades have made the choice of appropriate policy instruments and optimum design mixes far more complicated for R&D policy (and, in two of the four cases, for public policy more generally).

6.1. From linear to systemic thinking about R&D and innovation

Over the last 40 years, there have been significant improvements in our understanding of the nature of science, technology and innovation and their interrelationships (Landry and Varone 2005, 116). Of particular significance is the shift from linear to systemic approaches, which has brought about the development of a more interactive process between policy learning and innovation theory (Mytelka and Smith 2002). (Systemic technology policies are discussed by Crespi and Quatraro (2013) and other papers in that special issue of *Technological Forecasting & Social Change*.)

Elements of that move to a systemic approach to innovation (see e.g. Martin 2012) include:

- the shift from a linear to a chain-link model of innovation (Kline and Rosenberg 1986);
- the development of the "resource-based view" (RBV) of the firm and in particular the notion of "absorptive capacity" (Cohen and Levinthal 1990), drawing in knowledge generated externally as well as creating it internally;
- the emergence of the concept of national systems of innovation (Freeman 1987; Lundvall 1992; Nelson 1993), and later regional and sectoral systems of innovation (SI); the policy implications of these developments have been explored by authors such as Smits and Kuhlmann (2004), Chaminade and Edquist (2005), Hekkert et al. (2007), Doern and Stoney (2009a), and Kuhlmann, Shapira, and Smits (2010), while Herstad et al. (2010) have looked more specifically at challenges posed to national innovation systems by the emergence of globally distributed knowledge networks and open innovation;
- a shift in focus from market failure to systemic failure, bringing a changed rationale for public intervention (see e.g. Edquist 2001, 2011; Braun 2005; Laranja, Uyarra, and Flanagan 2008; Dodgson et al. 2011; Gustafsson and Autio 2011);
- the growing emphasis on the notion of open innovation pioneered by Chesbrough (2003) (see the discussion in e.g. Herstad et al. 2010; and von Hippel and de Jong 2010);
- evolutionary approaches to innovation following pioneering work by Nelson and Winter (1982) (for a discussion of the application of evolutionary approaches to sustainable innovation policies, see Nill and Kemp 2009).

This shift from linear to systemic thinking about R&D and innovation has been reflected in a shift in policy instruments from those focusing primarily on individual R&D actors to those attempting to develop new or stronger links between the various actors, with more emphasis, for example, on policy instruments aimed at stimulating university–industry links and other forms of collaboration, and the development of networks and clusters. However as Mazzucato (2016, this issue) makes clear, there is still a long way to go in terms of moving on from policy instruments based on the crude nature of market failure to ones that fully recognise the entrepreneurial and indeed transformative potential of government policies.

6.2. From national to multi-level governance

In the early years of science or R&D policy, national governments were the dominant actor in most countries, but now the situation is more complicated. Among the important trends are:

- from government to governance – a growing number of diverse actors (including quasi- or non-government actors) are now involved in funding, organising and implementing R&D policy (Kuhlmann 2001; Kuhlmann and Edler 2003);
- globalisation (e.g. Borrás et al. 2009);
- different levels of public intervention – (sub-national) state or region, national, supra-national region (e.g. EU), and global (Shapira, Klein, and Kuhlmann 2001; Perry and May 2007; Laranja, Uyarra, and Flanagan 2008; Langfeldt et al. 2012);
- the rise of "new public management" with its demands for public accountability, e.g. in the form of performance indicators (Elzinga 2010, 2012; Doern and Stoney 2009a);
- efforts to raise the level of public engagement – there have been growing demands for greater public involvement in issues relating to science and technology, in particular where there are historical sensitivities or an element of "risk" is perceived to be involved (Jacob 2005);
- initiatives responding to "Grand Challenges" – since these are global in nature and also cross-cut other traditional boundaries (e.g. those of government ministries), R&D policy needs to be integrated within a much broader array of policies (Cagnin, Amanatidou, and Keenan 2012).

6.3. From individual researchers/teams/labs/firms to collaborations and networks

For several decades, research and development have been characterised by increasing collaboration and knowledge exchange across institutions, sectors (e.g. university–industry) and countries. With this has come a growing emphasis on networks, clusters and other forms of collaborative links as opposed to the previous focus of policy instruments on individual actors (whether individual researchers, research teams, laboratories, firms or other organisations) (Doern and Stoney 2009a). All of this makes policy design and the choice of policy instruments far more complicated (Aksnes, Frølich, and Slipersæter 2008).

6.4. From individual policies to policy mixes

Over the years, R&D policy instruments have mostly tended to be developed and implemented on an individual basis (Edler 2009, 27), although there have been a few recent cases where two policy instruments may have been combined (e.g. R&D funding and cluster policy in Germany). Yet, each new policy instrument will clearly interact with and affect existing policy instruments in a complex and often unpredictable manner. There is an analogy here with prescription drugs when used in combination (as they often are with elderly patients). Each time a new medical problem is diagnosed, the doctor will prescribe a drug for that particular ailment. For many elderly patients, they may be on half a dozen different drugs for various medical problems. Those drugs interact with one another and with the underlying medical conditions in a highly complex manner. Consequently, while each drug may represent the best treatment for the specific condition for which it was originally prescribed, the overall "drug mix" may be far from optimum, with a drug for one medical problem specifically counteracting the effect of a drug aimed at treating another.

