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RESEARCH PAPER

Enacting knowledge exchange: a context dependent and 'role-based' typology for capturing utility from university research

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One of the key research and policy problems in innovation studies is the development of tools for understanding and measuring the impact of academic research on society. The paper contributes to resolving this problem by providing a typology that helps us to understand and analyse the roles researchers take on in order to make academic knowledge useful. A key finding is that utility creation is context dependent and varies between individual researchers and research groups. Attempts to measure impact ought therefore to allow for diversity with regard to the individual researcher or research group in the context of knowledge creation.

Introduction

The introduction of new public management has increased the demand for accountability from public universities and induced a switch from government to governance. Accountability pressure is not new in academe and the associated plea for relevance has always been a feature of the relationship between science and society, especially in applied disciplines. What is new is that: (a) academic knowledge is now supposed to be relevant to a broader range of activities than previously; (b) the introduction of multi-level governance of research and innovation has increased the number and variety of actors who can decide whether claims of relevance are supported by evidence; (c) relevance pressure is now accompanied by demands for measures or proof of impact; and (d) the mechanisms through which relevance expectations intrude into the academic profession have increased (Drucker and Goldstein, 2007).

Given the aforementioned, it should come as no surprise that policy and research attention is increasingly being devoted to finding ways of deepening our understanding of how academic knowledge is put to use in society. Thus far, indicators such as patents, citation counts, intellectual property rights (IPR) revenues and spin-off companies have dominated the praxis of impact measurement (Nelson and Winter, 1977; Martin and Tang, 2007) despite mounting evidence of their inadequacy (e.g. Van Leeuwen *et al*., 2003; Abramo and D'Angelo, 2007). One of the demonstrated problems with extant indicators is that they can capture impacts related only to codified forms of knowledge exchange. Several observers have maintained that many of

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the uses to which academic knowledge is put are related to non-codified knowledge exchange, e.g. long-term informal collaboration, or access to new knowledge networks (Jacobsson and Perez Vico, 2010; Jacobsson *et al.*, 2014). Moreover, these types of non-codified mechanisms are increasingly important channels of knowledge exchange (Blind and Grupp, 1999; Bekkers and Bodas-Freitas, 2008). Additional difficulties for tracing impacts arise because of time lags between knowledge production and impact, the intermingling of academic knowledge with other knowledge, and because users are keen on utility, but not on keeping track of the origins of the knowledge they use (NAS, 2003).

The demand for proof of utility often comes not from users, but from third parties, such as state funders. Typically, these third parties seek demonstrations of impact in terms that lay people can understand. Thus, the problem is not merely one of demonstrating utility or impact, but also translating this impact into terms that make sense to those who are far removed from the research context. Additionally, academics themselves need to have adequate tools to reflect upon the utility of the knowledge they produce. Such tools should take the individual researcher or research group as the point of departure because context dependency and complementarity to other individuals, groups or types of organisations are important determinants of utility. Hughes (2011, p.412) makes a similar point and argues that ‘the nuanced but distinctive role that universities play spans a wide range of people-based and problem-solving activities’.

Efforts have indeed been made to expand the understanding of the diversity of the utility of academic knowledge beyond bibliometric indicators (e.g. Molas-Gallart *et al.*, 2002; D’Este and Patel, 2007; Jacobsson and Perez Vico, 2010). Many of the presented approaches capture the utility of academic knowledge using non-actor specific objects of enquiry, such as activities, channels or linkages (see Jacobsson and Perez Vico, 2010). However, actor specific variation with regard to the emphasis on these objects of enquiry has been identified (e.g. Andersson and Vargas, 2010; Perez Vico, 2010; Jacobsson *et al.*, 2014).

Even so, few have addressed the difficulties in tracing utility arising from context dependent variations, such as complementarities within and outside academe on the level of an individual researcher or group. We reason from an insight developed in research on transforming academic inventions into innovations, where it has been shown the continued involvement of the inventor is necessary for success. We contend that an emphasis on the mere production of knowledge is not enough to generate utility. In cases where academic knowledge is made useful, researchers take on additional roles to achieve this end. Thus, it is not merely a matter of whether knowledge is useful or relevant on its own terms, but one of in what activities researchers need to engage to make knowledge useful.

We seek to contribute to deepening the understanding of utility by providing insights into how researchers or research groups create utility, taking the actors as a point of departure and including context dependent variations. We draw on extant literature, particularly an extension of the technological innovation systems approach (Jacobsson and Perez Vico, 2010) to present a typology of roles that researchers enact for making knowledge useful. We explore the roles outlined in the typology through two in-depth case studies of research groups at Chalmers University of Technology (CUT). We place particular emphasis on the complementarities within and between research groups and users. By doing so, we suggest opportunities for refining and fine-tuning evaluation schemes.

The paper is divided into four sections, including this introduction. The section immediately following contains an overview of the relevant literature that allows us to identify roles and describe typologies. The next section provides a brief account of the method used to collect the data for the case studies. The final section contains a brief summary of the roles, concluding remarks and policy implications.

