Research portfolio analysis in science policy: moving from financial returns to societal benefits

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Abstract

Funding agencies and large public scientific institutions are increasingly using the term "research portfolio" as a means of characterising their research. While portfolios have long been used as a heuristic for managing corporate R&D (i.e., R&D aimed at gaining tangible economic benefits), they remain ill-defined in a science policy context where research is aimed at achieving societal outcomes. In this article we analyze the discursive uses of the term "research portfolio" and propose some general considerations for their application in science policy. We explore the use of the term in private R&D and related scholarly literature in existing science policy practices, and seek insight in relevant literature in science policy scholarship. While the financial analogy can in some instances be instructive, a simple transposition from the world of finance or of corporate R&D to public research is problematic. However, we do identify potentially fruitful uses of portfolio analysis in science policy. In particular, our review suggests that the concept of research portfolio can indeed be a useful analytical instrument for tackling complex societal challenges. Specifically, the strands of scholarship identified suggest that the use of research portfolio should: i) recognize the diversity of research lines relevant for a given societal challenge, given the uncertainty and ambiguity of research outcomes; ii) examine the relationships between research options of a portfolio and the expected societal outcomes; and iii) adopt a systemic perspective to research portfolios – i.e., examine a portfolio as a functional whole, rather than as the sum of the its parts. We argue that with these considerations, portfolio-driven approaches may foster social inclusion in science policy decisions, help deliberation between "alternative" portfolios to tackle complex societal challenges, as well as promote cost-effectiveness and transparency.

1. Introduction

Tackling complex challenges – climate change, food security, poverty reduction, the risk of global pandemics – requires not only increased expenditure on targeted R&D, but also the exploration and eventual coordination of a variety of diverse research areas. Typically societal challenges benefit from the understanding of the physical and biological phenomena underlying a challenge (e.g. the virus and its genes), but also demand an understanding of the environmental and social contexts in which they occur, and the policy networks and instruments available in those contexts (Ely et al. 2014). Recent scholarship on so-called "grand challenges" has also highlighted a need to find alternative models for funding research, administering it and connecting it to policy outcomes (Swedish Presidency of the European Union 2009; Reid et al. 2010; Mowery 2012). Recent examples include the European Joint Programming initiatives[1], which aim to tackle pressing societal issues through alignment of funding and increased collaboration across EU countries, or the research and operational funding from the Bill and Melinda Gates foundation[2]. However, it is unclear whether research efforts such as these are successful in promoting closer alignment between the stated goals or expected societal contributions and the actual outcomes, despite new rhetoric or increased stakeholder engagement.

Science policy funding schemes for complex societal problems or grand challenges seek to better align science supply with social problems or needs.[3] To do so, they have to answer the question that lies at the "neglected heart of science policy" (Sarewitz and Pielke 2007): *how should resources be distributed across various research areas (science supply) so that they address societal needs (social demand)?* In this article, we investigate the notion of research portfolio in the context of public, problem-oriented research and we explore how this concept may be helpful as an analytical tool to help address grand challenges.

For the sake of clarity, let us begin by proposing a definition of "research portfolio", to be used just as a reference while we review of the different practices and understandings associated with the term. We understand a "research portfolio" as the ensemble or subset of research activities supported by a funding agency, a large research performing organisation or a given subset of agencies/organisations. It is a heuristic and analytical tool for an organisation to contrast its missions against its *de facto* priority setting as illuminated by the portfolio analysis, i.e. the areas in which it is putting effort, investments or achieving some outcomes. In medical research, it is common to think of portfolios in terms of therapeutic areas as research options, which can then be aligned with disease burdens or market demands (Agarwal and Searls, p. 2009, p. 868). Here we propose a different approach: to explore the activities of agencies and organisations for a given grand challenge (hence a subset of their overall activity), as a means to reflect on the research options that are being supported (and think as well about those that are lacking support).

[1] http://ec.europa.eu/research/era/joint-programming-initiatives_en.html
[2] http://www.grandchallenges.org/Pages/Default.aspx
[3] Following Hicks (2014), we define grand challenges as multifaceted, multidisciplinary, large-scale and policy oriented problems with both an intellectual and practical component.

To put it in a simple image, a research portfolio is like the palette of colours of painters, with colours representing research areas, as illustrated in science visualisations.[4] A portfolio analysis tells the analyst about the distribution of research options sustained. This conceptualisation of research portfolio is analogous to that developed for energy portfolios, in which different technologies (options) can be deployed to fulfill a societal need, in this case energy production (Awerbuch 2006; Stirling 2007; Bazilian and Roque 2008).

Since the assessment of research options is inevitably influenced by subjective judgements about what are the appropriate solutions for a given problem or need, accounting for research investment in purely monetary terms is neither possible (because of huge uncertainties in the type of "impact") or desirable (because it avoids societal deliberation on the values of research outcomes), as exemplified by challenges faced in recent attempts to quantify the returns on health research (Buxton et al. 2008). The inappropriateness of purely monetary measures has lead scholars and policymakers to inquire as to other measures of "value" of public research, namely in terms of desired societal outcomes (Bozeman and Sarewitz 2005; Cozzens and Snoeck 2010; Fisher et al. 2010; Bozeman and Sarewitz 2011; Foray et al. 2012). In this context, the notion of research portfolios is becoming increasingly popular as funders and performers of research strive not only to "maximize" the "performance" of individual research projects, but also to somehow consider the aggregate "performance" of a given set of projects in terms of their contribution to diverse ultimate objectives, often of some societal relevance.

The purpose of the paper is to explore how the notion of research portfolio could be used as a heuristic for fostering deliberation in science, primarily to reflect on research priorities and project selection in the face of a limited capacity to steer research in the short or medium terms in public organisations. We build on recent progress in exploring concepts such as research portfolio in the context of public research management (Srivastava et al. 2007; Dietz and Rogers 2012). But while previous research had discussed governmental research portfolios by combining qualitative and quantitative methods and examining both output-based and "human capital"-based portfolios (Bozeman and Rogers 2001), our focus is concerned with portfolios oriented towards explicit societal problems, such as climate change or obesity.

The article first reviews the literature on research portfolios and related science policy contributions. Second, it suggests some general principles on the basis of the reviews. Through a review of the literature within the public and private sectors, we find that methods applied to analyse private-sector R&D portfolios, though relatively well-developed, cannot simply be transposed to public science policy. A more holistic and multi-dimensional approach is required. The increased popularity of "research portfolio" in the public reflects a variety of issues beyond funding and evaluation: from accountability to skills to economic outputs. However, the notion is currently underdeveloped and generally used in an overly-simplified fashion by public-sector research organizations. The same can be said regarding its increased use in the scholarly literature, highlighting a gap in science policy discourse, despite the

[4] See for example, the illustration of (research) portfolios in terms of funding in the recent work of UberResearch. (http://www.uberresearch.com/visual-portfolios/) or in terms of publications in Rafols, Porter and Leydesdorff (2010) (http://www.idr.gatech.edu/maps).

availability of theories and methodologies which could be applicable to public-sector research portfolios. Our review of other relevant science policy literature, on the other hand, points to the possibility of a fruitful research agenda for developing a portfolio-based approach to tackle a given complex, multidisciplinary societal challenge. In particular, existing literature points to the need for recognizing the inherent uncertainty in the outcomes and research options, focusing on the alignment of research with societal outcomes, and examining research portfolios from a systems perspective. We conclude by discussing some possible implications of this approach, not only in terms of achieving global societal objectives, but also in terms of developing more efficient, transparent and inclusive science policy.

