BTO | December 2016

BTO report

A productive knowledge cycle: theoretical framework for analysing feedback loops from practical applications to the research process

KWR Watercycle Research Institute

BTO

A productive knowledge cycle: theoretical framework for analysing feedback loops from practical applications to the research process

BTO | December 2016

Project number
400554/176/002

Project manager
Jos Frijns

Client
BTO

Quality Assurance
Mariëlle van der Zouwen

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Sent to
This report is distributed to BTO-participants.
A year after publication it is public.

Year of publishing
2016

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Keywords

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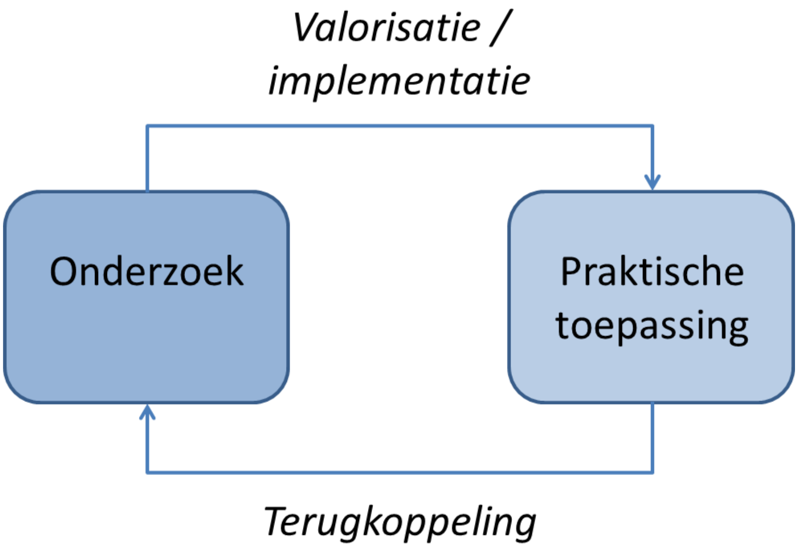
BTO *Managementsamenvatting*

Leren en profiteren van praktische toepassingen van onderzoek

Auteurs: Laurens K. Hessels en Emmy Bergsma
Het wetenschappelijk onderzoek binnen het BTO focust sterk op praktische toepassingen. Praktische toepassing is echter niet alleen het doel op zich: praktische toepassingen kunnen ook positieve effecten hebben op het wetenschappelijk onderzoek zelf. Terugkoppeling uit de praktijk kan cognitieve, financiële en sociale voordelen opleveren voor het onderzoek dat aan de basis staat van deze toepassingen. Over de aard en optimale uitvoering van deze terugkoppeling is echter nog weinig bekend. Op basis van een literatuurstudie en interviews met experts zijn daarom de eerste bouwstenen gelegd voor een theoretisch kader waarmee de terugkoppeling van kennis uit praktische toepassingen naar het onderzoeksproces kan worden geanalyseerd. Het belangrijkste mechanisme achter deze terugkoppeling is een intensieve interactie tussen onderzoekers en de mensen die zich bezighouden met de praktijktoepassing. In de literatuur zijn acht condities gevonden die deze interactie kunnen bevorderen: een gemeenschappelijke onderzoeksinteresse, een langetermijnperspectief, sociale nabijheid, een open onderzoekscultuur, gedeelde onderzoeksapparatuur, aandacht voor duurzaamheid, de karaktereigenschappen van de betrokken onderzoekers en voldoende financiering van samenwerkingsverbanden. Op basis van dit theoretisch kader zullen we empirisch onderzoek uitvoeren dat aanknopingspunten oplevert voor het vergroten van de synergie tussen onderzoeksprojecten in het BTO en de toepassingen van dit onderzoek in de praktijk.



Grafische weergave van een productie kenniscyclus

Belang: onderzoek laten profiteren van terugkoppeling uit praktijktoepassing

Een mogelijke strategie om de impact van wetenschappelijk onderzoek te vergroten, is het oprichten van een bedrijf dat de onderzoeksresultaten met commerciële waarde naar de markt kan brengen. Dit kan ook gunstig zijn voor het onderzoeksproces zelf: als de commerciële activiteiten op een productieve wijze kunnen worden gekoppeld aan het onderzoeksproces, kan kennis uit de toepassing terugstromen naar het onderzoek. Over hoe deze terugkoppeling effectief kan worden gerealiseerd is nog weinig bekend.

Aanpak: literatuurstudie en interviews met experts

Op basis van een literatuurstudie en interviews met vier experts op het gebied van de relatie tussen onderzoek en praktijk is een theoretisch kader ontwikkeld voor het analyseren van deze kennisterugkoppeling. Dit theoretisch kader dient als basis voor het empirische (vervolg)onderzoek van dit project.