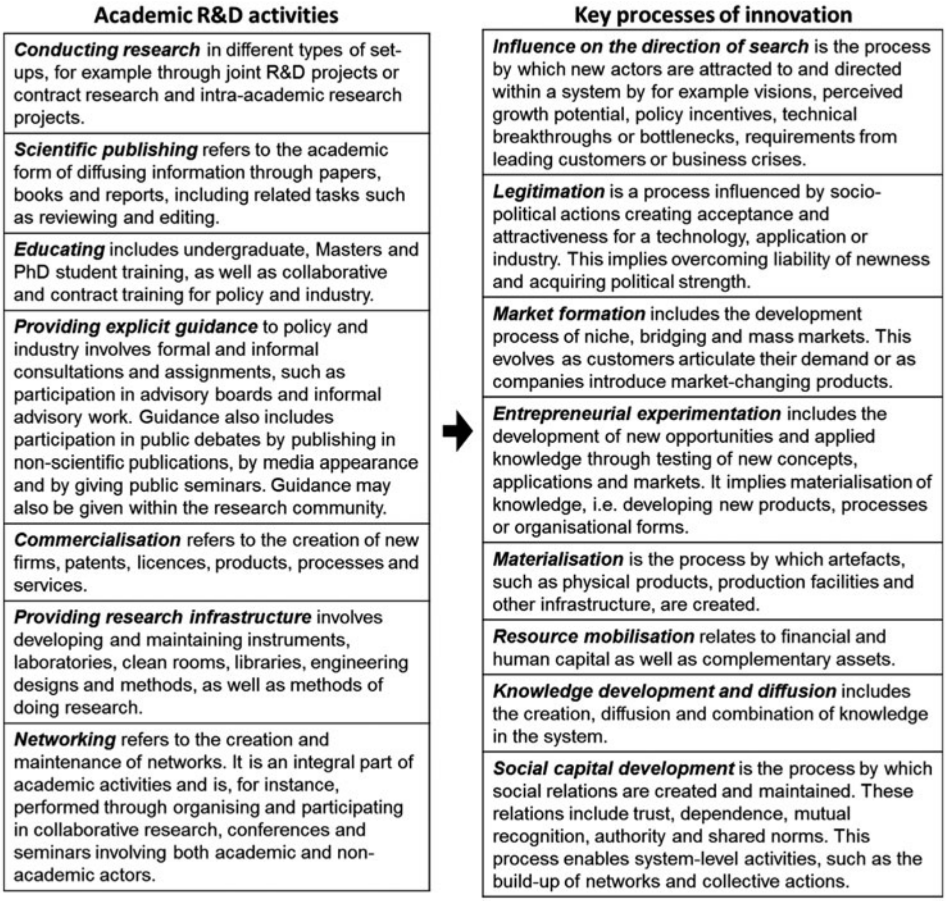
Making knowledge useful: a 'role'-based typology

Technological innovation systems (TIS) is one level of analysis in a family of approaches known as 'systems of innovation' (SI). The SI perspective features four discrete levels of analysis, three of which are national (Lundvall, 1992), sectoral (Malerba, 2002) and regional (Cooke, 1992). We have chosen to take our point of departure in TIS, which is the level of analysis with the finest grain because it allows a micro level perspective that suits our focus on individual researchers and research groups.

The TIS perspective has only recently been used to study impacts and utilities created through academic research. It complements existing approaches, such as STS studies, by explicitly focusing on researchers' impact on technological innovation systems and the different roles they play to make impact, rather than showing how research is made useful in a particular policy process, or analysing which factors impede the uptake of research (Woodhouse and Nieusma, 1997; Weiss, 1999; Kropp and Wagner, 2010). Although there are overlaps, the TIS perspective on research impact is also different from the work of Martin and Tang (2007) on communication channels, which has more of a macro perspective, attempting to explain how publicly-funded research contributes to economic growth. The merit of using a TIS perspective for studying impact is that the framework has been extensively used as a micro-oriented perspective for studying the development and diffusion of new innovation. Thus, this brings a micro perspective to the study of how individual researchers contribute to the utilisation of new knowledge.

TIS is commonly defined as '… a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or new product' (Markard and Truffer, 2008). TIS is usually delimited around a specific area of knowledge, as well as its products and market (Carlsson and Stankiewicz, 1991). The TIS approach provides the possibility of analysing different actors' contribution to innovation by tracing impacts on a set of key processes for the development and diffusion of innovation, such as those outlined in the right column of Figure 1 (see also Hekkert *et al.*, 2007; Bergek *et al.*, 2008a, 2008b).

These processes describe how a TIS works. For example, increased legitimation of a technological field through regulatory change influences an actor's direction of search. Subsequently, this actor enters the field, which extends networks, paving the way for the emergence of social capital that can develop and diffuse new knowledge. This may eventually result in a technological breakthrough that opens up new markets and thus creates new expectations, influencing the direction of search, which in turn attracts more actors to the field. Previous TIS studies show different patterns of interaction among individual researchers, research groups and their stakeholders. In what follows, we provide a brief review of extant work on the roles researchers adopt to make knowledge useful.