2. The conceptual assumptions behind research portfolios

Dietz and Rogers (2012) have recently shown the usefulness of re-examining the use of concepts (or buzzwords that contain them) such as "transformative research", which are polysemous and ambiguous yet often taken for granted in science policy discourse. Distinct analogies and metaphors are thus revealed. The effects (alleged "successes" or "failures") of putting such concepts in policy practice depend in part on a consistent understanding of what they entail. To examine how research portfolios are thought of and applied in public and private sector contexts we will, in the subsequent sections, analyze the conceptual "baggage" that various uses of the term research portfolio implicitly carry. In the present section, we provide some general justification for why this is necessary..

Metaphors and analogies are fundamental in developing new knowledge, be it in the context of new theories, applications or entire fields of research (Kuhn 1979; Freeman 1991). Similarly, analogies can play a central role in developing narratives which underpin decision-making, namely in the policy realm (Schwenk 1988). Here, we are concerned with the use of the term "portfolio" as a metaphor borrowed from the world of corporate management. This is an instance of a "conceptual metaphor" (Lakoff & Johnson, 1980): a concept which colours the way we think about phenomena, and help us make sense of them within the context of a given field of study – in this case, science policy. Indeed, just as much of the basis of neoclassical economics lies in metaphors borrowed from the physical sciences (Mirowski 1991; Bernard Cohen 1993), analogies from the field of economics permeate the natural sciences (Ghiselin 1978; Hammerstein and Hagen 2005) From a related perspective, the search for increased quantification – which often points to econometric or finance-based approaches – permeates many areas of the social sciences and of public policy (Porter, 1995). While analogies are an important source of creativity and a means to interpret and explain observed phenomena, we will show the need to move beyond a simple analogy of portfolios in finance or in private sector R&D towards more solid foundations for the management of public science.

Part of the difficulty with using the portfolio as an instrument for policy lies in the vagueness of the term itself, and thus its propensity to be interpreted based on existing analogous usages. A portfolio, taken on its own, might conjure up a collection of art projects, the responsibilities of a minister or, more likely, a set of investments. At a most basic level, a research portfolio refers a collection of research activities under a single umbrella, generally a funder, performer or an entire country, but each of these activities may have been conceived for a variety of reasons. In general the portfolio is an outcome of research activities rather than pre-conceived strategy. This contrasts with a research program in which the projects, or other activities, are part of the same directed endeavour with some specific pre-conceived timeframe and objectives. We do not set any *a priori* restrictions on types of research or fields that can be usefully explored with portfolio analysis, nor on the degree to which portfolios have been explicitly designed in a top-down manner (e.g., one can look at the portfolio of a specific research programs). Indeed, one can conceive of portfolios within any single discipline or within the context of purely "blue-sky" research, e.g. as a means of exploring the disciplinary diversity within a fundamental research organisation such as the European Molecular Biology Organisation (Rafols, Porter and Leydesdorff, 2010). In these cases, the interest of the portfolio is to understand the relative balance between research areas or approaches. However, we believe that portfolios can be particularly helpful tools on problem-oriented research such as health, agriculture or in complex societal challenges like climate change, because the portfolio may help illuminate and discuss hitherto hidden cognitive lock-in and biases that favour certain technological solutions over others (Sarewitz, 1996; Stirling and Scoones, 2009). The usefulness of portfolio analysis for mission-oriented research is also suggested by the fact that funding organisations such as the NIH or the Wellcome Trust are among the first to use it in science policy.

To provide a sense of the scope of usage in the literature, Figure 1 shows the increase in publications with the term "research portfolio" (or related terms[5]) within the English-language academic literature (covered by *Web of Knowledge*), which is dominated by titles such as *Research Technology Management, IEEE Transactions on Engineering Management, European Journal of Operational Research, Research Policy* and *Research Evaluation*. The increase is significantly greater than the overall rate of growth of publications found in the database (dashed line in Figure 1). As shown in Figure 2, an examination of the publications on portfolios reveals that there are three categories of articles and reviews according to a clustering algorithm (Waltman et al. 2009) that finds topics focused on biomedical research (top right), on science policy in general (bottom right) and on industrial research (left), which is the focus of this section. The size of the circles represents the number of occurrences (with the smallest circles representing 10 occurrences, for clarity), while the closeness between two given terms is a two-dimensional representation of the frequency of co-occurrences (i.e., the "relatedness") of the terms. These categorizations, in particular the distinction between health and science policy-oriented scholarship on the one hand, and innovation policy on the other hand, are supported out by a co-citation analysis of sources (not shown here) using the same software and data from the *Web of Knowledge*. Discussions of the management of private-sector R&D reveal more technical and in-depth discourse than discussions of public-sector R&D, where "research portfolios" are more often used to describe a phenomenon in practice (e.g., NSF spending), without associated theories or methodologies.

[5] Documents were downloaded from the Web of Knowledge in May 2014. The search was limited to original articles, reviews and editorial material, and to any of the following search strings and their plural forms: "research portfolio", "science portfolio", "research and development portfolio", "R&D portfolio", "scientific portfolio", "portfolio of research", "portfolio of R&D".

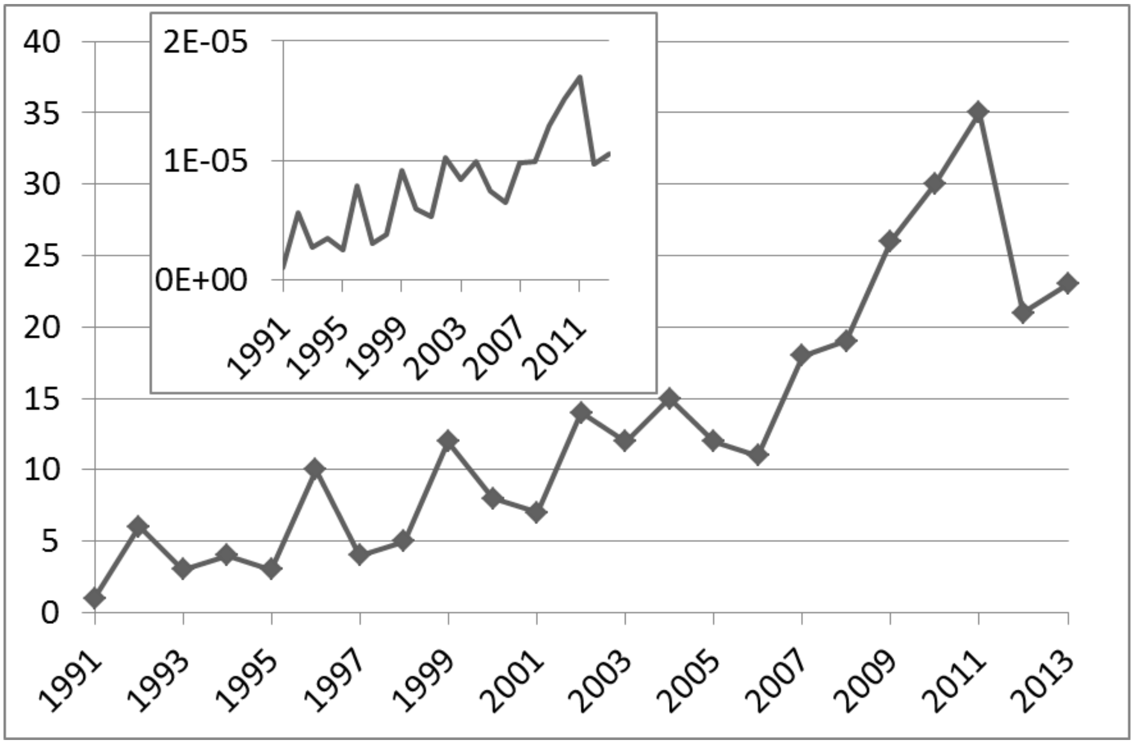

Figure 1: Main graph: Number of publications related to research portfolios in titles, keywords and abstracts in scientific literature (Web of Knowledge). Inset: Data expressed as a ratio of total number of documents present in the Web of Knowledge database (approx. 2.2M in 2013), to show that the increase is not an artefact due to overall database size[6].

