THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOFY

The Impact of Academia on the Dynamics of Innovation Systems

Capturing and explaining utilities from academic R&D

EUGENIA PEREZ VICO

Environmental Systems Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
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Environmental Systems Analysis
Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover: "The wave", Illustration by Alexandra Dahlqvist. The figure with a microscope head symbolises a researcher who is being fed research funds through a slot from the hand of a research funder. The wave filled with objects coming out of the sampling plate in the researcher's hand illustrates the diverse utilities that materialise out of academic research.

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“If we knew what it was we were doing, it would not be called research, would it?”

- Albert Einstein

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Eugenia Perez Vico

Environmental Systems Analysis, Chalmers University of Technology, Sweden

Abstract

The notion that academic research creates societal benefits is widely recognised. However, there are varying perceptions of what such benefits may include, and diverse ideas regarding the ways in which they are created. Some research policy actors expect academic research to generate tangible and direct outputs related to commercialisation, such as spin-off companies, patents and licences. Others argue that academic research may generate utilities in more subtle and indirect ways that are not encompassed by commercialisation, and which are linked to complex, uncertain processes that span decades. The perceptions of how utilities are generated influence evaluation procedures and policy initiatives, which is why realistic representations are paramount.

This thesis aims to contribute to the understanding of how utilities are generated from academic research and development. The thesis draws on concepts from technological innovation systems and research policy literature to examine three cases: Swedish nanotechnology research, energy and environment research at a technological university and the research of a physics professor.

This thesis develops a framework for capturing and explaining academic R&D utilities. First, by enriching the technological innovation systems approach with a typology of activities springing from or embedded within academic R&D, this thesis identifies and examines multidimensional academic utilities. Second, by tracing utilities through innovation sub-process interdependencies, the thesis identifies long-term and indirect utilities created in 'sequences of impact'. Third, the diverse 'roles' of researchers are examined based on their main activities. This framework allows identifying utilities that transcend conventional indicators; understanding individual variations in how researchers create utilities; capturing more subtle, long-term and indirect utilities; and explaining how wider contexts condition the development of utilities. The thesis concludes with key implications for research policy which should develop an informed view of academic utility that acknowledges the great diversity of benefits, especially those of an indirect and long-term character. Policy should also offer support systems that encourage the development of diverse benefits; apply a systems perspective on policy-making; and recognize the great challenges of assessing the utility of academic R&D.

KEYWORDS – impact of academic R&D; technological innovation system; research evaluation; utility of research

List of publications

The following papers are included in this thesis:

Paper I: Jacobsson, S., Perez Vico, E., 2010. Towards a systemic framework for capturing and explaining the effects of academic R&D. *Technology Analysis & Strategic Management* 22, 765–787.

Paper II: Perez Vico, E., Jacobsson, S., 2012. Identifying, explaining and improving the effects of academic R&D: the case of nanotechnology in Sweden. *Science and Public Policy* 39, 513–529.

Paper III: Jacobsson, S., Perez Vico, E., Hellsmark, H., 2013b. The many ways of academic researchers: How science is made useful. Manuscript in review (minor revision) *Science and Public Policy*.

Paper IV: Perez Vico, E., 2013. Tracing sequences of impact from academic R&D: An in-depth study of a professor in physics. Manuscript in review (major revision) *Science and Public Policy*.

Paper V: Perez Vico, E., Hellsmark, H., Jacob, M., 2013. Enacting knowledge transfer: A context (in)-dependent and "role-based" typology for capturing utility from University research. Manuscript submitted to *Prometheus: Critical Studies in Innovation*.

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Contents

1. Introduction

It has long been recognised that academic research creates societal benefits (Geiger, 2006). However, perceptions vary as to what the process of generating benefits encompasses and how it unfolds. It may be tempting to apply a simple view, expecting inputs in the form of public funding to generate tangible and direct outputs. This is similar to feeding a goose, hoping it will produce golden eggs of societal use.[1] Some research policy approaches expect these eggs to primarily be utilities related to commercialisation, such as spin-off companies, patents and licences (Jacobsson et al., 2013). When these eggs are fewer than expected, the research is claimed to be insufficiently useful. The Swedish Minister for Enterprise, Annie Lööf, exemplifies this approach (Sveriges Radio, 2012, author's translation):

"In Sweden, we are very good at research but very poor at commercialisation; that is, getting bang for the buck"

However, others argue that the process of creating utilities is "complex, uncertain, somewhat disorderly, and subject to changes of many sorts" (Kline and Rosenberg, 1986 p. 275). In this sense, creating societal benefits from research is more like surfing an unpredictable ocean than feeding a goose that lays golden eggs. Just as surfing involves catching a wave at precisely the right moment by interacting with an uncontrollable ocean, creating societal benefits from research involves timing and interaction with an ever-changing society.[2] Researchers can build excellent capabilities and conduct first-class research but if the timing is wrong or the ocean goes flat, the rush, that is the utility, will be left out. Nevertheless, as new waves approach, capabilities are needed to be able to continuously respond to changes in the ocean, just as in relation to society.[3]

There has been growing interest over the past several decades in evaluating and improving the process of generating utilities from academic research (OECD, 2009). This is due to increased expectations on universities to contribute to improved global competitiveness in a rising knowledge-based economy, as well as to the introduction of

[1] This analogy is adopted from Rip (2003).
[2] This analogy is adopted from Kurzweil (2005), although he applies it to invention.
[3] This is often referred to as response capacity, i.e. the capability of academia to respond to changing societal needs (Jacobsson, 2002).

new public management ideas in research policy (Boden et al., 2006; Drucker and Goldstein, 2007). Worldwide, university managements and policy-makers have launched numerous initiatives to enhance the utility from academic research (Mowery and Sampat, 2005).

How we look upon the process of generating utilities from research will influence the tools we use to evaluate and improve it. Therefore, realistic representations of what the process of generating benefits encompasses, and how it unfolds, are needed. Failing to produce such representations may lead to misguided expectations and efforts.

It is a challenging task to produce these representations, as the process of generating utilities is "complex, uncertain, and somewhat disorderly". Thus, it may be tempting to just start counting golden eggs in the form of spin-off companies, patents and licences.

However, the limitations of this simple approach to accounting for utilities soon become apparent. Research has pointed to failures in capturing less tangible and indirect utilities, accounting for the influence from surrounding settings and considering the substantial time lags involved (e.g., Martin and Tang, 2007; Nelson and Winter, 1977; Salter and Martin, 2001).[4] These limitations point to the need to capture and explain a wide range of utilities, incorporate contextual influences and allow for an appropriate time scale. Indeed, there are studies embracing some of these aspects (e.g., Gibbons and Johnston, 1974; Mazzoleni, 2005; Saxenian, 1994), as are approaches identifying a wide range of channels, mechanisms or outputs from research (e.g., Cohen et al., 2002; D'Este and Patel, 2007; Faulkner and Senker, 1995; Meyer-Krahmer and Schmoch, 1998; Molas-Gallart et al., 2002; Pavitt, 1998; Salter et al., 2000). However, a framework that systematically accounts for all of these aspects is lacking.

A framework that appears promising in the light of these aspects is that of technological innovation systems (TIS) (Bergek et al., 2008a, b; Carlsson et al., 2002; Carlsson and Stankiewicz, 1991; Hekkert et al., 2007). It is widely used in studies of technical change. Its use has lately been explored in the research policy field (e.g., Hellsmark and Jacobsson, 2009; Jacobsson, 2002; Mohamad, 2009), although the opportunities for this field have not yet been fully exploited. The TIS framework enables a holistic analysis

[4] These arguments are further developed in Paper I.

through a descriptive systems approach that seems suitable for capturing less tangible utilities. Moreover, it focuses on key subprocesses in the development and diffusion of innovation, through which utilities may be captured and contextual influences incorporated.[5] In addition, it allows for capturing long-term and indirect utilities through the interdependences between subprocesses.

1.1. Purpose, aim and scope

The purpose of this thesis is to explore how utilities from academic research and development can be captured and explained using the TIS approach.

This purpose is addressed by constructing a framework from combining existing conceptualisations of how research creates utilities and empirically applying it in three case studies. The thesis addresses a real-world research policy issue by offering an empirically and theoretically grounded framework that, acknowledging the limits of science in representing reality, offers relevant insights for the issue.[6]

By doing so, this thesis aims to enrich the understanding and debate of the role of academic research in society, as well as support subsequent actions by beneficiaries[7] from this thesis. The main beneficiaries are found in three domains. First, this thesis aims to support sound policy-making by informing politicians and civil servants. Second, the thesis aims to support academics and university management in reflecting on, improving and communicating the utility of the research conducted at universities. Third, this thesis aims to contribute to future research in the field of TIS and research policy.

A number of features set the scope of this thesis. First, its empirical domain is engineering and natural science research. The cases cover Swedish nanotechnology research, energy and environmental research at a university of technology, and the

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[5] In earlier work, these subprocesses have been referred to as functions or merely processes. This includes some of the papers in this thesis. The term *subprocesses* is used to distinguish from other uses of the term *processes* (such as the research process).
[6] Research policy is often mentioned in relation to the adjacent and overlapping area of innovation policy. This thesis uses the term *research policy* but includes aspects of innovation policy related to the utility of academic research. Another related term is *science policy*. Research policy and science policy are seen as synonymous in the context of this thesis given that it focuses on academic research.
[7] In this thesis, the term *beneficiary* includes actors that are positively or negatively influenced by research. As the thesis shows, this influence may take many different forms such as changed perceptions or adoption of a new technology.

research of a physics professor. Therefore, its applicability for studying the domain of social science research has not yet been explored.[8] To reflect this focus, this thesis prefers the term *R&D* rather than the wider term *research*, as the latter may draw attention to a wider set of disciplines.[9] Second, this thesis is situated within innovation studies in economics, management and engineering. However, there are other perspectives to utility from academic R&D, such as sociology or history. Third, the thesis captures and explains utilities, excluding assessing their value.[10] This thesis assumes that the studied technology or knowledge fields will yield desirable societal developments.[11] Fourth, the cases in this thesis are in a Swedish setting, although it includes some international linkages. Fifth, this thesis applies a systems perspective that offers a way to understand a complex and complicated phenomenon that *cannot* be understood by subdividing it into separate components, studying these in isolation, and recombining them (Ingelstam, 2002). Thus, this thesis assumes that aggregating outputs from a set of academic R&D activities will not explain their systemic impact. Instead, the whole system needs to be understood.

1.2. The research process

This thesis continues a 20-year research tradition on the TIS concept at Chalmers University of Technology and is part of a research project conducted with Halmstad and Lund Universities (Jacobsson and Lindholm-Dahlstrand, 2006). The purpose of this larger project is to develop a methodology to trace the effects of academic R&D and understand the systemic determinants of the magnitude and character of these effects. It includes four parts: Conducting an international literature review; developing an analytical framework; conducting empirical studies; and explaining the causal mechanisms behind the patterns observed by applying an innovation systems

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[8] Some social science elements in areas such as environment and energy policy, as well as life-cycle management, are covered.

[9] For instance, criminology, linguistics and history of religion are disciplines very different from those studied in this thesis.

[10] Assessing the value of utility is complicated, as it depends on the perspectives of different stakeholders. For instance, when an academic contributes to the development of technology A, it is of positive value for an actor interested in the growth of system A. However, an actor interested in the growth of competing system B, or simply opposed to developing technology A, may perceive the value to be negative. Also, as stakeholder perspectives vary over time, so does the perceived value of the utility.

[11] This assumption is explored in the field of technology assessment and foresight studies. More recently, scholars have suggested that there are opportunities in linking the TIS framework with technology assessment (e.g., Bergek et al., 2008b; Fogelberg and Sandén, 2008; Weber and Rohracher, 2012).

perspective. As will become apparent, this thesis contributes to all four parts of the project, but is supplemented by the work of others in the project (e.g., Gabrielsson et al., 2013; Jacobsson et al., 2013; Lawton Smith et al., 2013).

As mentioned, the research process includes constructing a framework by combining existing literature and empirically applying it to three cases. Figure 1 shows an overview of the research process, including references to corresponding sections of this chapter. The two theoretical points of departure, the domains of research policy and TIS, are illustrated by rectangles. From these, the framework is constructed in four steps, illustrated as ovals. First, a taxonomy of seven activities springing from or embedded within academic R&D is compiled from a set of key references.[12] Second, the activities are linked with seven key innovation subprocesses in the TIS approach in order to understand the types of direct utilities that these activities generate by interacting with the surrounding setting. This thesis defines a utility as the impact of an activity on an innovation process. Third, indirect utilities are captured in the form of sequences of impact. These are patterns that unfold as impacts are traced by interdependences between innovation subprocesses. Finally, the individual impact patterns of researchers, or research groups, which emerge in the three first steps, are explored in a typology of seven roles and some meta-roles that researchers enact in making science useful.[13]

[12] The concept of 'activities springing from or embedded within academic R&D' captures the fact that the thesis focuses on utilities from academic R&D. The phrase 'springing from or embedded within' attempts to include activities, in addition to that of conducting research, which are relevant for creating utilities and are closely connected to conducting research. If referring to this as 'what academic researchers do' or solely 'academic activities', the reference back to academic R&D is lost.
[13] At this point, the reader might wonder about the frequent appearance of the number seven, which is why it might be of interest to know that creating lists of seven elements was not a deliberate focus.