Academic R&D activities

Conducting research in different types of set-ups, for example through 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 non-scientific publications, by media appearance 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 methods of doing research.

Networking refers to the creation and maintenance of 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 non-academic actors.

Key processes of innovation

Influence on the direction of search is the process by which new actors are attracted to and directed within a system by for example visions, perceived growth potential, policy incentives, technical breakthroughs or bottlenecks, requirements from leading customers or business crises.

Legitimation is a process influenced by socio-political 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 through testing of new concepts, applications and markets. It implies materialisation of knowledge, i.e. developing new products, processes or organisational forms.

Materialisation is the process by which artefacts, such as physical products, production facilities and other infrastructure, are created.

Resource mobilisation relates to financial and human capital as well as complementary assets.

Knowledge development and diffusion includes the 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.

Figure 1. Activities springing from or embedded within academic research and key processes of innovation
Source: Adapted from Bergek *et al.* (2008a, 2008b) and Perez Vico (2014).

Jacobsson *et al.* (2014) show that a strong focus among faculty on education and related activities can facilitate knowledge diffusion and mobilisation of human resources. This can, in turn, facilitate entrepreneurial experimentation in a field. This finding also fits with previous research which contends that attempts to capture impacts of academic knowledge need to focus as much on knowledge exchange through education as on research (D'Este and Patel, 2007). Yet another strand of research shows that the creation of research infrastructure – e.g. pilot and demonstration plants, instruments and databases that provide technological opportunities (entrepreneurial experimentation) – can further knowledge development beyond the laboratory (Blind and Grupp, 1999; Hellsmark 2010). Hellsmark (2010) also provides some insight into how academic networks, among other things, mobilise resources and exchange knowledge from one geographical context to another. Hellsmark and Jacobsson (2009) illustrate how an academic took on the role of a system builder and managed to have a major impact on all key innovation processes in a TIS, except for market formation.

Jacobsson and Perez Vico (2010) present a framework for capturing and explaining the effects of academic research and development. This framework consists of seven key activities, presented in the left column of Figure 1, and an analysis of the impact of these activities on the innovation processes. When applying this framework, Perez Vico (2010) notes individual patterns in the type of activities that researchers emphasise. Previous TIS studies show different patterns of interaction among individual researchers, research groups and their stakeholders. This strongly suggests that different researchers take on different roles for making knowledge useful, without making this explicit. By translating the key activities outlined by Jacobsson and Perez Vico (2010), we can identify a set of seven roles that academics enact when making knowledge useful. Table 1 connects the activities described in Figure 1 with roles.

As Table 1 shows, we suggest seven roles – researcher, teacher, advisor, debater, entrepreneur, infrastructure developer and networker. Here, we offer a clustering with a resolution that can provide a good overview with sufficient level of detail for potential users of the framework. Later exploration of the roles in the cases confirmed the suitability of this clustering. When illustrating the role framework with our cases, we use TIS terminology to describe and make sense of the impact of the utility that the enactment of roles generates.

The researcher

The researcher role is probably the most obvious and self-explanatory category and involves a heterogeneous range of activities (e.g. scientific publishing, research leadership and evaluating other researchers work). Through research, academics develop knowledge, which can in turn lead to a number of potential impacts, e.g. provide market guidance, serve as an expert basis for the application of a technology in a new context, or contribute to the development of a new technology (entrepreneurial experimentation) (Klevorick *et al.*, 1995; Scott *et al.*, 2001). Taken together, this reduces uncertainty for firms in some aspects of their innovation processes and thus influences the direction of search (Nelson, 1986; Salter *et al.*, 2000; Jacobsson, 2002).

Table 1. Deriving the roles from the activities presented by Jacobsson and Perez Vico (2010)

Academic activities	Roles of researchers
Conducting research Scientific publishing	Researcher
Educating	Teacher
Providing explicit guidance	Advisor Debater
Commercialisation	Entrepreneur
Providing research infrastructure	Infrastructure developer
Networking	Networker

The teacher

Like that of researcher, the teacher role is one that involves a mix of different but related activities ranging from mentorship, executive education, under and postgraduate training as well as curriculum development. Depending on the field of specialisation, education may also involve active collaboration with specific stakeholder groups (e.g. engineering education often involves a high degree of collaboration with local firms and medical education involves collaboration with hospitals). It is also through teaching that universities have their greatest impact on knowledge diffusion and resource mobilisation (of human capital) as knowledge is diffused to and carried by students, who in turn utilise and disseminate the knowledge through various interactions (Mansfield, 1995; Salter and Martin, 2001; Jacobsson, 2002). Some of these students may be *avant gardists* that become policy and industry frontrunners within a new specific field. The teacher will thus influence their direction of search and potentially enlarge technological opportunity sets and change institutional regimes through these former students (Faulkner and Senker, 1994; Arnold *et al.*, 2008). A teacher may also develop social capital since a common educational background creates social coherence and provides a shared language and understanding, paving the way for community building (Saxenian, 1994). These ways in which knowledge is made useful are considered to be of great importance, though they are very difficult to measure (Salter and Martin, 2001).