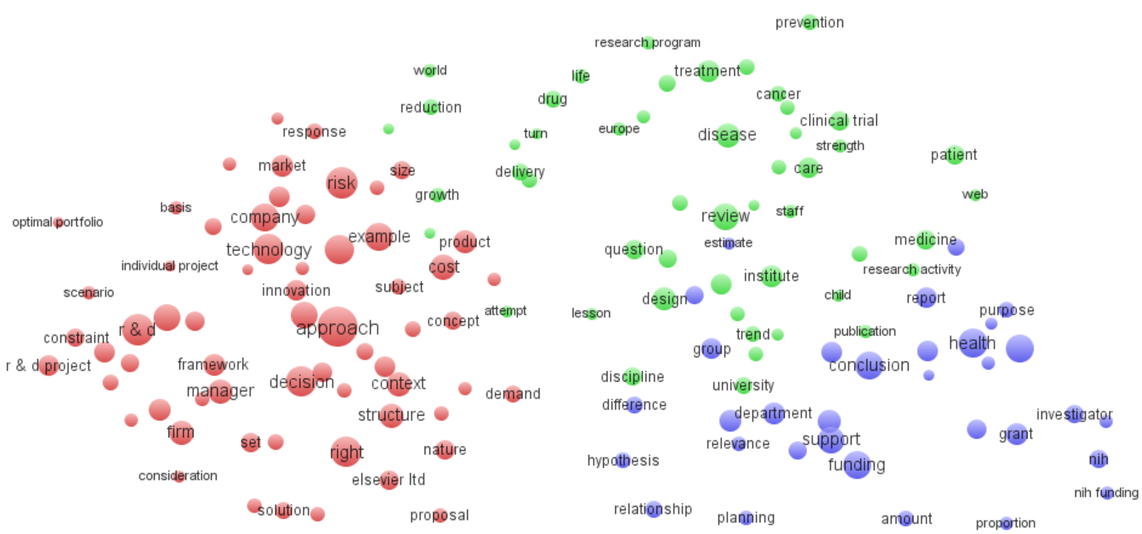

Figure 2. Map created from the co-occurrence network of terms found in scholarly articles on "research portfolios" in the Web of Science for the period, using the software VOSViewer. The red cluster (left side) corresponds largely to the literature on management of private-sector R&D, the green cluster (top right side) corresponds to biomedical research portfolios, while the blue cluster (bottom right) corresponds to broader science policy issues, with a focus on health.

[6] Data retrieved June 2014 from http://wokinfo.com/

In the following four sections, we review the practice and the scholarly contributions on research portfolios. We observe both reports of substantial practice (section 3) and scholarly work (section 4) on private R&D portfolios, increasing usage of the term research portfolio in science policy practice (section 5), but a relatively few and only recent explicitly scholarly contributions on the topic from a science policy perspective. In section 6 we review insights from science policy research which we believe are directly relevant to public portfolios. Table 1 below summarizes the main findings, highlighting the gap in the bottom-right quadrant which we address in the section 6.

Table 1. Roadmap of this review of existing practices and literature (sections 3 to 6).[7]

	Research policy practices	**Scholarly contributions**
Private R&D focus	**Section 3** • Using harmonized firm-wide management practices for R&D • Applying portfolio management tools to R&D	**Section 4** • Methods for ranking R&D projects (risk and return) • Measurement of correlations between projects • Quantitative tools (e.g., models) to support decision-making
Public R&D focus	**Section 5** • Focusing on improved accountability and management practices • Using tools and skill-sets for planning, managing and reporting on research • Using newly available data and new data analytics	**Section 6** *<u>Potential insights to fill existing gaps:</u>* • *Studies of technological risk and uncertainty* • *Priority-setting in STI policy* • *Evaluation of societal outcomes* • *Public-value mapping* • *Research as a "complex system"*

3. Research portfolio practices in the private sector

Somewhere between the financial analogy and how science policy scholars view public-sector research lies the treatment of corporate R&D. In the context of a manager seeking to maximize *returns on investment*, it may seem that it makes economic sense to approach R&D programs with a portfolio analysis, given the very high uncertainty in the success rate of individual projects. Considering each individual R&D project separately presents serious risks for the overall success of an R&D program, given the uncertainties in the associated chances of success and potential economic returns. Just as firms have often sought to integrate R&D within a broader product development cycle, managing the "R&D department" has meant adopting a birds-eye view of the entire set of research operations. In industrial

[7] We thank Tommaso Ciarli for suggesting to include this table as a means to organize and summarize much of the reviewed information.

R&D, one can also think of the origins of using portfolios as being simply a means to score or rank R&D projects (Souder and Mandakovic 1986).

Managing R&D has certainly evolved to be quite distinct from financial management, but the basic philosophies are *analogous*. In fact, while the quintessential "portfolio" approach to managing financial products is not considered straightforward (Altman and Saunders 1998), especially given the rise of new types of options pricing methods, efforts to use the approach for maximizing the return on research investment have continued to grow in popularity and complexity, while encountering little criticism. The rhetoric of optimization of investments, in various forms, has remained dominant in firms conducting R&D either as part of or the bulk of their operations (Devinney and Stewart 1988). One of the clearest illustrations of this point lies in the management of patents, which mirrors and informs the management of R&D at various stages along the commercialization spectrum. Patent portfolios can be explicitly viewed through strategic lenses for long-term firm growth, guarding against market-based risk, and focusing on the diversity of patents in order to gain a competitive edge, considering patents as equivalent to financial assets (Ernst 1998). A big research question is to which extent management practices follow the rhetoric of profit maximisation or instead are dominated by more strategic or political drivers.

Since one cannot draw a dividing line between public sector and private sector research management practices, the idea of R&D portfolio management has leaked into public science. Strong linkages between universities and private industry were already important in the development of science (and science policy) in the post-war years. The rise of new public management in the public sector over the past thirty years has sought to increase alignment with private sector practices (Georghiou 1998), and as a consequence, the administration of public research has been strongly influenced by the management of private sector R&D. But translation from corporate to public management is not always appropriate or insightful, particularly when we are speaking of research in support of complex societal challenges. In addition, efforts at managing public research according to private sector principles often fail to recognize the dominant (and diverse) organizational and disciplinary contexts.

4. Scholarly work on corporate R&D portfolios

R&D portfolios as a tool for decision-making in private-sector R&D have been extensively analysed in the academic literature, often in journals associated with management studies or engineering. Emerging in the post-war years, the literature on how to manage many R&D projects within a firm has been growing since the 1960s, and in particular between the late 1980s and the 2000s. This body of work not only has an impact on the overall literature, but also on public sector administration, which is often informed by private sector approaches to management (Eikenberry and Drapal Kluver 2004).