Likewise, as policy instruments have accumulated over the years in a series of initiatives launched (e.g. by successive government ministers) to promote a given aspect of R&D, so one particular policy instrument may be counteracting the effect of another. (Moreover, adding to the complexity is that, just as each individual reacts differently to a given drug, so each actor in a research system will react differently to a given policy instrument.) Clearly we need to know more about how different R&D policy instruments interact before introducing yet another policy initiative and its associated policy instrument(s). Periodic evaluations of existing policy instruments (like those carried out by OECD or for the EU) are thus essential to see how these should be modified, with some perhaps being dropped, in order to move towards a more optimum policy mix. To achieve this, there needs to be adequate coordination, coherence and consistency among the various policy instruments (Kaiser and Kripp 2010, 13).

This points to another issue of growing importance. Over time, such coordination costs have increased (Kaiser and Kripp 2010, 16). During the last 40–50 years, most nations have moved from a few simple policy instruments to a much larger number of more complicated policy instruments. Recently, the process has accelerated following the recognition that "one size fits all" policy approaches represent too blunt an instrument, and instead what are required are specific policies tailored to the needs and characteristics of different actors and sectors in order to ensure greater effectiveness (Branscomb and Florida 1998). This further adds to the range and complexity of policy instruments in operation at any one time, making the interactions between them more complex, and the effort and costs involved in coordinating them far greater.

Further complicating the situation is the dynamic nature of the interaction between policy instruments and the actors and environment on which they operate. If a policy is effective, by definition it brings about some change in those actors, their behaviour, and their interactions among themselves and with their wider environment. Hence, the "same" policy is operating on a somewhat different configuration of actors and interactions today compared with last month or last year. Just as Heraclitus noted that "No man ever steps in the same river twice", so no policy instrument operates on the same actors twice.

Besides adopting a range of coordinated R&D policy instruments, there is also a need for R&D policies to be integrated not just with closely connected areas such as HE policy

and innovation policy but also with policies for other sectors, including industrial and economic policy, health policy, environment policy, and defence or security policy. In particular, integration with regional policy has become much more important (Cooke 2004 a,b; Tödtling and Trippl 2005). In short, what is required is not just an optimum mix of R&D policy instruments but an optimum mix of a much broader range of policy instruments.

7. Research agenda

7.1. Expanded literature review

Where do we go from here? One obvious step is to expand this exploratory literature review to include official reports and other "grey literature", although many such studies may have been done on ad hoc basis, making it difficult to compare and synthesise the findings. Another possibility is to extend the search to studies that evidently deal with R&D "policy instruments" even though they do not make use of that specific term. It would also be worth looking at the NSF "Science of Science Policy" Programme and the studies it funded to see what has emerged with respect to policy instruments.

7.2. Development of a rigorous conceptual framework

In our efforts to develop a systematic conceptual framework for analysing R&D policy instruments, one essential step is to link this research more systematically to several, currently rather separate, bodies of work. One is the policy design literature discussed in Section 4. The challenge here is that much policy design work has tended to be rather general, while what literature there on R&D policy instruments is mostly very specific. A key issue is the context in which a particular R&D policy instrument is used, which can vary significantly, not least because of the interactions with other policy instruments. Moreover, the use of different evaluation methods can result in rather different assessments of the impact and effectiveness of that policy instrument. Hence, the taxonomies and other conceptual tools developed in policy design may need to be substantially adapted for use in the area of R&D policy.

As noted above, there have been only a few attempts to link policy design to R&D policy, mainly by researchers in Canada. For example, Landry and Varone (2005) showed how the shift in rationale for government intervention from "market failure" has implications for the choice of policy instruments with respect to (i) the unit of analysis (from individual actors to collaboration and networks), (ii) the intended target (from R&D funding to skills and knowledge exchange) and (iii) the key actors (from individual firms to firms in a cluster, region or sector). Doern and Stoney (2009a) also tried to bridge the gap, applying the concepts and analytical frameworks of policy design to policies aimed at strengthening innovation systems. Similarly, Henriques and Larédo (2013) have drawn upon the policy design framework with its five main stages in the policy cycle to help analyse the historical evolution of science policy.

A second link that would benefit from further development is that with the multi-level governance literature (e.g. Hooghe and Marks 2003; Bache and Flinders 2004). Some preliminary attempts have been made (e.g. in the PRIME Network of Excellence during the early 2000s), but there is considerable potential to extend and deepen these links.

A third initiative would be to link with the broader literature on "policy mix". Flanagan, Uyarra, and Laranja (2011) have made a promising start, attempting to develop "a more sophisticated, multi-actor, multi-level and dynamic understanding of the processes by which policies … emerge, interact and have effects" (Flanagan, Uyarra, and Laranja 2011, 702). They trace the notion of "policy mix" back to its origins in economic policy debates in the 1960s, and examine its transfer to innovation policy starting in the 1990s and more prominently in the following decade, particularly in discussions of evolving EU policy (ibid., 703). They link this with a recognition of the need for a more systemic approach to policy, and of the dispersal of power from national governments both upwards to supranational actors and downwards to sub-national actors as well as outwards to quasi-state and non-state actors. They argue that the conceptual framework set forward by Bressers and O'Toole (2005) based around different forms of influence offers a promising basis for analysing innovation policy instrument interactions (including the underlying tensions between instruments and their respective rationales, goals and methods). This analysis provides a fruitful starting point for future work on R&D policy instruments.