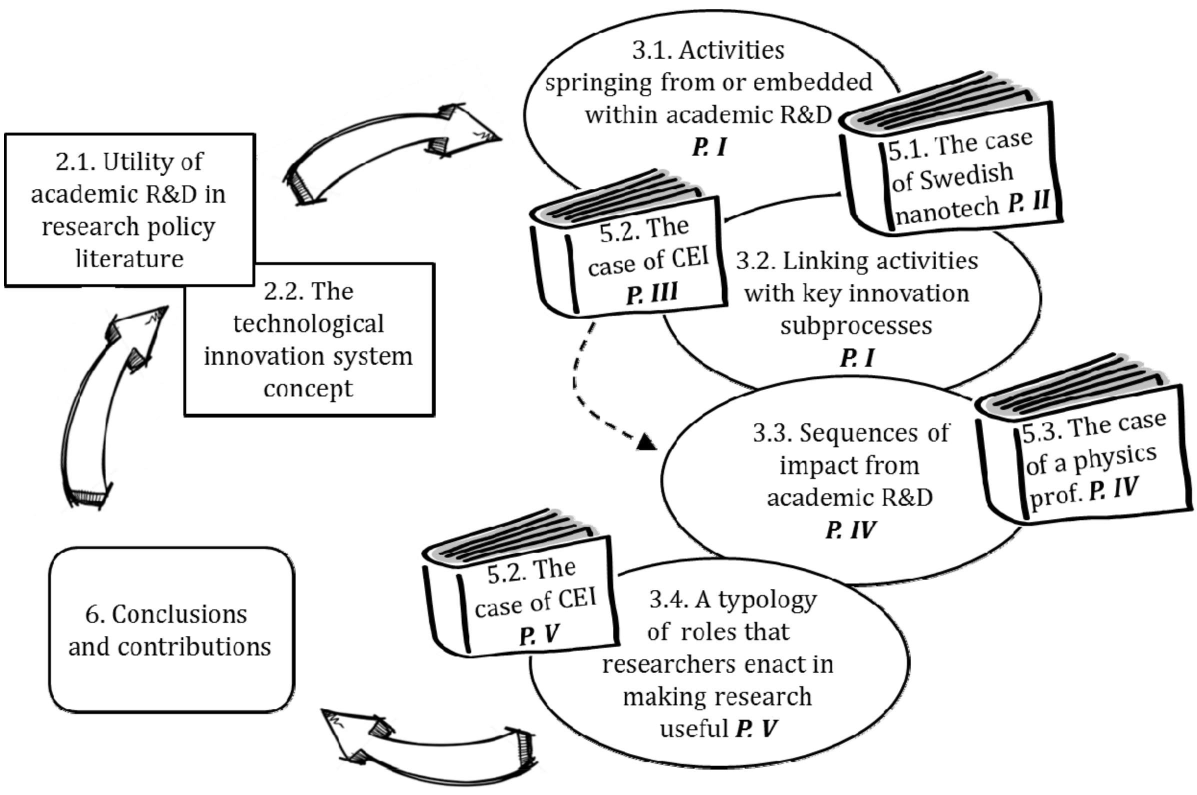

FIGURE 1. THE RESEARCH PROCESS OF THE THESIS. NUMBERS INDICATE THE CORRESPONDING SUBSECTION AND ROMAN NUMBERS IN BOLD ITALICS INDICATE THE CORRESPONDING PAPER.

Three in-depth exploratory case studies are conducted to explore and illustrate the framework. The first focusses on Swedish nanotechnology research and the second on the Chalmers energy initiative (CEI), which is a strategic research area at a Swedish university of technology. These two cases explore and illustrate the first two steps in constructing the framework: Identifying activities and linking them with TIS subprocesses. The case of CEI also illustrates some sequences of impact, which is step three in the development of the framework. The dashed arrow in Figure 1 illustrates this. The third case focusses on a physics professor, with an emphasis on illustrating sequences of impact. Finally, the CEI case illustrates the typology of roles. Figure 1 shows these cases as books placed according to the step upon which they focus.

Developing the framework has generated empirical and conceptual contributions, implications for research policy and areas of further research. This is illustrated by the rounded rectangle in Figure 1. These conclusions and contributions feed back into the two points of departure: The research policy domain and the TIS concept.

1.3. Some introductory notes on method

Many parts of this introductory chapter discuss methodological issues. Section 3 deals with issues concerned with developing the framework from existing literature. Section 4 discusses issues related to conducting case studies. Some general methodological issues related to the particular nature of the research task of this thesis are discussed below.

First, this thesis applies a qualitative research approach, which is preferred in exploratory and explanatory research (Marshall and Rossman, 2010). The thesis is exploratory because it investigates incompletely understood phenomena in a field that lacks an established theory. It is explanatory since it attempts to *explain* patterns of interaction related to utilities from academic R&D.

Second, the thesis' point of departure is a pragmatic research policy issue. Practitioners are the main beneficiaries of this work. In parallel to conducting research, the author worked as a policy analyst partly involved in the studied processes. These features are consistent with those of participatory action research, where the researcher seeks to change and improve professional practice, often as a practitioner. In line with participatory action research, this thesis aims to stay committed to the local reality, producing highly descriptive accounts of context-dependent phenomena that matter for creating appropriate policies, rather than developing theoretical, generalizable constructs (Marshall and Rossman, 2010).

Third, as the thesis concerns methodological development, it is necessary to reflect on generalizability, that is, the external validity of the developed framework in different fields and settings. This thesis develops a framework by a mixed-methods approach. It iteratively moves between combining concepts and models from established research areas and conducting descriptive empirical studies.[14] These two methods differ concerning generalizability. The thesis ties into research areas (the TIS concept and relevant research policy literature) and can be generalizable to a variety of settings where these areas are relevant (Marshall and Rossman, 2010). However, issues of generalizability of findings from the empirical studies require a bit more attention.

[14] This approach has similarities to 'systematic combining' (Dubois and Gadde, 2002).

There are two schools of thought concerning the generalizability of case studies (Eisenhardt, 1989). One is descriptive, focusing on offering rich accounts. The other is positivist, focusing on producing generalizable theory. However, there are middle grounds where varying degrees of effort are made to structure findings and assign them different constructs, which in turn may bring new insights. Indeed, rich descriptions of single cases have been proven critical to the development of even research areas dominated by positivistic methods (Flyvbjerg, 2006). Regarding the case studies in this thesis, there are motives for searching for middle grounds that lean toward the descriptive schools of thought. One motive is that this thesis concerns participatory action research. It also focuses on sociotechnical phenomena involving interaction between actors in a setting, which is highly complex and complicated. There are too many components and relationships to disentangle and break down a specific phenomenon into predetermined natural laws (Ingelstam, 2002; Marshall and Rossman, 2010; Sismondo, 2004).

The systems perspective in this thesis offers a suitable middle ground that attempts to capture complex and complicated phenomena by proposing a "way of thinking" (Ingelstam, 2002). The number and level of constructs used to capture a phenomenon need to be sufficiently detailed to give a good understanding, but still be feasible for analysis and keeping the overall big picture of the phenomenon. Unlike positivistic studies, results from a systems study do not provide direct and straight-forward answers but rather arguments that lay the ground for debate whose bearing depends on the specific situation (Sandén and Harvey, 2008). This blurs the boundary between the study and the use of its results, requiring a close interaction between researchers and practitioners. This is a key argument for participatory action research, such as in this thesis.

These arguments imply that systems studies, such as in the empirical cases of this thesis, are more transferable than generalizable. Transferability is the way in which a set of findings are "useful to others in similar situations, with similar research questions or questions of practice" (Marshall and Rossman, 2010, p. 201). The burden of proof for the applicability findings to another situation mainly falls on those making that transfer, rather than on the researcher. The burden of the researcher is to facilitate for others to see the transferability of findings by conducting a sound systems study.

1.4. Overview of the papers and their contributions

The thesis contains five papers. The roman numbers in Figure 1 illustrate how the papers deal with the different steps in the research process. Paper I is conceptual, and identifies the activities and links them to TIS subprocesses through an extensive literature review. Papers II and III apply the framework to two cases: Swedish nanotechnology research and Chalmers Energy Initiative. Paper IV introduces sequences of impact and illustrates this with a case study of a physics professor at Chalmers. Paper V introduces a taxonomy of roles that academics enact, illustrating it with data from the study of Chalmers Energy Initiative. Table 1 summarises the papers.

TABLE 1. SUMMARY OF THE PAPERS

Paper: Title and Type	Aims and Methods	Contributions to the Framework	Main Contributions (in addition to conceptual development)
I. Towards a systemic framework for capturing and explaining the effects of academic R&D *Type*: Conceptual with a literature review	To (a) Develop a framework for capturing, explaining and assessing the effects of academic R&D, and (b) Ascertain whether the strong belief in commercialisation as the key mechanism for making science useful is warranted by applying this framework to the literature. This is done by conducting a literature review that extends the TIS framework. The extended framework is then used to interpret a large body of research policy literature.	Taking the first two steps in developing the framework.	*Research policy implications*: Challenging the strong belief in academic entrepreneurship, patenting and licensing as central mechanisms for making science useful by demonstrating the multidimensional impacts of academic R&D.
II. Identifying, explaining and improving the effects of academic R&D: The case of nanotechnology in Sweden *Type*: Case study	To contribute to the literature on the impact of academic R&D by applying a development of the TIS framework (the framework presented in Paper I) to the case of nanotechnology research in Sweden. This in-depth case study is largely based on interviews and reports.	Exploring and illustrating the first two steps of the framework, as introduced in Paper I, in a case study.	*Nanotech policy implications*: The impact of academic activities is diverse and significant but constrained largely by factors beyond the influence of academia. *Research policy implications*: Illustrating the diversity of utilities and challenging the belief of poor impact of academic R&D.
III. The many ways of academic researchers: How science is made useful at a university *Type*: case study	Addressing three research questions: What patterns can be identified with respect to how science is made useful in an energy research group at a Swedish university; how can understanding these patterns improve assessment methods; and what is the relevance of these patterns to the belief of poor impact from academic R&D. The case study is largely based on interviews, but also includes a patent analysis.	Exploring and illustrating the first two steps and, to some extent, step three of the framework, in a case study.	*Research policy implications*: Contribute to the debate on the design of an evidence-based research policy with appropriate routines for evaluation and performance assessment.
IV. Tracing sequences of impact from academic R&D: An in-depth study of a professor in physics *Type*: Conceptual with an illustrating case study	To trace and characterise sequences of impact from academic R&D, as well as contribute to developing a methodology for capturing these impacts. This is mainly an interview-based, in-depth case of a professor.	Extending the framework in Paper I with a third step and illustrating it with a case study.	*Research policy implications*: *E*mphasising the importance of accounting for sequences of impact, using a decades-long time scale to understand the full effects of academic R&D.
V. Enacting knowledge transfer: A context dependent and 'role-based' typology for capturing utility from university research *Type*: Conceptual with illustrating cases	To provide insights into how academics make knowledge useful by introducing a typology of roles that researchers enact in enacting knowledge. This is achieved by building on the framework in Paper I and using two of the in-depth case studies included in Paper III.	Extending the previous three steps in the framework with a fourth step and illustrating it in two case studies.	*Research policy implications:* Publication performance and ex ante demand for relevance is insufficient to predict and promote utility. Understanding interactions and complementarities between different researchers or research group, as well as between them and the surrounding system, is central for understanding the utility.

1.5. Outline of the introductory chapter

As Figure 1 shows, Section 2 elaborates on the conceptual points of departure. Section 3 develops the analytical framework of this thesis in four steps. First, the activities are introduced (3.1), followed by their inclusion into the TIS framework (3.2). The concept of sequences of impact is introduced (3.3) and the section ends with the typology of the seven roles and meta-roles that researchers enact in making research useful (3.4). Each subsection in Section 3 includes the corresponding method used to take the step. Section 3 ends by explaining the multidimensional, dynamic, context-dependent aspects of the framework (3.5). Section 4 discusses the methods used in the empirical studies, while Section 5 presents the empirical findings, including conclusions with respect to empirical patterns (5.4), as well as reflections on the viability of the framework for studying academic utility (5.5). Section 6 concludes this introductory chapter of the thesis and discusses empirical contributions (6.1), conceptual contributions (6.2), implications for policy (6.3) and areas of further research (6.4).

2. Points of departure

This thesis has two points of departure: The research policy literature addressing the utility of academic R&D and the TIS literature. This section briefly outlines these to explain the background of the issues this thesis attempts to address and to introduce the foundations of the developed framework.