For private sector institutions conducting relatively large amounts of R&D, the aggregate level of analysis provided by a portfolio approach is critical in terms of identifying interdependencies among projects, namely in view of minimizing risk and maximizing financial return. In 2002, Chen-Fu Chien laid out a portfolio-based framework for selecting R&D projects by first summarizing existing portfolio selection processes (Chien 2002). The approaches and principles that he describes as guiding how companies maximize returns and minimize risk are not new: Chien describes how previous efforts have led to incremental methodological improvements to help organizations make decisions about projects not on the basis of their individual merit, but on their collective value. Another of Chien's significant contributions was to articulate a general process governing R&D portfolio selection, based primarily on the definition of portfolio objectives, on the selection of a scale which is appropriate for linking attributes (or measurements) of the entire portfolio with individual projects, and on making comparisons with alternative portfolios. The basic idea is to link project measurements and portfolio measurements with the consideration of project interrelation. In other words, a portfolio analysis should consider co-variance, seeking first to understand the interdependencies between projects, second trying to optimise the portfolio outcome that reflects the positive and negative effects of interdependencies on the performance, and third, comparing synergistic portfolio attributes such as diversity. Minimizing risk is central to all explicit treatments of corporate R&D portfolios we have examined and diversification is key to dealing with situations of high risk. While risk is simplified as the variance on return in purely financial approaches (Markowitz 1952), it can also refer to various concerns for R&D firms, related to uncertainty in market returns or to the inherent possibility of failure of a given technology, for example (Luo 2011).

Since overall portfolio risk is depends on how the projects are connected to each other, different strategies for diversification can be employed to mitigate risk (Bekkum et al. 2009).Given strong organisational pressures to avoid perceptions of failure, if portfolios are analysed at an individual project level, there is the danger that social learning is inhibited. Such a risk can be mitigated if portfolio management is carried at the level of the whole portfolio, as discussed in detail in section 6.3.

On this basis, various forms of "real option"-based strategies (i.e., decisions related to tangible elements of R&D projects) have been developed and are advocated to guide investment in R&D (e.g., Vonortas and Desai 2007), though even this is not straightforward to transport from the world of finance to R&D management (Perlitz et al. 1999). The underlying assumption in the R&D portfolios literature is that portfolio analysis would allow for more "rational" or "evidence-based" decisions regarding the composition or size of a portfolio in order to optimize return. Mathematical treatments purportedly allow one to better reach such an optimal composition or, at the very least, provide a range of options that can facilitate decisions. Various multi-criteria decision-making tools have thus been developed to analyze and, to some degree, interpret data pertaining to R&D projects (Linton et al. 2002). For example, one can envisage a multi-stage quantitative process for developing a portfolio which seeks to ensure that the projects selected are of high quality and are well aligned with a decision-maker's explicit priorities (Stummer and Heidenberger 2003).

But while monetary return dominates the way financial (and other) portfolios are constructed, one can envisage a set of guiding allocation principles, which can set risk tolerance, as well as extend to national capacity building or sustainable development criteria for example. Furthermore, different time horizons can be considered, which dramatically change how choices of projects or financial instruments are made. Nevertheless, the overarching concern of managers (and shareholders) of firms is to ensure the long-term and short-term viability of the program or organization.

Comparisons and analogies from the financial world have been instructive in suggesting features of a research portfolio, in particular related to interactions and risk. For instance, one can build a microeconomic theory which posits distinct "competition" dynamics from a standard market model (Dasgupta and Maskin 2012). However, if we broaden the objectives of the portfolio analysis to a range of "public good" outcomes, we must move away from a straightforward transposition of such approaches since a high "rate of return" and low risk can no longer be viewed as dominant objectives, as we will discuss in the sections that follow.

5. Portfolio-related practices in public research management

Like other fields of public management/administration or public policy, science policy is associated with a set of tools and approaches that supports and guides the organizational processes of public institutions. In this section, we explore the diversity of existing practices related to or research portfolios. This review is based on a "desk analysis" of scholarly work and policy documents and is thus of limited empirical robustness – an ethnographic study would be needed to confirm whether this discourse on portfolios is a fair representation of actual practices. Broadly, these practices often fall under the umbrellas of delivering individual public science-based programs, or of more "horizontal" functions such as planning and reporting on activities, or managing financial and human resources. But they represent disparate interpretations and, in many cases, the term "portfolio" is used in ambiguous or superfluous ways, in comparison with R&D project management.

The term "research portfolio" has in part become more frequently used due to the increased availability of (and ability to mine) data, possibly also due to the desire to use tools from other disciplines – namely economics – to examine science policy (Marburger 2005; Srivastava et al. 2007). The development of systems such as the US NIH *Research Portfolio Online Reporting Tools* (RePORT) or the UK Gateway to Research illustrates this trend towards public availability of portfolio-relevant data.[8] Particularly in the context of health research, this data has led science policy consultants such as RAND corporation to start thinking about new ways of assessing projects for funding purposes (Ismail et al. 2010; Guthrie et al. 2013). We can distinguish three main activities in which "portfolio" approaches are said to be used: 1) as the "bird's eye view" of the activities of an agency or organisation, 2) as the set of skills needed by research managers, or 3) as

First, portfolios are increasingly used to provide an overview of a set of projects or programs through an *ex post* review process. Organizations such as the Wellcome Trust have also begun carrying out portfolio analyses to see their funding on specific major health issues such as malaria as a means to take stock of existing research and explore future paths (Dolby et al. 2012). This is one of the few cases where the focus is on a set of identifiable societal outcomes; in general, portfolio reviews are focused on organizational priorities or measures of "research quality". In such instances, the portfolio being examined can be theme or program-specific, such as a recent review of human research at NASA (National Research Council 2012), or consist of a heterogeneous set of research projects conducted by a

[8] See http://report.nih.gov and http://gtr.rcuk.ac.uk

large unit, for example, at the scale of a university (Portfolio Review Group 2014), or perhaps even that of an entire country (National Science Board 2001).

Within the NIH, there have been several discussions of research portfolios in recent years – the term has been useful in beginning to frame inputs and outputs of research. The NIH has thus begun to use portfolios as a means to perform "strategic" reviews, but more importantly, as a tool for publically accounting for expenditures and understanding research outputs or outcomes. The NIH RePORT has also led to an increased ability of scholars to critically review specific research portfolios and make meaningful comparisons (Boyack and Jordan 2011; Meador et al. 2011). Specifically, individual institutes or topics (e.g., Alzheimer's research) are increasingly being thought of as portfolios of investments or projects which, together, constitute the budget of the organization. New computational algorithms and scientometric methods for clustering research areas and classifying scientific documents (grants, publications or patents) can help in constructing relevant units of analysis for various research outputs (Waltman and van Eck 2012; Skupin et al. 2013; Kay et al. 2014)[9]. Yet, there is still no agreement on how a public research portfolio is defined or how it should be analyzed.

Second, many public and private-sector organizations have begun a daily management of their research funds or operations that is, at least rhetorically, a "portfolio" approach. Here, we cannot associate the term with a particular methodology, but rather a management skill-set, which we contend is also borrowed from "portfolio managers" in the financial sector and focusing on "nimble" alignment with organizational imperatives, the capacity to manage and prioritise multiple projects, and an understanding of risk-management.[10] One can also view this in terms of a part of the trend towards the standardization of management practices across the both public and private sector. This also implies a shift in the focus of research portfolios from the organizational or societal objectives to the performance of the individual manager and the projects under his or her supervision (Golec 1996). This is illustrated through one of many job advertisements by research funding and performing agencies:

> "[The] Translational Research Manager [position]… will play an important role in ensuring that fundamental research is translated into new therapies and diagnostics, … working with [scientists and clinicians] to develop a *credible development plan and successful applications for funding*. The post holder will provide advice on *suitable public funding schemes* (e.g. MRC, Wellcome Trust), support the development and submission of grant applications, and provide project management support to successfully funded programmes."[11]

[9] There is even a new company, ÜberResearch (http://www.uberresearch.com/) specialised in the analysis of research portfolios of funding agencies.

[10] For example, see a typical description of such skills at: http://www.pmi.org/Professional-Development/Career-Central/Three-Must-Have-Skills-for-Portfolio-Managers.aspx (accessed June 20, 2014).