Fourthly, work on R&D policy instruments needs to be more closely linked to the literature on evolutionary systems/policy, building on efforts such as those by Metcalfe (1994), who argued that policies should stimulate diversity in the innovative efforts of firms, and more recently by Groenegen and van der Steen (2007, 351) with their emphasis on government being "a learning actor". In an ever more complex world, where the interactions between policy instruments and actors are becoming more difficult to understand, let alone predict, what is needed is a more experimental and evolutionary approach to policy and policy instruments, monitoring to see which ones "work" and encouraging "the survival of the fittest". Flanagan and Uyarra (2016, this issue) highlight various dangers in current approaches to innovation policy studies and suggest how these might be overcome, in particular through adopting a genuinely evolutionary approach to R&D and innovation policy.

7.3. Further empirical investigations

From this literature review, it is clear that more systematic research is required not only on the full range of R&D policy instruments currently deployed but also to derive "policy intelligence" on how they interact with one another (Nauwelaers and Wintjes 2002). This includes analysing the unintended consequences of R&D policy instruments, not least as a consequence of their interactions with other related policies such as regional or entrepreneurship policies. Moreover, there is a danger here, as Flanagan and Uyarra (2016, this issue) note, of viewing policy instruments as coherent rational choices rather than contested outcomes (or even muddles) mediated by a range of "involved" policy entrepreneurs and other actors, and influenced by such factors as path-dependency, fads and agency "turf wars".

A first step would be to develop a systematic inventory of R&D policy instruments. Attempts can then be made to classify these, perhaps using a development of the Hood/Howlett taxonomy described above. This is likely to require collaboration between policy design researchers and R&D policy researchers, helping to identify gaps where future research might be fruitfully targeted. Once this groundwork has been laid, efforts can then focus on more empirical studies of appropriate R&D "policy mixes" for different research and innovation systems.

In the case of the broader field of innovation policy, a promising start has been made in this respect in the NESTA project entitled "Compendium of Evidence on the Effectiveness of Innovation Policy Intervention Project". In this, researchers from Manchester University and elsewhere have produced 18 reports on different innovation policy instruments and one on policy mix and instrument interaction, several of which (those more specific to R&D policy) have been cited above. (The full set of reports can be found at http://www.innovation-policy.org.uk/compendium/ .) The synthesis report (Edler et al. 2013) sets out a typology of innovation policy instruments, distinguishing supply-side from demand-side instruments, and classifying instruments on the basis of seven innovation goals (e.g. increasing R&D investment, augmenting skills, strengthening system-wide capabilities). The final results of this project are due to be published shortly (Edler et al. forthcoming).

7.4. Development of a stronger evidence base for the design of policy

By drawing upon the above building blocks, we may begin to generate a conceptual and empirical framework for arriving at more evidence-based and effective R&D policies, with a suitable mix of policy instruments (Yawson 2009). This includes education and mechanisms for the diffusion of knowledge on R&D policy instruments to those involved in the implementation of policy. A key element is the further development of processes of policy learning (often based on evaluation of policies and policy instruments, as carried out by OECD or EU consultants, for example). As Flanagan, Uyarra, and Laranja (2011, 711) note, "We need to move towards substantial empirical innovation policy histories akin to the innovation histories which provided most of our understanding of the innovation process. This means not just histories of individual instruments … but histories of policy mixes" (ibid.).

8. Conclusions

In this critical review, I have first shown how the notion of R&D policy instruments needs to be set in the context of literature on policy design, with its well-established definitions, taxonomies and conceptual frameworks. Many who have written about R&D policy instruments in various forms appear to be ignorant of this established research field. Closer links with the policy studies community would undoubtedly benefit future research on R&D policy instruments.

Secondly, I have reviewed the rather fragmentary literature on R&D policy instruments, showing that most studies tend to focus on a single policy instrument. There are few systematic comparisons of different R&D policy instruments, and even fewer on their interactions and what makes for an effective "policy mix". This is an obvious subject for future research.

Thirdly, I have discussed how research on R&D policy instruments needs to take account of four major transitions – from linear to systemic thinking about R&D and innovation, from national to multi-level governance, from individual researchers/teams/labs/firms to collaborations and networks, and from individual policies to policy mixes. While a start on analysing these has been made, much more remains to be done.

Lastly, I have attempted to draw all this together and map out a research agenda for future work on R&D policy instruments. This will require forging closer links with policy design and multi-level governance scholars, with others who have been central in developing the notion of policy mixes, and with researchers in related areas of public policy including

industrial and economic policy, environment policy, health policy and regional policy. In addition, more empirical work is required on the full range of R&D policy instruments and on how they interact with one another. Such efforts are urgently needed if R&D policy researchers are to achieve the goal of creating a conceptual and empirical framework for arriving at more evidence-based and effective R&D policies, employing an appropriate mix of policy instruments.