Resultaten: cognitieve, financiële en sociale terugkoppelingen

In de literatuur hebben we positieve terugkoppelingen gevonden die cognitief, financieel en/of sociale van aard zijn. Deze terugkoppelingen worden gefaciliteerd door de interactie tussen onderzoekers en de mensen die de praktijktoepassingen gebruiken. Er zijn acht condities geïdentificeerd die belangrijk zijn voor een effectieve interactie: een gemeenschappelijke onderzoeksinteresse, een langetermijnperspectief, sociale nabijheid, een open onderzoekscultuur, gedeelde onderzoeksapparatuur, aandacht voor duurzaamheid, de karaktereigenschappen van de betrokken onderzoekers en voldoende financiering van samenwerkingsverbanden. In het vervolgonderzoek zullen we deze voordelen en condities empirisch toetsen en verdiepen.

Implementatie: onderzoek naar synergie tussen BTO en praktijktoepassingen.

Het theoretisch kader uit dit onderzoek biedt een goede basis voor meer empirisch onderzoek naar een productieve kenniscyclus. Het vervolgonderzoek zal aanknopingspunten bieden voor het vergroten van de synergie tussen de onderzoeksprojecten in het BTO en praktische toepassingen hiervan in binnen- en buitenland.

Rapport

Dit onderzoek is beschreven in rapport *A productive knowledge cycle: theoretical framework for analysing feedback loops from practical applications to the research process* (BTO 2016.098).

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Contents

1 Introduction

1.1 Project background and research aim

Literature on research and innovation suggests that the distinction between basic and applied research is blurring and that knowledge is increasingly produced in the context of application. There are also claims that research that is 'highly contextualized' is more 'socially robust' (Nowotny et al. 2001) and that the increasing interactions between academia, industry and government can lead not only to knowledge of more practical relevance but also of academic excellence (Etzkowitz and Leydesdorff 2000). This suggests that, under certain conditions, generating broader impacts from research will generate new knowledge that can feed back into the research process. However, there is limited empirical evidence available to support these claims and to specify the precise mechanisms for these knowledge feedbacks or learning loops.

Many research organisations are exploring ways to improve the broader impacts of their research. One potential strategy to do so is creating a spin-off firm that can bring commercially valuable research findings to the market. By applying newly developed knowledge in a practical context, new knowledge and new questions emerge. By upscaling technological solutions, new challenges often emerge. Moreover, commercial applications may give researchers access to new data, information and practitioners' knowledge.

An important question is how to connect these external activities in a productive way with the internal knowledge production system of research institutes. How can the knowledge generated through practical applications feed back into the research process of the research organisation? In other words: What structures and conditions stimulate a productive knowledge cycle (see figure 1)?

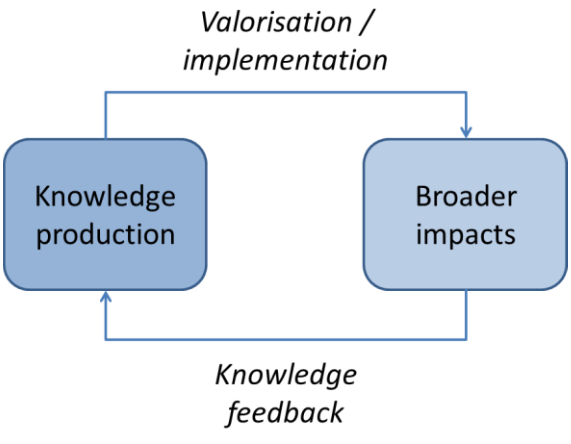

FIGURE 1. GRAPHICAL IMPRESSION OF A PRODUCTIVE KNOWLEDGE CYCLE, WHICH INCLUDES A FEEDBACK LOOP FROM THE GENERATION OF BROADER IMPACTS TO THE KNOWLEDGE PRODUCTION PROCESS.

The research project 'Feedback from Valorisation'[1] sets out to analyse the structures and conditions that facilitate a feedback loop from broader impacts to the knowledge production

[1] Part of the BTO-project 'Onderzoeken en Verbeteren Kennisnetwerken'.

process within the research practice. The project is set up in three consecutive steps. In the first step, based on an examination of the existing literature on knowledge cycles and expert-interviews, an overview is generated of the conditions for, and the benefits created by, feedback loops from research applications to the research practice. Based on this state-of-the-art of knowledge, a theoretical framework is drafted for analysing knowledge feedback loops in the research practice. In a second step, the project will empirically analyse a number of knowledge cycles between parent organisations and applied research initiatives within, but possibly also outside of, the water sector. The theoretical framework will be applied to those cases to study whether the conditions for productive feedback loops are present, and whether these feedback loops indeed create the expected benefits for knowledge production. Based on these empirical insights, the theoretical framework will be advanced in the third and final step of the project.

This report documents the results of the first step. It describes the findings of our literature scan and expert-interviews on knowledge cycles and presents the theoretical framework that we have drafted based on this. The questions guiding the analysis were:

1. What are the benefits researchers can gain from their activities in applying research results in practical domains?
2. What are the conditions facilitating the creation of these benefits?