[11] Excerpts from a recent job vacancy posting at the National Health Service (italics added). http://jobs.gstt.nhs.uk/job/UK/London/London/Guys_St_Thomas_NHS_Foundation_Trust/Biomedical_Research_Centre/Biomedical_Research_Centre-v318965 (accessed June 20, 2014)

Beyond anecdotal evidence, we can illustrate this diversity of discourse on the term "research portfolio" within the public sector through an exploratory "web-scraping" technique, whereby we extract the content from web-pages and parse it into a format which can be analyzed. Recent development of such techniques has showed promise in social sciences research (Marres and Weltevrede 2013). In this case, we search for the most relevant results of "research portfolios" in Google.com, restricted to domains often, but not exclusively, associated with the public sector[12]. Applying an identical mapping procedure as in Figure 2 with scientific abstracts[13] provides us with a sense of the breadth of contexts where "research portfolios" are mentioned as shown in Figure 3 (here we don't perform clustering since we are artificially selecting distinct sources through our web search). Figure 3 supports the insights of our manual cursory analysis[14] of these contexts, which are primarily related to: professional profiles and job offers, profiles of research organizations, strategic planning documents (including evaluations), and investment profiles. Separate high-density areas (i.e., high-occurrence of the term, in dark/red colour in the figures) are found around common terms such as "university" or "report", indicative of distinct contexts for research portfolios. As is found from the scholarly literature (see Figure 2, above), the health sector remains most prevalent among web results, which are associated primarily with universities, government institutes and private companies. However, the most important conclusion to draw from this exploratory exercise is that although the term is broadly used in public and private science policy contexts, it is so far used without semantic *specificity.*

[12] We perform a Google search for "research portfolios" from websites ending in: .eu, .ca, .uk, .au, and .gov, then extract the context of each "research portfolio" result using the *Outwit* software package. Finally, we perform a manual cleaning, removing spurious and duplicate results, which leaves us with 1186 distinct search contexts.

[13] Here, we keep all the relevant terms extracted, removing only "research" and "research portfolio" as terms which are common to the bulk of the results.

[14] Complementing the mapping approach, we perform a manual analysis of the results by looking for how often some of the most common strings occur. These strings are mainly related to employment ("job", "vacancy", etc.), planning and reporting ("accountability", "outcome", etc.), financial return ("investment", "fund", etc.), and general descriptions ("overview", "profile", etc.).

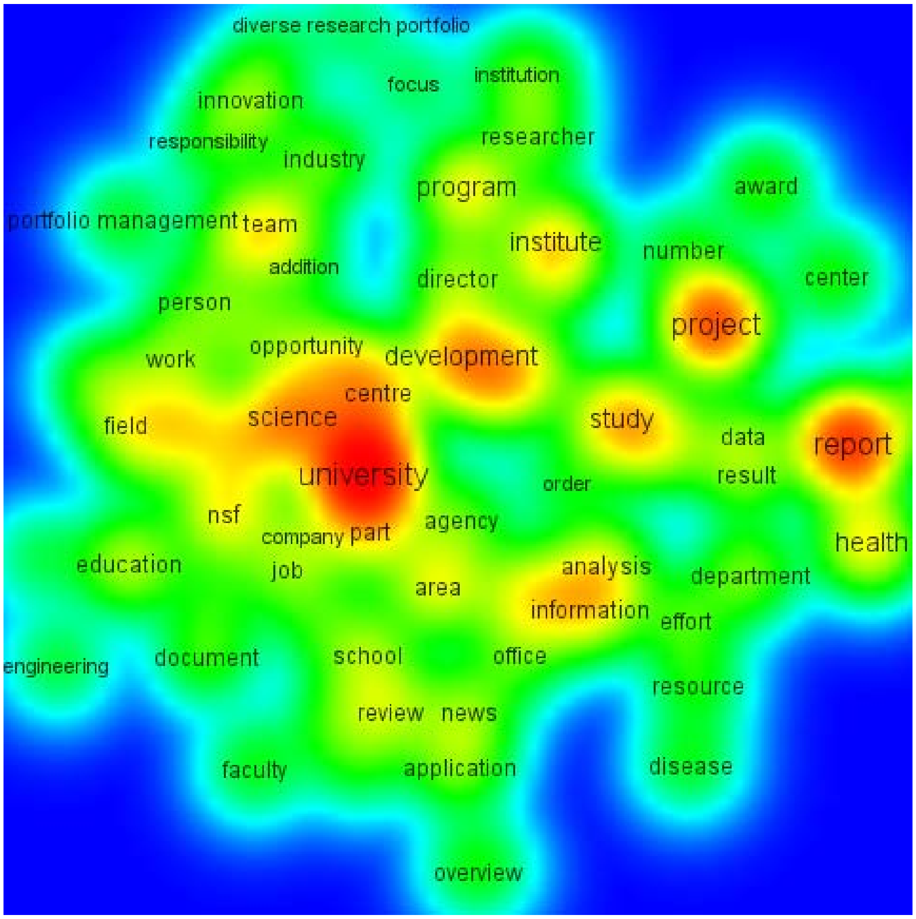

Figure 3: Density map obtained from co-occurrence of terms contained through "research portfolio" web search. Note the variety of contexts, from employment to innovation, as well as the diverse sectors: health (bottom right), universities (center/bottom left), government (center), and industry (top right). Red (darker) represents higher density and the font size is proportional to the number of occurrences of a term.

Overall, as a depiction of both an organization's activities or of a management skill-set, portfolios are often used as a rhetorical device that suggests some (actual or desired) managerial "improvement". Invoking portfolio analysis appeals not only to a more rigorous management of (public or private) research, but also points to a more in-depth, evidence-based or holistic view of research programmes. For instance, some of the earlier uses of the term "research portfolio" has been used to argue for basic defense-sponsored research (Wulf 1998) among other debates regarding the federal research budget, pertaining not only to funding levels but coordination issues (Sponberg 2005). In general, the appeal to the notion of a research portfolio is made in relation to mission-oriented research, for example, aging or agricultural research (Robertson et al. 2008; Liggins et al. 2010). However, it is also be used to bring together disparate types of research under the same umbrella, such as in the case of all national defense-funded basic research, or "high-risk" (in terms of potential malevolent misuse) research activities (Kuehn 2012). Finally, it may also refer to detailed discussions of methods for evaluating a set of research projects within specific contexts such as that of the NIH (Haak et al. 2012).

The concept of research portfolios also aligns well with more managerial science policy goals of cost-effectiveness, accountability and transparency. Indeed, recent years have seen greater effort to account for public funds spent on R&D. Initiatives such as Science of Science Policy and STAR Metrics led by U.S. science policy and science funding organizations are prime examples of a worldwide trend of trying to show and assess the contributions of research to society (Holbrook and Frodeman 2011; Largent and Lane 2012). This search for greater transparency and accountability is being developed by means of better data on social and economic benefits of research, but is also related to improving the way funds are allocated and their use is evaluated.

In most cases discussed in this section, exactly what defines a portfolio or how it is to be designed, managed or assessed are issues not explored in detail. Rather, the term tends to be used to suggest to a more efficient or holistic approach. Nevertheless, these developments underscore the fact that there is a demand for such a concept in policy circles.

6. Towards an appropriate use of portfolio analysis in science policy

After reviewing the very limited conceptual and methodological robustness of current portfolio analyses in practice, one may wonder whether portfolio analysis can be a useful tool in science policy. To answer this question in this section,we reviewed the scholarly contributions broadly related to research portfolios. Although there has been some science policy scholarship which specifically deals with the question (Bozeman and Rogers 2001; Sarewitz and Pielke 2007), most of the literature is not explicitly related to portfolios. We find that portfolio analysis can indeed be a useful instrument in science policy, but that an appropriate use requires some important general considerations. First, the recognition of the uncertainty and ambiguity of what are desirable outcomes of a portfolio. Second, the need to critically analyse the alignment between research options with expected outcomes. Third, the importance of taking a holistic view of the portfolio, i.e. of analysing synergistic dynamics and considering outcomes of the portfolio ensemble rather than its parts. Each consideration is discussed in a subsection below.