The advisor/expert role

The advisory or expert role is one well known to academics in all fields. In the social sciences and humanities, this is often the most common way in which researchers make their knowledge useful. The role of academic as expert is the one that has been most exhaustively researched (Rosenberg and Nelson, 1994; Pielke, 2007; Arnold *et al.*, 2008). We will, therefore, focus attention here on simply translating into TIS terms what this role entails. The academic as expert overlaps with the researcher role in terms of the utility it creates (i.e. knowledge diffusion, entrepreneurial experimentation and influencing the direction of search). The difference lies in the emphasis of activities: the researcher emphasis is on creating new knowledge and the advisor emphasis on dissemination directed to a particular set of actors. There are also similarities between the teacher and adviser roles in that they both include knowledge diffusion through mentoring. However, the teacher does so in the form of a teacher–student relationship, while the advisor acts through a theorist–practitioner relationship.

The legitimation of a technology or a technique often does not require additional activity, but may come about as a consequence of the enrolment of expert advisors. Researchers deploy their social capital as a persuasive and legitimating resource on behalf of government agencies or as ‘evangelists’ in political processes of importance to a specific technology, establishing an identity and drawing attention to the future impact and growth potential of the technology (Weiss, 1979; Lester, 2005). Although the role of expert/advisor is familiar, it is often very difficult to capture in evaluations. More difficult, but less discussed, is the fact that providing expert advice is not identical to impact. Experts are always on tap; thus, the fact that their views have been solicited and received does not necessarily mean they have had an impact on the outcome.

The debater/public intellectual

A debater initiates and participates in public debates in order to educate the public on issues related to his research, often through opinion pieces in newspapers, articles in popular science or online magazines, public lectures and appearances on TV and radio.[1] A debater may take a clear stand regarding an issue or a stated agenda, acting as an advocate towards a wider audience and creating public legitimation of an issue (Lester, 2005; Pielke, 2007). But a debater may also generally enrich a debate with new perspectives without taking a particular stand. This role diffuses knowledge to the wide audience and influences the direction of search; for instance, by making actors reflect on the implications of their actions and agendas (Lester, 2005).

The entrepreneur

This role makes knowledge from research useful through commercialisation; for example, involving filing a patent, licensing technology to existing companies or creating entirely new businesses (Jacobsson and Perez Vico, 2010). It also includes leading the development of products or processes, even when patenting, licensing or firm establishment are excluded. This role has an impact on entrepreneurial experimentation and influences the direction of search as it creates options and reveals opportunities for an industry (Rosenberg and Nelson, 1994). This influence is related to the entrepreneur's impact on materialisation since the viability of an idea is demonstrated (Hellsmark and Jacobsson, 2009). Also, application and market-related knowledge develops and diffuses through the entrepreneur's activities (Mueller, 2006). In particular, firms and the patent system are notable channels for the dissemination of knowledge, though their importance has been debated (Wallin and Lindholm-Dahlstrand, 2006). The entrepreneur seeks to influence market formation as start-ups may introduce new products and even create new markets (Mueller, 2006).

The infrastructure developer

One of the lesser known tasks in research work, but one through which research can often make considerable impact on society, is that of developing research infrastructure (e.g. databases, models, standards, tools, techniques, test beds, cleanrooms, pilot plants and other specialised equipment). Research in the history of technology, innovation policy and social studies of technology has shown in several cases how research infrastructure development has contributed to innovation (Rosenberg, 1992; Blind and Grupp, 1999; Sirilli and Tuzi, 2009). This mobilises resources in the form of infrastructure, meeting early system needs that may create industrial capabilities – that is if the industry is involved in constructing the infrastructure and in the related research. Diverse actors can share and utilise this infrastructure for further research (knowledge development) as well as for entrepreneurial experimentation (Rosenberg and Nelson, 1994). The value lies in accessing not only new and expensive research equipment and databases, but also related expertise (Faulkner and Senker, 1994; Molas-Gallart *et al.*, 2002). In addition, the role has an impact on materialisation since it illustrates the viability of an idea; for instance, through an instrument or a pilot plant (Hellsmark and Jacobsson, 2009).

The networker

Networking has always been a feature of research work, but creating and managing regional, national or international networks of different types of actors is now an indispensable part of academic work.[2] The networker's activities may be formal and sponsored by funding agencies, or informal in nature. Networkers may work in connection with demonstration plants and research centres, or through conferences, seminars series and committees. The networker role links different actors and enables knowledge diffusion (Faulkner and Senker, 1994; Meyer-Krahmer and Schmoch, 1998). For instance, researchers may cultivate relations between disconnected actors by establishing technological discussion fora around new applications and technologies (Lester, 2005). Thus, the networker may eventually contribute to the creation of knowledge spill-overs (Saxenian, 1994). The role is important not only for making knowledge useful, but also for developing new areas of knowledge. It also develops social capital, as it creates social cohesion and a common understanding around TIS-related issues (Saxenian, 1994; Perez Vico, 2014). In these ways, it enables other roles.