2.1. Utility of academic R&D in research policy literature

As early as 1776, Adam Smith recognised the role of research in societal development when introducing the concept of division of labour:

"[I]mprovements [in machinery] have been made by […]those who are called philosophers or men of speculation, whose trade it is not to do any thing, but to observe every thing; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects. In the progress of society, philosophy or speculation becomes, like every other employment, the principal or sole trade and occupation of a particular class of citizens" (Smith, 2007, p. 15).

Ideas during the Industrial Revolution were consistent with Smith, as research and technological progress were assigned prominent roles (Pålsson Syll, 1998).

Contemporary to the Industrial Revolution, Karl Marx included science in the economic system and recognised it as a significant contributor to productivity growth (Marx, 2001).

Despite these early recognitions in classical economics, the focus by the end of the 19th century was on explaining growth through allocation of capital, labour and land. This was a consequence of the diffusion of so called neoclassical economics (Ayres, 1988). Science and technological progress were considered exogenous to the economy and neglected. Science was perceived as objective and infallible, and was expected to be driven by curiosity and the quest for excellence, unrestricted by society's transient needs (Boden et al., 2006).[15] Consequently, there was little interest in exploring the contribution from science to societal development.

In parallel, the economist Joseph Schumpeter questioned the neoclassical ideas and combined economics, sociology and history to study the role of innovation in economic and social change (Fagerberg and Verspagen, 2009). Inspired by Marx, Schumpeter argued that innovation and technical progress are endogenous to the economy and significant for growth (Schumpeter, 2008). Nevertheless, he assigned science a less prominent role than that of innovation.[16] Despite Schumpeter's lifelong advocacy for innovation as a driving factor for growth, his influence was weak when he died in 1950 (Fagerberg and Verspagen, 2009).

However, the 1950s brought the rediscovery of the importance of science and technical progress for societal development. Neoclassical growth theorists showed that growth in productivity was largely due to technical progress by introducing growth accounting. This explored relationships between aggregate inputs, which included science and technology, and outputs (Pålsson Syll, 1998). In parallel, academic contributions to innovations during WWII and the Cold War, such as nuclear physics to the Manhattan project, spurred policy expectations for science to lead to technological supremacy (Fagerberg and Verspagen, 2009; Geiger, 2008). The famous science bureaucrat Vannevar Bush compared science with 'an endless frontier' of opportunities,

[15] This view on academia corresponds to the 'mode 1' knowledge production in Gibbons et al. (1994).
[16] Schumpeter distinguished between invention, an act of intellectual creativity, and innovation and diffusion which were economic acts. He established that innovation does not necessary include invention, and that invention may include the development of scientific knowledge, but does not necessarily do so.

emphasising its large potential for bringing benefits (Godin, 2006). These expectations led to a wave of generous, publicly funded, large-scale science projects. Advocates continued, though, to claim the infallibility of science, and research funding was implicitly assumed to automatically provide societal benefits (Rip, 2011). The focus was on a technology push; feeding the goose and waiting for it to lay golden eggs.

Despite these rediscoveries, the dominant view of how research was useful assumed that basic research feeds into applied research and development, which in turn feeds innovation, production and diffusion as a linear one-way process (Godin, 2006). This implies that (a) research only plays a role in an initial phase as input to innovation, (b) there is no feedback between research and other parts of the process and (c) specific volumes of high-quality research (input) automatically result in corresponding volumes of invention and innovation (output). This linear view largely justified government support of science and is still, to various degrees, held by many scientists and policy-makers (Gibbons et al., 2011).

Nevertheless, the rediscoveries created a need for a deeper understanding of how science was made useful, setting off a revival of Schumpeter's ideas (Fagerberg, 2003). Many started to study innovation and technical change as endogenous features of the economy (e.g., Levin et al., 1987; Nelson and Winter, 1977; Schmookler, 1966). Criticisms of the linear view of innovation were raised (Godin, 2006). A well-known example is that of Kline and Rosenberg (1986), who introduced the chain-linked model of innovation, which shifted the focus from science to innovation and emphasised the interactive and continuous role of research as one of many constituents in a process that included numerous feedbacks.[17]

Boden et al., (2006) suggest that the 1970s brought new influences to the research policy scene. First, a shift in perceptions occurred from science as objective to relativistic, which questioned the prior infallible view of science. Second, science was expected to contribute to economic well-being and competitiveness mainly through direct links to commercialisation processes. Third, new public management ideas were introduced into research policy, declaring that modern states were failing because of

[17] This presents an extended view on the role of research that also includes linear-model cases where research may well only be an input to innovation.

their unmanageable size and unjustifiable resource consumption. The answer was to downsize the state and allow markets to run free. Also, new public management demanded measurable results.

As a consequence, political interests shifted to schemes that directly linked science to societal needs (OECD, 2012). The focus on utilities related to commercialisation (such as spin-off companies, patents and licences) increased, and so did the call for performance and output measurements (Jacobsson et al., 2013). Much attention was given to growth accounting, largely building on the linear model (input and output indicators). Although the limitations of this type of measurement were acknowledged early on (Nelson, 1964), it was rooted in the measurement standards of influential organisations such as the OECD and the EU (Godin, 2006). This narrow focus on measurements and commercialisation was one of the factors stirring a widespread belief that publicly funded research in Europe was insufficiently useful compared to research in the U.S. (Jacobsson et al., 2013).[18] This is often framed as a paradox; a strong science base or extensive research funding is not transformed into economic growth. In other words, there are too few golden eggs. Although many have pointed to weaknesses in the assumptions that make up this belief and to the lack of empirical evidence, it has prevailed. The persistence of this belief is one of the factors that motivate this thesis.

The current effort of policy to link science to societal needs, increase the commercialisation of research and develop measurements of performance has attracted the interests of many scholars in economics, sociology, history, anthropology and management. This has paved the way for an extensive set of multidisciplinary, closely related, largely overlapping topics of relevance to this thesis. The central ones are discussed below.

A first concept is that of *technology transfer*. It grew out of considerably policy interest in crossnational and domestic transfer of technology, which also came to include that between universities and industry (Bozeman, 2000).[19] In line with this thesis, Bozeman

[18] This belief has also been articulated in the case of Sweden.

[19] Technology transfer concerns a subset of utilities from academic R&D, but covers additional aspects out of the scope of this thesis. The interest in the concept peaked around the turn of the century. A quick search in Scopus (www.scopus.com) shows that publications on this concept have declined since 2008.

(2000) concludes that technology transfer includes numerous concurrent processes and that its impacts often are varied and difficult to separate from other influences.

A second concept is *university-industry relations*. Studies have explored the nature and benefits of interactions between universities and industries (e.g., Hughes, 2006; Laursen and Salter, 2004; Mansfield, 1998; Saxenian, 1994; Scott et al., 2001), and the determinants for such interactions (e.g., D'Este and Patel, 2007; Mansfield, 1995). Several taxonomies have been presented (e.g., Bonaccorsi and Piccaluga, 1994; Cohen et al. 2002; Faulkner and Senker, 1995; Meyer-Krahmer and Schmoch, 1998). The literature on university-industry relationships overlaps extensively with the concepts of *academic engagement*, which Perkmann et al. (2013, p. 424) define as "knowledge-related collaboration by academic researchers with non-academic organisations," and *third-stream activities* which mainly concerns the "generation, use, application and exploitation of knowledge and other university capabilities outside academic environments" (Molas-Gallart et al., 2002, p. 2).

A third concept is that of *university entrepreneurship* or *academic commercialisation*, which has been given more scholarly atention than academic engagement (Perkmann et al., 2013; Rothaermel et al., 2007). Research focuses on universities as entrepreneurial organisations (e.g., Bramwell and Wolfe, 2008) or the creation and impact of academic spin-offs (e.g., Lindholm Dahlstrand, 2008; Shane, 2004). Academic commercialisation is an outcome or subset of the wider concept of academic engagement (Perkmann et al., 2013).

A fourth concept is found within the *research evaluation* literature. It studies the societal and economic impacts of academic R&D, using econometrics, surveys and case studies (Salter and Martin, 2001). Some scholars have focused on evaluating the capacity of specific research programs to achieve social goals (e.g., Bozeman and Sarewitz, 2011), while others focus on the nature and extent of benefits from research in general (Martin and Tang, 2007; Pavitt, 1998).

Fifth, the concepts of *modes of knowledge production* (Gibbons et al., 1994) and the *triple helix* (Etzkowitz and Leydesdorff, 2000) focus on the roles of universities in knowledge production that include cooperation with industry, policy and society at large. These link academia to larger societal needs.

Innovation systems is another concept. Drawing on Schumpeter's ideas, it embraces the view of research as a continuous, interacting part of a systemic process of innovation and diffusion. The innovation systems concept focuses on the interaction and on how it is conditioned by social, institutional and political factors (Fagerberg and Verspagen, 2009). The concept has been applied using national, regional, sectoral and technological scopes. The national innovation system (NIS) concept is acknowledged by policy actors such as the OECD and the UN (Sharif, 2006). The pioneers were Freeman (1987; 1994), who focused on the interaction between science, technology, innovation and growth, and Lundvall (2010a), [20] who emphasised the importance of the interactive processes of learning between actors. Although the NIS concept emerged from empirical attempts to describe national characteristics, later developments focused on theoretical elements (Lundvall, 2010b). However, these developments are not centred on searching for general theories, but on capturing real-life societal phenomena (Fagerberg and Verspagen, 2009). The regional innovation system concept focuses on geographical definitions (e.g., Asheim and Coenen, 2006), and the sectoral innovation system concept is defined around an industry or sector (e.g., Breschi and Malerba, 2013). Our attention now turns to the technological innovation system.

2.2. The technological innovation system concept[21]

The TIS concept shares many intellectual points of departure with other innovation system concepts, such as the use of ideas from systems theory and evolutionary biology to understand phenomena in social systems (Carlsson et al., 2010; Fagerberg, 2003; Ingelstam, 2002). The TIS concept emerged during the 1980s out of a critique against growth accounting schemes, a sense of economic crisis that included concerns about Swedish competitiveness and strong links between policy-makers, practitioners and scholars (Carlsson et al., 2010; Sharif, 2006).[22] The concept was an outcome from a policy initiated Swedish research project that brought together a group of scholars from the fields of economics, engineering, management and sociology (Carlsson et al., 2010). Consequently, the TIS concept has diverse intellectual foundations. In addition to the aforementioned influences shared with the NIS concept, inspiration came from

[20] The original version of this book was published in 1992.
[21] This subsection largely draws from Subsection 2.1. in Paper IV.
[22] Although the NIS approach developed out of similar circumstances, the NIS and TIS approaches developed rather independently.

Dahmén's work (1988) on 'development blocks,' which emphasised the dynamic nature of economic development and the importance of understanding entrepreneurial activities at the microlevel. Another contribution came from the 'network school' of industrial marketing. This microlevel approach contributed to the central networks aspect in systems thinking by emphasising the importance of long-term relationships that included learning, confidence and trust (Håkansson, 1989).[23] The TIS concept linked microlevel activities to macrolevel impacts by drawing on microperspectives to understand the mesolevel processes that underpin macroeconomic growth.

In contrast to the NIS approach, the TIS concept takes into account factors that are unique to a knowledge field. In the TIS concept's early development stages, it became clear that although national-level features were significant, diverse technological areas included different settings and dynamics (Carlsson et al., 2010).[24] Consequently, a TIS is delineated around a knowledge field (such as nanotechnology) or product (such as wind turbines) and includes an interacting group of components (Bergek et al., 2008a; Bergek et al., 2008b; Sandén et al., 2008). These components are actors (such as firms or universities), the technology (such as artefacts or coded and embodied knowledge), institutions (legal and regulatory aspects, culture and beliefs) and networks (such as political or learning networks). These structural elements, with exogenous factors such as financial or environmental crises, shape system dynamics. The distinction between a system's endogenous components and exogenous factors is gradual, from a truly exogenous event such as a natural disaster to endogenous elements deeply interwoven through numerous feedback loops. Given a set time scale, endogenous elements have a more intense circular interaction (feedback), while exogenous factors have minor circular interaction (Markard and Truffer, 2008; Sandén et al., 2008). Nonetheless, the one-way influence from an exogenous factor on a TIS may be substantial.

To gain a better understanding of TIS dynamics, the 'functional dynamics' of TIS approach was developed, building on a scheme of key subprocesses in the larger process

[23] A related and influential perspective for TIS was the aforementioned interactive processes of learning (Lundvall, 2010a).