6.1 Beyond the financial metaphor: from risk and returns to uncertainty and ambiguity in outcomes

A potential approach in public research portfolios would be to further develop the financial analogy used in private R&D portfolios (as reviewed in sections 3 and 4). In recent years, there have been many complex computational models explored to enable decisions on public portfolios (pertaining to research or other endeavours), given a set of explicit social preferences on the part of the decision-maker (Fernandez et al. 2013). However, these leave no room for diverging perspectives or for qualitative valuations of societal goals. Our contention is that, as it stands, the financial analogy cannot be applied to portfolios of public science whose primary objective is to achieve various types of public good outcomes; we must turn to new approaches. Similarly, tools and approaches developed for private-sector R&D cannot simply be transferred to public policies because they are not developed to work with multiple desirable outcomes.

One reason why the use of the financial metaphor in research portfolios is problematic is illustrated by work by Andy Stirling and colleagues on risk analysis and knowledge mapping (Stirling and Scoones 2009), as shown in Figure 4. In the financial metaphor it is essential to have precise estimates of the degree of risk (e.g. volatility) and returns (benefits of a given research outcome). This means developing metrics which assume that the knowledge of the type of outcomes and the knowledge of the likelihood of those outcomes are unproblematic (top left in Figure 4).

However in the case of public good research, making assumptions about the outcomes and likelihoods is extremely problematic. For example, the desired outcomes of research in virology might be the development of an antiviral drug or a vaccine, or perhaps improvements in diagnostics, but an unintended outcome might be an infection to the population via unintended release of a virus, for example. These various intended or unintended societal outcomes each have a very uncertain degree of likelihood (vertical axis in Figure 4) and different people will value them differently (labelled as "ambiguity" in Figure 4) which is why they cannot be simply added up into one dimension (this is analogous to concerns over methodologies in general, as found in Moravcsik 1984). As a result, the expected social return cannot be computed as a "return"—rather than risk-based expectations (top left corner in Figure 4), in the case of research portfolios we have both uncertainty and ambiguity, a situation of highly incomplete knowledge, close to ignorance. This is particularly true as the outcomes are further into the future, which could, for example require more exploratory research. How we treat uncertainty also depends on how well defined the specific challenge is, and to what degree a specific body of knowledge to address it already exists.

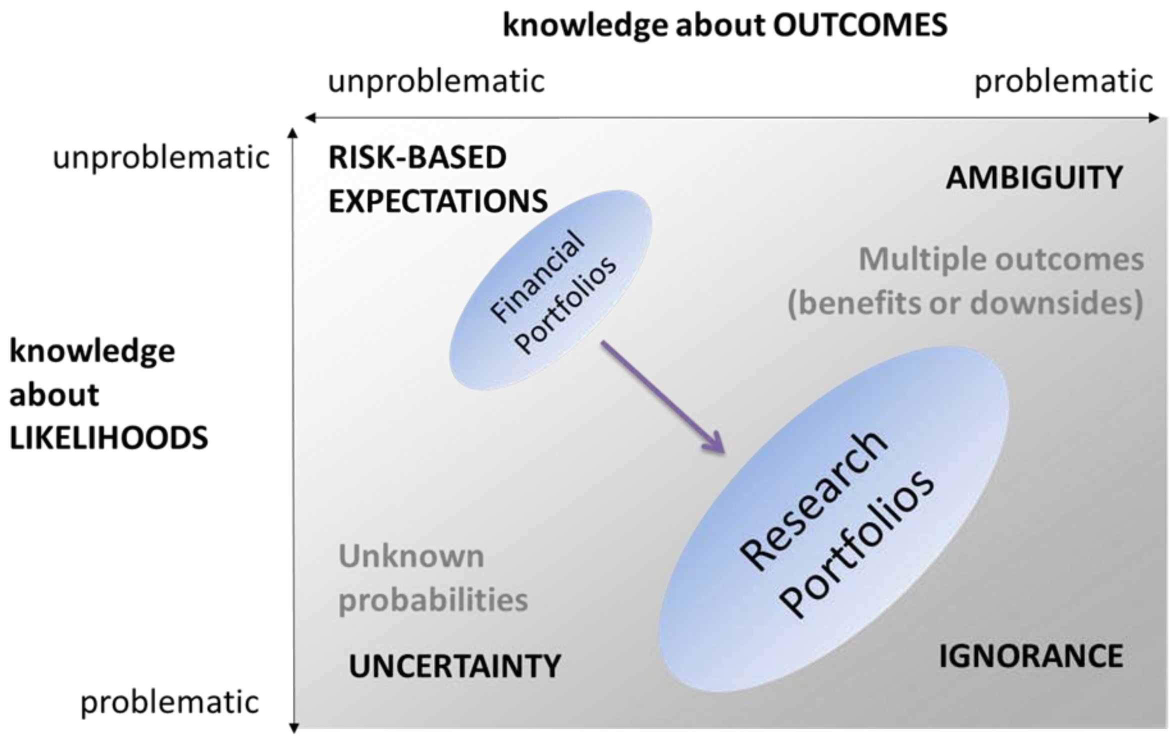

Figure 4: Schematic representation of contrasting states of incomplete knowledge (adapted from Stirling & Scoones, 2009)

Under conditions of highly incomplete knowledge, there is a need to consider multiple potentially valuable outcomes and multiple research options as pathways to each outcome. Hence there are two rationales for diversification: 1) in the vertical axis (from top to bottom) diversifying research options as a means to hedge against the uncertainty that a specific research options achieve the desired outcomes; 2) in the horizontal axis (from left to right) diversifying research options so that various outcomes are pursued, given that different actors have contrasting views on the relative value of outcomes. Drawing from the same example as above, there are different technical paths to developing effective vaccines to guard against deadly epidemics, but there are also many different outcomes (new vaccines, improved hygiene, new surveillance techniques) which can help mitigate this uncertainty --and each of them requires technical paths somewhat different from those needed by vaccines. These are two points that have been very salient in energy portfolios given the high volatility of energy prices (uncertainty) and controversies over the use of some technologies (e.g. in nuclear plants) (ambiguity). Work by Shimon Awerbuch describes how, under these conditions, in "dynamic and uncertain environments, the relative value of [energy] generating technologies must be determined not by evaluating alternative [energy] resources, but by evaluating alternative resource portfolios." (Awerbuch, 2006, p. 693; see also Bazilian & Roque, 2008)

Considerations of diversity should also include capacity-building objectives, as well as requirements for duplication (as a means to build in mechanisms for replication or to explore slightly different pathways) within a given portfolio and among different portfolios. In addition, high levels of specialization (and thus low diversity) for a given organisation in a certain field or sub-field may present perceived advantages for increasing levels of collaboration and developing transferable techniques or technologies. Moreover, if one were to consider a set of several research portfolios from different public institutions, where all would benefit from progress (either incremental or transformative) in a given area, then once again diversification for one organisation may not always be beneficial for the aggregate portfolio (Dasgupta and Maskin 2012).