The roles are interconnected in different ways. First, taking on one role may lead to the build-up of knowledge and capacity for taking on others. Indeed, several roles may be combined into meta-roles. For example, Hellsmark (2010) shows that the role of 'system memory' – being a resilient researcher and infrastructure developer over a long period of time – may be extremely important in order to respond quickly to changing needs. Another meta-role is 'system builder', which combines a large set of roles in order to take the key responsibility for the development of a field (Hellsmark and Jacobsson, 2009). Other plausible meta-roles are 'translator', a combination of researcher, networker, advisor and infrastructure developer, who transfers a technology from one context to another, and 'evaluator', who combines the roles of advisor and researcher to perform critical and independent evaluations that guide stakeholders, when facing a range of options.

Second, the roles complement and depend on one another. For example, when an academic entrepreneur commercialises a research instrument, it enables the further work of researchers and infrastructure developers. Complementarity and interdependence may be found at individual or group level. For instance, research group A acts as entrepreneur, group B as researcher and group C as infrastructure developer. Thirdly, there may be trade-offs between the roles (realising one role may take resources from realising another, particularly at an individual level). For instance, although being a researcher is a prerequisite for taking on the roles of advisor and debater, taking on these extra roles may come at the expense of the researcher role.

The enactment of knowledge exchange: two illustrative cases

In order to illustrate the potential merits of a role-based typology and how it can be used to describe the processes in which utilities from research are created, the typology is applied to two case studies. These have been selected to illustrate the framework rather than to make universal claims for its validity. We have chosen to study two research groups at a typical technical university in Sweden, Chalmers University of Technology (CUT).[3] The two groups studied are located at the CUT Department of Energy and Environment. One is the Life Cycle Assessment group and the other group is engaged in large-scale pilot and demonstration plants at the Division of

Energy Technology.[4] These groups were selected for three reasons. One is that they are internationally-recognised pioneers within their research fields and highly appreciated by their stakeholders. Secondly, although within the same institutional context, they constitute two contrasting cases, one working on the knowledge development associated with ‘hard’, large-scale mechanical equipment for combustion, gasification and carbon capture, and the other focusing on ‘soft’ conceptual models, methods, databases and management issues related to life cycle perspectives. This variety is conducive to creating thick descriptions of the activities and roles involved in knowledge exchange. Third, the authors had good access to the groups and previous contextual knowledge of the fields. This enabled data collection and facilitated the understanding of the utility of the research (Marshall and Rossman, 2010).

We conducted 19 interviews in total, seven with the key researchers (out of a total of around 30 senior researchers) and 12 with beneficiaries. We used the interviews with beneficiaries to capture different types of perspectives regarding the utility of research. The interviews lasted on average one-and-a-half hours and were conducted by one or two persons, who took notes and recorded. The interview data were transcribed and coded according to the activities of researchers and the innovation processes they influenced. From this, the roles of researchers could be identified and tested against the framework through an abductive approach (Dubois and Gadde, 2002). Our interpretations of the interviews were validated with all interviewees through email or other personal communication. Additional data were collected from evaluations of the research groups, as well as from presentations made during seminars and workshops.

Roles enacted by the Division of Energy Technology

In the late 1970s, the energy research at CUT consisted of one professor and two research assistants. It was in a poor shape with no international publications to speak of. However, this started to change in the wake of the international oil crises and later on climate concerns. The Division of Energy Technology (DET) managed to grow from a group of less than a handful of people to one of the largest division at CUT with a staff of over 60 researchers. A professor emeritus at the division explains how the growth was enabled by investments in research on incineration of more heterogeneous and difficult fuels, and by immediate involvement in diverse ways with stakeholders, thus taking on many different roles.

District heating in Sweden is generally large scale and has always played an important role in the energy system, supplying more than 30% of the residential heat in Sweden (Swedish Energy Agency, 2014). Before the oil crises, the main fuel was oil, but during the 1980s more and more plant owners shifted towards biomass and low grade coal, creating new problems for equipment manufactures that had to be solved. One of the major international manufactures of boilers at the time, Götaverken Generator, wanted a research facility for its new boiler development focusing on heterogeneous and difficult fuel. They turned to CUT, which needed to replace its own oil boiler for heat production on campus. In a joint effort, the two actors constructed not only a commercial boiler covering heat demand at CUT, but also a large-scale, combined commercial and research facility.

As the DET took on the role of infrastructure developers, mutual benefits were created, both for themselves and their stakeholder. For example, close ties to

Götaverken Generator were created, allowing the DET to gain access to an industrial research agenda and associated research problems, which generated ideas for new research topics of relevance to both industry and academia. In addition, as a professor at the division explained, the cooperation allowed the DET to build up a cost effective research infrastructure in which the feedstock costs of experiments and costs of associated laboratories could, to a large extent, be covered by the commercial operation of the plants instead of by only research grants. This is supported by the former head of research at the Vattenfall utility. In turn, this created strong incentives to conduct related experiments in combustion and later in gasification and carbon capture technologies, thus strengthening their role as infrastructure developers and researchers. A professor emeritus at the division explained how the combination of industry collaboration and direct access to a large-scale research boiler allowed the DET to move ahead rapidly in research, while simultaneously addressing several research problems for its stakeholder. The design and unique character of the research infrastructure stimulated knowledge development and entrepreneurial experimentation, enabling the DET to establish itself as one of the most prominent research groups in the field internationally, achieving many well cited publications in high ranking journals.