Acknowledgements

An earlier version was presented at the 3rd Lundvall Symposium on "Innovation Policy – Can It Make a Difference?", held at Aalborg in March 2014. The author is grateful to participants at that symposium, and especially to Kieron Flanagan, Michael Rothgang, two anonymous reviewers and the editors of this special issue for their constructive comments and suggestions.

Disclosure statement

No potential conflict of interest was reported by the author.

References

Aerts, K., and T. Schmidt. 2008. "Two for the Price of One?" *Research Policy* 37: 806–822.

Aksnes, D. W., N. Frølich, and S. Slipersæter. 2008. "Science Policy and the Driving Forces behind the Internationalisation of Science: The Case of Norway." *Science and Public Policy* 35: 445–457.

Arnold, E., and P. Boekholt. 2002. *Measuring 'Relative Effectiveness'– Can We Compare Innovation Policy Instruments?" Six Countries Programme Conference on "Innovation Policy and Sustainable Development: Can Public Innovation Incentives Make a Difference?* Brussels, 28 February–1 March, 2002. http://www.6cp.net/downloads/02brussels_arnold_boekholt_paper.doc

Bache, I., and M. Flinders, eds. 2004. *Multi-Level Governance*. Oxford: Oxford University Press.

Barge-Gil, A., and A. Modrego-Rico. 2008. "Are Technology Institutes a Satisfactory Tool for Public Intervention in the Area of Technology? A Neoclassical and Evolutionary Evaluation." *Environment and Planning C: Government and Policy* 26: 808–823.

Bloom, N., R. Griffith, and J. Van Reenen. 2002. "Do R&D Tax Credits Work? Evidence from a Panel of Countries 1979–1997." *Journal of Public Economics* 85: 1–31.

Boekholt, P., M. Lankhuizen, E. Arnold, J.Clarke, J. Kuusisto, B. de Laat, P. Simmonds, S. Cozzens, G. Kingsley, and R. Johnston. 2001. *An International Review of Methods to Measure Relative Effectiveness of Technology Policy Instruments*. Final report to the Dutch Ministry of Economic Affairs EZ, Technopolis, Brighton. http://www.technopolis-group.com/resources/downloads/reports/261_EZ_Final_010723.pdf

Borrás, S. 2009. "The Widening and Deepening of Innovation Policy: What Conditions Provide for Effective Governance?" *CIRCLE Working Paper* 2009/02 http://www4.lu.se/upload/CIRCLE/workingpapers/200902_Borras.pdf

Borrás, S., C. Chaminade, and C. Edquist. 2009. "The Challenges of Globalization: Strategic Choices for Innovation Policy." In *The Innovation Imperative: National Innovation Strategies in the Global Economy*, edited by G. Marklund, N. S. Vonortas, and C. W. Wessner, 7–23. Cheltenham: Elgar.

Borrás, S., and C. Edquist. 2013. "The Choice of Innovation Policy Instruments." *Technological Forecasting & Social Change* 80: 1513–1522.

Borrás, S., G. León, M. Bucar, J. Edler, K. Halme, A. Havas, S. Kuhlmann, et al. 2009. *The Open Method of Coordination in Research Policy: Assessment and Recommendations*. Brussels: European Commission, EUR 23874. http://www.eurosfaire.prd.fr/7pc/doc/1255593891_omc_coordination_2009.pdf

Branscomb, L. M., and R. Florida. 1998. "Challenges to Technology Policy." In *Investing in Innovation: Creating a Research and Innovation Policy That Works*, edited by L. M. Branscomb and J. H. Keller, 3–39. Cambridge: MIT Press.

Braun, D. 2005. "How to Govern Research in the 'Age of Innovation': Compatibilities and Incompatibilities of Policy Rationales." In *New Governance Arrangements in Science Policy*, edited by M. Lengwiler, and D. Simon. Berlin: WZB. http://bibliothek.wzb.eu/pdf/2005/p05-101.pdf

Bressers, H Th A. 1988. "A Comparison of the Effectiveness of Incentives and Directives: The Case of Dutch Water Quality Policy." *Review of Policy Research* 7: 500–518. http://doc.utwente.nl/70846/1/Bressers88comparison.pdf

Bressers, H. A., and L. J. O'Toole. 2005. "Instrument Selection and Implementation in a Networked Context." In *Designing Government: From Instruments to Governance*, edited by Eliadis, P., M. M. Hill, and M. Howlett, 132–153. Montreal: McGill-Queen's University Press.

Brown, R. 2016. "Mission Impossible? Entrepreneurial Universities in Peripheral Regional Innovative Systems." *Industry and Innovation* (this issue).

Cagnin, C., E. Amanatidou, and M. Keenan. 2012. "Orienting European Innovation Systems towards Grand Challenges and the Roles That FTA Can Play." *Science and Public Policy* 39: 140–152.

Carew, R. 2005. "Science Policy and Agricultural Biotechnology in Canada." *Review of Agricultural Economics* 27: 300–316.

Chaminade, C., and C. Edquist. 2005. "From Theory to Practice: The Use of Systems of Innovation Approach in Innovation Policy." *CIRCLE Working Paper* 2005/02 http://www4.lu.se/upload/CIRCLE/workingpapers/200502_Chaminade_Edquist.pdf.