1.2 The knowledge cycle and feedback loops: gaps in the available literature

In spite of the broad societal support for basic research, the most important driver behind knowledge creation has always been its practical utility. For a long time, businessmen and governments stood at the basis of knowledge development. Even during the Enlightenment in the 17th and 18th centuries, which boosted the development of independent and objective scientific knowledge, governments and businesses continued to guide the research practice (Baker 1975). This triangulation reached a maxim at the end of the 18th and early 19th century. Inspired by utilitarian thinkers such as Claude Henri de Saint-Simon, Jeremy Bentham and John Stuart Mill, the importance of improved access to and circulation of rational knowledge for economic and social productivity was increasingly stressed (Baneke 2011; Van der Vleuten 2004). Throughout the 19th century, scientific knowledge was produced through a close collaboration between the state, business leaders and scientists (Hoed and Keizer 2007).

After the Second World War, changes occurred in the knowledge production process. First of all, the war had demonstrated the importance of science being disconnected from the operations of the state (Heffernan 2003). The ideology of pure science that deserves protection from societal influences was expressed in an influential paper called 'Science, the Endless Frontier' (Bush 1945). In addition, the spread of neoliberalism as a new political ideology in the 1980s meant a withdrawal of the state in social affairs, including knowledge production. In the second half of the 20th century, knowledge was predominantly produced within universities and other certified scientific research institutes (Martin 2003).

In recent decades, a renewed interest emerged in collaborations between science, business and government in the production of knowledge. Now that a substantial share of publicly funded research is produced within relatively isolated domains of universities and scientific research institutes, the main question became 'has the knowledge production process not become too far removed from its practical and actual value?' In reaction to this question, science scholars, particularly within the subfield of Science and Technology Studies, call for breaking open traditional knowledge production processes by incorporating new actors (e.g., state actors, businesses, interest and public organisations, lay people), with alternative (non-scientific) forms of knowledge (Collins and Evans 2002; Gibbons et al. 1994). Creating stronger links between science and practice, according to these authors, contributes to the development of more 'robust' forms of knowledge (Jasanoff 2004).

An influential account in this field has been offered by Helga Nowotny, who coined the notion of socially robust knowledge (Nowotny et al. 2001; Nowotny 2003). She claims that the more strongly contextualized a scientific field or research domain is, the more socially robust is the knowledge it is likely to produce.

Social robustness is a quality of knowledge that can be compared to reliability or acceptability, but it has a somewhat larger scope, indicating not only the level of support in the scientific community but among a broader range of stakeholders. According to Nowotny, social robustness is a relational idea, it is not relativistic or absolute. Social robustness can only be judged in specific contexts. The accumulation of social robustness is a process that may reach a certain stability. It is produced when research has been infiltrated and improved by social knowledge. Finally, socially robustness is strongly empirical, it is subject to frequent testing, feedback and improvement

Nowotny claims that research fields that continue to preserve a 'sterile space' that traditionally characterizes scientific practice (weakly contextualized) are tending to become less creative and productive. However, fields who embrace, willingly or otherwise, a diversity of external factors, and which can be described as strongly contextualized, are not only more 'relevant', but may also be more successful in terms of both the quantity and the quality of the knowledge they produce. According to Nowotny (2001: 168), highly contextualized knowledge is not only inevitable and relevant, 'but even scientifically beneficial (in the limited sense that a wider range of perspectives and techniques may be brought to bear on scientific problems.)'. Contextualized knowledge is likely to be more reliable , because it remains valid outside the 'sterile spaces' created by experimental and theoretical science. 'Reliable knowledge, as validated in its disciplinary context, is no longer self-sufficient or self-referential. Instead, it is endlessly challenged, and often fiercely contested, by a much larger potential community, which insists that its claims to be heard are as valid as those of more circumscribed scientific communities and demands that its preferences, too, be taken into account.' (Nowotny 2001: 177)

In her account, Nowotny calls for a new kind of science. There is literature suggesting that this new science is actually emerging. Theory-building around the so-called 'Triple Helix' claims that industry, universities and government are becoming increasingly interdependent and that an 'overlay of reflexive communications' between industries, universities and governments is emerging. 'The sources of innovation in a Triple Helix configuration are no longer synchronized a priori. They do not fit together in a pregiven order, but they generate puzzles for participants, analysts, and policymakers to solve. This network of relations generates a reflexive subdynamics of intentions, strategies, and projects that adds surplus value by reorganizing and harmonizing continuously the underlying infrastructure in order to achieve at least an approximation of the goals.' (Etzkowitz and Leydesdorff 2000) (112-113)

Nowotny's theory emphasizes the importance of creating knowledge feedback loops from the practice to the knowledge production process. The Triple Helix theory suggests that intensive interactions between research organisations and other organisations are an important driver for the innovation of knowledge production and can help to establish productive feedback loops in the knowledge production process. Both theories do not, however, give a clear view on the effects created by these feedback loops for knowledge production, or on the conditions that allow these feedback loops to establish in research environments. While they emphasize dynamic forms of interaction between knowledge developers (researchers) and knowledge appliers as an important precondition for productive feedback loops to establish in the knowledge production process, they don't specify in much detail the conditions under which these dynamic interactions develop or the benefits created by these interactions. For our literature analysis, therefore, we have turned to the more empirically-oriented literature aligned to certain research domains to start filling in the gaps left in the existing literature.