Because of the shift from fossil fuels to biomass and a general growth of the industry, the division has set up several educational programmes and courses. Students graduating from these have been much sought by industry. A professor at the division argues that taking on the role of teachers allowed the division to create even stronger ties through former students (for example, to energy utilities and equipment manufacturers). The research infrastructure has, thus, functioned as a boundary object for various industrial interests and placed the DET in a position where its research and teaching activities associated with the boiler could be leveraged. In addition, because of the social capital being created with stakeholders, other roles could be enacted. For instance, two professors at DET and the CEO of the Gothenburg biomass gasification initiative argued that DET often functioned as an independent source of expertise for energy utilities and assisted in reducing the costs of technology search for the utilities, thereby enacting the role as advisor.

Moreover, a professor emeritus of the division explained how DET’s access to a unique low-cost research facility also enhanced its attractiveness as a partner for national and international research projects. Through these projects, the group was able to increase its social capital because of its relations with other leading research environments and companies in Europe. This has enabled the mobilisation of significant financial resources (resource mobilisation) and allowed the group to become a node in an international network, allowing it to take on the role of networker. When combining the roles of researcher and advisor, the DET could enact the role of evaluator, assessing different options for industry and thereby influencing industry’s direction of search. In addition, by taking on the roles of researcher, advisor, infrastructure developer and networker, the DET was acting as translator. As translator, DET not only evaluated different options, weighing them against each other, but also translated various options into new contexts and applications by developing new concepts and technical artefacts in terms of new products, processes and models.

A professor at DET argued that, in the enactment of these two meta-roles, DET enabled effective exchange of knowledge with significant long-term potential for industry at a low additional cost. For example, it was through this combination of international networking and research that the idea of using chemical looping as an option for carbon capture and storage could be translated from the original applications in the United States and Japan during the 1950s and 1980s. The idea of chemical looping had been picked up at a meeting with Japanese researchers, and the DET's position enabled the division to mobilise European Union financing and construct three different pilot plants (in connection to their large-scale boiler) for testing different aspects of chemical looping. According to the former head of department at the utility Vattenfall, the results received global attention and Vattenfall invested in the technology.

The example of chemical looping shows how additional pilot and demonstration plants could be constructed quickly and at a relatively low cost thanks to DET's access to a well-functioning infrastructure with trained personnel and workshops funded through the boiler. Two professors from the division gave further examples of large-scale experiments that could be translated from other contexts: (a) Oxyfuel – a promising alternative technology for carbon capture and storage; and (b) indirect biomass gasification – for large-scale production of 'green' methane.

When realising these technological options for industry at a significant scale, the DET took on the role of entrepreneur. However, it did not focus on patents and start-ups, which are common elements associated with the entrepreneurial role. On the contrary, three professors at DET argued that patents are difficult to defend, have very little economic value for DET and industry, and that their potential can only be realised by large multinational firms. Hence, the professors argued that focusing on patents and start-ups makes little sense for the DET. In conclusion, by taking on the role of infrastructure developer, DET strengthened its social capital in relation to its stakeholders, enabling the division to take on additional roles over time. For each role, mutual benefits appear to have been created for industry and academia.

Roles enacted by the Life Cycle Assessment group[5]

Towards the end of the 1980s, a loose group consisting of CUT researchers, a few individuals at Volvo Cars, the Swedish Federation of Industries (Industriförbundet), the Swedish Environmental Research Institute (IVL), and Chalmers Industrial Technology (CIT)[6] initiated a series of breakthrough research projects in Life Cycle Assessment (LCA) (Westblom and Höglund, 1996). When a Competence Centre for Environmental Assessment of Product and Material Systems (CPM) was established in 1996, the CUT researchers were central to this development. During the first 10 years, CPM was funded with €7 million from the Swedish Agency for Innovation Systems (VINNOVA), CUT and a number of large Swedish firms that were active participants (e.g. AkzoNobel, ABB, SCA, SKF and Volvo Technology) (Westblom and Höglund, 1996). During these years, CPM grew beyond its initial founding members into a multidisciplinary group that included staff from other departments, such as Computer Science and Geology at CUT and from the School of Economics at Gothenburg University (Baras *et al.*, 2000). A professor at CUT and the director of CPM explained that collaborating companies openly shared information and experience, and that research projects were formulated in dialogue between industry and academia. These projects were both long term (for capacity building) and short term (giving immediate results). An official at the Swedish Environmental Protection Agency stated that policy actors eventually began to collaborate and undertook several joint research projects with CPM through which they developed and diffused knowledge. In time, the group was able to create a solid scientific background for the LCA technique and through this contribute to its legitimation (Baras *et al.*, 2004). CPM created a critical mass of resources and the CUT researchers benefited from access to industrial experience, tools and data (Baras *et al.*, 2000). In this way the LCA research group at CUT took on the role of researcher, which enabled them to take on several other roles.