Chesbrough, H. W. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Clausen, T. 2009. "Do Subsidies Have Positive Impacts on R&D and Innovation Activities at the Firm Level?" *Structural Change and Economic Dynamics* 20: 239–253.

Cohen, W. M., and D. A. Levinthal. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35: 128–152.

Cooke, P. 2004a. "Life Sciences Clusters and Regional Science Policy." *Urban Studies* 41: 1113–1131.

Cooke, P. 2004b. "Biosciences and the Rise of Regional Science Policy." *Science and Public Policy* 31: 185–197.

Crespi, F., and F. Quatraro. 2013. "Systemic Technology Policies: Issues and Instruments." *Technological Forecasting & Social Change* 80: 1447–1449.

Cunningham, P., J.Edler, K.Flanagan, and P.Laredo. 2013b. "Innovation Policy Mix and Instrument Interaction: A Review." *NESTA Working Paper* 13 (20). London: NESTA.

Cunningham, P., and A.Gök. 2012. "The Impact and Effectiveness of Policies to Support Collaboration for R&D and Innovation." *NESTA Working Paper* 12 (06). London: NESTA.

Cunningham, P., P. Laredo, and A. Gök. 2013a. "The Impact of Direct Support to R&D and Innovation in Firms." *NESTA Working Paper* 13 (03). London: NESTA.

Cunningham, P., and R. Ramlogan. 2012. "The Effects of Innovation Network Policies." *NESTA Working Paper* 12 (04). London: NESTA.

Czarnitzki, D., B. Ebersberger, and A. Fier. 2007. "The Relationship between R&D Collaboration, Subsidies and R&D Performance: Empirical Evidence from Finland and Germany." *Journal of Applied Econometrics* 22: 1347–1366.

Czarnitzki, D., P. Hanel, and J. M. Rosa. 2011. "Evaluating the Impact of R&D Tax Credits on Innovation: A Microeconometric Study on Canadian Firms." *Research Policy* 40: 217–229.

Czarnitzki, D., and C. L. Bento. 2012. "Evaluation of Public R&D Policies: A Cross-Country Comparison." *World Review of Science, Technology and Sustainable Development* 9: 254–282.

David, P. A., B. H. Hall, and A. A. Toole. 2000. "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence." *Research Policy* 29: 497–529.

Dodgson, M., A. Hughes, J. Foster, and S. Metcalfe. 2011. "Systems Thinking, Market Failure, and the Development of Innovation Policy: The Case of Australia." *Research Policy* 40: 1145–1156.

Doern, G. B., and C. Stoney. 2009a. "Federal Research and Innovation Policies and Canadian Universities: A Framework for Analysis." In *Research and Innovation Policy: Changing Federal*

Government-University Relations, edited by G. B. Doern and C. Stoney, 3–34. Toronto: University of Toronto Press.
Doern, G. B., and C. Stoney, eds. 2009b. *Research and Innovation Policy: Changing Federal Government-University Relations*. Toronto: University of Toronto Press.
Edler, J. 2009. "Demand Policies for Innovation in EU CEE Countries." *Manchester Business School Working Paper* 579 http://www.mbsportal.bl.uk/secure/subjareas/techinnov/mubs/wp/114396WP579_09.pdf.
Edler, J., and L Georghiou 2007. "Public Procurement and Innovation—Resurrecting the Demand Side." *Research Policy*: 949–963.
Edler, J., M. Berger, M. Dinges, and A. Gök. 2012. "The Practice of Evaluation in Innovation Policy in Europe." *Research Evaluation* 21: 167–182.
Edler, J., P. Cunningham, A. Gök, and P. Shapira. 2013. "Impacts of Innovation Policy: Synthesis and Conclusion." *NESTA Working Paper* 13 (21). London: NESTA.
Edler, J., P. Cunningham, A. Gök, and P. Shapira. Forthcoming. *Handbook of Innovation Policy Impact*. Cheltenham: Edward Elgar. July 2016. http://www.e-elgar.com/shop/handbook-of-innovation-policy-impact
Edquist, C. 2001. "The Systems of Innovation Approach and Innovation Policy: An Account of the State of the Art." Paper presented at The DRUID Conference, Aalborg, 12–15 June 2001 http://www.druid.dk/uploads/tx_picturedb/ds2001-178.pdf
Edquist, C. 2011. "Design of Innovation Policy through Diagnostic Analysis: Identification of Systemic Problems (or Failures)." *Industrial and Corporate Change* 20: 1725–1753.
Edquist, C., and L. Hommen. 1999. "Systems of Innovation: Theory and Policy for the Demand Side." *Technology in Society* 21: 63–79.
Eliadis, P., M. M. Hill, and M. Howlett, eds. 2005. *Designing Government: From Instruments to Governance*. Montreal: McGill-Queen's University Press.
Elzinga, A. 2010. "New Public Management, Science Policy and the Orchestration of University Research—Academic Science the Loser." *The Journal for Transdisciplinary Research in Southern Africa* 6: 307–332.
Elzinga, A. 2012. "Features of the Current Science Policy Regime: Viewed in Historical Perspective." *Science and Public Policy* 39: 416–428.
Engel, D., M. Rothgang, and V. Eckl. 2016. "Systemic Aspects of R&D Policy Subsidies for R&D Collaborations and Their Effects on Private R&D." *Industry and Innovation* (this issue).
EPUB. 2002. *RTD Evaluation Toolbox*. Report of EPUB the thematic network on the socio-economic evaluation of public RTD policies prepared by the Institute for Prospective Technological Studies of the Joint Research Centre, and the Institute of Technology and regional Policy, Joanneum Research.
Fier, A., and O. Heneric. 2009. "Public R&D Policy: The Right Turns of the Wrong Screw? The Case of the German Biotechnology Industry." *International Studies in Entrepreneurship* 19: 147–168.
Flanagan, K., E. Uyarra, and M. Laranja. 2011. "Reconceptualising the 'Policy Mix' for Innovation." *Research Policy* 40: 702–713.
Flanagan, K., and E. Uyarra. 2016. "Four Dangers in Innovation Policy Studies—And How to Avoid Them." *Industry and Innovation* (this issue).
Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.
Georghiou, L., J. Edler, E. Uyarra, and J. Yeow. 2014. "Policy Instruments for Public Procurement of Innovation: Choice, Design and Assessment." *Technological Forecasting & Social Change* 86: 1–12.
González, X., and C. Pazó. 2008. "Do Public Subsidies Stimulate Private R&D Spending?" *Research Policy* 37: 371–389.
Groenewegen, J., and M. van der Steen. 2007. "The Evolutionary Policy Maker." *Journal of Economic Issues* 41: 351–358.
Guellec, D., and B. Van Pottelsbergue De La Potterie. 2001. "The Effectiveness of Public Policies in R&D." Revue d'Économie Industrielle 94: 49–68.
Guerzoni, M., and E.Raiteri. 2012. "Innovative Public Procurement and R&D Subsidies: Hidden Treatment and New Empirical Evidence on the Technology Policy Mix in a Quasi-Experimental Setting." Dipartimento di Economia "S. Cognetti de Martiis" Università di Torino,