[24] An adherent concept to sectorial, regional and technological innovation systems is that of business clusters (Porter, 1998). These business or industry clusters include business co-location and underlines the importance of economic geographic aspects, such as localized knowledge flows, relationships, networks and incentives, for gaining global competitive advantages. These systemic aspects are well in line with the core ideas in the innovation systems concept.

of innovation and diffusion (Bergek et al., 2008a, b; Hekkert et al., 2007; Jacobsson and Bergek, 2004; Johnson and Jacobsson, 2001). This thesis uses a slight modification of this approach, focusing on the subprocesses (or functions) in Bergek et al. (2008a).[25]

TABLE 2. KEY SUBPROCESSES OF INNOVATION

Influence on the direction of search is the process by which new actors are attracted to, and directed within, a system by visions, perceived growth potential, policy incentives, technical breakthroughs/bottlenecks, requirements from leading customers or business crises.
Legitimation is a process influenced by sociopolitical actions creating acceptance and attractiveness for a technology, application or industry. This implies overcoming liability of newness and acquiring political strength.
Market formation includes the development process of niche, bridging and mass markets. This evolves as customers articulate their demand or as companies introduce market-changing products.
Entrepreneurial experimentation includes the development of new opportunities and applied knowledge by testing new concepts, applications and markets. It implies materialisation of knowledge, such as developing new products, processes or organisational forms.
Resource mobilisation relates to financial and human capital, as well as complementary assets.
Knowledge development and diffusion includes creation, diffusion and combination of knowledge in the system.
Social capital development is the process by which social relations are created and maintained. These relations include trust, dependence, mutual recognition, authority and shared norms. This process enables system-level activities, such as the build-up of networks and collective actions.

Elaboration on Bergek et al. (2008a) and Paper I, presented in Paper IV.[26]

These subprocesses describe how the system works. For example, increased *legitimation* of a technology, such as solar cells, through new regulations and the climate-change debate, may *influence the direction of search* of an actor that then enters the field. This may extend networks, paving the way for *social capital development*. The networks may *develop and diffuse* new *knowledge* that leads to a technological breakthrough which subsequently creates expectations and *influences the direction of search* of new actors that are attracted to the field.

[25]The modification concerns the subprocess *development of positive externalities*, which is replaced with *social capital development.* This is because *development of positive externalities* works largely through other subprocesses. For instance, it includes the development of pooled labour markets and knowledge spillovers that are aspects of human *resource mobilisation* and *knowledge development and diffusion*. However, it also includes networking aspects not covered by other subprocesses. These are included in *social capital development*, which is presented in Paper IV.

[26] This elaboration is also presented in Paper III, but since Paper IV was produced first, the elaboration in Paper IV is more detailed.

This TIS approach has been used to study the development and diffusion of new technologies, with a strong focus on energy, over the past decade. The emphasis was on understanding challenges for system growth in terms of weaknesses that may be explained by specific blocking mechanisms within or outside the system. These blocking mechanisms may guide policy that aims to support a specific technology.[27]

Recently, the TIS approach has been utilised in the domain of research policy to study the role of academia in the dynamics of specific technological fields. For example, Hellsmark and Jacobsson (2009) illustrate how an Austrian professor conducting research on gasified biomass strongly influenced *resource mobilisation*, *entrepreneurial experimentation* and *knowledge development and diffusion*. This resulted in an extensive build-up of the national technology base and knowledge networks, for which Austria gained international recognition. Mohamad (2009) gives another example by showing how two Singaporean universities pioneered in the area of fuel cells, *developing* a *knowledge* base and *mobilising* human *resources* that were essential for the innovation system. Researchers also extensively engaged in networking activities and participated in diverse advisory boards and panels that strengthened *legitimation* and *influenced the direction of search* of policy and industry.

These examples illustrate how academia influences subprocesses of innovation and, therefore, contribute to system dynamics. This thesis will now explore how TIS can be extended to study the academic utilities from academic R&D.

3. A framework for capturing and explaining utilities from academic R&D

This section introduces the extension of the 'functional dynamics' of TIS that the framework of this thesis encompasses. The extension is made in four steps, which are presented in corresponding subsections. Figure 2 shows the complete framework. It includes the structural elements, subprocesses and exogenous factors from the TIS approach, and the extended parts with corresponding subsections.

[27] Bergek et al. (2008a) offers a scheme for analysing functional dynamics of technological innovation systems where identifying blocking mechanisms is a final step. This step was included in the analysis in Paper II.

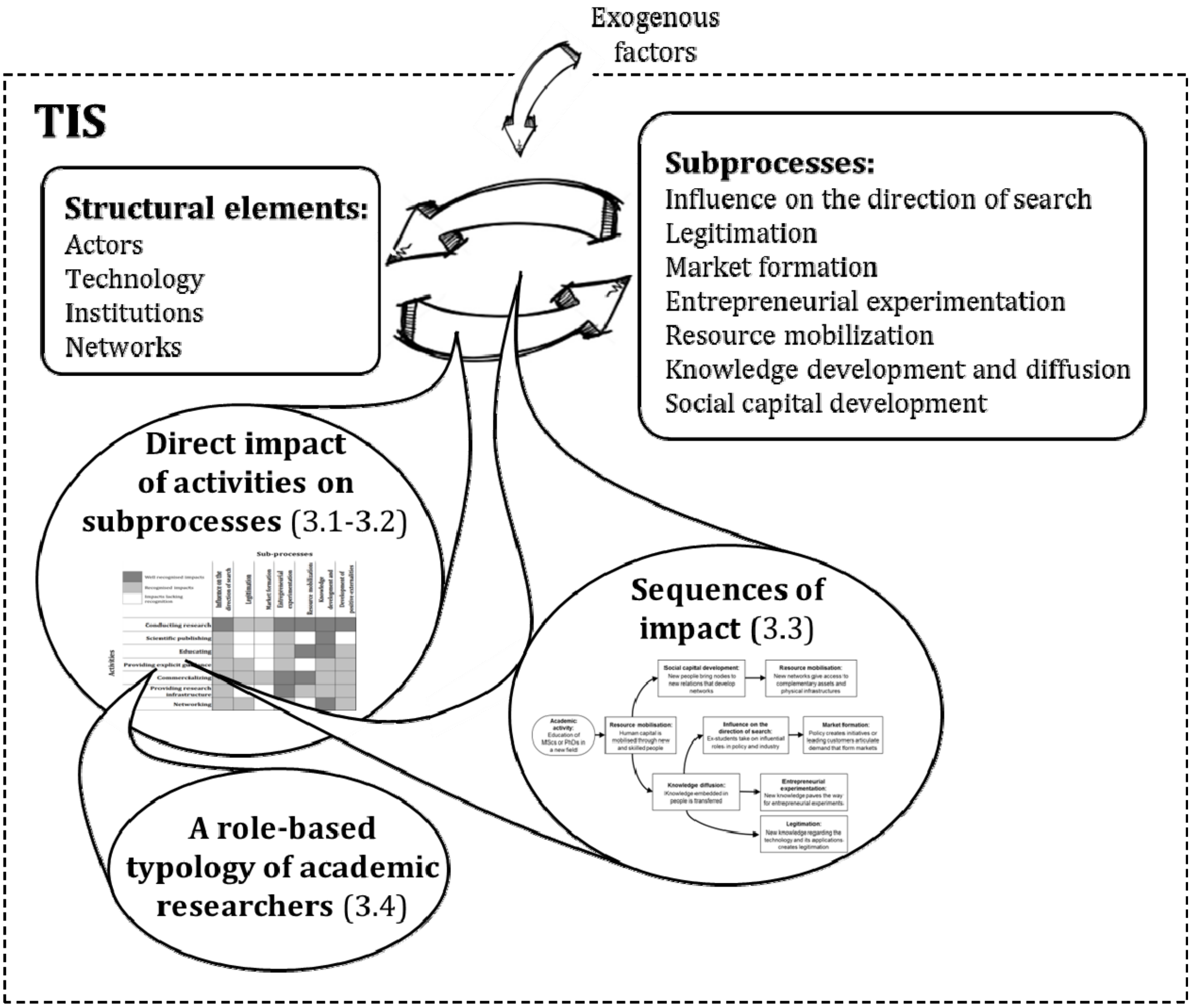

FIGURE 2. THE FRAMEWORK OF THE THESIS: THE 'FUNCTIONAL DYNAMICS' OF TIS EXTENDED WITH THE IMPACT OF ACTIVITIES ON SUBPROCESSES, SEQUENCES OF IMPACT AND A ROLE-BASED TYPOLOGY. NUMBERS INDICATE CORRESPONDING SUBSECTIONS.

The first step specifies activities springing from or embedded within academic R&D and the second links these activities with the key innovation subprocesses in a TIS, establishing direct impacts. These two steps focus on academia's particular contribution as an actor (structural element) to the subprocesses. This is illustrated by the horizontal right arrow. The third step introduces sequences of impact, captured by tracing how impacts from activities are diffused through interdependencies between subprocesses (both horizontal arrows). This thesis defines utilities as the impact of an activity on a subprocess, including indirect impacts transmitted as interdependencies between subprocesses. The fourth step develops a role-based typology of researchers, drawing on their activities.

Before continuing with these steps, the system delineation in this framework deserves some attention. The point of departure is academia (an individual or a group of individuals) and its activities. From these, one or several innovation processes are identified, defined around a set of technologies or knowledge fields of potential relevance to the activities. The innovation processes delimit the TIS in which the role of academia is studied. Academia is one of the actors within a TIS if the feedback with the rest of the system is significant. However, academia could be exogenous to a TIS if its activities were just inputs that influenced a system which in turn did not influence academia. In this case, the view of the role of academic R&D in the innovation process resembles that in the linear innovation model. Nevertheless, in this case, the utilities from academic R&D can still be studied through their impact on the TIS.[28]

3.1. Activities springing from or embedded within academic R&D[29]

As mentioned in Section 2.1, the research policy interest in assessing academic research utility has allowed scholars to develop various frameworks. From these, a set of key references were selected from an extensive literature review (Cohen et al., 2002; D'Este and Patel, 2007; Faulkner and Senker, 1995; Jacobsson, 2002; Meyer-Krahmer and Schmoch, 1998; Molas-Gallart et al., 2002; Pavitt, 1998; Salter et al., 2000). However, most of these focus on products or outcomes of academic R&D (such as papers, patents and artefacts), which risks treating the process of generating utilities as a 'black box.'[30] Indeed, reviews of research evaluations (e.g., Salter et al., 2000; Elg and Håkansson, 2011) show that individuals' capacity, or knowledge and skills, is a key element of the utility from academic R&D. To open the black box, it is necessary to distinguish between activities (what academic researchers do) and the impact of these activities. Drawing on the literature, seven groups of activities were identified (see Table 3).[31] Combinations and variations of these constitute everyday life for academic researchers.

[28] As noted, Figure 2 only illustrates academia as an endogenous system element. The figure is a simplification to keep a good overview of the framework.
[29] This subsection mainly draws from Subsection 3.1 in Paper I.
[30] The exceptions were Molas-Gallart, et al. (2002), which focused on 'third stream activities' and D'este and Patel (2007), which focused on 'university-industry interaction activities'.
[31] This typology of activities includes all aspects given in the eight references. However, none of the references covers all the presented activities.

TABLE 3. A TYPOLOGY OF ACTIVITIES SPRINGING FROM OR EMBEDDED WITHIN ACADEMIC R&D

Conducting research in different set-ups, such as by joint R&D projects or contract research and intra-academic research projects.

Scientific publishing refers to the academic form of diffusing information through papers, books and reports, including related tasks such as reviewing and editing.

Educating includes undergraduate, masters and PhD student training, as well as collaborative and contract training for policy and industry.

Providing explicit guidance to policy and industry involves formal and informal consultations and assignments, such as participation in advisory boards and informal advisory work. Guidance also includes participation in public debates by publishing in nonscientific publications, media appearances and by giving public seminars. Guidance may also be given within the research community.

Commercialisation refers to the creation of new firms, patents, licences, products, processes and services.

Providing research infrastructure involves developing and maintaining instruments, laboratories, clean rooms, libraries, engineering designs and methods, as well as research methods.

Networking refers to creating and maintaining networks. It is an integral part of academic activities and is, for instance, performed through organising and participating in collaborative research, conferences and seminars involving both academic and nonacademic actors.

3.2. Linking activities with key innovation subprocesses[32]

To understand the types of direct utilities that the activities may generate, they are linked to the seven key subprocesses.[33] This generates a 7x7 matrix of hypothetical utilities,[34] as shown in Figure 3.

[32] This subsection mainly draws on Subsection 3.2 in Paper I.
[33] Jacobsson (2002) introduced the idea of linking academic R&D utilities to key subprocesses of innovation. Mohamad (2009) compared each of the TIS functions in Bergek et al. (2008a) with the 'impacts on innovation by universities' (Salter et al., 2000), although one impact was only linked to one function.
[34] Utilities are labelled 'points of impact' in Paper I.