1.3 Research approach

A study carried out by one of the authors of this report has shown that the relationship between practical applications and scientific productivity varies strongly across scientific fields (Hessels 2010; Hessels et al. 2011). In most of the fields studied, a (weak or strong) tension was found between practical applications and scientific productivity. Only in three out of eight fields a synergy was found: in catalysis, animal breeding & genetics and in paleo-ecology. This means that in our study of the knowledge cycle, we have to take into account disciplinary differences.

The literature analysis undertaken for this project focuses on three empirical domains that represent different variations of the knowledge cycle we are interested in:

1. Relationships between spin-off firms and parent organisations
2. Relationship between clinical practice and medical research
3. Relationships between academic teaching and academic research

Each domain represents a distinct practice of research contextualisation. In each case, research findings are applied in a certain practical setting, where they are confronted with different audiences, challenges and limitations not present in the laboratory setting. For each domain we have carried out a brief scan of the available literature on knowledge cycles and feedback loops. Our analysis most extensively reports on the first domain, both because of the availability of relevant literature and because of the direct relevance of this domain for water research in the Netherlands.

In addition to the literature scan, we have interviewed four individuals which are experts either in one of the domains or on the knowledge cycle in general:

1. Rik Wehrens PhD, Erasmus Medical Centre, expert on collaborative research centres in the medical domain
2. Erwin van Rijswoud PhD, Radboud University Nijmegen, expert on the role of scientists in politics and the media
3. Drs. Leonie van Drooge, Rathenau Institute, expert on valorisation of academic research
4. Arend Zomer PhD, Twente University, expert on university spin-offs

1.4 Structure of the report

In the following chapters, the results of our literature analysis are depicted. Chapter 2 focuses on knowledge cycles and feedback loops in the literature on spin-off firms and parent organisations. Chapter 3 looks at the literature on knowledge cycles in the clinical practice and medical research. Chapter 4 dives into the literature on the link between academic teaching and research. In the conclusion, these domains are comparatively analysed, based on which a theoretical framework is drafted that links the conditions for the establishment of productive knowledge feedback loops to their expected benefits.

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2 Spin-offs and parent organisations

2.1 Introduction

Within the literature about entrepreneurship and academic spin-off companies, there are a number of studies on the relationships between start-ups (spin-offs) and their parent organisations. Although the focus of most publications is primarily on the conditions required for successful entrepreneurship, some studies also pay attention to the (potential) benefits for the parent organisations, such as universities or research institutes. So far, however, there has been little research on the cognitive relationships between academic organisations and their spin-off firms[2].

In the general literature on the knowledge cycle, interactions between science and practice are highlighted as an important precondition for the establishment of productive knowledge feedback loops. Therefore, this chapter starts out with a characterisation of these forms of interaction between parent organisations and their spin-offs, before discussing the effects of and conditions for this interaction.

2.2 Characterisation of parent-spin-off interactions

A paper by Treibich and co-authors *(Treibich et al. 2013)* provides insights into the dynamics of the interactions between spin-off companies and their parent organisations. The analysis is based on extensive interviews with 25 spin-off firms in Switzerland and France in the areas of ICT, micro/nano and life sciences. For each firm they have analysed the intensity of the interaction with parent organisation and the degree of knowledge co-production over time.

When analysing the life time of the spin-off firms (between 4 and 15 years old), they have found a variety of patterns of interaction. Few pairs have a stable interaction intensity over time. However, there are also no alternating trajectories with multiple changes.

Four types of interaction dynamics can be distinguished:

1. Manifest segregative: pairs that show little to no interaction, and no co-production of knowledge.
2. Delayed segregative: Initially intensive interaction and knowledge co-production. Then the relationship is either completely cut or limited to equipment sharing.
3. Manifest interactive: frequent and intense interactions, joint projects. In these cases collaboration also helps to get third party funding.
4. Delayed interactive: joint research only started when the firm reached a critical size.

The patterns varied across the research areas. The sample suggests that spin-offs in IT are more often segregative, while interactive patterns are more common in micro/nano technology. Biotech cases distribute evenly. The authors explain this difference by the facts that sharing of equipment is more essential and that patents are more common in biotech and micro/nano than in IT.

2.3 Effects of parent-spin-off interactions

[2] Interview Arend Zomer.