Working paper 18/2012. http://www.unito.it/unitoWAR/ShowBinary/FSRepo/D031/Allegati/WP2012Dip_L%26B/18_WP_Momigliano.pdf.
Gustafsson, R., and E. Autio. 2011. "A Failure Trichotomy in Knowledge Exploration and Exploitation." *Research Policy* 40: 819–831.
Guston, D. H. 1996. "Principal-Agent Theory and the Structure of Science Policy." *Science and Public Policy* 23: 229–240.
Hall, B., and J. Van Reenen. 2000. "How Effective Are Fiscal Incentives for R&D? A Review of the Evidence." *Research Policy* 29: 449–469.
Harper, J. C. 2013. "Impact of Technology Foresight." *NESTA Working Paper* 13 (16). London: NESTA.
Harris, R., Q. C. Li, and M. Trainor. 2009. "Is a Higher Rate of R&D Tax Credit a Panacea for Low Levels of R&D in Disadvantaged Regions?" *Research Policy* 38: 192–205.
Hekkert, M. P., R. A. A. Suurs, S. O. Negro, S. Kuhlmann, and R. E. H. M. Smits. 2007. "Functions of Innovation Systems: A New Approach for Analysing Technological Change." *Technological Forecasting & Social Change* 74: 413–432.
Henriques, L., and P. Larédo. 2013. "Policy-Making in Science Policy: The 'OECD Model' Unveiled." *Research Policy* 42: 801–816.
Herstad, S. J., C. Bloch, B. Ebersberger, and E. van de Velde. 2010. "National Innovation Policy and Global Open Innovation: Exploring Balances, Tradeoffs and Complementarities." *Science and Public Policy* 37: 113–124.
Himanen, L., O. Auranen, H. M. Puuska, and M. Nieminen. 2009. "Influence of Research Funding and Science Policy on University Research Performance: A Comparison of Five Countries." *Science and Public Policy* 36: 419–430.
Högselius, P. 2008. "Lost in Translation? Science, Technology and the State since the 1970s." *CESIS Electronic Working Paper 119*. http://www.kth.se/dokument/itm/cesis/CESISWP119.pdf.
Hood, C. 1983. "Using Bureaucracy Sparingly." *Public Administration* 61: 197–208.
Hood, C. 1986. *The Tools of Government*. London: Chatham House.
Hooghe, L., and G. Marks. 2003. *Multi-Level Governance and European Integration*. Lanham, Maryland: Rowman & Littlefield.
Howlett, M. 2011. *Designing Public Policies: Principles and Instruments*. London: Routledge.
Howlett, M., and J. Rayner. 2007. "Design Principles for Policy Mixes: Cohesion and Coherence in "New Governance Arrangements"." *Policy and Society* 26 (4): 1–18.
Hussinger, K. 2008. "R&D and Subsidies at the Firm Level: An Application of Parametric and Semiparametric Two-Step Selection Models." *Journal of Applied Econometrics* 23: 729–747.
Jacob, M. 2005. "Boundary Work in Contemporary Science Policy: A Review." *Prometheus* 23: 195–207.
Jacob, M., and V. L. Meek. 2013. "Scientific Mobility and International Research Networks: Trends and Policy Tools for Promoting Research Excellence and Capacity Building." *Studies in Higher Education* 38: 331–344.
Johansson, B., C.Karlsson, and M.Backman. 2007. "Innovation Policy Instruments." *CESIS Working Paper* 105. http://www.kth.se/dokument/itm/cesis/CESISWP105.pdf.
Kaiser, R., and M. Kripp. 2010. "Demand-Orientation in National Systems of Innovation: A Critical Review of Current European Innovation Policy Concepts." Paper presented at the DRUID Summer Conference, Imperial College, 16–18 June 2010.
Klette, T. J., J. Møen, and Z. Griliches. 2000. "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconometric Evaluation Studies." *Research Policy* 29: 471–495.
Kline, S. J., and N. Rosenberg. 1986. "An Overview of Innovation." In *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, edited by R. Landau and N. Rosenberg, 275–305. Washington, DC: National Academy Press.
Köhler, C., P.Laredo, and C.Rammer. 2012. "The Impact and Effectiveness of Fiscal Incentives for R&D." *NESTA Working Paper* 12 (01). London: NESTA.
Kuhlmann, S. 2001. "Future Governance of Innovation Policy in Europe – Three Scenarios." *Research Policy* 30: 953–976.
Kuhlmann, S. 2003. "Evaluation of Research and Innovation Policies: A Discussion of Trends with Examples from Germany." *International Journal of Technology Management* 26: 131–149.