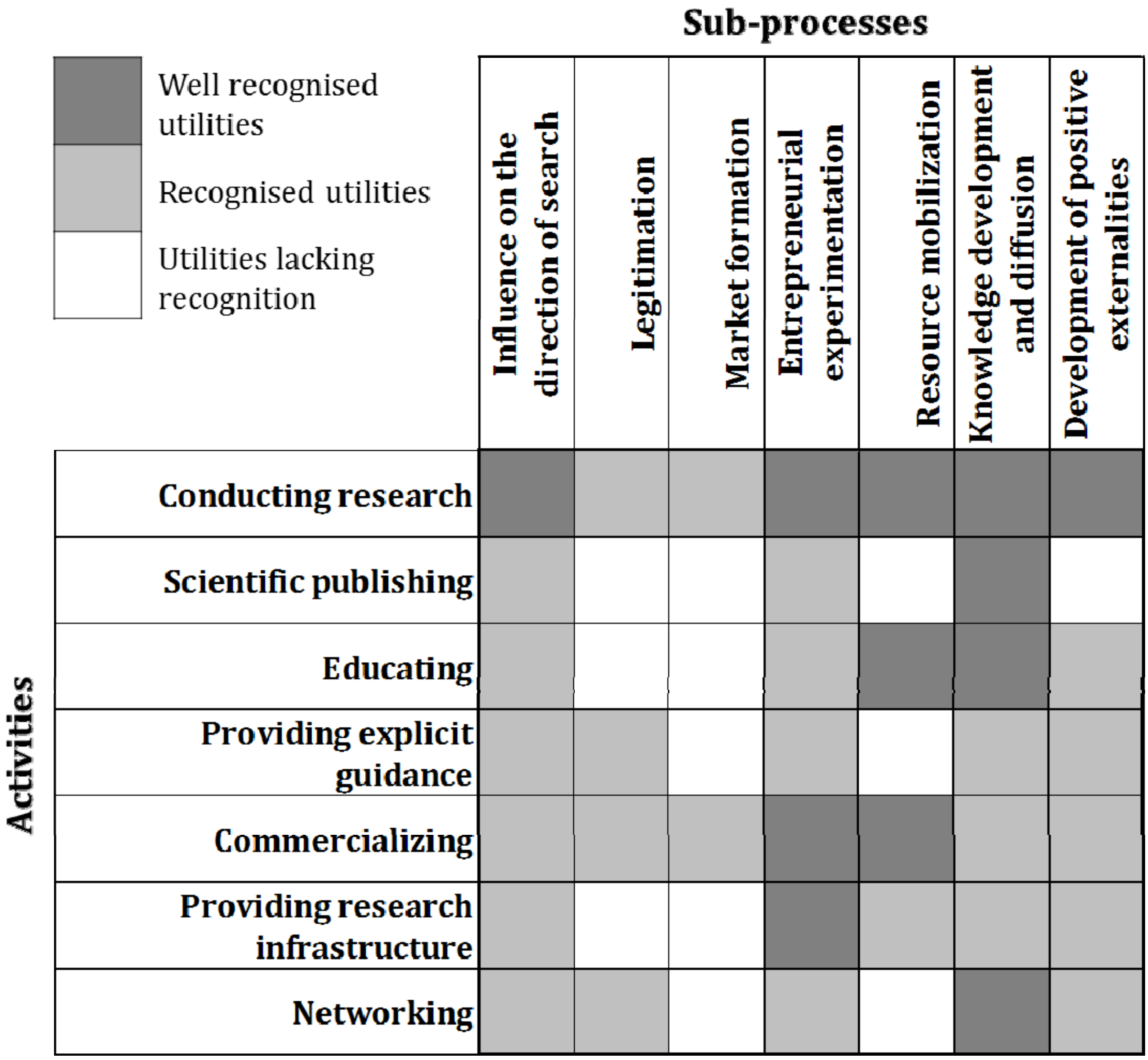

FIGURE 3. MAPPING DIRECT UTILITIES FROM ACADEMIC R&D ACTIVITIES ON THE SUBPROCESSES OF INNOVATION. ADOPTED FROM PAPER I. HYPOTHETICAL UTILITIES WERE CHECKED AND CLASSIFIED AS WELL RECOGNIZED (MORE THAN 10 REFERENCES), RECOGNIZED (1–10 REFERENCES) AND LACKING RECOGNITION (NO REFERENCES).[35]

Each square in the matrix represents a hypothetical utility from an activity. For example, by doing research and transferring the new knowledge to MSc students, academia influences *knowledge development and diffusion*. Academia may participate in public debates, which *legitimises* a technology, or start a new company, influencing

[35] The subprocess of *development of positive externalities* appears instead of *social capital development*. This is because the replacement of the former with the latter was made in a later stage of the research process. Consequently, the analysis presented in this subsection, as well as that in Paper I, includes *development of positive externalities* instead of *social capital development*. As a reminder, *social capital development* includes many of the aspects in *development of positive externalities*. Please see footnote 25 for further implications of the replacement.

entrepreneurial experimentation. The *direct* impact of academia is understood by its initial influence on the development of these subprocesses.

An extensive literature review was conducted in order to discover the extent to which these hypothetical utilities have been recognized. This covered a broad range of relevant fields, such as 'impact assessment', 'innovation systems', 'university-industry relations' and 'the role of universities in economic growth'. There were three points of entry into this literature. First, a set of articles covering a range of impacts were identified (Cohen et al., 2002; Jacobsson, 2002; Mansfield, 1995; Mohamad, 2006; Molas-Gallart et al., 2002; Salter and Martin, 2001). Second, databases were searched using relevant key words.[36] Third, references were retrieved from fellow researchers' recommendations. From these initial references, relevant citations were traced which were followed until a substantial part of the literature re-occurred. This resulted in 74 references.

Each hypothetical utility was given a recognition level according to the number of references that identified it: Lacking recognition (no references), recognized (one to 10 references) and well recognized (more than 10 references).

Thirty-seven of 49 hypothetical utilities were recognized in the literature, revealing multidimensional ways in which academic R&D is useful.[37] As seen in Figure 3, *knowledge development and diffusion*, *resource mobilisation* and *entrepreneurial experimentation* were impacted by several activities. However, the subtle, but important subprocesses of *influence on the direction of search, legitimation* and *development of positive externalities*[38] were also recognized as being impacted by many activities.

3.3. Sequences of impact from academic R&D[39]

The previous subsection focused on direct utilities, but academia's impact may also be indirect. For instance, a researcher's networking activities, such as close cooperation with industry, may initially directly impact *knowledge development and diffusion*.

[36] Examples of keywords are: Impact of academic R&D, research assessment, effects, U-I relationships, societal impact, and innovation system. The main data base used was Science Direct. Others were JSTOR and the Chalmers University of Technology library databases.
[37] These figures should not be seen as exact, given methodological limitations.
[38] The subprocess *development of positive externalities* is a remnant from earlier versions of the framework. As a reminder, *social capital development* includes many of the aspects in *development of positive externalities*. Please see footnotes 25 and 35 for further explanations.
[39] This subsection mainly draws on Subsection 2.2 in Paper IV.

Industry may then utilise the new knowledge in *entrepreneurial experimentation*. Subsequently, these experiments may be ground-breaking, paving the way for the *development* of new *markets.* In this way, sequences of impact unfold. A sequence of impact is the pattern of impact from an actor (in this case, academia) that unfolds through cumulative interactions within a system. Sequences of impact can be captured through the interdependences between innovation subprocesses. Bergek et al. (2008a, b), Hekkert et al. (2007), Jacobsson and Bergek (2004) and Suurs (2009) establish such interdependences. Sequences of impact build on two assumptions in TIS literature: Actors may affect the development of innovation subprocesses; and these subprocesses are interdependent.

Moreover, the chain-linked model of the innovation process (Kline and Rosenberg, 1986) recognises the continuous role of research, as well as the feedback between research, existing knowledge and the central chain of innovation. The model illustrates complex information flow paths and cooperation in line with the concept of sequences of impact. In this innovation process, academia may produce knowledge through research and establish links between research, existing knowledge and innovation, not just in the initial phase, but in later phases or throughout the process.

Bergek et al. (2008a, b) trace subprocess interdependences via structural changes, as illustrated by the two horizontal arrows in Figure 2. For instance, a strengthened legitimation (subprocess) may lead to the entry of new actors (structure) bringing new resources into the TIS (subprocess). Capturing sequences through both structural change and subprocesses provides a solid understanding of dynamics but is extremely complex to show. This complexity may be reduced by focusing primarily on process-to-process interdependencies. Hekkert et al. (2007) and Suurs (2009) establish interdependences through 'leads-to' relationships between events (in other words, what subjects do or go through that are important to a TIS).[40] Events are aggregated to the subprocess level and the leads-to relationships between events make up subprocess interdependencies. Academic R&D activities can be considered events. Figure 4 gives an example of how sequences of impacts can evolve in relation to an academic activity.

[40] Examples of events are policy initiatives, initiation of research programmes and company start-ups.

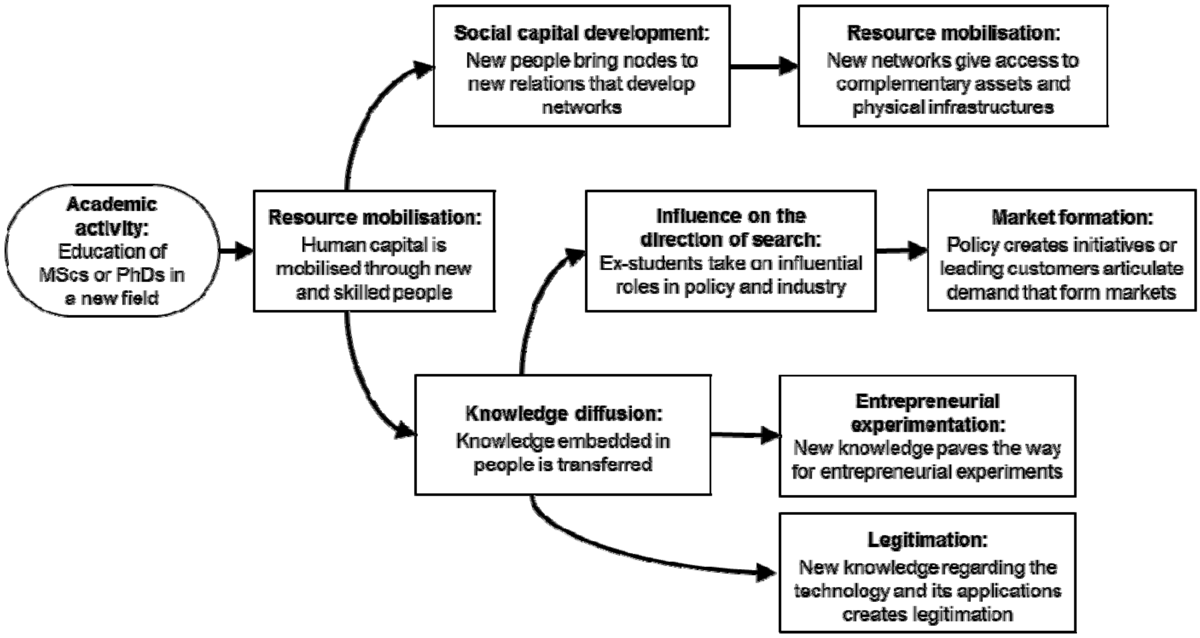

FIGURE 4. AN EXAMPLE OF A SEQUENCE OF IMPACT RELATED TO A SINGLE ACADEMIC ACTIVITY.

An educational activity initially *mobilises resources* in the form of individuals. These carry *knowledge* that may *influence the direction of search* as they become policy-makers or industrial managers. Subsequently, these influential individuals may *form markets* by launching demand-creating policy initiatives or leading as customers. New knowledge may also pave the way for *entrepreneurial experiments* and *legitimation*. In parallel, the initial *resource mobilisation* may induce *social capital development* as new individuals bring new relationships, providing access to complementary assets and infrastructure that may strengthen *resource mobilisation* further. In addition to the initial activity, academia may recurrently strengthen these processes directly through other activities. In this manner, sequences may evolve through subprocess interdependencies, making up a multidimensional pattern of impact.

3.4. A typology of roles that researchers enact in making research useful[41]

This step is largely a reorganisation of the first two steps that further *explains* utilities. Evaluating and improving academic utility is often done with regard to the particular researcher or research group who shows different patterns of utility that depend upon the context. Also, the utility of researchers or research groups depends on their

[41] This section draws on Section 4 in Paper V.

interaction with other researchers or research groups. There are thus complementarities.

The empirical exploration of the three first steps of the framework reveals variations with regard to activities that researchers or research groups focus upon, complementarities with other researchers or actors, and the resulting utility. These variations distinguish different roles. The roles are defined in terms of the emphasis of an actor (a researcher, a group of researchers or an entire organisation) on the combination of activities and subactivities.[42] Also, reflecting on utility in terms of roles allows for understanding complementarity between different researchers or research groups.

A typology of seven roles in making science useful is generated: *Researcher*, *teacher*, *advisor*, *debater*, *networker*, *infrastructure developer* and *entrepreneur*. The roles are cognitively distinct, since the knowledge and skills required to fulfil them vary, depending on the particular role**.** Table 4 shows the roles, together with related activities, subactivities and corresponding subprocesses that the roles mainly affect.

[42] Roles may be clustered in different ways. The offered clustering has an appropriate resolution for good overview with sufficient level of detail. Empirical exploration of the roles confirmed the suitability of this clustering. The subactivities are presented in Paper I.

TABLE 4. SUMMARY OF THE ROLES OF RESEARCHERS, RELATED ACTIVITIES/SUBACTIVITIES AND THE MAIN SUBPROCESSES IMPACTED, ADOPTED FROM PAPER V.