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Zomer et al. (2010) provide more insights in what benefits parent organisations precisely can gain from their interactions with spin-off firms. The analysis is based on case studies of four university research institutes (at Utrecht University and University of Twente) and two non-university public research organisations (centre for mathematics and informatics (CWI) and TNO research institute) in the Netherlands (Zomer et al. 2010). The cases are located in the micro- and nano sciences, life sciences, information and computer sciences. The selected departments did not differ significantly in size or focus of other departments in their institutes.

In the study we can identify four types of benefits for parent organisations:

1. Reputation: some departments indicate that the creation of spin-off firms contributes to institute reputation, in particular the ones at the technical university and TNO. In these cases the generation of spin-off company contributes to the legitimacy and credibility of the institute as a producer of technically relevant knowledge. However, spin-off creation does not benefit the reputation in the scientific community.

2. Access to funding: Spin-off companies often participate in research consortia that help their parent research organisation to acquire public funding from competitive funding instruments. In this way, they legitimize public support and enhance the research capacity of research institutes. This role could in principle also be fulfilled by other industrial partners, but cognitive, social and geographical proximity makes spin-offs an attractive partner. Also, even if they do not participate actively in a project, PROs still mention their spin-offs in project proposals, since they expect this to raise their chances of getting their proposals funded.

3. Direct funding: In two cases (pharmaceutical and medical) a PRO-department performs a research project for the spin-off in the order of several million Euros annually. However, often the spin-offs have little resources to spend. Moreover they do not have the time perspective to fund complete PhD-projects.

4. Knowledge: Spin-off companies can provide information to researchers about real-life issues that relate to basic scientific research questions. In this way the collaborations with spin-off companies serve as a ‘reality check’ and inform researchers about the relevance of their research questions and the feasibility of potential solutions. ‘‘We know what the developments are in the sector. The research institutes sometimes don’t look at that at all’’(quote from entrepreneur). Most respondents value the informal relationships with spin-offs, since they provided both research departments and spin-off companies with updates on developments, know-how and access to physical resources, such as computer chips and biochemical materials. In this study the creation of a spin-off company always led to informal relationships in which test data, instruments or prototypes were exchanged between a research department and its spin-off company.

Perhaps surprisingly, the direct benefits in terms of joint scientific output were limited. In most cases the spin-off firms and parent organisations produce only few collaborative publications and collaborative patents. The quality and volume of scientific output appears not to be affected by exchange relationships with spin-offs. Only in the cases where spin-offs directly contributed large funds, these significantly influenced the research agenda and resulted in high quality publications.

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2.4 Conditions for parent-spin-off interactions

Treibich et al. (2013) report two observations regarding the conditions for knowledge feedback. First, it turns out that similarity of research interest is a crucial condition for collaboration. In the dataset a major change in research agenda of one of the partners was accompanied by major change in interaction intensity. Second, informal relations are a prerequisite for formal collaboration. Informal relationships play an important role in trust building as a basis for future formal relations or in maintaining the link when partners are not directly working together. The analysis shows that the ability to manage conflicts and competition issues matters strongly for the success or failure of a relationship. Two of the 'segregative' cases indicate how much such conflicts can hinder the exploitation of a latent interaction potential. In one other case, the ability to repeatedly renegotiate the respective fields of activity of the partners turned out an important element in maintaining successful interactive relations.

The interactions and benefits varied across research areas. In the biomedical area, the relationships between the spin-offs and their parent departments were the most intense. These firms provided more funding for research, there were more co-authored patents and double affiliations. In computer science the spin-offs were of a smaller size with limited research budgets and short time orientation. The spin-offs in nanoscience had no significant research budgets, but they did provide access to a substantial government-funded research project. Moreover, in this area there was significant informal exchange in a clean-room facility of the parent research organisation.

In the interview, Arend Zomer indicated that a fruitful interaction between the spin-off and its parent organisation depends on a lot of factors, including:

- Characteristics of the spin-off firm, such as growth rate and geographical distance from parent organisation.
- Characteristics of the parent organisation, such as laboratory facilities and entrepreneurial culture
- Individual characteristics of the researchers involved: individuals with a dual affiliation can serve as a personal link
- Cognitive match: often the cognitive match between the two organisations decreases rapidly after creation of the spin-off, since the spin-off continues working on one highly specific technology while the academic group will proceed in new directions

Stijn et al. have recently identified 14 'university-startup interaction practices'. The aim of the study was to explore the conditions under which university-startup interactions are mutually beneficial to both universities and start-ups in terms of resources (van Stijn et al. under review).

Most of the 14 practices mainly concern the educational tasks of universities, including entrepreneurship education. Three of the 14 practices are particularly interesting for research activities:

1. Collaborative research: this refers to research undertaken in collaboration between universities and start-ups, including renting out laboratory space and specialized equipment, possibly against a fee. This type of research can clarify whether a

technology has real commercial value ('opportunity recognition'). For universities, collaborative research is a means of acquiring financial capital through research funding or renting out physical capital. In addition, collaborative research allows universities to acquire technical or scientific knowledge. Moreover, the collaboration expresses researchers' expertise in a specific discipline and thus provides credibility, which helps attract additional funds. This practice strengthens the implementation of applied research and contributes to research commercialisation.