Kuhlmann, S., and J. Edler. 2003. "Scenarios of Technology and Innovation Policies in Europe: Investigating Future Governance." *Technological Forecasting & Social Change* 70: 619–637.
Kuhlmann, S., P.Shapira, and R.Smits. 2010. "Introduction. a Systemic Perspective: The Innovation Policy Dance." In *The Theory and Practice of Innovation Policy*, edited by R. E. Smits, S. Kuhlmann, and P. Shapira, 1–22. Cheltenham: Edward Elgar.
Landry, R., and F. Varone. 2005. "The Choice of Policy Instruments: Confronting the Deductive and the Interactive Approaches." In *Designing Government: From Instruments to Governance*, edited by P. Eliadis, M. M. Hill, and M. Howlett. Montreal: McGill-Queen's University Press.
Langfeldt, L., H. Godø, A. Gornitzka, and A. Kaloudis. 2012. "Integration Modes in EU Research: Centrifugality versus Coordination of National Research Policies." *Science and Public Policy* 39: 88–98.
Laranja, M., E. Uyarra, and K. Flanagan. 2008. "Policies for Science, Technology and Innovation: Translating Rationales into Regional Policies in a Multi-Level Setting." *Research Policy* 37: 823–835.
Larsen, I. M. 2000. "University Research Policy in Norway - Walking the Tightrope between Internal and External Interests." *European Journal of Education* 35: 385–402.
Laurent, B. 2011. "Technologies of Democracy: Experiments and Demonstrations." *Science and Engineering Ethics* 17: 649–666.
Lundvall, B.-Å. 1992. *National Systems of Innovation*. London: Pinter.
Mansikkasalo, A., and P. Söderholm. 2012. "Energy Efficient and Low-Carbon Technology in Process Industries: Innovation, Diffusion and the Role of Public Policy." Proceedings of the 9th International Conference on the European Energy Market EEM 2012, 10–12 May 2012. doi:10.1109/EEM.2012.6254743.
Martin, B. R. 2012. "The Evolution of Science Policy and Innovation Studies." *Research Policy* 41: 1219–1239.
Matt, M., S. Robin, and S. Wolff. 2012. "The Influence of Public Programs on Inter-Firm R&D Collaboration Strategies: Project-Level Evidence from EU FP5 and FP6." *Journal of Technology Transfer* 37: 885–916.
Mazzucato, M. 2016. "From Market Fixing to Market-Creating: A New Framework for Innovation Policy." *Industry and Innovation* (this issue).
Metcalfe, J. S. 1994. "Evolutionary Economics and Technology Policy." *The Economic Journal* 104: 931–944.
Mytelka, L. K., and K. Smith. 2002. "Policy Learning and Innovation Theory: An Interactive and Co-Evolving Process." *Research Policy* 31: 1467–1479.
Nauwelaers, C., and R. Wintjes. 2002. "Innovating SMEs and Regions: The Need for Policy Intelligence and Interactive Policies." *Technology Analysis & Strategic Management* 14: 201–215.
Nelson, R. R., ed. 1993. *National Innovation Systems*. Oxford: Oxford University Press.
Nelson, R. R., and S. W. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard University Press.
Nill, J., and R. Kemp. 2009. "Evolutionary Approaches for Sustainable Innovation Policies: From Niche to Paradigm?" *Research Policy* 38: 668–680.
Papaconstantinou, G., and W. Polt. 1997. "Policy Evaluation in Innovation and Technology: An Overview". In *Policy Evaluation in Innovation and Technology: Towards Best Practices*. Paris: OECD. http://www.oecd.org/sti/inno/1907871.pdf
Parry, I. W. H. 1995. "Optimal Pollution Taxes and Endogenous Technological Progress." *Resource and Energy Economics* 17: 69–85.
Parry, I. W. H. 2003. "On the Implications of Technological Innovation for Environmental Policy." *Environment and Development Economics* 8: 57–76.
Pastor, M., and J. Sandonís. 2002. "Research Joint Ventures Vs. Cross Licensing Agreements: An Agency Approach." *International Journal of Industrial Organization* 20: 215–249.
Persson, B. 2008. "The Development of a New Swedish Innovation Policy: A Historical Institutional Approach." *CIRCLE Working Paper* 2008/02 http://www.circle.lu.se/upload/CIRCLE/workingpapers/200802_Persson.pdf.
Perry, B., and T. May. 2007. "Governance, Science Policy and Regions: An Introduction." *Regional Studies* 41: 1039–1050.