Role *Activity* (sub-activity)	**Main subprocesses impacted**[43]
Researcher *Conducting research/ Scientific publishing*	Influence on the direction of search Knowledge development and diffusion Entrepreneurial experimentation Social capital development
Teacher *Educating*	Influence on the direction of search Resource mobilisation Knowledge development and diffusion Social capital development
Advisor *Providing explicit guidance* (participation in policy/industry boards, informal advisory and consultation)	Influence on the direction of search Legitimation Entrepreneurial experimentation Knowledge development and diffusion
Debater *Providing explicit guidance* (participation in public debates)	Influence on the direction of search Legitimation Knowledge development and diffusion
Entrepreneur *Commercialisation*	Influence on the direction of search Market formation Entrepreneurial experimentation Materialisation[44] Knowledge development and diffusion
Infrastructure developer *Providing research infrastructure*	Entrepreneurial experimentation Materialisation Resource mobilisation Knowledge development and diffusion
Networker *Networking*	Knowledge development and diffusion Legitimation Social capital development

The roles interconnect in different ways. First, taking on one role may lead to the build-up of knowledge and capacity for taking on others. Different meta-roles may emerge from combinations of several roles. For example, Hellsmark (2010) shows that the role of system memory may be extremely important to quickly respond to changing needs. System builder is another meta-role, which combines many roles in order to take the key responsibility for the development of a field (Hellsmark and Jacobsson, 2009). Second, the roles complement and depend on one another. For example, when an *infrastructure developer* presents a new research instrument, it may enable the further work of *researchers* and *entrepreneurs'* commercial experimentation. Complementarity and interdependence may be found at an individual or group level. The previous example

[43] The subprocesses in this column are the ones most recognized in the received literature and cases. The roles also affect other subprocesses but to a lesser extent.
[44] In Paper V, the subprocess of materialisation is extracted from the process of entrepreneurial experimentation. Materialisation includes aspects of entrepreneurial experimentation that deal with creating artefacts such as physical products, production facilities and other infrastructure.

can be applied to three groups, where research group A acts as *infrastructure developers*, group B as *researchers* and group C as *entrepreneurs*. Third, there may be trade-offs between the roles. Realising one role may take resources from realising another, particularly at the level of an individual.

3.5. A multidimensional, dynamic and context-dependent framework

These four steps result in a *multidimensional*, *dynamic* and *context-dependent* framework for capturing and explaining utilities from academic R&D. These characteristics stem from the systemic nature of the framework. The framework is *multidimensional* since it enables accounting for a diverse set of activities, impacts, sequences and roles that researchers enact in making research useful.

The framework is *dynamic* since it traces impact as changes in several steps that include feedback and long time scales as compared to solely structural change (such as new companies and their growth, extended network or changes in institutional frameworks). A significant benefit is that a dynamic approach partly handles the problem of long time lags until the full impact of academic R&D is revealed, often taking several decades. Impact on the subprocesses may indicate potential structural changes (Sandén et al., 2008). Also, the dynamic framework enables capturing and explaining long-term and indirect utilities through sequences of impact.

The offered framework is *context-dependent* since it systematically accounts for influence from academia's surrounding setting, as other structural elements and exogenous factors also contribute to TIS dynamics. This has two main implications for the framework. First, system endogenous and exogenous factors condition the utilities from academic R&D. They influence the development of sequences of impact and affect the ability of a researcher to take on a role. These endogenous and exogenous factors can be very difficult, or even impossible, for academia to influence within a particular time scale. For instance, it is difficult to sustain the role of an *advisor* without an interested beneficiary. However, other actors in the system may support utility development by creating favourable conditions by strengthening innovation subprocesses. In this way, other system actors may complement academic activities and roles. For example a company may fill the role of an *entrepreneur*, and a research institute may be an *infrastructure developer*.[45] Second, an initial activity, which may result in a utility or a sequence, does not emerge from *tabula rasa* but springs from an existing system. A utility or a sequence is part of a continuous development and may also be studied with another actor's activities as a starting point, such as a company or an institute.

4. Method for conducting the empirical studies

Applying the framework calls for a method that can bring out rich exploratory and explanatory descriptions. In-depth case studies provide rich descriptions and high realism of context. This is why they offer the most suitable approach for the empirical studies in this thesis (Marshall and Rossman, 2010). The methodology for undertaking the three case studies is explained below.

4.1. Case selection

The three in-depth case studies have varying scopes and were chosen to illustrate different aspects of the framework. The first case covers Swedish nanotechnology research and explores and illustrates the first two steps of constructing the framework: Identifying activities and coupling these with subprocesses (see Paper II). Nanotechnology was selected for three reasons. First, it is a field of great growth potential, and policy-makers are concerned about insufficient benefits being generated from academic R&D. Second, nanotechnology is a chiefly science-based, emerging area where academic researchers are significant actors. Third, it includes an empirical domain that the author is familiar with. This strengthens the study's validity since the availability of appropriate background knowledge and the facility of accessing key actors is of great benefit when seeking rich descriptions.

The second case focuses on the research in an energy initiative at Chalmers University of Technology. It explores and illustrates the first two steps in the framework, but also illustrates some sequences of impact (see Paper III). In addition, a section of this case illustrates the typology of roles (see Paper V). This case was selected since the energy initiative includes world-class academic research in a wide range of fields that the Swedish government expects to be of great benefit for industry. It provides a rich,

[45] This illustrates that not all roles or activities necessarily need to be fulfilled by academia.

relevant case for exploring and illustrating the framework. In addition, the access to interviewees was very advantageous and facilitated obtaining rich descriptions.

The third case focuses on the research of Bengt Kasemo, a professor in physics at Chalmers University of Technology. It mainly illustrates sequences of impact; the third step in the framework (see Paper IV). There were three main reasons for this case selection. First, Kasemo is well-established in physics and provides a rich case with a long time axis, which was suitable for generating detailed, rich descriptions. Second, narrowing the scope to Kasemo's activities, and the activities of key individuals in the research group around him, made the data collection and analysis manageable. This is beneficial since a rich case risks becoming difficult to manage, owing to the extensive data and analysis required to explore multidimensional sequences over an extended time period. Third, the author had significant access to, and understanding of, Kasemo's environment, which is beneficial to the validity of the study.[46]

4.2. Data collection and analysis

Conducting the case studies in this thesis involved iterative search processes, where the method partly developed on the way. Iterations particularly occurred between the closely interrelated stages of data collection and analysis, which is a common procedure in TIS studies (Bergek et al., 2008a).

Collecting data for the case studies required immersion into particular settings using multiple methods, but primarily semi-structured interviews. These interviews were booked and prepared with an interview template structured from the framework. However, the phrasing and sequence of the interview questions needed to be adapted to each interviewee, since the case studies required interviewing different actors, such as researchers, beneficiaries, research managers and policy-makers. The interview template also developed along the way. The initial interviews were a form of pre-testing, and the template was refined as interviews were conducted and hypotheses emerged. Conversational interviews and email correspondence were also included. The Swedish nanotechnology case included 35 interviews, the energy research case had 29 and the

[46] The fact that there were no formal links between the author and Kasemo further strengthens the validity.

case of the Swedish physics professor had 22 interviews.[47] The interviews were transcribed, which involved interpretation as the conversational language was condensed and adopted. Transcribing also allowed for micro-analysis of the data, enabling intuitive reflections that were later tested.

Data were also collected from secondary sources such as reports, books, research evaluations, event records, news articles and on-line documentations. Moreover, data were collected from patents and publications databases. In addition to the use of these data as metrics, they identified actors (organisations and individuals) and relationships.

The resulting data, consisting of transcriptions and secondary textual material, were extensive and needed structuring. Data were coded as activities, subprocesses and other labels, such as people, programmes, organisations, regulations, incidents, years or places. The case of Swedish nanotechnology research was manually coded. The other cases were coded using the software Atlas.TI. The analysis included deep engagement in the extensive, structured data, searching for utilities, sequences of impact and roles. This was partly an informal process. Intuitive interpretations emerged as data was collected and structured. These interpretations were then formulated and tested on the data.

The extensive, diverse data presented great opportunities for validation through triangulation. Results were compared from different type of data or from interviewing people with different perspectives. Generous access to interviewees also allowed for checking interpretations and hypotheses by following up with respondents.

4.3. Methodological reflections from the empirical studies

Several methodological reflections emerged from the case studies. First, as mentioned in Subsection 1.3, case studies are often criticised with regard to limitations for positivistic generalisations from results. However, the three cases in this thesis offer sufficiently rich descriptions for others to assess the appropriateness of transferring the findings. Therefore, the transferability criterion is met. In this sense, and given the explanatory and exploratory aim of this thesis, “the force of example” of these cases overshadows the

[47] The author of this thesis conducted all of the interviews for the Swedish nanotechnology case and the case of the Swedish physics professor. In the energy research case, the author participated in 11 out of 29 interviews.

conventional need for generalisations. Still, further research is needed to add to descriptions of utilities or sequences, as well as to manifest other observations.

Second, there were concerns about biases regarding the interviewer in relation to interviewees, and interviewees in relation to the subject of inquiry. This thesis comprises action research, and the interviewer was acquainted with some of the interviewees and involved in some of the processes. This has provided access to environments, people and background knowledge that are hard to obtain otherwise, but may have biased the interviewer, since preconceptions of a phenomenon may influence interpretations. There are also strong incentives for academics to prove the utility of their research. This may have influenced their behaviour when interviewed for this thesis. In addition, the case of the physics professor included interviewing informants who worked close to him, which is why their objectivity may be questioned. However, their well-informed insights are crucial. To their advantage, all three case studies included diverse data and informants. This allowed for validation of statements and hypotheses through triangulation, which enabled handling concerns regarding bias. In particular, independent research evaluations and interviews with nonacademic actors were used.

Third, conducting the case studies included a complex, iterative research approach, where the method partly developed along the way. This involved challenges regarding feasibility, given the time-consuming task of data collection and analysis, and presenting a sufficiently clear, detailed description of the method to allow re-analysis.[48] Thus, the analytical process in this thesis may be blurry compared to quantitative approaches. However, given that this thesis includes explorative action research, it seeks relevance and realism before a reliability and tractability.

5. Results and conclusions from the empirical studies

This section summarises the results of the three cases.

[48] For instance, the matrix allows for 49 hypothetical utilities. Gaining a thorough understanding of each of these, including insights of the larger system in the same study takes time. However, the analysis can focus on selected utilities or be simplified through a lighter mapping of the structure. Likewise, exhaustively tracing sequences of impact is not feasible. In this case, emphasis in references and the informed judgments of interviewees may be used to select key sequences upon which to focus.

5.1. The case of Swedish nanotechnology[49]

The purpose of this first study is to contribute to the literature on the impact of academic R&D by applying the first two steps of the framework (upper left oval in Figure 2) to the case of Swedish nanotechnology research. By doing so, a multidimensional picture is revealed of how researchers create utilities as 32 of 49 hypothetical utilities are recognised. The case reveals that the activities of conducting research and commercialising have a particularly multidimensional impact since they affect many different subprocesses. Several activities impact subprocesses that are relatively strong: *Knowledge development and diffusion*, *resource mobilisation* (regarding human capital) and *entrepreneurial experimentation*.

Impacts are, however, constrained by blocking mechanisms affecting several subprocesses. For instance, academics attempted to strengthen *legitimation* by networking and providing guidance through developing strategic policy suggestions. However, the impact of these activities on structural change largely remains to be seen, for reasons that are difficult for academic researchers to influence. Identifying these blocking mechanisms helps explain what conditions utility generation and guides policy toward interventions that may improve it. These mechanisms all lay outside of the academic sector: Paucity of knowledge of environmental risks, overly large institutional and market uncertainties, and inadequate access to innovation-related capital. This illustrates the need for policy to apply a systemic perspective when aiming to improve the impact of academic R&D.

5.2. The case of Chalmers Energy Initiative[50]

The second case aimed to understand patterns with respect to how the energy research group at Chalmers University of Technology makes science useful. It is framed by the Chalmers Energy Initiative (CEI), a government-funded research area of strategic importance to Sweden. The first two steps of the framework are mainly applied to this case, although features of the third step (sequences of impact) are also included.[51] This case reveals significant multidimensional utilities from networking, providing infrastructure, providing explicit guidance and educating. Many of the utilities were

[49] This subsection summarises the empirical results in Paper II.
[50] This subsection summarises results from Papers III and V.
[51] However, the conceptual work on the sequences of impact was made in Paper IV.

subtle, such as providing a neutral meeting place that facilitated the development of trust, continuous dialogues that guided beneficiaries and specialized human capital that drove collaboration by creating social coherence. Some utilities unfolded in sequences, as activities *indirectly* impacted *resource mobilisation*, *influence on the direction of search* and *entrepreneurial experimentation* (including patenting) over an extended period of time. For instance, many CEI PhDs engage in patenting, drawing on knowledge gained at CEI, only after being employed at firms. The indirect impacts point to a possible limitation of indicators (such as the number of patent applications by academic researchers) in reflecting the contribution of academia to entrepreneurial experimentation. Results also point to the importance of understanding the knowledge field and the context of academia to appreciate their value and extent, particularly for subtle utilities.