2. Academic consulting: this practice consists of university staff providing direct advice or expertise to the start-up, or the provision of networking opportunities. This practice contributes to social capital and the credibility of academics. Academic consulting also contributes to research commercialisation.

3. Piloting: this refers to the activity of universities in providing start-ups with a pilot site for their product, usually the campus. With new technologies on campus, universities may also gain financial capital by contract. Moreover, the visibility of being a test bed for innovations provides credibility. In the clean-tech domain it was also found that campus sustainability offices value the new technologies in terms of establishing a "green" campus culture.

To conclude, this study found that interactions between universities and start-ups often help universities to gain credibility and social capital. A selection of practices also help to acquire knowledge, which could be either business knowledge or technical/scientific knowledge.

There are also publications on the relationship between entrepreneurship or spin-off creation and research productivity. One study found that researchers in biomedical science and engineering at public research organisations who create spin-off companies are, on average, more productive researchers than their peers, even before they started a firm. Their productivity does not decrease following firm formation. The study was based on a sample of 150 entrepreneurs across 15 research institutions. They are also more likely to be high impact scientists (Lowe and Gonzalez-Brambila 2007). This suggests that productivity functions more as an explanation than as an effect of spin-off creation. Research output is largely dependent on the characteristics of the scientific researcher, not on the fact that a company created by the scientific researcher contributes to the research portfolio.

An analysis of Max-Planck directors, top-tier scientists in Germany, found a complex relationship between spin-off involvement and research output. The authors found no significant negative impact on short term. In the long run, however, their data do suggest a detrimental effect of spin-off involvement on research productivity. Interestingly none of the scientists in the dataset entered into the operative management of a spin-off. Note that this is a highly specific sample. In this sample, spin-offs were often started in the late stage of careers (Buenstorf 2009).

3 Clinical practice and medical research

3.1 Introduction

There are some studies about the relationship between research quality and the quality of care. Below we present insights from four publications into the effects of research on clinical care.

3.2 Effects of interactions between clinical care and medical research

First, we looked at a statistical analysis of data on departments in cardiology, oncology and orthopedics in 50 US-based university hospitals, which shows that high-quality research contributes stronger to the quality of care than high-volume research (Tchetchik et al. 2015). This suggests that there is a positive relationship between research quality and its practical applications. It does not specify, however, whether more efforts in terms of clinical care also contribute to the quality of medical research.

Second, we included a cross-sectional analysis of secondary data of in-hospital risk-adjusted mortality for congestive heart failure and acute myocardial infarction (2002–2004) and several bibliometric measures of publications (1996–2004) in cardiovascular disease. This study found a low-to-moderate negative correlation between risk-adjusted mortality ratio and the weighted citation ratio (Pons et al. 2010). This supports the idea of a positive relationship between research quality and effectiveness of clinical care, but it does not provide clarity regarding the direction of causality in this relationship. The authors suggest exploring the possibility to include research quality indicators into the comparison of hospital quality.

Third, we considered a literature review that scrutinized 33 papers on the question whether research engagement improves healthcare performance, of which 28 indeed showed improvements (Boaz et al. 2015). Seven reported improvements in health outcomes, the others reported improved care processes. Based on the literature, the authors also made an inventory of possible mechanisms that may be responsible for the positive relationship between research and care, including: change in attitudes and behaviour that research engagement can promote, the use of the infrastructure created to support trials more widely, or for a longer period, to improve patient care, and a greater awareness and understanding of the specific research findings. Almost all of the listed mechanisms deal with the influence of research engagement on care performance. However, the paper also suggests that ‘Mechanisms such as practice facilitators, project development meetings and network convocations allow two-way knowledge exchange throughout a research network, enabling clinicians to engage with question generation and the resulting research, and ensuring that the research is more relevant to practitioners’ (p11). This indicates that performing research in a clinical environment enhances the relevance and possibly the broader impact of medical research.

Finally, we incorporated a PhD thesis about academic collaborative centres (‘academische werkplaatsen’) in the Netherlands. In this thesis, the ways in which participants of these centres deal with different regimes of accountability was analysed (Wehrens 2013). The study does not explicitly examine the influence of the participation in such centres on academic research practices. However, in an interview, the author indicated that he noticed that the participation of researchers in these centres did help them to come across topical themes for new research that they would not have known about otherwise. When carrying out the research, it turned out difficult to create real synergies between the academic and practical research activities. While the academic researchers needed large projects to gather sufficient data for scientific analysis, the practitioners preferred shorter projects that yielded results within a couple of months.

These publications demonstrate the positive effects generated by medical staff participating in research activities for medical care. Remarkably, we have not found any publications on the influence of care activities on the quality or content of research activities. In addition, information on the conditions that encourage productive interactions between research and care activities was also difficult to find. In conclusion, feedback loops from the valorisation of research activities in the medical practice back to the research process are an underexplored topic in the literature.