Petrakis, E., and J. Poyago-Theotoky. 2002. "R&D Subsidies versus R&D Cooperation in a Duopoly with Spillovers and Pollution." *Australian Economic Papers* 41: 37–52.
Rip, A., and A. J. Nederhof. 1986. "Between Dirigism and Laissez-Faire: Effects of Implementing the Science Policy Priority for Biotechnology in the Netherlands." *Research Policy* 15: 253–268.
Rubio, J. E., and N. Tshipamba. 2010. "Elements of the Public Policy of Science, Technology and Innovation." *Canadian Social Science* 6: 61–80.
Sá, C. M., and J. Litwin. 2011. "University–Industry Research Collaborations in Canada: The Role of Federal Policy Instruments." *Science and Public Policy* 38: 425–435.
Sandhu, S., and I. Anghel. 2010. "The Interaction of Policy-Mix Instruments Conducive to Increasing Investment in Romania." *Curentul Juridic* 42: 150–162.
Sanz-Menéndez, L., and L.Cruz-Castro. 2005. "Explaining the Science and Technology Policies of Regional Governments." *Unidad De Politicas Comparadas CSIC Working Paper* 05 (10) http://digital.csic.es/handle/10261/1644
Shapira, P., H. Klein, and S. Kuhlmann. 2001. "Innovations in European and US Innovation Policy." *Research Policy* 30: 869–872.
Shapira, P., and J. Wang. 2007. "R&D Policy in the United States: The Promotion of Nanotechnology R&D." *'Policy Mix' Working Paper* http://stip.gatech.edu/wp-content/uploads/2010/05/PM-CaseStudy_US_Nanotech_2007.pdf.
Smits, R., and S. Kuhlmann. 2004. "The Rise of Systemic Instruments in Innovation Policy." *International Journal of Foresight and Innovation Policy* 1: 4–32.
Squicciarini, M. 2008. "Science Parks' Tenants versus out-of-Park Firms: Who Innovates More? A Duration Model." *Journal of Technology Transfer* 33: 45–71.
Takalo, T. 2009. "Rationales and Instruments for Public Innovation Policies." *ETLA Working Paper* 1185 http://www.etla.fi/wp-content/uploads/2012/09/dp1185.pdf.
Takalo, T., T. Tanayama, and O. Toivanen. 2010. "Innovation Policy Reform." *Working Paper* http://www.econ.kuleuven.be/public/N10076/Takalo_Tanayama_Toivanen_050310.pdf.
Tödtling, F., and M. Trippl. 2005. "One Size Fits All?" *Research Policy* 34: 1203–1219.
Uyarra, E., and R. Ramlogan. 2012. "The Effects of Cluster Policy on Innovation." *NESTA Working Paper* 12 (05). London: NESTA.
Van der Meulen, B. 1998. "Science Policies as Principal–Agent Games." *Research Policy* 27: 397–414.
Vedung, E. 2010. "Policy Instruments: Typologies and Theories." In *Carrots, Sticks, and Sermons: Policy Instruments and Their Evaluation*, edited by M. L. Bemelmans-Videc, R. C. Rist, and E. Vedung, 21–58. New Brunswick: Transaction.
von Hippel, E., and J. P. J de Jong. 2010. "Open, Distributed and User-Centered: Towards a Paradigm Shift in Innovation Policy." *EIM Working Paper*. Zoetermeer. http://www.ondernemerschap.nl/pdf-ez/H201009.pdf.
Warnke, P., and G. Heimeriks. 2008. "Technology Foresight as Innovation Policy Instrument—Learning from Science and Technology Policy Studies." In *Future-Oriented Technology Analysis: Strategic Intelligence for an Innovative Economy*, edited by C. Cagnin, M. Keenan, R. Johnston, F. Scapolo, and R. Barré, 71–87. Berlin & Heidelberg: Springer-Verlag.
Wu, Y. 2005. "The Effects of State R&D Tax Credits in Stimulating Private R&D Expenditure: A Cross-State Empirical Analysis." *Journal of Policy Analysis and Management* 24: 785–802.
Yawson, R.M. 2009. "The Ecological System of Innovation: A New Architectural Framework for a Functional Evidence-Based Platform for Science and Innovation Policy." The Future of Innovation" Proceedings of the XXIV ISPIM 2009 Conference, Vienna, Austria, 21–24 June 2009 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1417676