The case of energy research at Chalmers also illustrates the roles put forward in the final step of developing the framework. First, the case illustrates roles in terms of how researchers differ in the types of activities they undertake and, consequently, the utilities that they generate. In particular, roles that previous research has given less attention to, such as *advisor*, *debater*, *networker* and *infrastructure developer*, appear to be important here. Second, it shows how the roles are interconnected, in particular how taking on one role is a prerequisite for taking on another and how roles are combined into meta-roles. Third, it illustrates how the roles interact with, and depend upon, the rest of the system.

5.3. The case of a professor in physics[52]

The purpose of the third case was to trace and characterise sequences of impact from academic R&D, as well as to contribute to the development of a methodology for capturing these impacts. It demonstrates the third step (right oval in Figure 2) – sequences of impact – with the case of the Chalmers physics professor Bengt Kasemo. Long-term and multidimensional sequences are traced in catalysis, biocompatible materials and research policy by showing interdependences between subprocesses of innovation. The impact on *knowledge development and diffusion* and *influence on the direction of search* is continuous and cumulative, and enables *legitimation*, *resource*

[52] This subsection summarises results from Paper IV.

mobilisation and *social capital development*. The latter two enable further impacts on the other subprocesses, including, *entrepreneurial experimentation* and *market formation*. Kasemo's impact was deeply intertwined with, and enabled by, his strong networks with competent, engaged partners. Sequences of impact unfolded when the timing was right and engaged actors were in place. This led to materialisation and industrial development, often within several decades.

The case revealed impacts on different levels: Individual, organisational, industry and national. Some sequences started with an individual, continuing with an organisation (such as a governmental agency or a company) or a research programme, followed by a sector and finally national level. As sequences moved through these levels, the impact from academia was further intertwined with that of other system actors.

This case also illustrates how utility generation depends on the context, out of the influence from academia. For instance, a car company's timely interest, owing to tightening automotive emission regulations, resulted in a long-term cooperation with Kasemo. This enabled utilities from Kasemo's research to unfold in sequences of impact over several decades.

5.4. Revealed empirical patterns on utilities from academic R&D

The cases show a number of common patterns. First, all illustrate wide-ranging patterns of impacts, showing the multidimensionality of utilities from academic R&D. They reveal utilities that are well-known, such as impacts from the activities conducting research, educating and commercialisation on the subprocesses *knowledge development, resource mobilisation* and *entrepreneurial experimentation*. However, they also reveal utilities that are very important but that previous literature gives less attention to. Examples are utilities from activities such as providing explicit guidance by being an intelligent conversation partner and enriching societal debates, or networking by being a node in or a gatekeeper to a network where actors develop collective world views. These target the innovation subprocesses of *influence on the direction of search*, *legitimation* and *social capital development*. In all, the cases reveal utilities that went beyond spin-offs, patents and publications.

Second, the cases highlight the long time scales involved in making science useful. Many utilities emerged to a substantial degree only after several decades. Third, the CEI and physics professor cases illustrate how substantial parts of the utilities are mediated by students, firms or policy-makers in sequences of impact. They show how utility creation is extensively intertwined with the actions of other system actors. Fourth, all three cases highlight the importance of networking in the development of *influence on the direction of search* and *social capital development*, which appears to be significant in enabling sequences.

Fifth, all cases illustrate how the wider environment that academia hardly influences conditions utility development. This pertains to favourable settings, such as a car company's timely interest in the case of the physics professor. The environment may also hinder utility development, such as in the case of Swedish nanotechnology where the lack of knowledge about environmental and health risks held back the development of utilities.

5.5. Viability of the framework for studying utilities from academic R&D

The framework enabled in-depth studies that stayed close to the real-world setting, which was crucial for identifying multidimensional utilities as well as understanding how they depended on the setting. In all, the framework was useful, particularly since it enabled identifying subtle, long-term and embedded utilities that were significant but could easily have been overlooked. The application of the framework also allowed exploring how utilities are induced or obstructed by factors that are hard for academia to influence, given the time scale.

However, there are some aspects that need to be taken into account when considering the viability of the framework. First, some activities are very closely interwoven, which presents challenges when analytically distinguishing them.[53] For instance, providing explicit guidance and networking are deeply embedded in other activities. Although this may present problems in identifying the type of activity from which a specific utility can be derived, it did not present considerable challenges in this thesis.

Second, there are challenges regarding the delimitation of innovation subprocesses. Some present tight intertwining, similar to the aforementioned activities. For instance, *entrepreneurial experimentation* includes *knowledge development*, while of a more

[53] See Paper I for a closer description of this consideration.

practical nature. *Influence on the direction of search* inherently includes *knowledge diffusion*, as does *resource mobilisation* of human capital. An additional concern regarding delimitation is that some subprocesses involve many different aspects. An example is *resource mobilisation*, which includes financial and human capital, and complementary resources. However, these intertwinings and diverse inclusions did not present significant problems in analysing the cases in this thesis. Occasionally, it required a more detailed re-interpretation of the data with further clarified definitions of the aspect included in each subprocess.

Third, although this framework allows for capturing long-term utilities, including indirect and subtle ones, there are challenges in attributing the contribution from a particular activity or even a specific researcher or group. For instance, attributing the particular contribution from a conversation (*providing explicit guidance*) to the change in an actor's attitude (*influence on the direction of search*) involves interpretations, both by the interviewee and the interviewer. Moreover, the particular contribution is conditioned by the influence from other factors. As this embeddedness increases with time, so do the challenges of attribution.[54] Triangulation with diverse types of data and follow-ups with respondents allowed meeting these challenges.

6. Conclusions and contributions

This thesis offers a framework for capturing and explaining utilities from academic R&D. It captures and explains (i) direct utilities through enriching the TIS approach with a typology of activities springing from academic R&D; (ii) long-term and indirect utilities as sequences of impact by tracing utilities through subprocess interdependencies, and (iii) diverse roles of researchers based on their main activities. The framework applies a systems perspective on utilities from academic R&D. This makes it *multidimensional* since it enables capturing a diverse set of utilities, *dynamic* since it traces impact on subprocess dynamics as compared to solely structural change and *context-dependent* since it systematically accounts for contextual influence.

[54] A fourth consideration is related to the aspect of additionality (Molas-Gallart et al., 2002). For example, a researcher acts as a government commissioned policy-maker, legitimizing a technical field. In the absence of the academic action, would the system not have changed, would the same system dynamics unfold regardless or would the system have adapted and substituted the action, resulting in the same dynamics?

Applying the framework in this thesis draws attention to a number of aspects that could easily be overlooked, but are essential to capture the full benefits of research. First, the thesis accounts for utilities that go much beyond those captured by conventional indicators such as spin-offs, patents and publications. This includes accounting for variations in how researchers create utilities through a role-based typology. Second, it draws particular attention to more subtle roles and utilities, such as guiding beneficiaries by being a longstanding conversation partner, facilitating the development of social coherence by providing neutral meeting places or educating specialised human capital whose affinity drives collaboration. These utilities are largely related to significant, yet less tangible, subprocesses such as *influence on the direction of search*, *legitimation* and *social capital development*. Third, applying the framework allows for not only including immediate utilities, but also long-term indirect benefits. These unfold in sequences of impact, mediated through students, firms or policy-makers. Thus, this framework enables explaining how the generation of utilities is deeply intertwined in the actions of others. Fourth, this thesis contributes to understanding how the wider setting conditions utility development. This pertains to other structural elements in the TIS that may be hard for academia to influence, as well as to external factors. The framework not only enables identifying utilities but also contextual factors that condition the impact, guiding policy in systemically improving utilities. Fifth, the thesis shows how utilities may unfold over a long time period. It illustrates how it may take several decades for the substantial impact to emerge.

The multidimensional, dynamic and context-dependent character of the framework presented in this thesis offers a way of looking at academic utility that takes into account timing and interaction with an ever-changing setting. Thus, it is well suited to capture and explain how utilities from academic R&D are created by surfing the complex, uncertain and somewhat disorderly ocean of society. Its application to literature and cases clearly illustrates the limitations of applying a narrow view of the utility of research, such as counting golden eggs only related to commercialisation. The next section lays out the contributions of the thesis findings to the TIS approach and the research policy literature. It also presents policy implications and areas for further research.

6.1. Empirical contributions

There are a number of key empirical contributions from this thesis. The cases capture a notably wide set of utilities, acknowledging those in studies by Faulkner and Senker (1995), Meyer-Krahmer and Schmoch (1998), Mansfield (1995), Salter and Martin (2001), Salter et al. (2000), Saxenian (1994) and Scott et al. (2001). This is apparent in Figure 5. All utilities recognised in the literature review of Paper I were also revealed in the cases. In addition, the cases contribute by recognising six additional utilities that also appear in Figure 5. For instance, the case of Swedish nanotechnology showed how the provision of research infrastructure diven by academia, such as developments of the European Spallation Source (ESS) and Max IV synchrotron radiation facility, *legitimated* Swedish nanotechnology.

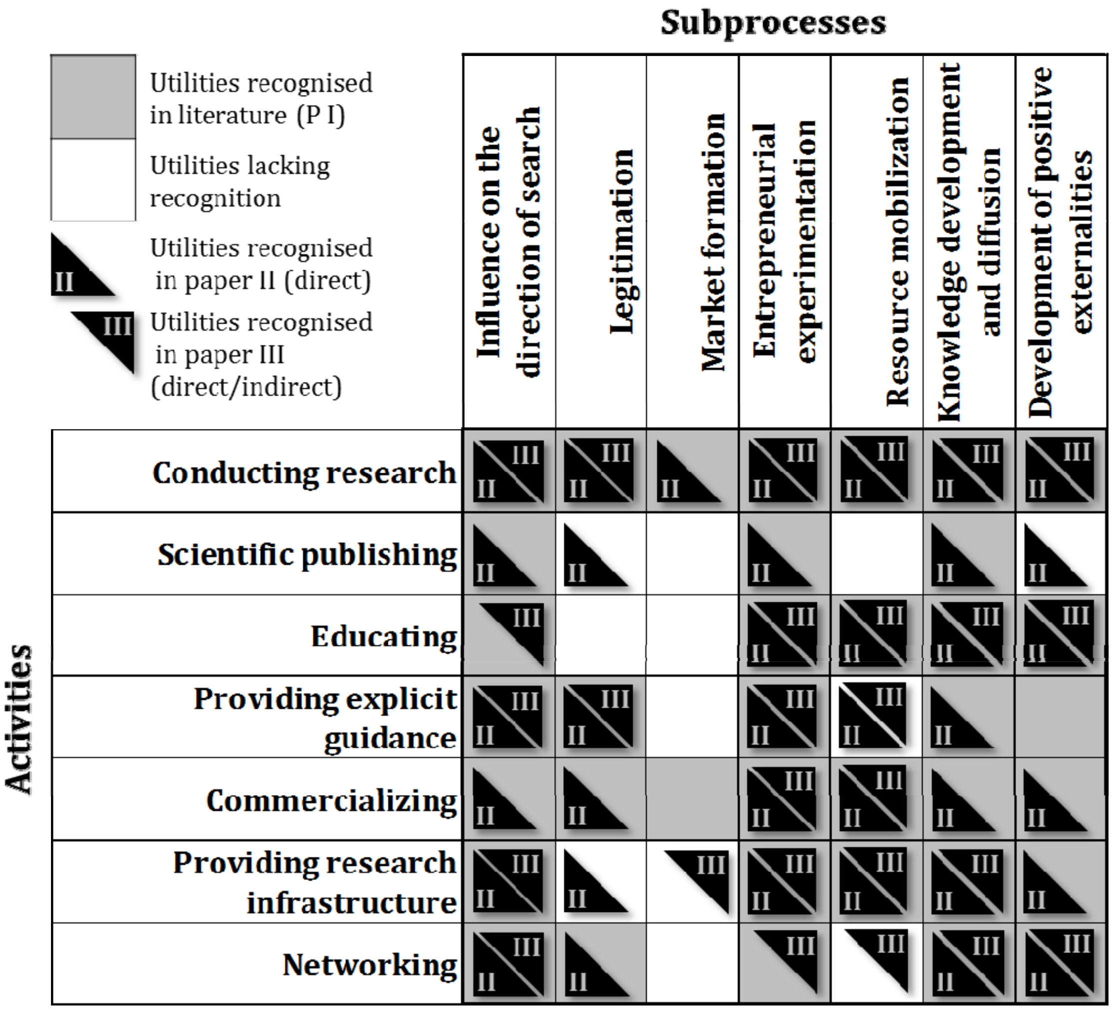

FIGURE 5. RECOGNISED UTILITIES IN PAPERS I, II AND III.[55]

[55] Note that Paper III did not analyse utilities from *scientific publishing*. Also, in the case of Paper III, the recognised utilities noted in this figure include indirect utilities.