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4 Academic teaching and academic research

4.1 Introduction

There is a substantial body of knowledge about integration of research into higher education, often under the heading of the 'research-teaching nexus' (Marsh and Hattie 2002; Robertson 2007). Assuming that education is a practical context in which research findings encounter new audiences and constraints, this literature can inform us about possible mechanisms and conditions for a productive knowledge cycle. Below, we summarize the insights delivered by this literature on knowledge production processes and feedback loops in these processes.

4.2 Effects of interactions between teaching and research

In interviews about the research-teaching nexus, academics indicate two intangible benefits of teaching activity for research (Neumann 1992):

1. *Broadening effect*: 'Teaching enables academics to place their area of research into a somewhat broader context and not just be confined to their specific, narrow area of 'specialisation'. They benefit from reviewing their section of their discipline and placing their own work in the wider context. Preparing lectures make it necessary to reconsider and reflect on what is known, remain in touch with broader developments in the disciplines. Thus academics often gain a clearer comprehension by having to see their field in a different light. Added bonus is that academic can discover gaps in their own knowledge of which they were not aware. In some cases this can lead to new research lines.

2. *Youthful contact:* Interaction with students, who provide positive stimulation and force academics to articulate issues, and in the process clarify and enhance their own understanding. And constant contact with young intelligent people stimulates, keeping them alert, alive and 'on their toes'. Students are continually fresh source of contact with wider world, preventing insularity and staleness.

A more recent interview study in the Netherlands (N=30 in Faculty of Humanities of Leiden University) revealed three types of benefits of teaching for research (Visser - Wijnveen et al. 2010):

1. input of students (when students participate actively in research projects)

2. stimulating reflection,

3. broadening your research scope

The following interview quote from this study shows that some teachers clearly recognize a synergy between research and teaching activities. 'The goal is twofold. It is important for the researcher to be able to test his own ideas, including testing them out with his students. ... For students it is a way to become informed about the state of play in the research field.' (interview quote on p203)

The literature on the ‘research-teaching nexus’ focuses mainly on the benefits of research activities for the quality of teaching, but there is also some attention for benefits of teaching to research, in the form of a broader research scope and improved reflection. Similar to our findings in the medical domain, there is little information on the conditions that stimulate dynamic interactions between researchers and students in classrooms to facilitate the creation of these benefits.

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5 Comparative analysis and conclusions : A theoretical framework

5.1 Introduction

This report scanned the existing literature on knowledge cycles and feedback loops within these cycles in three domains that represent different relational and contextual variations of the knowledge cycle: the domain of research organisations and spin-off firms, of medical research and the clinical practice, and of academic research and teaching. We were specifically interested in information on the feedback loops from practical applications to the research practice in these domains, as these may provide valuable contributions increasing the quality of knowledge by making it more ‘socially robust’. However, these practical feedback loops remain empirically underexplored in the existing literature on knowledge production (Nowotny et al., 2001). Based on a comparative analysis of knowledge cycles in the three domains, this chapter develops the first building blocks of a theoretical framework to guide empirical analyses on this topic. It is a first step in identifying and understanding the mechanisms that may be responsible for the creation of socially robust knowledge.

5.2 Benefits created by practical feedback loops in the knowledge cycle

Based on our literature scan, we can distinguish three categories of benefits that are created by the application of scientifically developed knowledge in commercial or practical environments.

As a first category, the literate mentions a number of *cognitive benefits* created by practical applications of scientific knowledge. These benefits include access to new sources of data that can be incorporated in the research process (Hessels et al. 2011; van Stijn et al. under review). Furthermore, the application of scientific knowledge in commercial environments may produce new forms of (non-scientific) knowledge and new insights (Zomer et al. 2010), which can broaden the scope of existing research agendas (Visser - Wijnveen et al. 2010) and help to identify relevant research questions (Hessels et al. 2011; Neumann 1992). More indirectly, being involved in research activities as well as in practical applications of knowledge are also claimed to increase researchers’ comprehensive and reflexive qualities (Neumann 1992).

As a second category, *financial benefits* are mentioned as an important co-benefit of science to practice applications. Most importantly, practical links between parent organisations and spin-off firms help increase access to research funding. On the one hand, it can increase direct access to funding when the spin-off firm hires the parent organisation, or when the parent organisation hires the spin-off firm, for conducting certain tasks in the research process (van Stijn et al. under review; Zomer 2011). On the other, it may increase access to third-party funding when governmental program require collaborations between science and industrials partners in research applications. Sometimes only mentioning the existence of a spin-off firm even helps to get funding (Zomer et al. 2010).

Third, *social benefits* can be created. Interactions between parent organisations and spin-off firms generate social capital (van Stijn et al. under review). The involvement of researchers in applied projects may improve the reputation of a research organisation by expressing its researchers' expertise in a broader, sometimes more public, domain (van Stijn et al. under review). In this public domain, the demonstration of research expertise may also increase the legitimacy of the research produced by an organisation (Zomer et al. 2010).