Researchers at CPM developed knowledge of and expertise in database formats, tools and methods for performing LCA, thus taking on the role of infrastructure developer. The director of CPM, supported by Baras *et al.* (2004), argues that this enabled further knowledge development. The active companies utilised the infrastructure at CPM in different ways. For instance, several companies, such as the pulp and paper company, SCA and Volvo Cars implemented data documentation formats developed at CPM or created their own databases based on these formats (Baras *et al.*, 2004; CPM, 2007). In time, LCA tools became important to the decision-making and product and process development processes of some CPM member companies, thus influencing their direction of search and enabling entrepreneurial experimentation (Baras *et al.*, 2004). A sustainable development manager at the chemicals company AkzoNobel states that mostly thanks to CPM, LCA became important in product and process development at AkzoNobel. Also, AkzoNobel, Volvo, the automation company ABB and the pulp and paper producer SCA, integrated the LCA perspective in their research processes (CPM, 2007).[7]

The LCA group also took on the role of teacher. Researchers at CUT were able to institutionalise LCA as an academic area through master, doctoral and executive education, often in connection with CPM. A professor at CUT explained that the masters education included an element of collaboration with industry in that firms were allowed to use student labour, supervised by CPM staff, for commissioned projects. The integration of firm collaboration in the educational activities of the group substantially mobilised resources and diffused knowledge as students graduated and were often employed by partner companies, thus becoming effective technology transfer agents (Baras *et al.*, 2000). The Ph.D. graduates constituted a closely connected group with shared understandings, contributing to the development of social capital. There were also industrial Ph.D.s at the LCA group at CUT. These paved the way for environmental work at several of the CPM member companies (such as the cement producer, Cementa, the pulp and paper company, Stora Enso, and the ball bearing company, SKF). The sustainable development manager at AkzoNobel explained that a substantial proportion of the individuals in the LCA group at AkzoNobel had CPM-related education. A professor at CTU recalled that graduates from the LCA group at CUT also worked in the public sector and so influenced policy.

Researchers connected to CPM came to be important networkers. Early on, CPM became a networking platform that enabled generous interactive knowledge development and diffusion between academia and industry in general, and particularly between CPM and their collaborating partner firms (Baras *et al.*, 2004). The director at CPM explained that, although the researchers were the central nodes, networking was enabled by the open knowledge sharing of collaborating firms. The networker role was of particular importance to the development of LCA since most individuals linked to CPM started off working alone with LCA perspectives at their respective companies. A professor at CUT explained that these individuals were initially required to legitimate LCA techniques at their companies, as well as to use LCA in their work. A manager at AkzoNobel recalled how he met peers from different companies and knowledgeable researchers at CPM, who became important support and discussion partners. This aspect of networking was also highlighted in an evaluation of CPM (2007). A CUT professor recalled that 'there was much talking during workshop breaks and participants shared experiences on how to anchor the LCA work and get support for their ideas'. These interactions built on, and further developed, mutual trust, recognition and openness (social capital development) (CPM, 2007). Both a manager at a partner company and a professor at CUT stated that, eventually, this resulted in mutual knowledge development and diffusion and in many participants managing to legitimise LCA and to influence the direction of search in partner companies. For instance, participants said that taking part in CPM left them with a feeling of confidence, both in their companies and towards clients (CPM, 2007). Researchers connected with CPM provided beneficiaries with access to global expert networks (knowledge diffusion) where they could identify future opportunities (Baras *et al.*, 2004).

Many CPM researchers acted as advisors as they actively participated in the standardisation of the LCA methodology, the development of the carbon footprint idea, and other approaches that influenced the direction of industry search (Baras *et al.*, 2004; CPM, 2007). CPM researchers were also important advisors for policy makers. For instance, an official at the Swedish Environmental Protection Agency explained that researchers provided an important source of expertise that the agency could draw on when dealing with LCA-related issues in policy.

Over time, the LCA researchers at CUT managed to combine different roles and take system responsibility in the field of LCA as they built a readiness to meet a growing industry need for environmental efforts. This enabled them to perform the role of system builder. Through mutual knowledge development and diffusion, they mobilised human resources and provided infrastructure and legitimation that subsequently contributed to entrepreneurial experimentation. LCA perspectives became valuable as market differentiators for products, providing further legitimation (Baras *et al.*, 2004). CPM researchers also helped companies to develop knowledge of how to operationalise LCA in industrial processes. The group further diffused knowledge both within and outside CPM, serving as a model to other companies and industries. CPM also provided an important networking platform that developed social capital, substantially enabled by open and engaged industry participants. By the end of 2011, around 70 people were connected to CPM (according to its manager), and the centre was classified as the most prominent LCA research centre in Europe. A professor at CUT and the director of CPM both stated that the research group gained much from the collaboration with beneficiaries through access to data, real-world problem formulation that opened up new research tracks, legitimation from working with recognised industrial partners, and access to financial resources.