The cases also contribute by illustrating how utilities from academic R&D were deeply embedded into different settings. The role of networking was important in creating this embeddedness. These findings are in line with those by pioneers such as Lundvall (2010a) and Håkansson (1989), particularly regarding the importance of long-term relationships built on trust and mutual understanding. The influence of system endogenous and exogenous factors on the generation of utilities is another aspect of embeddedness. In this regard, the cases contribute by illustrating how factors, such as lack of interest from beneficiaries, condition the development of utilities. This is an issue that has been given less attention in the literature on academic utility.

Finally, all cases show that it takes time for substantial impact emerges. Thus, the thesis confirms previous conclusions on how it may take several decades for the significant effects of academic R&D to appear (e.g., Martin and Tang, 2007; Nelson and Winter, 1977; Salter and Martin, 2001). In addition, the cases illustrate how utilities unfold, which adds to the understanding of why these long periods of time often are required.

6.2. Conceptual contributions

This thesis explored the connection between the TIS literature and the research policy literature on academic utility by merging selected parts of these two research fields. In doing so, this thesis contributed to each of them.

Contributions with respect to the TIS approach

First, the framework contributes to the development of the TIS approach by deepening the understanding of the role of a particular type of actor (academia). It provides insights into how this actor influences innovation subprocesses and enables system dynamics. This contribution comes in the form of microlevel foundations for understanding the dynamics of innovation systems.[56] This thesis traces how a range of academic R&D activities (such as educating a student) contributes to microlevel changes (such as a policy-maker's decision), which are deeply intertwined with the actions of others through a sequence, eventually contributing to systemic impacts at the mesolevel (such as the development of a market). Other contributions in understanding a particular actor's influence on TIS dynamics comes from Hillman et al. (2011), who focus

[56] Markard and Truffer (2008) emphasised the importance of laying out the micro-foundation for TIS dynamics.

on the role of governance and policy actors; Andersson and Vargas (2010), who describe impacts from research institutes; and Musiolik (2012), who studies how the strategic moves of firms influence a TIS. Together, these approaches enable deeper knowledge of how a TIS evolves.

Second, the thesis contributes to refining the list of subprocesses of innovation in the TIS approach. Variations have been offered, and this list is still evolving. The contribution from this thesis includes replacing the subprocess development of positive externalities with social capital development. The contribution also include pointing to how some subprocesses involve features that, depending on the research question, could be quite different. For instance, some versions of the list of TIS subprocesses have divided knowledge development *and* diffusion into two separate subprocesses (e.g., Hekkert and Negro, 2009; Hekkert et al., 2007). However, Lundvall (2010a) emphasises the close interaction between knowledge development and diffusion related to interactive learning. Still, some utilities identified in this thesis clearly emphasise knowledge development (such as pushing the research frontier in a basic research project), while others emphasise knowledge diffusion (such as being a node or a gatekeeper to a network). Similarly, the impact on resource mobilisation often concern one resource, namely human capital. Thus, the findings in this thesis open up for discussing the list of subprocesses and exploring how it can be adapted to the needs of particular applications of the TIS approach.

Third, the concept of sequences of impact enables exploring indirect and long-term impact by interdependences between different TIS subprocesses. By tracing the sequence of impact from one subprocess to another, the interdependence is established at the microlevel, adding to the understanding of how the system unfolds. This adds to the work of others, such as (Suurs, 2009), on subprocess interdependences.

Fourth, this thesis offers a rather new take on TIS delineation. The conventional delineation of a TIS is around one or a set of predefined technologies or knowledge fields. In the case of the physics professor, the development of the area of research policy, which is not a conventional technological knowledge field, was studied as a TIS. However, TIS subprocesses were useful, mainly because the subprocesses in the TIS describe the conditions for structural change in general. The subprocesses are extracted from innovation literature that not only cover technological, but also organisational, innovations (Bergek et al., 2008a).

Contributions to the research policy field with respect to academic utility

A first contribution of this thesis is proposing a conceptualisation of the generation of utility from academic research that offers an alternative to the narrow focus on performance measurements and commercialisation. This thesis illustrates a wide range of utilities, of which many are subtle and qualitative. The offered framework enables analyses that capture such utilities, and contributes to handling the problem with the long time lags up to the point when the full impact of academic R&D unfolds.[57]

A second contribution is proposing a conceptualisation of the generation of utility that offers an alternative to the linear model of innovation. The linear model assumes that research is merely initial input to innovation; there is no feedback between research and other parts of the process; and that specific volumes of high-quality research automatically result in corresponding volumes of innovation output. In contrast, this thesis shows that (a) academic R&D plays multiple roles in diverse part of the innovation process beyond only initial input, (b) numerous feedbacks exist between academia and factors related to various parts of the innovation process, and (c) contextual factors condition utility development, which implies that the impact on innovation of a specific volume of research may vary in both size and form. This fits well with the call for applying a systems approach to capturing utilities from academic R&D (e.g., Arnold, 2004; Hughes, 2006; Martin and Tang, 2007). This thesis puts forward a framework that applies such a systems approach. It allows identifying and accounting for multidimensional utilities that include feedbacks and opens up for explaining how contextual factors condition utilities.

A third contribution digs deeper into the causalities of how utilities are generated. This framework offers tools to trace utilities as contributions to microlevel changes (such as policy-makers' decisions) which, deeply intertwined with the actions of others, result in subprocess impacts (such as strengthened legitimation) and further contribute to impacts at a mesolevel (such as the emergence of an industry). Therefore, this

[57] While other approaches trace utilities in terms of snap shots of some outcomes, such as number of firms, patents and licenses, this framework focuses on changes in the subprocesses that may be identified before changes in the structure appear.

framework provides an opportunity for extending research evaluation approaches that merely build on aggregations of academic R&D output (such as number of papers, public appearances or patents) to include casual links.

A fourth contribution includes deepening the understanding of the role of academia in innovation systems. This opens up for exploring links to other conceptualisations of science, such as the mode 2 of knowledge production and the triple helix. Although these approaches are often seen as unrelated options to the innovation systems concept, they share the key aspect of continuous and subtle interaction between academia and its settings (Lundvall, 2010b).

6.3. Implications for policy

This thesis has implications for research policy. First, policy should support the development of an informed view on research utility that acknowledges the great diversity of impacts from academic R&D, including indirect and long-term impacts. In particular, the views of (a) direct commercialisation as a key mechanism for making research useful, and (b) insufficient commercialisation (few golden eggs) as an evidence of poor effects of academic research, should be questioned, given the results in this thesis.[58] Policies based on misleading views of how research is made useful may result in misspent resources and unintended consequences, such as a misguided pressure on academic researchers to deliver utilities that may be of little relevance to their setting.

Second, policy should offer support systems that induce developing a wide set of utilities and move beyond those focusing exclusively on producing specific and tangible products or outcomes, such as patents and publications, or supporting conventional commercialisation. Current support systems for making research useful at universities are still dominated by incubator programs and technology license offices that fail to support a wider set of utilities.[59] Support systems should also induce the development of

[58] There are signs of a change in this perception in the Swedish research policy debate. For instance, a more diverse view of utilities from academic R&D was displayed by some key actors during a seminar hosted by the Royal Institute of Technology (KTH, 2013).

[59] This is slowly changing. For instance, one of the most active university offices for innovation in Sweden, the Innovationskontor Väst, has lately adopted a wider view on research utilisation and expanded their activities accordingly. The ongoing work at Chalmers University of Technology on research collaboration and utilisation also reflects a broader view.

utilities that may be subtle and that provide value to beneficiaries in direct and indirect ways.

Third, a systems perspective on policy-making should be applied when aiming to improve academic utility generation. Solely focusing on direct research policy measures will limit the extent to which policy can induce utility generation. Instead, measures that combine and coordinate several policy areas, such as environmental, industrial and energy, may be required. A clear example of this was the nanotechnology case, where several blocking mechanisms that required policy attention concerned other policy areas besides research. Also, as system challenges vary depending on the domain (such as an industry, a societal sector or a technology), a systems perspective on policy-making requires domain-specific competence. These requirements present a great challenge for policy, since there often are substantial differences in the perceptions and tasks of policy actors in different areas, as well as inertia to change. Policy organisations serve under a regime built on preceding policy tasks that answered to outdated blocking mechanisms. Coordination between new combinations of policy areas is essential to support the development of a new area, and, thus, the corresponding utilities from R&D.

Fourth, this thesis highlights great challenges when assessing the utility of academic R&D. Given the dynamic and context-dependent nature of utilities from academic R&D, research evaluations should be conducted with great care. The implications of any research evaluation should be drawn with caution and first and foremost provide the foundation for discussion and learning. Nevertheless, the results in this thesis offer guidance in developing appropriate research evaluation schemes, recommending the use of schemes that account for long-term, multidimensional utilities and consider the influence from the wider context. Solely focusing on quantifiable indicators narrowed down to spin-offs, patents and publications, fails to capture the full impact. In addition, largely relying on impact indicators (such as firm growth or market shares) that are conditioned by factors which are difficult for academia to influence will not deliver a realistic assessment of the impact. Therefore, an appropriate evaluation scheme should, tentatively, account for a wide set of utilities; include quantitative indicators on activity levels; and comprise qualitative indicators on impact in the form of case stories that take into account indirect impacts, including sequences of impact. This would allow for ex-ante reasoning on potential utilities from activities and ex-post evaluations based on qualitative indicators that are well grounded in real settings.

Fifth, research evaluation and support systems for research utility should acknowledge that researchers and research groups undertake different types of activities and enact different roles in making science useful. Comparing researchers and research groups independently and assessing them on the same criteria will not take into account their systemic value. The systemic value arises from the complementarity between individual researchers, or groups, and their academic colleagues.

Sixth, this thesis has implications for the policy debate on needs-driven research in relation to curiosity-driven research. [60] This thesis shows the utility of a broad spectrum of different types of research, spanning from providing universal theories that lay the ground for further knowledge developments and cover future uncertainties, to contract research that responds to specific current needs.[61] It also illustrates how different types of research are complementary in generating utilities. Feedback and connectivity are the key aspects in this, both between the diversity of types of research in this spectrum and between research and the outside world that formulate needs. As needs change over time, sometimes with very short time scales, a disproportionate focus on needs-driven research risks exhausting knowledge development, as knowledge advances that need long time scales will not be given space. Yet, too strong a focus on disconnected and purely curiosity-driven research risks missing out on its mission to contribute to societal development. Instead, policy should strive for a balance between long-term and short-term knowledge developments, appropriate responsiveness to contemporary societal needs and connectivity between diverse knowledge developments.

6.4. Areas for further research

As a follow up to this thesis, there are a number of research areas worth exploring more. First, only three case studies of varying scopes were included. More cases are needed to further explore the framework and manifest general observations regarding patterns of

[60] These two research drivers are similar to the mode 1 and mode 2 of knowledge production (Gibbons et al., 1994). This implication was developed in correspondence with Professor Bengt Kasemo.
[61] In reality, this distinction is not very clear among research practitioners. The debate has mainly been among policy-makers. Also, a particular type of research (needs-driven/curiosity-driven) does not always generate a certain kind of utility (universal theories/specific and current needs).

utilities, sequences and roles that researchers enact. Additional case studies should preferably include other fields of knowledge, industry life-cycle phases, types of customers or regional settings than those covered in this thesis. Undoubtedly, new considerations related to the framework and method will emerge, pointing to areas of improvement.

Second, the complementarity and division of labour between different types of researchers and research groups could be explored more to better understand the dynamic interaction between different types of research. The offered typology of roles appears to be a suitable tool for this. Complementarity and division of labour could also be explored between academic actors and other types of actors. The possibility of including these aspects in research assessment tools could also be explored.

A third line of future research could explore the hypothetical utilities from the 7x7 matrix that remain to be recognised. Figure 5 shows six unrecognised hypothetical utilities, in particularly related to the subprocess of *market formation*. Additional work is needed to either reveal these impacts, or explain their absence. This could be undertaken in the form of an extended literature analysis or in-depth case studies.

Fourth, the viability of research evaluation schemes used by policy-makers and consultants could be evaluated using the framework in this thesis. As this thesis has brought forth rich descriptions with high realism of context, it offers a point of reference for testing how well current evaluation schemes reflect reality. Are they sufficiently workable proxies of the real impact, or do they miss out on significant utilities? Assessments of schemes could be conducted through parallel studies of the utilities generated by a particular research group, using both existing evaluations schemes and the framework of this thesis.

Fifth, the framework of this thesis provides the foundation for developing an alternative evaluation scheme that is multidimensional, dynamic and context-dependent. Although the framework proved useful as a scholarly tool, conducting the case studies was time-consuming, implying that conventional evaluation schemes have significant feasibility advantages. Thus, it is necessary to rationalise the framework to make it useful as a research evaluation scheme. This would include two steps. First, a survey of a larger number of academic researchers, companies and policy actors could be conducted to collect a wide set of indicators on activity level. Second, this could be followed up with impact-level case stories that capture and explain utilities, even in sequences of impact. The framework also opens up for the development of evaluation schemes based on the typology of roles.

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