6.2 Alignment of research options with outcomes

That science is conducted in conditions of incomplete knowledge does not mean that the analyst cannot make decisions based on informed guesses about the relation between research and social impact: it is well documented that certain research options are much better aligned to certain outcomes (Sarewitz 1996, 31–49). A trivial example might be that research on mosquitoes is more likely than research on asteroids to be relevant to malaria. Historically, several lines of inquiry in science policy have explored the alignment between research options and outcomes, namely related to priority-setting and evaluation of research, but also to broader considerations related to the "supply" and "demand" of policy-relevant science. In order to deepen our understanding on the issue of alignment, here we review three research strand: 1) priority-setting in funding; 2) evaluation of socio-economic outcomes of research, including public value-mapping,

First, while priority-setting (i.e., choosing scientific fields or approaches) is distinct from our focus on constructing a portfolio for a given problem, it raises many of the same questions. The debate over how priorities of research are decided dates back to postwar science management. In 1963, Alvin Weinberg famously posed the question of how to decide between what types of science to perform, citing scientific, technological and societal factors, with the latter dimension being the most problematic (Weinberg 1963). Weinberg tentatively posits some criteria – such as the transdisciplinary relevance of a given field – for assessing the societal benefits of a field of research. Once again, spurred on in part by the growth of what was perceived as "Big Science", Michael Moravcsik (1988) took up the same debate two decades later, arguing for the importance of assessing scientific fields according not only to internal (disciplinary) criteria, but also to broader social impacts and relevance to the scientific community. Similarly, on a national scale, one can envisage a set of criteria which could enable the comparison of alternate research programmes – or portfolios – based on "social needs" (Snellen 1983). These debates highlight the importance of considering scientific work beyond narrow disciplinary boundaries and in terms of broader societal outcomes, namely through inclusion of a broader range of factors and stakeholders (Brooks 1978). A specific instance of priority-setting in the literature has dealt with health research, in particular examining which diseases are and should be the target from large research efforts, based on public health demands or a measured "burden" of diseases (Agarwal and Searls 2009, 867–869; Røttingen et al. 2013; Evans et al. 2014).

This literature acknowledges that priority-setting is essentially political. In the 1990s, following the end of the cold war, public science in the United States and elsewhere saw an increased push for new goals, for setting priorities and allocating funds (McGeary and Smith 1996). At the very least, scientists and science managers became increasingly aware of the need to compete for funds with other public programs, for example after the cancellation of the US Superconducting Supercollider (Sarewitz, 1996, pp. 1-4). In the field of health research, for example, patient groups, doctors and the private sector engage in dialogue while having diverging views and interests on priorities for research (R. Smith 1988).

Indeed, many funding organizations engage in extensive consultations to determine some of these priorities. But little is currently said or done about the implementation of these (generally high-level) priorities through research portfolio analysis. Priority setting has been argued to be especially important when there are shrinking or flat budgets (as it the case now) since one can argue that incremental changes from year to year do not allow to adapt investment to changing environments such as new societal problems or emergence of scientific fields. This highlights the need for so-called "risky" research with potentially high payoffs (which is not well served by peer review selection, as suggested by Nicholson and Ioannidis, 2012), as well as for making potentially painful judgments across fields (McGeary and Smith 1996).

Second, there is a wealth of literature pertaining to evaluation of public science according to societal needs or demand, which discusses the desirability of including a broader social and economic context in research evaluation. In particular, scholars focused on *ex post* evaluation have made strides in capturing some of the societal outcomes associated with research, but this continues to be both very difficult and controversial (Cozzens 1997; Salter and Martin 2001; Martin 2011). This difficulty, as well as a paucity of data, may partially explain why many over-simplified indicators and methods of evaluation continue to dominate evaluations in the public sector. Today, intrinsic surrogate measures of "scientific quality" (such as journal impact factor or citations) remain central to measuring research in support of societal outcomes, despite a willingness of managers and policymakers to include a greater variety of evaluation methods and indicators (Feller 2012; Scientific Management Review Board 2013).

More specifically, and setting aside for a moment the obvious lack of quantitative data, the attribution of changes in the social or economic spheres to research projects, or even areas, is often extremely problematic (European Commission 2005; Cozzens and Snoeck 2010). Nevertheless, in the health sciences, substantive efforts have been made to explicitly capture public policy outcomes of scientific research (Hanney 2003; Boaz et al. 2008). New interpretations of standard quantitative indicators on outputs (e.g., from bibliometric data) (Hanney et al. 2005) and new frameworks, such as that of productive interactions (Molas-Gallart and Tang 2011; Spaapen and van Drooge 2011), have proven useful in gaining insight into the impacts of scientific research on social spheres, such as industry or policy. However, in the case of *ex ante* evaluation there is still a lack of tools for mapping potential socially-beneficial outcomes to research programs, as demonstrated by the challenges in expanding the role of peer review processes to focus on relevance or alignment (Holbrook and Frodeman 2011; Frodeman and Briggle 2012).

The idea of pragmatically applying "public values" to the evaluation of research has developed in recent years thanks in part to the work of Daniel Sarewitz and Barry Bozeman (Bozeman and Sarewitz 2005; Bozeman and Sarewitz 2011) who move away from strictly economic thinking about societal outcomes of science. Their treatment of public research extends a justification for public investment in science beyond what is simply considered a "market failure". Their understanding the public values and societal outcomes associated with specific areas of science could be part of a toolkit of methodologies for research portfolios analysis and for assessing the relative value of "alternative" portfolios that to move beyond the status quo.

Bringing public values to the forefront in portfolios not only poses the challenge of moving beyond a dominant economic model of thinking about the science policy process, but also that of identifying criteria for success or failure in either public or private research in addressing these public values. The co-existence of divergent criteria puts the focus on some mechanisms of societal *deliberation* as part of the portfolio-building process which includes as a first step identifying what values are articulated by stakeholders. This implies seeking or eliciting a plurality of views which may often not be explicit in public discourse. The onus is thus on the policymakers to identify the values being considered, to identify where public and private failures exist and ensure that the public values persist at the forefront of a given science policy process. Finally, at the heart of the deliberation is the fact that the priorities of scientists, science managers and potential social demands rarely align.

To foster alignment it is necessary to better understand the current state of the science (the *supply*) and what is required to achieve social goals (the *demand*) (Garfinkel et al. 2006; Sarewitz and Pielke 2007). The "demand" side must consider not only the plurality of outcomes, but also various ways of articulating specific science- or technology-driven pathways for achieving them. Similarly, the "supply" side is not just about how much "high-risk, high-return" research should be undertaken, but also about what type of outcomes are somewhat likely (in spite of high uncertainty) to result from a given line of research.

By putting the emphasis on the outcomes and on their connection to research enterprise, a portfolio analysis helps bridge the gap between the supply and demand. The former implies public and stakeholder engagement in shaping a research portfolio, revealing the values and expectations and attempting to connect them to potential research avenues. The latter implies considering how the social and institutional mechanisms affect the links between allocated resources and outcomes (Laudel and Gläser 2014). More broadly, understanding these micro-mechanisms (which is a big challenge!) would allow connect governance and research content, namely via the actions of researchers in responding to and in influencing science policy decisions (Gläser 2012). Identifying the explicit expectations of stakeholders becomes paramount for portfolio analysis in the case of societal challenges. For example, organizational or national imperatives related to capacity development mean that in specific instances research portfolios should be described in terms of learning and capabilities rather than research outputs (Bozeman and Rogers 2001).

In summary, in this subsection we have argued that portfolio analysis for public research should consider the alignment between supply and demand -- and found that there is a substantial and growing literature on priority setting and socio-economic benefits of research that can be mobilised for exploring this alignment.

6.3 A systemic, whole portfolio-level approach

The preceding two sub-sections, as well as our examination of the dominant existing practices (both drawn from corporate R&D analogies and from current public research imperatives), point to the need to tackling research portfolios in a systemic manner. By a systemic approach we mean that the portfolio should analysed as a whole, taking into account interactions and synergistic properties of the research options. Specifically, this means that the values or performances investigated in a research portfolio should not only be the sum of the individual performances of research options. Instead, portfolio performances should include interactions and synergies between research options, as widely as thoroughly discussed in the literature (Chien 2002, 364–365; Stirling 2007, 712–714).[15] In sum, the idea is that the analysis should be carried out to the portfolio as a whole, and that analysis should compare whole portfolios between them rather than research options. This approach means to carry out the management of portfolio at the whole portfolio-level.