5.3 Conditions for a productive knowledge cycle

While the literature studied in this report provides ample examples of benefits created by applications of scientific knowledge by spin-off firms, considerations of the conditions that allow these benefits to be produced are more scarce. Mostly, the scholars underscore the importance of establishing dynamic forms of interaction, but how these interactions should be set up and maintained is not specified in detail. Scoping through the different articles, we have found some indicators that could be described as conditions for the establishment of productive science-practice interactions that may contribute to the establishment of productive feedback loops within the knowledge cycle. An overview of these conditions is provided in the schema below.

Based on our literature scan, we identify the following conditions that encourage science-practice interactions to develop in a knowledge domain:

1. Similar research interests (Treibich et al. 2013)
2. Similar time horizons (Zomer et al. 2010)
3. Good informal relations (Zomer et al. 2010)
4. An open research culture. Economic sectors each have their own strategies for protecting intellectual property. In the case that patents are a common strategy, this can provide a vehicle for collaboration between spin-offs and their parent organisation. In areas where secrecy is a more common strategy, collaboration may be more difficult
5. Equipment sharing. If research in a certain area requires costly equipment, this can stimulate interactions between spin-offs and parent organisations (Zomer et al. 2010)
6. A focus on sustainability. In areas with a sustainability orientation, interactions with spin-offs generate additional benefits (van Stijn et al. under review). In these areas supporting a spin-off can help to improve the green or clean image of the parent organisation and in this way contribute to its societal legitimacy
7. Personal characteristics of researchers involved (e.g., productivity).
8. Stable source of funding. When collaborative research projects are upheld by a sufficient amount of funding, the involvement of researchers in practical applications of their knowledge is likely to have a more permanent character (Zomer et al. 2010). Since intensive collaboration (or even sponsorship by spin-off firm) requires a substantial budget from the spin-off side, these interactions will more frequently occur in sectors where young firms have a stronger potential for fast growth.

5.4 First building blocks of a theoretical framework for analysing knowledge feedback loops

For the objectives of this study the cognitive benefits are most relevant, as they indicate positive effects on the quality of knowledge. Therefore, in the development of our theoretical framework we will focus on the cognitive benefits. In the table below, these benefits are correlated to the conditions for the establishment of productive knowledge feedback loops to establish, as identified above. Beside these conditions, we will also investigate the role of geographical proximity, since this has been shown to play a significant role in research and innovation partnerships (Heringa et al. 2016). This table can be applied in the case studies

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conducted in the next phase of this research project. The results generated by this activity will be used to further specify the benefits and conditions, and the link between them, as part of the theoretical framework this project aims to deliver.

TABLE 1. CONDITIONS AND BENEFITS

Benefits /Conditions	Cognitive benefits				Financial benefits	Social benefits
	More data	New insights	Research agenda	Reflexivity		
Similar research interests						
Similar time horizons						
Good informal relations						
Open research culture						
Equipment sharing						
Focus on sustainability						
Personal characteristics						
Stable source of funding						
Geographical proximity						

5.5 Research agenda

Altogether this literature scan has shown that there is relatively little knowledge about knowledge feedback loops, in spite of the relevance of this topic[3]. This report only provides some tentative answers to the questions of our project. In our further research, we will try to learn more about the knowledge cycle based on empirical research. Our research questions are the following:

1. How does knowledge flow from practices of knowledge application to practices of knowledge generation in different domains?
2. What general mechanisms can be recognized across different domains?
3. How do different conditions facilitate these mechanisms to occur?
4. What domain-characteristics influence the mechanisms of knowledge feedback?
5. What other resources do researchers or research organisations gain from practices of knowledge application, such as data, reputation, legitimacy and funding?

[3] This observation was confirmed by Leonie van Drooge.

Based on the current report, the following domains seem interesting for further study:

1. Watertechnology. It seems highly interesting deepen our insights into the relationships between spin-off firms and parent organisations by an analysis of spin-off firms in water technology. To acquire a symmetrical perspective on these interactions, interviews with representatives of both the spin-off firms and their parent organisations would be required.
2. Medical care. How (much) do medical researchers benefit from their clinical experience in their scientific work? This question could be addressed by interviewing people at UMCs, NKI or collaborative centres ('academische werkplaatsen'). It may make sense to focus on a specific sub-domain, for example biobanks (Parelsnoer initiatief) or Q-Koorts (Q-support, a patient organisation that actively supports academic research).
3. Social scientists and humanities scholars who participate actively in the media. What do they learn from their media appearances? Interviewing researchers at institutes such as SCP, CPB and Clingendael could be informative.
4. Engineering, in particular deltatechnology. The interactions between construction work and research projects would be very interesting. Possible cases include Oosterscheldekering or Building with Nature (TU Delft).

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