Conclusions and implications of the typology

We have presented a typology of seven roles that researchers take on, drawing on the literature and illustrated through two case studies. The roles are summarised in Table 2, together with the main processes they influence and some examples of how the roles can be clustered into meta-roles. Probably all researchers perform some, if not all, these roles. There are no measurable criteria, such as a particular threshold or indicator, for determining whether a researcher plays a particular role. However, there are differences in the emphasis of a researcher's work that can be used to distinguish different roles. These roles are often combined in different ways and we

Table 2. Summary of the roles of researchers, influenced TIS processes and meta roles

		Examples of meta roles			
Role	Processes influenced[a]	System memory	Translator	Evaluator	System builder
Researcher	Direction of search Knowledge development Entrepreneurial experimentation Social capital development	X	X	X	X
Teacher	Direction of search Resource mobilisation Knowledge diffusion Social capital development				X
Advisor	Direction of search Legitimation Entrepreneurial experimentation Knowledge diffusion		X	X	X
Debater	Direction of search Legitimation Knowledge diffusion				X
Entrepreneur	Direction of search Market formation Entrepreneurial experimentation Materialisation Knowledge development and diffusion				X
Infrastructure developer	Entrepreneurial experimentation Materialisation Resource mobilisation Knowledge development	X	X		X
Networker	Knowledge diffusion Legitimation Social capital development	X		X	

Note: [a]The processes presented in this column are those recognised in the literature and in the two cases.

have offered some example of this in the illustrated meta-roles. These show how the roles may be clustered in different ways to understand how a researcher or research group makes knowledge useful.

Diverse factors will condition what roles researchers enact. One factor is what roles other academics play, as different researchers or research groups may interact or complement each other's roles. This is of particular importance when evaluating the role of an individual or a group. Complementarity and interdependence may also be found between academe and other actors. Non-academic actors may support a limited capacity of academia to fulfil a particular role by creating favourable conditions. An industrialist may, for example, fulfil the role of an entrepreneur and a research institute that of an infrastructure developer. A policy actor may support an academic entrepreneur by introducing market-developing policy instruments, such as tax or procurement schemes. Non-academic actors may also hinder researchers from fulfilling a role. It is, for instance, difficult to sustain the role of advisor without an interested beneficiary. This shows that not all roles necessarily need to be fulfilled by academia. Other conditioning factors may be the researcher's personality, experience or the culture within a research group. Exploring these factors is beyond the scope of this paper.

The cases selected here are from a technical university and we have chosen research areas of high relevance. This is arguably a skewed sample, which may undermine generalisation. However, what we have sought to show here is the importance of taking context into account when measuring impact. This finding fits well with that of Molas-Gallart *et al.* (2002), Molas-Gallart and Castro-Martínez (2007) and Perkmann *et al.* (2011). The approach that we present brings out issues that are of policy import. One of the issues is that producing relevant knowledge is not in itself enough. For this knowledge to come to use, researchers have to be willing to engage in a number of activities, as illustrated by both our cases. The paper also shows that converging sets of interests of different actors, access to specific kinds of infrastructure, as well as local contextual factors, such as proximity to important industrial actors and their interests in knowledge development, are enablers.

Applying a roles-based perspective on research utility reveals multifaceted relations between the everyday activities of researchers and societal benefits. This implies that the impact of research is more complex than is captured in one-dimensional assessment approaches, such as those relying on bibliometrics. The cases suggest that it may be useful to consider several parallel indicator sets, even in the context of the same evaluation. For example, the DET case shows that research excellence and high utility coexist, though this does not imply that this is a robust relationship or that the two variables are in any way correlated.

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Notes

1. In contrast to an advisor, who turns towards specific actors, a debater addresses a broader public audience or large groups of politicians or industrialists. Although the debater can be said to 'educate' the public on particular issues, she/he does not interact with specific students in the way an educator does.
2. This role touches upon the advisor's knowledge of who knows what in a TIS. But, while the advisor knows about only the network nodes (who's who), the networker actively works to integrate, renew and expand the network.
3. CUT is the second largest technical university in Sweden, employing approximately 2000 researchers and teachers at different levels (including approximately 800 Ph.D. students, but excluding administrative personal).

4. Since this group dominates most of the activities at the Division of Energy Technology we will, hereafter, refer to this larger part of the Division of Energy Technology simply as the Division of Energy Technology.
5. The Life Cycle Assessment group refers chiefly to those researches at CUT who were connected to the Competence Centre for Environmental Assessment of Product and Material Systems (CPM) There were additional researchers at CUT conducting LCA research who were not engaged through CPM.
6. CIT is the technology transfer office of CUT. It also works as a consultancy and project management organisation, coordinating contract research and training.
7. A tangible example is the reduction in the environmental impact of the production of AkzoNobel's new low temperature washing powder (CPM, 2007).

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