Quantitative and qualitative approaches have been developed for assessing how scientific and non-scientific programs are performing "as a whole", beyond the mere sum of individual projects (Ruegg 2007; Srivastava et al. 2007). *Ex ante* evaluation has thus benefitted from new methods which can examine entire fields such as energy R&D (National Research Council 2005). More generally, recent years have seen significant developments in the construction of frameworks for performance indicators that take into the dynamics of entire sectors as well as a broader set of potential socio-economic impacts (Jordan et al. 2008). However, despite efforts in this direction and calls for change within the scholarly literature (Arnold 2004), the assessment of interactions has little formalisation – in contrast, for example, to economic studies such as the "product space" formalism in the context of export/import goods (Hausmann et al. 2013).

At the heart of portfolio analysis lies the expectation that one should seek *support for positive interaction between research projects or areas.* While straightforward numerical optimization algorithms are difficult to envisage in the context of complex and multi-faceted socio-economic outcomes, advances in data availability and improved understanding of research as a "complex system" can lead to useful heuristics (K. Smith 2000). The characterization of research avenues in disciplinary terms, specific methods, as well as their institutional or social settings, can help decision makers conceive of linkages between projects. Similarly, potential or planned interactions between projects can also be identified through the narratives associated with them and through the underlying objectives that purport to drive the work.

Research portfolio analyses may help to explicitly value and recognize social, institutional and cognitive complementarity and synergy, which in turn can lead to new means of coordination or new collaborations, for example. In the health sciences, in particular, this is in line with efforts to foster translational research, i.e., bringing together clinical and basic research (Woolf 2008). More generally, policy instruments that encourage collaborations and the flow of information are key to fostering interactions within portfolios, including learning derived from failures. The complexity of linkages across areas (for which measures exist) can be associated with richness of the underlying knowledge capabilities, which in turn, can be associated with the capacity of a country or an organisation to solve problems or to create prosperity, when viewed from a social or economic perspective (Hausmann et al. 2013).

One means of seeking out these positive interactions is through trying to understand the structure and dynamics of the topic-based research landscape, which we define as the ensemble of original scientific

[15] To avoid confusion, let us stress that this definition of system is purely functional and, in principle, unrelated to the literature of national, regional or technological innovation systems.

work underway on a given topic. It can be based on data related to funding and publications, and/or from consultations with a range of experts. And it can be viewed through a lens of cognitive, social and institutional proximity, in the context of the overall breadth of global science. In particular, by showing cognitive proximity, global maps of science offer provide a sense of the range of existing theories and methodologies with a connection to a given set of outcomes, which is conducive to identifying potential gaps and positive interactions (Rafols et al. 2010). However, these type of global (either disciplinary or journal-based) maps are likely to prove of limited usefulness in many specific problems in which research options are topic specific rather than disciplinary (Wallace & Rafols, manuscript in preparation).

Since portfolio analysis is most meaningful at scales where one can envisage – and measure – positive interactions between elements, the entire set of research projects of large country, for example, may be more challenging to consider (although one can certainly talk about priority-setting). Conversely, when operating at the level of a few projects, or a larger number of projects which focus on a very narrow line of research, a portfolio analysis (as we describe it here) may have little added value as the criteria for decisions become scientific nature and can be directly judged by peers (Weinberg 1963, 164–165). Thus the "meso-level" of analysis which has been advocated for evaluation (Hage et al. 2007; Jordan et al. 2008) and which is also particularly useful for capturing social impact (Molas-Gallart and Tang 2011), may also be the most useful scale for portfolio analysis and design. Such a scale could be broad enough to capture the "realm of possibilities" as a means to generate new ideas for *alternative* portfolios, and to allow for thinking about wider governance issues (legal, institutional, policy and cultural aspects of a socio-technical regime) which empower or constrain such alternatives (Geels 2004).

In summary, this subsection has argued that portfolio analysis is most appropriate at a systemic, whole-portfolio level, in particular using the notion of a topic-based research landscape as a heuristic and operating at a "meso-scale", which allows interactions among portfolio elements to become visible or measurable.

7. Conclusion

This article has explored the concept and use of research portfolio analysis as a tool for management in science policy. We have traced several applications and uses (at highly varying degrees of rigor and sophistication). We found that the basic financial metaphor and corporate R&D approach is inadequate for public policy and that its current, wide-ranging uses in science policy are sometimes can be useful in some instances, but are too often ambiguous and rarely refer to specific tools or concepts. Instead we propose three considerations for carrying our portfolio analysis, namely: i) recognising uncertainty and ambiguity in the research areas and outcomes; ii) fostering the alignment between research supply and demand; iii) carrying out a systemic, whole-portfolio level analysis. This approach namely implies that one-dimensional and reductionist characterizations of portfolios in terms of risk and return must be replaced with portfolio analyses that consider multiple options and plural outcomes.

We view this study as a first step towards developing more concrete policy design and implementation recommendations. Applying portfolios as an analytical tool has implications for how some of the societal problems of public research—climate change, poverty reduction, global diseases, etc.—are addressed.

For example, the portfolio analysis also provides an opportunity for moving beyond a simple dichotomy of "applied" vs. "basic" research, blurring the already poorly-defined distinction between the two (Calvert 2006) and focusing instead on the diversity of approaches and methodologies aligned with expected or desired outcomes.

Greater emphasis on portfolios can favour a more balanced approach to managing public research, which is currently dominated by a push for "excellence", despite the fact that this term is itself problematic (Rafols et al. 2012; Stilgoe 2014). We have proposed a move away from a unidimensional view of a portfolio focused on a single "performance" measure (be it in terms of "scientific quality" or financial return). Similarly, this might also imply a move away from an over-reliance of evaluation on the current peer-review system, which also tends to focus on a narrow, field-specific view of excellence. The dominance of peer-review has recently been called into question, not only in terms of the burden it can entail (particularly if it is to be the only means to assess a project), but also in the context of a lack of a transparency and a tendency to force conformity among applicants (Ioannidis 2011; Nicholson and Ioannidis 2012; Chalmers et al. 2014), not to mention contributing to high levels of false findings or "wasted resources" (Ioannidis 2014). Portfolio analysis, on the other hand, could help in diversifying rather than promoting homogeneity, namely by actively exploring a range of alternative portfolios and explicitly considering levels of diversity. Portfolio analysis can also favour a shift towards a management of public science with a greater focus on interdependencies between projects or research areas (including a focus on standardization, collaboration, data sharing, etc.) than is currently the norm.

The focus on societal challenges in this paper is driven by our perception that the logics of a public portfolio analysis are particularly well suited foster societal benefits related to a given goal or more generally for mission-oriented research. One can also apply a research portfolio analysis to large public research organisation or university. In this case, the portfolio logic still may apply in terms of the socioeconomic missions of the organisations and in terms of promoting accountability and transparency, and thinking strategically about balance of research options.

Efforts to develop research portfolios for the public sector, beyond the dominant "financial" analogy, could help allocate funding to better align science with underlying societal outcomes and public values, improve integration and foster new synergies, while promoting a more transparent science policy process. As research portfolios are becoming increasingly used in policy, in this article we have attempted to "unpack" and "untangle" the use of the term "research portfolio". By clarifying some of the assumptions underlying this term and by pointing to potential paths forward for practice and scholarship, we hope to advance debate and dialogue among (and between) scholars and policy-makers so that science can become more successful in helping address societal needs.

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